ADVANCES IN INDUSTRIAL ERGONOMICS AND SAFETY IV

EDITOR S. KUMAR

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Advances in Industrial Ergonomics and Safety IV

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ADVANCES IN INDUSTRIAL ERGONOMICS AND SAFETY IV

Proceedings of the Annual International Industrial Ergonomics and Safety Conference held in Denver, Colorado, 10–14 June 1992

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Edited by

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PREFACE

It is with great pleasure that I write this preface. It is the first time since I agreed to organize the Annual International Industrial Ergonomics and Safety Conference 1992 (AIIESC ’92), that I can see a tangible product as a source of information emerging. The usefulness of this book as a reference will be due to the authors and the quality of their contributions. I would like to thank them for their efforts. I also thank the International Foundation for Industrial Ergonomics and Safety Research for having the vision and faith in this technical and professional movement. The conferences and “Advances” series are satisfying a need and filling the void in the industrial ergonomics arena. The increasing prestige of these annual events and volume series is evident through the increasing international participation, the breadth and depth of the content, and finally, the quality of contributions. I am satisfied with our collective effort, especially in view of competing demands and interests.

The dissemination of up-to-date knowledge, as it is being discovered, feeds the professional engine with fuel to inspire and accelerate activity and growth. It is our profession. Let us help it help us. Let us realize our collective potential.

For the Annual International Industrial Ergonomics and Safety Conference ’92 Denver, 277 abstracts were received from 20 countries around the world. Of these, following a review process, 240 abstracts were selected for presentation. A total of 203 manuscripts authored by 376 scientists and practitioners representing both academia and industry were chosen for publication in the Advances in Industrial Ergonomics and Safety IV. The preparation of this volume has been a special and gratifying challenge.

An overall organizational approach to ensure coherence of concepts and content has been adopted. The wider and general issues have been dealt with first before focussing on specific topics. To maintain a similar flow, a strategy similar to the overall organization has been used within each category, excepting the category of International Ergonomics. The latter category has been partitioned along the arbitrary lines of nationality. I apologize to my overseas colleagues if they feel their work has been left conceptually unintegrated.

I would like to take this opportunity to extend my heartfelt thanks to the University of Alberta, Department of Physical Therapy Chair, Dr. D.J.Magee and the Administrative Assistant, Mrs. Dorothy Tomniuk who have supported this project in numerous ways, both directly and indirectly. My thanks are also due to Mrs. Kim Dalmer for her help in the organization of the conference and the preparation of this volume. Last, but not least, my thanks are due to my wife Rita, son Rajesh, and daughter Sheela for their thoughtful understanding and support during the execution of this project. With genuine pleasure, I dedicate this volume to them.

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DEDICATED TO RITA, RAJESH, AND SHEELA KUMAR

CONFERENCE ADDRESSES

ERGONOMICS—A SCIENCE OR A TECHNOLOGY

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The research base of ergonomics knowledge, world wide, shows a healthy activity, as the increasing size and number of journals demonstrates. The improvement in working life,however, does not increase at a similar rate. Accepting that it needs more than ergonomics to improve working life, are we improving quickly enough that part which ergonomics can deal with? Are we, too, exploiting it with other contributions so that we can increase its effectiveness? It is suggested that there is an imbalance in the effort put into ergonomics which downplays application in favour of knowledge research. A broad development of applied methodology is needed to put the practitioner in a stronger, and more effective professional role.

INTRODUCTION

The title of this contribution is not to be taken too seriously—we would probably all agree that ergonomics is a science based discipline with the purpose of improving the effectiveness and well-being of people in their work, as well as in other aspects where they interface with our technological world. Some of us look even a little wider, and see the interactions between people as being of interest to ergonomists, not just the co-ordinated operations of a working group, but the generation of attitudes, motivations and satisfactions arising from the organisation of such groups which will influence their performance.

Although a science-based discipline, heavily dependent for our effectiveness on the reliability of our scientific under-pinning, much of the scientific ground on which we stand is still very thin. At a previous talk in this series, Tom Singleton pointed out, in the context of safety, that much theoretical formulation was conceptual in nature, very rarely could we provide a mathematical formulation. It will be our common experience, too, that prediction, from our models is, as yet, an inexact science. This is not to pretend that our models have no utility—of course they have, and are getting stronger all the time. But it is to suggest that we might be paying a little more attention to the problems of application in our teaching and in our publications, problems which arise, in part, from the incomplete nature of our models. Alphonse Chapanis' recent plea for every published paper to include the design implications of its findings is a plea towards the same end.

In my view, if we look more towards the real applications of our findings we will keep more in mind the complexity of what we are looking at, as well as revealing a host of important problems which we tend not to notice. By "the real applications" I mean some serious thinking about how our research can be used in a real world problem, rather than some rather sweeping claims for practical utility which, as a journal editor, I see too often added at the end of a piece of laboratory work. When speaking of complexity, the numbers of conflicting variables which are present in any field problem are a commonplace of life to the practitioner. In a recent paper, Peacock and Koby (1988) discussed automobile seat design. They listed seven areas where ergonomics contributed in a major way. One of these areas was "seat dimensions and contours." Yet how many ergonomists, if asked, would describe seat dimensions and contours as the content of ergonomic seat design?

ABOUT PROBLEMS

When looking at a problem, it is not easy to see it as it really is, in an ergonomic context, which is as a component in a system. We are taught about seating, lighting, cognition, sensation, static work and a host of other factors, but though many ergonomics courses begin by pointing out the systems nature of people at work, that gets forgotten later in the course. We forget, therefore, that a seat is a tool to help us do the work, that its design is affected by what we do, and that it is used over a period of time.

This may seem rather sweeping, but look at some of the published work on seating. A number of the seating requirements either date from early times when not so much was known about the sitting person, or are frankly assertions which have some face validity—part of the "ergonomics is common sense" school. So we have seats which slope forwards, back rests which follow you as you lean forwards and commercial claims for ergonomic seats, many of which are rubbish. In spite of Shackel, Chidsey and Shipley (1969) the evaluation of a seat whilst real work is going on is the exception rather than the rule.

To do the evaluation whilst work is on-going is, of course, difficult. Our perceptions of research say "reduce the number of independent variables and hold everything else constant". This is a good rule for laboratory work, when we are looking for some relationships to put another brick into the scientific edifice. But real life is about complexity, and we have to find ways of dealing with it, or else our findings and recommendations are going to be sub-optimal, or even harmful.

One of the factors increasing this complexity is the effect of time. We are all familiar with the demand for numbers—"How many keystrokes per minute is safe?" With such a question we realise the reality of the query, but the impossibility of an answer. Only by maintaining our systems view and recognising the need to take into account not just the keystroking activity but the whole context of the task, will we be able to deal with the problem from which the query arose.

This “missing the wood for the trees” situation can arise from a number of reasons. It will be useful to consider some of them, and consider, too, what might be done about them.

One problem has already been touched on, that of trying to “force” theory to fit the observed scene. This is analogous to having a solution looking for a problem; it arises in some responses by reviewers to papers, who will be critical of authors who do not define their theoretical position prior to pursuing the study. There is, of course, some good reason here, in that any investigator has some concept of the situation under study and of the way the various factors might be operating. What is of concern is that there is pressure to squeeze these concepts into the frame of already existing theory, a procedure which could inhibit the occurrence of new insights into how the various factors might be operating.

A further consequence of this is that data may be evaluated in relation to the chosen theoretical position, but not mulled over sufficiently to enable further information to be drawn from it. The extreme position is the “correlation is causation” trap. An analysis of variance shows some significances, which are assumed to be causative. Then other possibilities, which due to the design were consigned to error, are overlooked.

Experienced investigators recognise such problems, they are part of the “art” of ergonomics, that intrinsic understanding which comes with experience and cannot always be clearly described. We will come back to this later, for now let us look at some other aspects.

One which arises from consideration of the previous point is the possiblity of leaping towards a solution before the problem is fully appreciated. Operations researchers lay much stress on formulating the problem before seeking a solution, do we as ergonomists stress this point enough?

Our pre-conceived or initial ideas can be a heavy bias in decision making. Yet, too, early impressions before we get immersed in the situation can be useful. It is good guidance which urges us to note these impressions down at the time, and equally good guidance which suggests that we then put them away until later in the investigative process!

A deeper understanding of the problem, as of the data mentioned earlier, comes from fuller immersion, requiring us to see a rounder view than that of an idealised model. The perspective of those who actually do the work is a key dimension. They know more about the impact of the work than anyone and, in a very real sense are the owners of it. A mistaken “specialist” stance must not prevent us from cooperating with the job holders in a joint exploration of the problems. Not to do so is to depersonalise those who do the jobs, to reduce them to another factor of no more importance than others in the problem. This is profoundly not ergonomics, for it removes people from a central position in the study, and from the investigation of their position in relationship to all other factors.

This centrality of the people in the system is important. For the concept of ergonomics as a system it is necessary not to depart from the view of the individual as at the centre, with surrounding and interactive spheres of influence which affect performance, health, etc. These influencing environments include a social one. A recent article by Munipov (1992) on the Chernobyl disaster illustrated graphically how the social organisation of the

Soviet nuclear power programme led to perceptions of the reliability of the Chernobyl plant which allowed the operating staff to pursue totally wrong procedures. If our work is not based on our best assessment of reality, then no matter how good our subsequent designs, the consequence will be failure.

ABOUT APPLICATIONS

This rehearsal of some of the problems in ergonomics is probably familiar to many. But what can be done about it? I shall put forward four areas for consideration, by no means all that can be done, but areas of concern. These four areas deal, firstly with the academic and teaching area. The second consideration is within the area of our applications, the problems of getting our contributions recognised and accepted. Thirdly, there are some concerns related to peoples' perspectives on others, who are seen as important, where should we be putting our efforts, and to whose welfare are we contributing? The fourth area grows from the previous three, the question of professionalism.

Academia ranks sound theory highly, and performs a major service in shaking down the expanse of knowledge into structured theory. It has been argued for much of technology that science follows practice, someone shows that something works, then science explains why it works. This is a bit unkind to science, but there have been very many examples of knowledge expanding in this way. But in teaching, where we tend to teach theory because it is far more efficient than teaching only examples, do we lean too far in the direction of theory? Is our theory strong enough—or should we deal more extensively with practice?

This is not a plea for teaching mainly practical skills, but a greater recognition that the work of the ergonomist in the field differs in major ways from his research and laboratory colleagues. Most of our students will not be doing research, yet many of their illustrative material and laboratory "practicals" are research based. This is very convenient, especially in the beginning of an ergonomist's training, to understand some of the basic relationships. But later learning experiences should surely focus heavily on practical methods and projects. One of the major benefits of doing this is to keep in the forefront of the student's minds the complex and interactive nature of the practical ergonomics problem. This is easy to overlook with many "sanitised" lab studies.

Our second area is one where we face major difficulties, but also have some major allies if we will join them. Recognition of the value of ergonomics is strengthening in the area of health and safety, and in standards. Occupational health and industrial hygiene professionals are our natural allies, as are safety specialists and consumer interests. But these tend to be a limited group, most readily stirred by illnesses or failures. We are not yet strong enough at the predictive end of the business, in design, either in the operational end where people are working or in the product end where things are created. There are, of course, some major notable exceptions here, e.g. the military and aerospace, but the more mundane end of the working world sees little of our skills.

Have we distributed ergonomics widely enough? Should not every engineer, designer and manager have an appropriately tailored course in ergonomics relevant to their needs? Are we publicising good cases widely enough, or in the right way?

Are the data relevant to these other professions structured in a form in which they can use it? Have we ergonomised ergonomics for them? Are we taking sufficient interest in the applications of information technology for the dissemination of our subject? Amongst other things, do we draw sufficient attention to the importance of feedback from users and its relevant interpretation? All the professionals mentioned above should be aware of the importance and value to them of well-structured feedback from their “customer” groups.

Part of the problem of recognition for the contributions of ergonomics hinges on its perceived value to the customer. As we are all aware, we live in an age of management gurus, instant solutions (preferably labelled “Japanese”) and management by cliche. When two days is enough to learn all you need to know about, say, Quality Management, how do we get across the subject of ergonomics?

If “the bottom line” is the correct cliche, then we need to get ergonomics down there! We need to take as broad a view of the costs and benefits of ergonomics as we do of the subject itself. This means that direct costs of implementation and direct financial gains from increased output are nowhere near enough. The benefits of ergonomics spread to the improved effectiveness, health and attitudes of the workpeople concerned, and all of these have a value for the organisation, in that the organisation benefits from their improvement, (Corlett, 1988). The changes can be measured from the status quo ante, but the many values to put on the changes need some further research. This is an area of considerable importance for the future acceptance of ergonomics beyond a statutory minimum, and should be a subject for early and major study.

ABOUT PROFESSIONALISM

A position which many practitioners will recognise is the ambivalent role of the professional ergonomist. Who is he working for? To say that he is working for the person who pays him is an insufficient answer; after all, will our professional do everything which the employer asks? Clearly not, yet where does this person stand?

The professional code of, say, the Human Factors Society requires its members to be objective and accurate about their work, in so far as it is possible, and not to create conditions which are injurious to others. (This is a paraphrase, interested readers are referred to this excellent code for more detail). Yet, unknowingly, we can think of others as different, assign to them a place, or expectations ensuing from our own prior conditioning. We see xenophobia and fascist tendencies growing again in one country after another. We know that children pull loads in the mines in S. America, that they work 12 hr. days in textile mills in S.E. Asia and that slavery is widespread in many parts of the industrially developing world. Many of these countries supply the cheaper goods with which the free market puts pressure on the working conditions of the more industrialised nations.

The challenge here is an integrated one, for ergonomists, technologists and managers alike, to use our abilities to maintain our way of life. The point where efficiency is finally demonstrated is at the person-process interface, and efficiency here is in total ergonomic terms, as briefly described earlier, not just output costs.

It will be evident that we have backed ourselves into the subject of ethics; we are again asking "Who are we working for?" Ergonomists must have a position on this question. Clearly they cannot solve all the world's problems, but they must try not to put more blocks in the way of their solution. Different ergonomists will have different positions since they will have different religious or philosophical positions. But there should be a limit, based on a truly ergonomic perspective of the commonality of people, beyond which no professional should go.

We have used the word "professional" with considerable freedom in what has gone before, and perhaps now is the time to look squarely at it. Several ergonomics societies have set out to specify what they mean by a professional ergonomist. In the U.S. and in the Netherlands, a preferred route has been to set up a cerificating body separate from the society of ergonomically interested people, In the U.K. the route traditionally adopted by other professionals has been taken, where the learned society activities and professional certification proceed through the same body, and the Ergonomics Society set up a professional board to register those who wish to, and fulfil the requirements to become professionals.

In the European Community there has been, over the past decade or so, a process of hamonisation of various aspects of the arrangements in the different countries, a process which still continues. One aim of this has been to enable anyone from one country to work in any other without any hindrance. In the field of professional people this has been a very difficult exercise and there are still outstanding problems. Nevertheless the aim has been substantially achieved.

It seemed to the committees of the various E.C. ergonomics societies that, for the benefit of both ergonomists and users of ergonomists in the EC, some common agreement should exist about the level of someone describable as a professional ergonomist. After two years of work, and reference to both the committees and memberships of the constituent societies, agreement has been reached. It is now in the process of being implemented and the joint organising committee hopes that they will be ready for business at the beginning of 1993.

After comparison with the proposals put forward by the body for cerification in the U.S. it looks as if there are minor differences of operation, but little of substance. It may be, therefore, that we shall see as widespread an acceptance of the ergonomist as a recognised professional as we do, today, of an engineer or medical doctor. Providing that we do not focus our attentions solely on protecting our professional position, but continue to remain open to inputs from the human and physical sciences from which we arose, this can only be good for the subject.

So, what of our title? It has become very clear that, far from being one or the other, ergonomics is both a science and a technology. Each supports the other, and it is up to us to avoid the implied—and sterile—argument in favour of encouraging each component to continue to illuminate the other. Perhaps, from a biased viewpoint, I might suggest that ergonomics without applications might be less interesting than chess, and that if we have any purpose it is to create a working and living world which is matched to our capacities, abilities and needs; a world fit for others to live in should suit us very well!

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BIOMECHANICS OF LOW BACK PAIN—PREVENTION STRATEGIES

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THE NATURE OF THE PROBLEM

There are now 11.7 million low back pain impaired within the United States, 5.2 million disabled, 2.6 million permanently disabled, and 5% of the population has a low back pain (hereafter identified as 'LBP') episode every year. Lee et al (1985) analyzed the 1978 Canada Health Survey and found a prevalence of 4.4% with "serious back and spine problems." The total number of disability days exceeded 21 million, and the average sickness absence period was 21.4 days. Table 1 (below) presents the prevalence (all cases) and incidence (all new cases) of LBP taken from a variety of studies.

The prevalence rates very from 12.0% to 35.0%. The lifetime incidence rates are higher and range from 48.8% to 69.9%. Unfortunately, the probability of returning to work with low back pain decreases with time such that people who are out of work six months have very little possibility of returning to work.

There are well over 2 million occupational injuries per year of which 1/4 of those are due to over-exertion and a large proportion of these are due to lifting. Spengler et al.

(1986) analyzed work-related injuries among 31,200 employees at the Boeing Company during 1979 and 1980. Nine hundred back injuries were reported (19% of all workers' compensation claims) were responsible for 41% of the total cost. Ten percent of back injuries were responsible for 79% of the cost. Material handling was the most common cause (Bigos et al., 1986). Most injuries occurred in workers 25 years of age and younger, but those injuries were typically more benign than injuries occurring in the older population. In Swedish studies, the same kind of relationship of injuries by occupation can be noted. In the Swedish building industry Ostlund (1975) found that 22% had lost work time because of LBP during the preceding year. The forestry industry showed an incidence of 37.5% and a prevalence of 18% (Tufvesson, 1973). A Danish study of LBP among males aged 49–50 report that 25% of all had LBP in the previous year. Biering-Sorensen (1985, 1986) reported on the national Danish statistics on work-related injuries.

Particularly high accident rates were reported for hospital work, home nursing, and patient treatment, which accounted for 42% of all injuries from 1979 to 1981. A sample of 295 male Finnish concrete reinforcement workers were interviewed about musculoskeletal symptoms and were radiologically examined (Wickstrom et al. 1978, Wiikeri et al. 1978). The lifetime prevalence of LBP was 80%. More injuries occur in those occupations involving manual materials handling.

As we consider the workplace factors contributing to musculoskeletal injuries, it is important to realize that low back pain is multifactorial in etiology. With anthropometric and constitutional factors playing some role and fitness also playing a role. However, mechanical load, the risk of accident and psychosocial factors are perhaps the most important In the NIOSH study, it was found that the twenty-four to twenty-nine age group, particularly in males, were the most prone to LBP injury.

THE IMPORTANCE OF PHYSICAL WORK FACTORS

Overview

There is, notwithstanding, some contradictions in the literature, undoubtedly a positive relationship between occupational stressors and the causality of LBP. Thus, a great potential for LBP prevention exists in the workplace if attention and emphasis should be placed on physical work factors, specifically lifting, pulling, pushing, work posture (including sitting), and cyclic loading.

In practice it is difficult to fully determine the relationship between occupational factors and low back pain because a musculoskeletal injury may be triggered by a direct trauma, a single overexertion, or frequent or sustained loading. The strengths of the various tissues are influenced by such factors as age, fatigue, and concomitant diseases and thus the loading level at which an injury occurs may vary greatly. In the case of direct trauma, several structures may be hurt at the same time. Repetitive loading may cause fatigue failure (a partial tissue rupture) but the partial tear may not propagate to failure if rest periods allow healing to occur. Temporal factors, as well as healing properties, are therefore critical.

The NIOSH Guide (1981) states that both the number of injuries per hour and the number of hours lost because of injury per hours increase significantly when: 1) Heavy objects are lifted; 2) The object is bulky or cannot be held close to the body while lifting; 3) the object is lifted from the floor; 4) the object is frequently lifted.

Lifting

Many workers have found that when a worker’s capacity is exceeded, LBP is more likely to occur. Similarly Chaffin and Park (1973) found that over a one year period LBP was three times greater in workers who were less strong than their jobs required. This was validated in a later study (Chaffin et al. 1977). A large study of 55 industrial jobs comprised of almost 3,000 different manual tasks was conducted by Herrin, Jaraiedi, and Anderson (1986). Various physical job stress indices were used to rank the manual exertion requirements of these jobs. The analyses disclosed that if the peak L5–S1 disc compression forces (predicted by the models discussed earlier) were greater than 7.000N, then both musculoskeletal problems were almost twice as severe. Also, if the strength requirements of the task were such that only 10% of the population could be expected to perform the most strenuous tasks (as judged by both a psychophysical and biomechanical strength analysis) the incident rates of (1) back problems were about 2.5 times greater, (2) musculoskeletal problems were about 4 times greater, and (3) overexertion injuries were almost 5 times greater, compared to the rates associated with jobs that over 90% of the population could perform.

As we evaluate lifting injuries, we can study these injuries by means of mathematical models. Even a simple model can give great insight. In these sagittal symmetric models one determines a moment equilibrium and a force equilibrium. Using these concepts, we can compute the moment on the back by the product of the load being carried and the distance from that load to the body. Minimizing this distance will minimize the load on the spine. As an example, with the bent knee lift, the total forward bending moment will be 212 Newton meters as compared to 151 Newton meters with the load closer to the body. From such simple models one can readily demonstrate the high disc loads that ensure when large packages (increased moment arm) or long reaches are part of the job. The back, glutei and the hamstring muscles are all myoelectrically active during lifting. The abdominal muscles are less active. The levels of activity in these various muscles are directly related to the external moment and are, therefore, influenced by the weight lifted, the body posture, the location of the mass center of the weight, and the speed of the lift. Seroussi and Pope (1987) found that asymmetric lifting can cause high muscle forces. Marras and Wongsam (1986) determined that the myoelectric response of trunk muscles is a function of trunk velocity, trunk position (both forward bending and asymmetric angle), and trunk torque.

Most people lift many times per day. Magora (1972) found that repetitive lifting (5 kg or more for an average of at least 10 times per hour of the working day) was found to be related to low back pain when combined with poor lifting technique. These data have also been confirmed by Kelsey et al. (1984) for risk of disc herniation. Chaffin and Park (1973) found increased risk of back pain in persons performing “more than 150 lifts per day.” In a study on handling and transport of dustbins Luttman and colleagues (1983) reported that lifting of the dustbins occurs at a rate of approximately 75 per workday. The peak compressive load on the L5–S1 segment of the lumbar spine was estimated at 6 to 8 kilo Newton (kN) (Jager and Luttmann, 1986).

Pushing-pulling

There is little information regarding pushing and pulling activities and their role in work-related LBP. White and Panjabi (1978) have shown high disc loads accompany pushing and pulling. A biomechanical model by Chaffin, Andres and Garg (1983) found that isometric pushing and pulling resulted in an L5–S1 disc compression force of 3,300 N, when the load is positioned at about 66 cm from the floor. Much lower compression forces and low back moments resulted when the load cell was raised to about waist height or slightly above the shoulders. In the latter posture, arm strengths seemed to limit the push and pull forces, thus protecting the back from large moments.

Posture

Another mechanism of injury relevant to the workplace is sustained static loading of tissues. Interference with the circulation of blood in a muscle (and thereby with oxygen) supply and removal of breakdown products, occur at contraction levels of 10% of maximum contraction. Strong contractions rapidly become fatiguing and secondary changes may occur in the muscle. The intervertebral disc may lose capacity to obtain nutrition while in a fixed posture due to the avascular nature of the disc. It has been shown that a disc that is immobilized does not get nutrition through the two main routes, the end plate and the outer annulus.

Several studies indicate increased risk of low back pain in patients who perform work in a fixed sitting (Hult 1954, Kroemer 1969, Lawrence 1955, Lloyd 1986, Magora 1972, Partridge 1969). There is also an increase in symptoms in subjects with preexisting LBP who are required to sit for prolonged periods. Kelsey (1975) found that men who spend more than half their workday in a car have a threefold increased risk of disc herniation. Whether this is caused by the sitting posture, by vibration, or both, is unclear. Magora (1974) showed that LBP sufferers are found in sedentary as well as physically demanding occupations. Video display terminal (VDT) users are particularly at risk because of the constrained postures inherent in their tasks (LaVille 1980). Studies have been done to define optimum seating conditions. Andersson (1974) showed that the myoelectric activity of the trunk muscles was influenced by the posture of the seated subject, by supports incorporated into the chair, and by the specific work activities performed. The use of a reclined backrest was particularly important to reduce the muscle activity.

Vibration

There are a variety of epidemiologic studies confirming the relationship between vehicular use and low back complaints (Christ & Dupuis 1966, Christ 1973, Christ 1974, Dupuis & Zerlett 1986, Hulshof 1987, Kelsey & Hardy 1975, Rosegger R & S 1960, Seidel & Heide 1986). Buckle et al. (1980), Frymoyer, Pope and Costanza (1980), Backman (1983), Damlund et al. (1982), and Biering-Sorensen and Thomsen (1986) all report an association between driving and low back pain. Those who drive tractors or trucks had as much as four times as many low back complaints as those who did not (Gruber 1976, Kristen 1981, Wilder 1982). Kelsey (1975) found that trunk drivers were four times more likely than others to have a disc herniation. Pope, Wilder, and Frymoyer (1980) analyzed vibration and found that many vehicles vibrate at a fundamental frequency similar to the body’s natural frequency.

Many vehicles exceed those International Organization for Standardization (ISO) standards for vibration. Studies of the effects of vibration on seated individuals demonstrate a mechanism by which LBP may occur. Measuring the transmission of vibration through the body, reveals that certain frequencies are accompanied by enhanced transmission and greater energy absorption. These particular frequencies are a function of the material properties of the spine and its supportive structures. This phenomenon of enhanced transmission and energy absorption is termed resonance and represents a frequency at which there are potential destructive forces.

The implication of these observations is that vehicle operators are being exposed to vibration at the resonating frequencies of their spines. It remains to be established that this effect can be responsible for spinal degeneration, but it is a convenient explanation for the greater prevalence of degenerative lesions in vehicle drivers.

CONCLUSIONS

Low back pain is related to excessive loads being applied to the tissues of the spine. This can occur through lifting, particularly if large load moments are utilized. Other risk factors include asymmetric postures, excessive exposure to a static posture, pushing and pulling and vibrational exposure.

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Table 1: Prevalence and Lifetime incidence of Low Back Pain (LBP)

		Prevalence %		Study Group		
Study	Lifetime Incidence (%)	Point	Period	N	Age	Sex
Biering-Sorensen (1982)	62.6 61.4	12.0 15.2	–	449 479	30–60 30–60	M F
Hirsch et al. (1969)	48.8	–	–	692	15–72	F
Hult (1954)	60.0	–	–	1193	25–59	M
Frymoyer et al. (1983)	69.9	–	–	1221	28–55	M
Nagi et al. (1973)	–	18.0	–	1135	18–64	MF
Svensson & Andersson (1988; 1982)	61 67	–	31 35	716 1640	40–47 38–64	M F
Valkenburg & Haanen (1982)	51.4 57.8	22.2 30.2		3091 3493	20– 20–	M F
Magora & Taustein (1969)	–	12.9	–	3316	–	MF
Gyntelberg (1974)	–	–	25		40–59	M

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INDUSTRIAL ERGONOMICS

A MACROERGONOMIC APPROACH TO WORK ORGANIZATION FOR IMPROVED SAFETY AND PRODUCTIVITY

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The concept of macroergonomics is reviewed, along with the nature of organizational structure and sociotechnical systems. Sociotechnical system considerations in macroergonomically improving organizational effectiveness are briefly explained. The relation of macro- to micro-ergonomic design, and the potential for exponentially improving productivity, safety and QWL in complex industrial organizations are noted.

INTRODUCTION

As with other professions, one way to conceptualize ergonomics is by its unique technology. From my perspective, the unique technology of ergonomics is human-system interface technology. In this context, a system can be as simple as one person using a hand tool or as complex as a large multinational industrial organization. The science of ergonomics is concerned with developing knowledge about human performance capabilities, limitations and other characteristics as they relate to the design of the interfaces between people and other system components. The practice of ergonomics is concerned with the application of this human-system interface technology to the design or modification of systems to enhance system effectiveness, including productivity, safety, and the quality of work life.

Human-system interface technology can, in turn, be subdivided into at least four distinct functional subareas, as follows.

Hardware ergonomics

First, there is human-machine interface technology or hardware ergonomics. This technology primarily is concerned with human physical and perceptual characteristics. It is applied to the design of controls, displays and workspace arrangements in order to optimize system performance and minimize human and error.

Environmental ergonomics

Secondly, we have a human-environment interface technology. It is concerned with human capabilities and limitations with respect to the demands imposed by various environmental modalities (e.g., heat, noise, lighting, vibration, etc.). It is applied to the design of human environments to minimize environmental stress on human performance, including both comfort and safety, and to enhance productivity.

Software ergonomics

Thirdly, over the last several decades we have developed a user-system interface technology or software ergonomics. Because this technology primarily is concerned with how people conceptualize and process information, it often is referred to as “cognitive ergonomics”. The major application of this technology is to the design or modification of system software to enhance its usability.

Macroergonomics

The newest part of our human-system interface technology is organizational-machine interface technology or macroergonomics. The central focus of the first three ergonomics technologies has been the individual operator and operator teams or subsystems. The primary application of these technologies thus has been micro-ergonomic in focus. In contrast, because it deals with the over-all structure of the work system as it interfaces with the system’s technology, the organizational-machine aspect of the human-system interface tends to me macro in its focus; hence, it is referred to as “macroergonomics”. More will be said about this aspect of our ergonomics technology later.

The nature of sociotechnical systems

From a sociotechnical systems perspective, human-machine systems can be conceptualized as having four major components: A technological subsystem, a personnel subsystem, an organizational structure, and an external environment which permeates and affects the system. Most importantly, these four components repeatedly have been found to interact with one another in determining overall systems effectiveness, including productivity, safety and quality of work life (e.g., see Emery and Trist, 1960; Trist and Bamforth, 1951). Tamper with any one of these four elements and it will effect the other three—sometimes for the better and, not infrequently, for the worse. Optimal system effectiveness thus depends upon the joint optimization of the technological and personnel subsystems in the light of the system’s external environment.

This, in turn, requires designing the system's organizational structure to harmonize with the characteristics of the two subsystems and the external environmental demands.

It is significant that the major interfaces of the four sociotechnical system components have corresponding human-system interface technologies. Each technology thus is able to contribute to our understanding of people and systems and to improving complex industrial system effectiveness—including productivity, safety and quality of work life.

Of the four ergonomic technologies, only macroergonomics truly deals with the system as a system. It is the only one that directly involves the simultaneous study of all four system elements and their interactions. Because of this scope, macroergonomics potentially has the capability of effecting improvements in system performance that far exceed those possible through a purely microergonomic approach to complex industrial systems. More will be said about this later.

The nature of macroergonomics

Conceptually, macroergonomics is a top-down sociotechnical systems approach to organizational and work systems design and the design of related human-system interfaces. In order to understand its sociotechnical system nature, one must first have a grasp of the key dimensions of organizational structure.

Dimensions of organizational structure

The structure of an organization can be conceptualized as having three major components: complexity, formalization, and centralization (Robbins, 1983).

Complexity refers to the degree of differentiation and integration inherent in the system's structure. Three major types of differentiation are found in organizations: Vertical differentiation, or the number of hierarchical levels, horizontal differentiation, or the extent of departmentalization and specialization; and spatial dispersion, or the extent to which facilities and employees are geographically separated from the headquarters location. Increasing any one of these three increases the organization's complexity.

Integration refers to the extent to which structural mechanisms for facilitating communication and control across the differentiated elements of the system have been designed into its structure. Some of the more common integrating mechanisms are formal rules and procedures, liaison positions, committees, system integration offices, and information and decision support systems. Vertical differentiation also serves as a primary integrating mechanism across horizontally and spatially differentiated elements. In general, as the degree of differentiation increases, the need for integrating mechanisms also increases for optimal system effectiveness.

Formalization. From an ergonomics standpoint, formalization may be defined as the degree to which jobs within the organization are designed so as to restrict employee discretion over what is being done, when or in what sequence tasks will be accomplished, and how they shall be performed. High formalization is characterized by explicit job descriptions, detailed rules, and extensive procedures covering work processes (Robbins, 1983). Often, the design of the system's hardware, software, and related human-system interfaces in themselves restrict employee discression. Too much formalization tends to inhibit innovation and flexibility and may adversely impact on employee motivation; too little formalization results in inadequate coordination and control for effective system functioning.

Centralization refers to the extent to which decision-making is concentrated in an individual or unit, usually high in the organization, thus permitting employees only minimal input into decisions affecting their jobs (Robbins, 1983). Too much centralization inhibits ability to respond quickly to rapidly changing situations, restricts bottom-up expert input into decisions, and can adversely affect employee motivation and commitment. Too little centralization can result in poor coordination and control, and ineffective decision-making.

For all three dimensions of organizational structure, optimization is possible through a macroergonomic analysis of critical sociotechnical system variables.

SOCIOTECHNICAL SYSTEM CONSIDERATIONS IN MACROERGONOMICS

The effective ergonomic design of an organization's structure involves consideration of the key elements of the other three major sociotechnical system components: The technological and personnel subsystems and the external environment, as noted above. Each of these three major components has been studied in relation to its effect on organizational structure; and empirical models have emerged that can be used to macroergonomically optimize a system's design.

Technology

Technology, as a determinant of organizational structure, has been defined in various ways. The first of these was in terms of modes of production (craft, mass, and process) based on the classic work of Joan Woodward and her colleagues in the UK (Woodward, 1965). Woodward found that different organizational structures were optimal for different production modes. Thompson (1967) defined technology by the strategies for reducing technological uncertainty.

To date, the most widely validated and most generalizable model of the technology-organizational structure relationship is that of Perrow (1967). Perrow uses a knowledge-based definition of technology. He begins by defining technology by the action one performs upon an object in order to change that object. Perrow notes that this action always requires some form of technological knowledge. Using this approach, Perrow has identified two underlying dimensions of knowledge-based technology. The first of these is task variability or the number of exceptions encountered in one's work. For a given technology, these can range from routine tasks with few exceptions to highly variable tasks with many exceptions. The second dimension concerns the type of search procedures one has available for responding to task exceptions, or task analysability. For a given technology, the search procedures can range from tasks being well-defined and solvable by using logical and analytical reasoning to being ill-defined with no readily available formal search procedures for dealing with task exceptions. In this latter case, problem solving must rely on experience, judgement and intuition. The combination of these two dimensions, when dichotomized, yields four cells representing different knowledge-based technologies as shown in table 1.

Table 1. Perrow's knowledge-based technology classes.

		Task variability	
		Routine with few exceptions	High variety with many exceptions
Problem analysability	Welldefined and analysable	Routine	Engineering
	Ill-defined and unanalysable	Craft	Non-routine

Routine technologies have few exceptions and well-defined problems. Mass production units often fall into this category. Routine technologies are best accomplished through standardized procedures, and are associated with high formalization and centralization.

Non-routine technologies have many exceptions and difficult to analyse problems. Aerospace operations can be representative of this category. Most critical to these technologies is flexibility. They thus lend themselves to low vertical differentiation and formalization and to decentralization

Engineering technologies have many exceptions, but they can be handled using rational-logical processes. They lend themselves to centralization, but require the flexibility that is achievable through low formalization.

Craft technologies typically involve relatively routine tasks, but problems rely heavily on the experience, judgement and intuition of the craftsperson. Consequently, decentralization and low formalization are required.

Personnel subsystem

At least two aspects of the personnel subsystem are important to organizational design: The degree of professionalism and the psycho-social characteristics of the work force.

Degree of professionalism refers to the education and training requirements of a given job and, thus, of the incumbent. From an ergonomic design standpoint, there is a trade-off between formalizing the organizational structure and professionalizing the jobs and related human-system interfaces. As positions in the organization are designed to require considerable education and training, they also should allow for considerable employee discression. Accordingly, the organization's structure needs to be characterized by low formalization and decentralization. Conversely, jobs requiring little employee discression lend themselves to high formalization and centralization.

Psycho-social characteristics include cultural norms, values and mores regarding work, supervision and peer relationships, among others, which may make one form of organizational structure more effective than others. In addition, I have found the most useful integrating model of psycho-social influences to be that of cognitive complexity. Harvey, Hunt and Schroder (1961) have identified the higher-order structural personality dimension of concreteness-abstractness of thinking or cognitive complexity as underlying different conceptual systems for perceiving reality. We all start out in life relatively concrete in our cognitive functioning. As we gain experience we become more abstract or complex in our conceptualizing; and this changes our perceptions and interpretations of our world.

In general, the degree to which a given culture or subculture (a) provides through education, travel and media an opportunity for exposure to diversity; and (b) encourages through its child-rearing and early educational practices an <u>active</u> exposure to this diversity (i.e., an open-mindedness to learning from new experiences) the more cognitively complex those persons are likely to become. Relatively concrete adult functioning consistently has been found to be characterized by authoritarianism and a relatively high need for structure and order and stability and consistency in one's environment. Concrete functioning persons tend to see their views, values, norms, and institutional structures as relatively unambiguous and static. In contrast, cognitively complex persons have a relatively low need for structure, order, stability and consistency; and tend to see their views, values norms and institutional structures as dynamic (i.e., they <u>expect</u> these things to change as they gain new experience and as circumstances change). In view of these findings, it is not surprising that I have found evidence to suggest that relatively concrete persons function best under relatively high vertical differentiation, central-ization, and formalization. In contrast, cognitively complex functioning persons seem to function best under relatively low vertical differentiation, centralization and formalization (Hendrick, 1990, 1979).

<u>Environment</u>

Of the three major sociotechnical system components, the elements of an organization's external environment upon which it is dependent for its survival and success is the most critical to organizational design. Neghandi (1977), based on field studies of 92 industrial firms in five different countries, has identified five external environments that significantly impact on organizational functioning. These are <u>socioeconomic, educational, political,</u> legal, and <u>cultural</u>. Of particular importance to us is the fact that these environments vary along two dimensions that strongly influence the effectiveness of an organization's design. These are the degree of <u>environmental change</u> and <u>complexity</u>. The degree of change is the extent to which a specific environment is dynamic or remains stable over time; the degree of complexity refers to whether the number of critical environments to which the organization must respond is few or many. Taken together, these two dimensions determine the <u>environmental uncertainty</u> of an organization.

Numerous studies (e.g., Burns and Stalker, 1961, Duncan, 1972, Emery and Trist, 1965, Lawrence and Lorsh, 1969, Negandhi, 1977) have shown environmental uncertainty to be the single greatest factor to which organizational structures must be responsive if they are to survive and be successful. In general, the greater the degree of environmental uncertainty, the greater must be the level of professionalism; and the lower must be the vertical differentiation, centralization and formalization of the organization's structure. With low environmental uncertainty, just the opposite tends to be true.

Most industrial organizations throughout the world today find themselves operating under conditions of relatively high environmental uncertainty. It is my observation that many of these have not yet adequately adopted their organizational and work systems design to remain competitive for the long term.

INTEGRATING MACRO- WITH MICRO-ERGONOMIC DESIGN

Macroergonomics prescribes microergonomic dimensions of design

By first ergonomically optimizing a system's organizational structure, many of the characteristics of the jobs to be designed into the system, and of the related human-system interfaces already have been prescribed. For example, decisions concerning formalization and centralization will dictate (a) the degree of routinization and employee discretion to be ergonomically designed into the jobs and attendant human-machine and user-system interfaces, (b) the level of professionalism required, and (c) many of the ergonomic design requirements for information, communication and decision support systems. Similarly, Decisions concerning horizontal differentiation will prescribe how narrowly or broadly jobs must be designed and, often, how they should be departmentalized.

Vertical differentiation decisions, coupled with those concerning spatial and horizontal differentiation, centralization and formalization, will prescribe many of the design characteristics and interface requirements of supervisory and managerial positions. These include span of control, decision authority, nature of the decisions to be made, information and decision support requirements and qualitative and quantitative professionalism requirements (i.e., education, training and experience needed).

IMPROVING PRODUCTIVITY, SAFETY AND QWL VIA MACROERGONOMICS

From the above, it should be apparent that macroergonomics has the potential to improve the ergonomic design of complex industrial systems by ensuring that the organizational structure harmonizes with the system's critical sociotechnical characteristics. Equally important., macroergonomics offers the means to ensure that the design of the entire work system, down to each individual job and work station, harmonizes with the over-all structure of the system. A widely accepted view among system theorists and researchers is that organizations are synergistic (e.g., see Emery and Trist, 1965, Trist and Bamforth, 1951); that the whole is more, or less, than the simple sum of its parts. Because of this synergism, I believe the following occur in our complex industrial organizations.

Incompatible organizational design

When organizational structures are grossly incompatible with their sociotechnical system characteristics, and/or jobs and human-system interfaces are incompatible with the organization's structure, the whole is less than the sum of its parts. Under these conditions we can expect the following to be poor: (a) productivity, especially quality of production, (b) accident rates and adherence to safety, and (c) motivation and related aspects of quality of work life. Further, these detriments will be greater than a simple "sum of the parts" would indicate.

Effective macroergonomic design

When organizational structures have been effectively designed from a macroergonomics perspective, and that effort is carried through at the microergonomic level, then production quality, safety and quality of work life will be greater than the simple sum of the parts would indicate.

Implications for our potential

Assuming these two propositions are true, then microergonomic approches to productivity, safety and OWL have the potential to improve organizational functioning exponentially rather than linearally. For example, accident rates, scrap rates, and employee job satisfaction indices should not show the typical 10% to 20% improvement often seen as the result of successful micro-ergonomic and organizational development efforts. Instead, improvements of 60% to 80% more typically should occur (and in some cases, much greater).

Already, there is some empirical support for this expectation. For example, a recent Finish Institute of Occupational Health program for improving safety by a managerial emphasis on improving the work environment—in particular, cleanliness and neatness—and reinforcing related behaviors among the workers has resulted in reductions in accident rates of 70% or more (I.Kuorinka, 1991; personal communication). Such indications suggest a great potential for our profession to contribute to the improvement of our industrial systems; and at a level that was not possible with a purely microergonomic approach.

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INTEGRATING INDUSTRIAL ERGONOMICS INTO THE DESIGN PROCESS ACCOMMODATING THE DESIGN ENGINEER

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Ergonomic tools are available to assist design engineers in the evaluation of a product or process design. Short of having an ergonomist on hand during design synthesis stages, however, there is no effective way to infuse ergonomics concepts and criteria into early component, assembly, and process design, especially in a concurrent engineering strategy. This paper summarizes the prototype ergonomic expert system and hypertext tools of CDEEP (Concurrent Design Engineering for the Ergonomics of Production), currently under development. Using backward chaining and directed hypertext in the early design phases, CDEEP queries the user for decisions necessary to make industrial ergonomic inferences, and presents him/her with appropriate ergonomic background information and the ability to browse to any level of detail at will. As component and assembly designs progress, CDEEP relies primarily on the hypertext and forward chaining inference to guide the user toward detailed process and work area designs.

INTRODUCTION

From an ergonomic viewpoint, humans *must* be considered as an integral part, for purposes of design and evaluation, of any system that will interface with people. Few professionals in the field of ergonomics will disagree with this viewpoint, and many have in fact appealed for such an approach (e.g., Meister, 1987; John, 1988; Pikaar et al., 1990). Doing so, however, has proved extremely troublesome. Unlike the inanimate materials that are combined in a given design, which can be modelled and controlled with some certainty using traditional engineering tools, the human is very difficult to model and control. Humans may exhibit extreme variations within and between themselves. Machines and the materials they are constructed of, on the other hand, can be quantified and controlled, relatively speaking, to be repeatable within and between. Perhaps it is this difficulty with quantifying, understanding, and controlling the human that has resulted in inadequate attention to the human role in system design.

Because humans differ in psychological and physical characteristics, individuals with psychology, physiology, biomechanics, safety, engineering, and many other disciplines all contribute to the body of ergonomic knowledge. This mix of professional expertise, with the idiosyncrasies and language of each, has made the dissemination of ergonomic knowledge and consequent application quite slow and limited.

Clegg (1988) summarizes concerns with ergonomics from the viewpoint of practicing designers and managers.

1. Relevant ergonomics expertise is very fragmented and the disciplines and interests of the contributing disciplines are poorly integrated.
2. Ergonomists often have a scant understanding of engineering principles. Engineers have to learn something regarding human and organizational issues to meet their job requirements.
3. Ergonomists have failed to provide useful models, checklists, methodologies, or tools to help designers.
4. Ergonomists have not been effective at educating and persuading designers in their views and methods.
5. Ergonomists have failed to demonstrate that ergonomics is worth the effort, partly because of the points above, but also financially. Ergonomic justifications are more often negative, as opposed to predicting positive benefits or opportunities.

Swierenga et al. (1990) found that while engineers did consult “human engineering” data on a monthly basis, they had difficulty accessing, interpreting, and applying it. The designers indicated that an integrated hard copy or electronic information resource would increase their use of human factors in making design decisions. Corbett (1990) notes that when existing ergonomic design criteria are used by designers it “is predominantly used reactively to evaluate a design option once it has been chosen.”

Ergonomic aspects of a process are affected by design decisions, and aside from health and safety issues, neglecting it can have negative impacts on productivity, quality, and reliability throughout the product life. The focus of this research is to provide a methodology to infuse industrial ergonomics into design for manufacturing strategies via an expert system format. Design changes become progressively more expensive as a design becomes more defined. It is therefore crucial that if ergonomics is to be incorporated into design principles, then the necessary ergonomic criteria and tools must be available at the beginning of the design process in a form that is easily accessible, usable, and justifiable in the mind of the designer.

We suggest facilitating designers with a knowledge based, or expert system, which also features a hypertext facility. Our prototype system, referred to as CDEEP (Concurrent Design Engineering for the Ergonomics of Production), has been formulated to present ergonomic criteria in a form that will be understood and appreciated by engineers at the earliest and most appropriate step in the design for manufacturing (or concurrent design) process. It should be noted that CDEEP will provide guidance and recommendations solely relating to industrial ergonomics pertaining to component, assembly, process, and work area design. However, CDEEP is being constructed to be easily expanded, and so that it can be one of many engineering tools available to a designer in a common computing environment.

Ergonomics has been identified as a prime candidate for expert system technology, and many systems have been proposed and prototyped (e.g., Karwowski et al., 1986; Taylor and Corlett, 1986; DeGreve and Ayoub, 1987; Laurig and Rombach, 1989; Brennan et al., 1990). While some of the ergonomic expert systems reviewed seem promising if developed further, most require significant input of data by the user before they offer advice, and most appear to be primarily design evaluation tools, as opposed to design synthesis tools.

A problem with requiring a user (assumed to be a non-expert) to input much of the data pertaining to task design before the system offers conclusions is two-fold. First, much of the data input required is exactly the subject matter on which the user requires help. Secondly, if the system offers a solution based upon the user input, the expert system may recommend a "best solution" for the given data, but that solution may still be ergonomically hazardous due to uninformed decisions made by the user regarding initial design constraints. This type of expert system is certainly useful for evaluation or redesign situations, where a task is already defined. However, there is a danger of providing a false impression and security that a task has been "ergonomically designed," when that in fact is not the case. It is the design of the assembly components, tasks and tools in conjunction with the workstation which defines the human requirements. This is where ergonomic input is required, yet does not currently exist in any easily useable and easily accessible form beyond human expertise.

Utilizing primarily backward chaining inference techniques and the hypertext facilities, CDEEP guides engineers toward ergonomically informed design decisions early in the component and assembly design stages. In the manufacturing process design stages the system will rely primarliy on forward chaining inference techniques to provide detailed workstation design criteria.

OVERVIEW OF CDEEP

A typical expert system consists of a user interface, an inference engine, and a knowledge base. The knowledge base contains the rules that encode expert knowledge pertaining to the particular problem domain. The inference engine is specialized software that "reasons," or infers conclusions from the rule-base depending on the information gathered from the user via the user interface. Figure 1 shows this basic structure, and also identifies particular features that are unique to CDEEP.

The system is being prototyped in Common Lisp using Hyperclass, an object-oriented programming environment tool with. A hypertext information browsing extension has been added to Hyperclass. MRS (Meta-level Reasoning System) is being used as the inference engine, which has both forward and backward chaining ("reasoning") facilities. MRS is similar to Prolog, but MRS (Genesereth et al, 1984) is Lisp based and also has a meta-level reasoning faciliy.

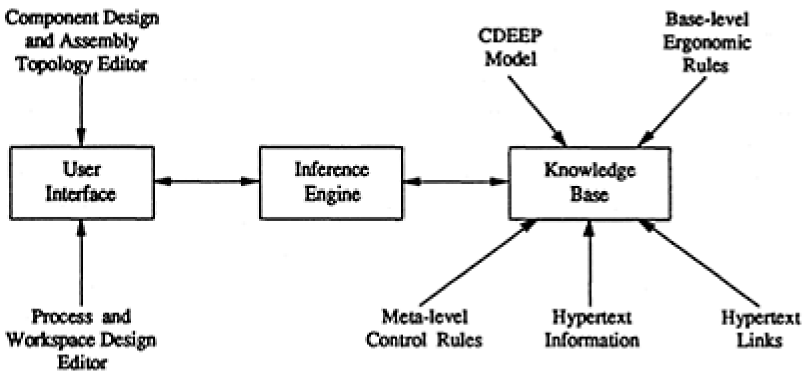

Figure 1. The boxed text shows the basic structure of an expert system. The free texts identify specific features of CDEEP.

Component Design and Assembly Topology Editor

Many expert system projects have gone unused because they are stand-alone products that can not be integrated with other systems in a common computing environment. To avoid a similar demise, CDEEP has a Component Design and Assembly Topology Editor feature as part of its interface. This approach is modelled after Next-Cut (Brown et al., 1990), a computational framework for concurrent engineering. Such an interface acts as a common computing environment which could connect to other engineering computing tools. In this editor a design engineer defines components and the connections that form an assembly or sub-assembly. This editor is currently in the form of figure 2, which shows a representation of the connection between stem and shell components in a side view automobile mirror. The

Figure 2. The Component Design and Assembly Topology Editor

representation of a side view mirror stem and shell assembly.

rectangular boxes represent components. The small squares on the components represent ports, which are defined as any point where the object contacts or is connected to another object. The line between the components represents the connection between the stem and shell, via their ports. Future plans include incorporating a geometric modeller (CAD) in addition to the current schematic representation.

Process and Workspace Editor

Since this paper focuses on integrating ergonomics into the design of components and assemblies, we do not present detailed information concerning the Process and Workstation Design Editor (refer to Brown et al. (1992) for additional examples of interface and functional features of CDEEP).

CDEEP Model

The CDEEP model consists of numerous objects which represent physical, functional, and procedural features of the components, assemblies, processes, workspace, environment, and worker population. There is not enough space here to describe the entire CDEEP model, but we present some examples of objects associated with the threaded connection between stem and shell from figure 2. The generic object structure appears on the left. As a user defines the stem and shell components and the threaded connection between them, specific objects such as those shown on the left are created.

Component	Rear-view-mirror-part
name	shell
weight	1 lb.
shape	rectangular
size	40 in^3
ports	shell-port-1 and glass
support	
Port	Threaded-through-hole-pattern
name	shell-port-1
home component	shell
opposing port	stem-port-1
Connection	Threaded
name	stem-to-shell
connected ports	stem-port-1 and shell-port-1
fasteners	screws
sweep angle	360 degrees
minimum sweep distance	1 in.
fastener recess	0 in.
Screw	Screw-48
threads per inch	12

thread length	0.5 in.
screw length	0.8 in
thread class	2B
head style	standard-oval
neck style	fin
Threading-Task	Thread-stem-shell
required driving torque	15 in-lb
required final torque	20 in-lb
required torque accuracy	5%
revolutions	6
tool	*unknown*

CDEEP stores common component objects for easy retrieval, and also has predefined objects representing specific fasteners and their attributes, such as “screw-48” above.

The weight, shape, and size attributes of the “component” object are useful in inferring handling and gripping (which are objects not shown) characteristics of components. The sweep angle, sweep distance, and recess distance in the “connection” object record information concerning the accessibility of the screws, which is useful for tool selection or redesign suggestions. The “threading-task” object contains information pertaining to torque requirements and repetition, which is again useful for tool selection or redesign suggestions. The objects shown here represent only a small part of the overall CDEEP model pertaining to the early design stages.

Base-level Ergonomic Rules

The base-level rules record the core of the ergonomic design criteria encoded in the form of facts and “if, then” statements, modified by boolean operators. For example, the following facts and rule (expressed in common language, not in the syntax required by MRS) are adapted from Konz (1990).

Facts Contained in the Rule-Base:

1) Moderate skill is required to operate scissors
2) Scissors are a handtool

A Rule in the Rule-Base:

If the skill requirements for a task are moderate,

and a handtool is used,
and the operator is a novice,
and the nonpreferred hand is used,

then the skill decrement for the task is 50%.

Given that the user specified the facts that scissors were to be used by novices in their nonpreferred hands for a particular task, CDEEP would use forward chaining to infer that a 50% skill decrement would be expected for the task.

For ease of expansion, navigation, and organizational clarity, the base-level ergonomic rules are arranged into separate subjects, called thoeries in MRS. For example, one theory contains all of the rules pertaining to manually operated torque handtools. Another theory contains rules for power torque handtools. Yet another theory contains the rules necessary to choose between power or manual handtools depending on point-of-operation requirements such as torque (driving and final), torque accuracy, repetition, location, orientation, etc.

Meta-level Control Rules

Meta-level control rules are rules about the base-level rules. For CDEEP, the meta-level rules determine which base-level rule theories or problem solving strategies should be used, depending on what information is known at the time. Meta-level rules may also determine whether a forward or backward chaining inference procedure should be used.

Hypertext Information

Hypertext information in CDEEP exists in two basic forms: Hypertext cards which contain specific information regarding a specific action or situation; and general ergonomic sources for browsing. The cards are designed to explain why CDEEP may be asking for certain information from the user, and offer the user the choice of pursuing specific topics further by browsing. Using this method, CDEEP can initially guide the user to the most appropriate information, but also give the user freedom to browse to greater levels of detail at will.

Hypertext Links

The hypertext links are closely tied to the rules in that a particular rule may link to a specific hypertext card. Once a card has been opened, the links are between key words in the text on the cards and a selected top level hypertext document covering that topic. From that level, the links provide browsing facilities through a linked hypertext network.

The CDEEP Advantage

CDEEP is expected to reduce the gap between designers and available ergonomic knowledge by acting as an intelligent design assistant. Using hypertext facilities, meta-level control strategies, and backward chaining early in the design of components and their connections, CDEEP can guide a designer toward ergonomically informed decisions which may affect the design itself, or may positively influence the selection of tools, fixtures, and the final design of the manufacturing process, workstation, and work environment. As more ergonomically guided design, assembly and process decisions are made, CDEEP uses forward chaining inference and hypertext to provide specific advice as to final task, workspace, and environment design criteria.

CONCLUSIONS

A variety of ergonomic information and data have been compiled in various formats and offered as ergonomic design tools, design criteria, databases, and reference materials, yet designers complain that there is no available information. Ergonomists counter the argument by pointing to the numerous sources and complaining that designers just don't appreciate the need for ergonomics and therefore don't use the available information. Engineers want hard facts and solutions, while ergonomists consider such requests a search for a "quick fix."

The goal of this research is to infuse ergonomic knowledge into the design synthesis stage using a knowledge based system and hypertext, and continue as a "smart" assistant through design evaluation and process design stages for concurrent engineering programs. CDEEP is built to be a flexible module that can tie in with other design tools in a common computing environment. It is a prototype at this time, but is expected to become a fully operational system in the future.

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NEW ORGANIZATIONAL FORMS AND THE ROLE OF THE PHYSICAL ENVIRONMENT

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INTRODUCTION

Although it has been widely established that the way in which a building is designed and planned affects the pattern of interaction and relations between people, the main focus of earlier research has been simply on the direct influence of the physical environment on people's behaviour and perceptions. A variety of environmental aspects and people's reactions to these have been considered.

Few researchers have treated the organization of activities as a point of departure, and posed questions on the suitability of the physical environment in relation to this. Some such questions, which draw attention to the interaction between organization and physical environment are: *How are organizational ideas expressed in the physical environment? What scope does the physical environment allow for organizational change? What demands, pre-conditions and obstacles apply to this mutual interaction, and what do these mean in terms of the work environment that people are offered?*

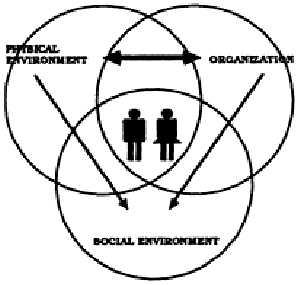

Figure 1. Interaction between the physical, organizational and social

environments that jointly comprise the
work environment for the individual.

Implementation of an organizational change generally involves efforts to change and adjust the physical environment so that the requirements of the new organization can be met. In turn, this involves changes in the social environment. It is a question, therefore, of an intimate form of interaction between the physical environment on the one hand and the organizational and social environment on the other; these jointly constitute the work environment of the people who work there (figure 1). This paper describes a study of an organizational change which was accompanied by the simultaneous rebuilding of the work premises—to stress and reinforce the new organizational ideas.

THE ORGANIZATIONAL CHANGE: ITS UNDERLYING AIMS AND FORM

A research project was taking place at Swedish Telecom Services in Sundsvall in the northern part of Sweden. A radical change in the nature of work activities had been initiated, based on a combination of newly-designed premises and a new task structure.

As well as having certain goals in terms of profitability, the reorganization had the aim of eliminating a variety of problems that were proving extremely difficult to solve, by making radical changes to the task structure. One problem was the nature of the physical workload to which telephonists were subjected; another, the extreme monotony and repetitiveness inherent in their tasks; a third, the inadequacies of the existing premises. Taken together, these deficiencies were regarded as the cause of the high rate of absenteeism; from the perspective of the company, this constituted a fourth problem.

In the autumn of 1989, the plant had about two hundred employees, of which 140 were telephonists in long-term service; there were also a growing number of engineering workers from the TELI company in Sundsvall (who had been released from their jobs and retrained as telephonists) and some newly-recruited employees. During the first quarter of 1990, the total number of employees came to 260, a figure that includes all those who, for various reasons, were on long-term leave. 40 employees were to be recruited during 1990, and the recruitment of around a hundred more was planned.

A proposal that contained the following elements was developed by Swedish Telecom management:

* The work organization should be changed with a view to creating greater variation in the tasks undertaken by telephonists and greater scope for physical mobility. Their traditional tasks would be combined with so-called “service work”, of which there would be both a compulsory and an optional component.

* Computer facilities should be developed (in the long rather than the short term) which would allow work stations to fulfil a multiplicity of functions.

* The organizational structure should be changed in order to create opportunities for a sense of community to develop and to provide company for telephonists while doing their work. The working group, containing around 20 people and headed by a job supervisor, would be the basic organizational unit; such groups would then be assembled into

production units (with 6 working groups in each production unit). Financial responsibility would be delegated, and located further down in the organization.

* The premises should be adapted to the new form of organization; they should be redesigned and rebuilt so as to satisfy the physical conditions necessary for community at work to be attained. (During the first phase of the study, the telephonists still worked in the old physical environment, but the new organization into groups and production units had already been introduced).

THE AIMS OF THE STUDY

One aim of the study was to examine how the ideas on group organization found expression in the physical environment, and what, as a whole, this provided for the telephonists. This paper will focus on the interaction between the physical environment on the one hand and the organizational and social environment on the other. *How were the new premises designed, and how were they perceived by the personnel? Did the design of the premises help to attain the aims of the organizational change? Did the design of the premises have any unintentional effects through interaction with the new group organization? What happened within and between groups and production units?*

The reseachers had the further aim of evaluating the various combinations of tasks that had been tested from the perspective of the work environment. *Were the combinations offered to and tried by the telephonists adequate in terms of eliminating the deficiencies that had been reported?*

METHODS AND MATERIALS

The study took the form of a longitudinal research into the three-year reorganization at Swedish Telecom Services. (Figure 2)

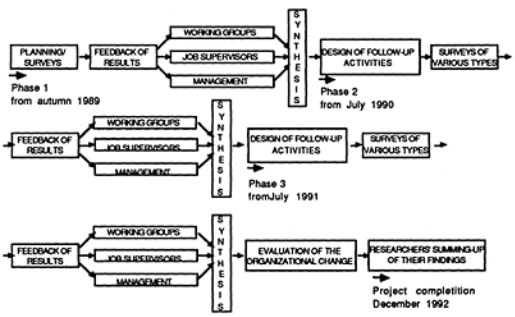

Figure 2. The course of the research—interaction between the researchers and the company

Data were collected through a mixture of questionnaire surveys and working group discussions, using data obtained from the questionnaires as a key element in the discussions. Questionnaire data were used to establish which task combinations prevailed at which points in time, both for the staff as a whole and for personnel within the various working groups. Task structure was related to the telephonists' own evaluations of their work, as these emerged from responses to the questions posed in the questionnaires. Questions on office design and work organization provided a basis for analyzing the nature of the interaction between the physical and organizational/social environments and whether the new office design had had the intended effect of reinforcing the new form of organization.

The findings from the surveys were presented by the researcher to the various working groups and to their job supervisors. A discussion took place in each working group over what the findings had provided, what the group itself could confirm to be true, and what the group wished to investigate, improve or develop further. The researchers supplied accounts of experiences from other workplaces and views on the value of the findings of the surveys, making suggestions as to what might be included in subsequent phase.

Table 1. Number of telephonists covered by the study at phases 1 and 2, plus number of missing cases.

	Phase 1	Phase 2	(Phase 3)
Invited	N=223	N=280	Not included
Participated	N=216	N=269	in this paper
Missing cases	n=7(3%)	n=11(4%)	

RESULTS

The new premises

The premises were rebuild in accordance with the ideas put forward on how the new organization should function. This was achieved in the following manner. Inside TELI's former factory building a "village", perhaps better described as an "area of terraced houses", was constructed, where each group had its own "family house".

Each house contained 8 telephonists' desks of its own, which were shared by the group's 20–24 members at different times of the day and night, plus a private room for the job supervisor. The "houses" were located so that there were "streets and squares" between them. Located there were also communal "houses" for service tasks, meetings, and meal and other breaks. Here, it was thought, informal contacts between the groups could be developed.

The interaction between physical ervironment and organization

The vast majority of telephonists considered that the new premises represented a considerable improvement on the old. The telephonists also had greatly improved opportunities to set a personal stamp on their group's own working area. This was perceived as a highly favourable change in comparison with previous arrangements. With respect to various aspects of privacy, such as lack of opportunities to work in seclusion, or the possibility of being overheard or watched over, there was perceived to be no major difference between the old open-plan offices and the new group arrangement. Most telephonists did not express a complaint about this, in relation to either the previous open or the new group environment.

The design of the new premises made it easier to achieve the new organization's aim of promoting a sense of community within working groups. On the other hand at the same time, these groups, and particularly the three production units, came to regard their areas as their own territory and competition between them intensified (table 2). This was an unintended effect. The opportunities for spontaneous personal contact between groups deteriorated, which can be partly explained by the fact that the different production units also had their own rest rooms and canteens.

Table 2. Question: Do you think that there is a protective attitude towards territory…(N=269)

	Not at all	To a small extent	To quite a great extent	To a very great extent
a) within your own group?	70%	25%	4%	1%
b) between groups in your production unit?	35%	45%	18%	2%
c) between production units?	15%	27%	42%	16%

The development of a new computer system took considerably longer than estimated. The aim of equipping each telephonist's desk with facilities for dealing with all types of traffic had still not been achieved after two years. This placed unplanned demands for flexibility on the organization: i.e. telephonists needed to move from their own group space to that of another group in order to deal with various types of traffic at off-peak hours. The resistance of telephonists to working in the space of another group became so great that any attempt to persuade personnel to work on other premises had to be abandoned. Identification with one's own group had become very strong, while a sense that Telecom Services was a unit in its own right had diminished (table 3 and 4).

Table 3. Question: What do you feel about the sense of community and degree of cooperation…(N=269)

	Very good	Quite good	Rather poor	Very poor
a) within your own group?	45%	49%	5%	1%
b) among groups in your production unit?	9%	57%	28%	6%
c) among production units?	1%	13%	45%	41%

The old environment was equipped with queue displays, showing how many calls were waiting. These were removed in the new premises, with the result that the telephonist's personal control over the traffic was reduced: it was no longer possible to plan breaks according to the traffic situation. When telephonists took a break, they did not know whether a small or a large number of calls were waiting. Moreover, with the new (partitioned) office design, it was not possible for them to see who else was at their work station, which was why too many could take a break at the same time. This was a contributory reason for why answering times often became unacceptably long. After two years, queue displays were reinstalled in all group rooms.

Table 4. Question: If you think back on the old arrangements and compare them with what it is like with the new premises, are things better, worse or the same with respect to…(N=167)

	Much better	No dif ference	Much worse
a) sense of community within your own group?	51%	40%	9%
b) sense of community among groups?	16%	35%	49%
c) feeling of community within Telecom Services as a whole?	22%	34%	44%
d) job contentment?	50%	22%	28%
e) work efficiency?	28%	46%	26%
f) your overall impression of the premises?	84%	7%	9%

Combinations of tasks

Excessive answering times were also one of the reasons why it was difficult to implement the new ideas on variation in job tasks (through the introduction of so-called service tasks) to the extent that originally had been intended. Traffic work, which was the activity that provided income and was a precondition for the survival of the company, had to be given priority. After two years, just over half of the telephonists had been allocated one or a couple of tasks in addition to traffic work. Of these, around a half considered that the amount of time devoted to these tasks was far too limited to provide either satisfactory job variation or an opportunity to recover from terminal-intensive traffic work. A further problem was to find job tasks that both benefitted the company and were meaningful and a source of skills development from the point of view of the telephonists. This became a central point of discussion as the project developed.

DISCUSSION

The design of the study—a longitudinal research project covering a period of three years—provided unique opportunities to follow the program for change at Swedish Telecom Services, and to monitor the course of events over time. The results demonstrate the importance of seeing organizational change as a whole and of making specific interventions with respect to its various elements: the physical, social and organizational environments. But, it also shows that unforeseen events can occur and that a variety of measures may have unpredicted effects over time. These also need to be followed up in a systematic manner.

The original idea lying behind the new design of the premises, that of promoting a sense of group community, was clearly successful, but it also had the unintended effects of creating a territorial outlook and promoting competition between both groups and units. By contrast with the old open-plan format, the new office layout was rigid and inflexible in comparison. No attempt had been made to achieve flexibility at the planning stage; rather, the aim was to generate a sense of stability and give roots to group identity.

When the new computer system did not come into operation as planned, this became a source of conflict in terms of the interaction between the physical and organizational environments. It was just this system that was designed to provide flexibility—by making it possible for all types of traffic to be directed to each and every telephonist's desk. When traffic bottlenecks arose, it was demanded that the telephonists themselfs should provide the necessary operational flexibility—by moving to desks normally occupied by other groups. This had been normal in the previous open environment, but not after a sense of belonging to a group and the group's own work space had developed.

The social environment was improved within groups but was worsened between groups, and especially between production units. This latter effect may have been less pronounced if, at least, certain communal areas had been made available, e.g. rest rooms and canteens.

The transformation in job routines, which it was hoped should be accomplished by introducing "service work", progressed extremely slowly. One important reason for this was that priority had to be given to traffic work when answering times became too slow. But, it may also be explained by the fact that it was difficult to find job tasks which naturally supplemented telephonist's work and could be integrated into it—both from the perspective of the company and in terms of the telephonists' own occupational development.

This extended case study forms one part of a larger research project. In this case, there has been a conscious striving to achieve the mutual adaptation of the organization and the physical environment. In other cases, the primary emphasis has been on the organization, and physical conditions have had to be accepted in the light of organizational requirements. Or, the opposite has applied: the design of the premises has been of primary importance, but this has not been triggered off by organizational demands or needs.

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APPLICATION OF SYSTEM METHODOLOGIES TO MACROERGONOMIC DIAGNOSING

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The paper present the macroergonomic diagnosing methodology of the manufacturing systems redesign and design. Fundamental methodical conceptions combine the analytic research procedure and industrial aplication in one methodical system. Investigations of three types: detailed, causal and comparative make the basic diagnosis more profound and verify it. Are provided both variety application of worked out methodology and results of the development research for theory and practice requirements.

INTRODUCTION

At the present stage of development—ergonomics, as an interdyscyplinary applied science, is under the neccesity to work out propriety, complex methods of manufacturing systems modernizing and designing, according to requirements both current industrial practice and real—life.

Several years since the new term “macroergonomics” appears (e.g. Hendrick, 1987, Jahns, 1991).

Hendrick (1987) found that ergonomics has experienced three generation of development. First generation: human—machine interface technology, second generation: user—system interface technology and third generation—machine interface technology. The last generation first of all is a result of the progressively increasing automation of factory. Most of the work of the first two generation was focused on the design of specific jobs, work groups, and related human—machine interfaces. So first and second generation have represented applications at the subsystem level or “microergonomic” level.

The emerging third generation is focused at the “macroergonomic” or overall organization—machine system level and concentrates on the development and application of organization—machine interface technology. One cannot effectively design specific atomistic components of a manufacturing system without first making scientific decision about the overall organization, including how it is to be managed. The start—point and essence of the manufacturing system macroergonomic design or redesign is assessment of mentioned, on the basis of diagnostic approaches, using suitable methods.

The paper present the result of many years’ methotol ogical research works on the manufacturing systems macroergonomic diagnosing, in order theirs modifying and designing in a complex way. Research has been carried out within the Department of Industrial Engineering at the Technical University of Poznań. The methodological conception were veryfied and put into practice at several Polish productive plants.

METHOD

Basic methodical conception of macroergonomic diagnosing

The manufacturing systems are defined as statystic and dynamic combinations of human, physical and financial resources which transform input feed (work, means of work, objects of work and informations) into output states exhibited in material form (industrial goods, material services) or in a form of information. The basis of the marcoergonomic diagnosis of the manufacturing system makes the analytic procedures of the input data, so called diagnostic symptoms of the system under egzamination. Research procedures are based on a checklist, enclosing the macroergonomic subject field. Questions included in the list assume the form of the hierarchic, three degrees schedule, connected with detailed evaluation criteria (standards, ergonomic requirements).

The macroergonomic subject field is divided into 22 main issues, presented below:

1/ The parametres of the working area
2/ The problem of seats
3/ The floor
4/ The equipment of the work stand
5/ The acoustic and tangible reception of information
6/ Decision making
7/ The visual reception of information
8/ The psychological burden connected with controlling
9/ The burdening of effectors connected with controlling
10/ Vibrations in human’s working envinroment
11/ Noise in human’s working envinroment
12/ Light in the work stand
13/ Pollution by dust and toxic compound
14/ Microclimate in human’s working envinroment
15/ The emission of energy harmful for the worker
16/ Posture during work
17/ The structure of the movements connected with service at the work stand

18/ Muscule burden
19/ The univocal character of the signal used
20/ The rate and the quality of information connected with the organization of work
21/ The possibility of committing simple errors
22/ The rytm and rate of work

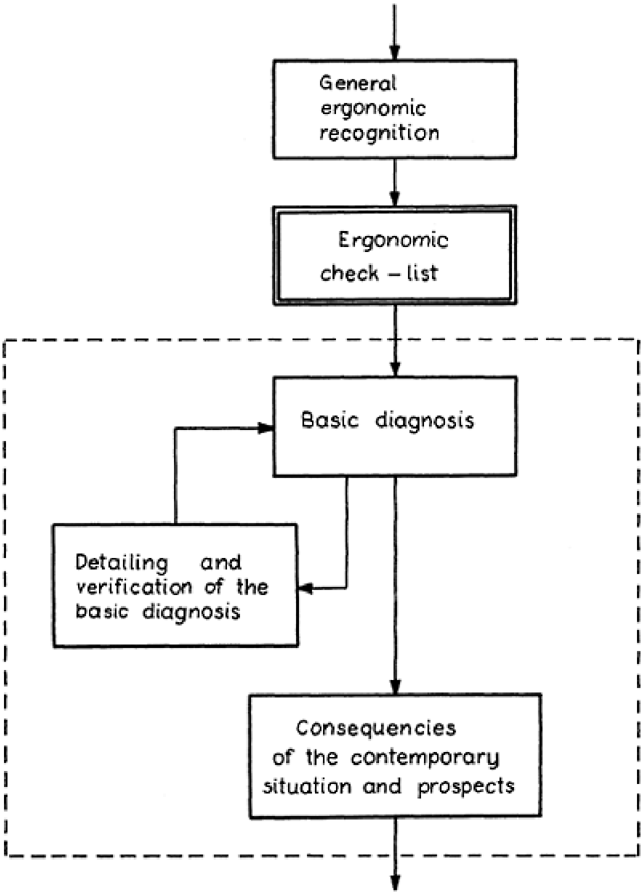

Fig. 1. The general form of the diagnostics methods development cycle.

The macroergonomic approach to the manufacturing system diagnosis causes in the range of methodical conception, that diagnostic methods expand with the prospect of a further development of the examined system; the prospect being related to diagnostic methods. It has been assumed, the evolution of investigative methods in ergonomics as a science should be originated from research based on a check—list and develop them in two directions.

On the one hand check list must be based on the so called general ergonomic recognition; on the other hand research should be directed toward making the basic recognition more detailed and verified.

The block diagram of the general methodical conceptions is showed on the Fig. 1.

Formulation of the basic diagnosis of the manufacturing sys-

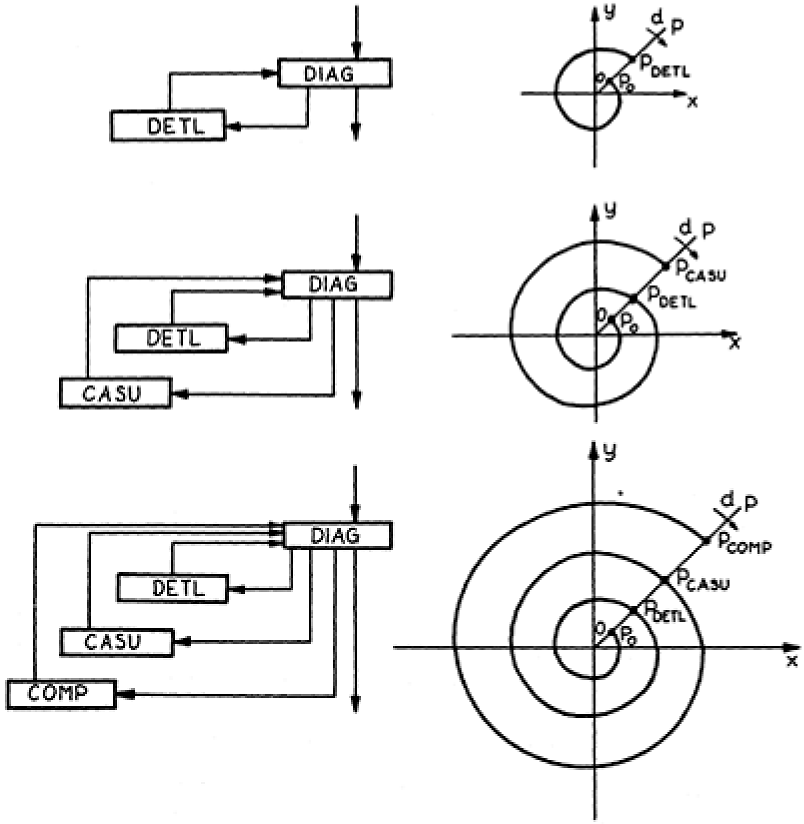

Fig. 2. Progressive extension of the ergonomic subject area.

tem is executed by experts in three stages mode: it takes into consideration:

– opinions of an ergonomic team,
– opinions of workers in direct production,
– results of measurements taken at particular facilities of the production system.

The complete cycle of the manufacturing system diagnostics i nvest i gati i on, on the macroergonomic base realized, should comprise investigation of “three types:

– detailed diagnosis (DETL)

– causal diagnosis (CASU)
– comparative diagnosis (COMP).

Above cycle, presented on the Fig. 2., make the basic diagnosis more profound and verify it.

The first stage of diagnostic investigation: DETL (detailed diagnosing) enable to obtain necessary ergonomic data in order setting up the modernizing activities within the system under examination in a complex way.

Two last stage of diagnostic investigation: CASU (causal diagnosing) and COMP (comparative diagnosing) are connected with the current redesing and development of system, if necessary is answer the question like: what prospects? what do we do we now? how directions activities from the system development viewpoint? All three stages of diagnosis: (DETL), (CASU), (COMP), are connected also with progressive extension of the ergonomic subject area, what ilustrate Fig. 2.

Fig. 2. makes detailed spread of the—distincted part of the Fig. 1.

Ergonomic data on the system and single subsystem level

Mentioned earlier check list make the basis of the research procedures relating to manufacturing system under examination. The list correspond to the 1ist of modernizing activities. Conception of the systems diagnosing on the macroergonomic approaches base has been designed for use computer data processing.

Due to interdisciplinary character of diagnostics evaluation (made in a multiobject manufacturing system) a basic ergonomic diagnosis assumes the matrix form.

Computer analysis of the matrix—the worked out mathematical formulas aided—permit to designate:

– factors of preference for the modernizing activities on the system level,
– priorities of modernizing activities on the system level,
– global index of “ergonomicity” of the examined system,
– global indices of “ergonomicity” of the single human—machine subsystems.

RESULTS

Presented in this paper methodological conception were verified and put into practice at several Polish productive plants, especially in metal industry, also in woodworking industry and power industry.

Practical application of the macroergonomic diagnosing methodology allows to control the level of working conditions quality in a complex way.

The scale of control1ing to cover: manufacturing system under examination, complex systems of a plant and the group of establi shments.

Application of the macroergonomic approach to the manufacturing systems design, especially redesign enclose:

– changes of the character of the technological process,
– machine and production facilities modernization,

– improving organization and equipping of work stands,
– redesign production structures and methods of current management of a production run.

CONCLUSIONS

Several years since the opinions within the human factors/ergonomics area are emerging, that an attempted research are frequently overly specialized and are limited to findings, that has little or no generalizabi1ity to other problems. It does very little to generate new knowledge within the field and move the field forward. On the other hand, quality of the more general research is criticized.

Prezented in this paper ergonomic diagnosing methodology in the "macro"—scale is an attempt of the above mentioned charges answering.

Basic methodical conception, in different industrial conditions realized, the emergence of the new, particular research problems caused. Solving of this detailed problems (e.g. Pacholski and Mateja, 1982, Pacholski and Jasiak, 1982, Pacholski, 1988, Jasiak, 1991) makes the advances both in theory and practice of ergonomics, connected with the main direction of the systems diagnosis approache (Pacholski, 1982).

The multistage macroergonomic diagnosis of manufacturing systems is closely connected with general systems improvement and development.

The particular stages of diagnosing methodology: (DETL), (CASU), (COMP)—combine the increase of systems technical level (modern technology, automation, computerization) with the increase of systems "ergonomicity" level. It seems, that above approach outlines the new complex, and coherent development trends of human factors/ergonomic area. Many problems of these trends, in macroergonomics aspect, extend the traditional domain of human factors/ergonomics.

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STATUS OF MANUAL, HYBRID, AND AUTOMATED INSPECTION RESEARCH AND APPLICATION

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Inspection is a necessary activity that controls the outgoing product quality and involves search, detection, and measurement or diagnosis. Traditionally, inspection tasks have been allocated to humans. Attempts to automate industrial inspection, in order to eliminate errors and alleviate monotony, have faced difficulties due to technological limitations and/or prohibitive implementation costs. An occasional compromise is partial automation (hybrid inspection). This paper reviews published research in manual, hybrid, and automated inspection to understand the current research status.

INTRODUCTION

Quality control is mainly concerned with detecting problems and then taking corrective actions. Inspection is a critical activity in the overall control of product quality and identifies good products from bad. Inspection is carried out before and during manufacturing, and after the completion of manufacturing process to ensure that the outgoing product quality level is consistent with the design standards and the product will meet users' expectations. Thus inspection is one of the most important manufacturing activities.

Traditionally, inspection has been performed manually. Unfortunately, manual inspection activity is not error-free (Hayes, 1950; Fox and Haslegrave, 1969; Carroll 1969; Drury and Addison, 1973). An inspector may label a good item defective (false alarm) and a defective a good item (miss). It is critical that these errors are reduced, if not completely eliminated, since significant tangible and intangible costs, such as customer complaints and rejection of lots, are associated with them.

Inspection can also be carried out in automated (completely automatic) and hybrid (partially manual and partially automatic) modes. Recent technological developments in pattern recognition, image processing and computer vision have led to increased potential for automated inspection. Monotony and errors in manual inspection are impetus for this increased emphasis. However, technical limitations and higher implementation costs associated with automated inspection still leave a majority of inspection tasks to humans. Occasionally, partially automated systems (hybrid) are installed as acompromise. For automation to be successful, it is imperative that both designers and practitioners understand the factors that influence inspection performance and then allocate various inspections functions to humans and machines.

The objective of this paper is to review published research in manual, hybrid, and automated inspection and draw conclusions to improve the effectiveness of inspection activities.

INSPECTION TAXONOMY

Industrial inspection can be categorized as: (1) monitoring-where inspector monitors the processes for deviations from normal or acceptable, (2) examining-where inspector searches for defects in the items, (3) measurement-where inspector, using instruments and tools makes decision about the status of an item as good or defective, and (4) patrolling-where inspector checks and organizes others work. Among these, examining a part is an activity that both humans and machines can perform satisfactorily. While machines are more suitable for monitoring and measurement activities, humans are more adapt in patrolling work (Czaja and Drury, 1981a, b).

MANUAL INSPECTION

Manual inspection activity involves detecting defects and, based upon the type of defect, making a judgement whether to accept, reject or rework the part. The entire activity involves a search, fault recognition, and finally decision-making. The factors that affect inspection performance can be categorized as job related factors, organizational factors, environmental factors, motivational factors, and personal factors.

Job-related factors

Many researchers have investigated the effects of various job-related factors on inspection performance. These studies are grouped by the factor and briefly reviewed here.

Self-pacing versus external-pacing. McFarling and Heimstra (1975) studied inspection of printed circuit boards and observed that self-paced inspectors caught more defectives when given a choice to work at their pace. The inspectors also rated self-paced inspection to be more comfortable than when required to maintain a certain pace (machine or forced pace). Elwany et al. (1981) in inspection of steel washers (32 mm dia and 1.8 mm thickness) found that as the viewing time per unit increased, from 0.25s to 0.75s, the inspection efficiency increased. The inspection efficiency, defined as the ratio of number of non conforming parts rejected to total number of non conforming parts, also decreased with increase in belt speed. The authors also found that as the percentage defectives increased, the average inspection efficiency increased. Peddada and Bennett (1984), in inspection of pennies, found that as the machine pace changed from 90, 100, 110, 120, and 130 percent of self pace rate, fewer defectives were identified, although more pennies were inspected. The task was also perceived more difficult as the pace increased.

In Eskew and Riche's study (1982), machine-paced and self-paced inspectors performed inspection of electrical schematics simultaneously. The self-paced inspector had superior performance due to control of information presentation. Schlegel and Beneke (1986) reported that for machine-paced task, inspection accuracy increased when the viewing time was increased. No difference between self-paced and machine-paced performance existed provided the viewing time was sufficient. The time required for inspection increased, as expected, with increase in flaws.

The studies reviewed here lead us to conclude that, in general, manual inspection, when self-paced, is better than force-paced inspection. However, when machine pacing is the same as self-pacing or when there is sufficient time for inspection, performance differences that can be attributed to pacing do not exist. Self-pacing is expected to be superior since the inspector has a greater control over the inspection activity. Furthermore, self-pacing provides opportunities for the inspector to overcome short-term effects of fatigue.

Multiple product flaws and task complexity. Neisser et al. (1963) reported that up to 10 product characteristics could be simultaneously searched for as quickly as a single characteristics. Matthews (1986) reported that searching for two faults was as accurate as searching for a single fault when the faults were located on the same component, although with increase in search time. But with size defects, i.e. undersize or oversize, there was a reduction in inspection accuracy with increase in search time. The combination of size and form defects also resulted in accuracy decrement and increase in search time. When inspectors attempt to maintain the after inspection quality (outgoing quality) level constant, or improve it, fault detection performance drops (Drury and Addison, 1973).

Noro (1980) showed that time required remained virtually unchanged when the number of defects ranged from 1 to 4, but as the number of defects increased beyond 4, time required showed marked increase. Gallwey and Drury (1986) also found that additional faults (different types) deteriorated performance during the search phase. They further observed that distribution of faults, whether they occurred in predetermined region or over the whole item, had no effect on the performance.

Kochhar and Pelosi (1981) observed that performance with symmetric geometric shapes is much better than with random shapes. In general, one can conclude that inspection performance deteriorates with task complexity and variety of flaws.

Inspection time. One would, intuitively, expect inspection accuracy to improve with the inspection duration. This expectation has not always been substantiated. Drury (1975), for instance, reported that if the time to inspect metal sheets is increased, the percentage of both correct rejection of flawed objects as well as incorrect rejection of acceptable objects increased. Teichner and Mocharnuk (1979) found that as the number of stimuli displayed increases the total stimulus information and the stimulus processing rate also increase. Kochhar and Pelosi (1981) reported that as the viewing time is increased the percentage of correct responses increase. The worst case performance was observed for the shortest viewing time and the best performance was observed for the longest viewing time. Megaw and Richardson (1979), on the other hand, did not find increases in search time with introduction of target uncertainty.

Fault density. Drury and Addison (1973) found that the fault detection performance drops with decrease in fault density. However, Elwany et al. (1981) showed that inspection efficiency improves with increase in either the defects percentage or the viewing time. They also indicated a decay in performance over an extended work period (120 minutes).

Frequency of defects. Vigilance literature suggests that performance deteriorates with prolonged attention. Jenkins (1958) has shown that as the number of signals to be detected increase the number of correct responses also increase.

Inspection method. There are two ways to inspect multiple faults. The first is one item at a time where each Item is inspected for all the defects resulting in minimum physical work and maximum mental work. The second method is to inspect for one defect at a time where all items are examined for one type of defect at a time resulting in maximum physical work and minimum mental work. Su and Konz (1981) reported that inspection time was higher for one defect at a time method although fewer errors were made compared to inspecting one item at a time.

Tactile inspection. Kleiner et al. (1987) reported that crack detection probability increases with increase in crack width and decrease in the probe-tip diameter. The vision did not contribute to the performance. The work is considered significant in the area of tactile inspection and for understanding the possibility of accommodating visually impaired people for such jobs. Desai and Konz (1983) examined the effect of gloves on tactile inspection performance while testing hydraulic hoses with base hand, surgeon’s gloves, playtex gloves, vinyl-impregnated gloves. They found that for good and bad hoses, gloves did not affect the error-rate for either diameter or surface defects.

Environmental factors

Search during inspection predominantly depends upon human visual abilities. Therefore, variables that affect visual performance are critical. Wei and Konz (1978) reported that targets larger than 2.5 min. of arc do not require magnification whereas targets below 2.5 min. of arc do. The time of performance also increases with decrease in illumination. Illumination, however did not have any effect on errors. Misra and Bennett (1981) examined the effect of colored lighting for the detection of “red dumet” defects in fluorescent lamp mounts. They found that blue lighting increased the hit rate for this defect but other defect detections were not affected.

Organizational factors

Self-inspection. In self-inspection, production personnel are also responsible for the quality of the product. It can be hypothesized that since the same person performs both the jobs, the job is enlarged and hence the effect of monotony is reduced up to certain extent. Other possible advantages of self-inspection include direct feedback, less time for detection, fewer quality characteristics per operator (Knight and Thomas, 1986). However, there is no strong evidence to suggest the advantage of self-inspection at this time.

Two inspectors. In order to improve the effectiveness of inspection, two inspectors can be assigned to the task. The inspectors can be paired in 5 different ways: each inspector inspects half the batch, item is accepted only if both inspectors accept it, item is rejected only if both of them reject it, item is reinspected only if it is accepted, and item is reinspected only if it is rejected. Drury et al. (1986) reported that the first case does not offer any advantage over single inspector and is not advantageous than having the better inspector inspect the whole batch. Their findings are as follows: better inspectors give better results, the incoming quality has no effect on the system performance indicating that the two inspectors together can overcome the fault-rate effect, and it makes little difference which inspector inspects first if the payoff matrix is optimized.

Arrangement of material and working in pairs. Lion et al. (1975) assessed the performance on a single line, 3-line, 6-line and working in pairs. They did not observe any significant difference between the mean score of subjects who sat at the right and left hand side of the conveyor. The mean number of errors decreased significantly from single line to 3-line to 6-line belt. When operators worked in pairs they made fewer errors compared to working alone. They also found that even though the number of items displayed per unit time was the same for single and 3-line conveyor, subjects found the single line more difficult and made more errors in inspection. The same time per unit was achieved by change in speed for single and 3-line conveyor.

Motivational factors

Knowledge of Results or Feedback. Drury and Addison (1973) demonstrated that introduction of more rapid feedback of performance to inspectors after 12 weeks of study significantly reduced the percentage of misses (by half). Micalizzi and Goldberg (1989) showed that knowledge of results significantly increased the sensitivity of inspection and the time to make a decision decreased.

Training. Embrey (1979) has outlined four different approaches to training: knowledge of results (KR), cuing, whole, and feature analysis approach. KR involves providing knowledge of the outcome of response. Cuing involves presentation of a series of good and bad Items. The whole approach requires presentation of the item in intact form. The feature-analysis involves synthesis of separate aspects or features of the defect.

Czaja and Drury (1981a), using active and passive training schemes, showed that active training scheme, rather than a passive training scheme, significantly reduces number of task errors. Goldberg and Gibson (1986) also confirmed this finding when they found that randomized and logically ordered training manuals did not affect the inspection miss rates. They also demonstrated that checklist is useful but only if it is arranged logically.

Personal factors

Age. Response time decreases with age and sensory and perceptual skills deteriorate. Drury and Sheehan (1969) reported a decline in detection with age and a significant negative correlation between sensitivity, in terms of Signal Detection Theory, and age. Czaja and Drury (1981a) found that search time increases with increase in age because of the slowing of central perceptual processes. In an another study reported by them (1981b), they further found that with increase in age, search time and overall errors both increase. However, Jamieson (1966) found an increase in accuracy with increase in age. Evans (1951) did not observe any age effect.

Gender. Information on gender effect on inspection is scanty. In earlier studies, reported by Gale et al. (1972), no gender differences were found. Mikami et al. (1988) found that there was no difference in the ocular accommodation functions of male and female workers although the occurrence of weariness, desire to change, feelings of fatigue, and level of consciousness were lower in female workers. Based on the number of grasping errors and number of finished parts the authors concluded that work efficiency of female workers is higher than those of male workers.

Individual differences. Schwabish and Drury (1984) classified subjects into four groups: reflectives (longer times, fewer errors), impulsives (shorter times, more errors), fast-accurates (shorter times, fewer errors), and slow-inaccurates (longer times, more errors) using Matching Familiar Figures test (MFFT). From the results of the laboratory visual inspection task they found that reflectives and fast-accurates were significantly faster than impulsives and slow-inaccurates in detecting certain flaws and they also made fewer judgement errors. The impulsives and slow-inaccurates detected more flaws. Schoonard et al. (1973) found that modal duration of eye fixations of trained inspectors was about 200 msec. The most accurate inspectors made the fewest eye fixations and were fastest.

Visual Acuity. Static foveal acuity is a measure of the minimum angle subtended by the test object at the eye that can be resolved. Johnston (1965) reported that search speed and foveal acuity were not correlated. Erickson (1964) found that search time was negatively correlated with peripheral acuity, and foveal acuity and search time were not correlated. Both Johnston and Erickson found a lack of correlation between foveal and peripheral acuity. Similar conclusion was drawn by Bellamy and Courtney (1981). Harris and Chaney (1969) found that foveal acuity was not a good predictor of inspection performance. Smith (1961) and Leachtenaur (1978) also indicated that search performance and peripheral acuity are related for targets surrounded by non-targets. In general, it has been shown that the foveal acuity does not affect search performance but higher the peripheral acuity, higher the search speed.

HYBRID INSPECTION

Attempts to improve inspection efficiency led to hybrid (semi-automated) inspection systems. Hybrid systems are systems that aid inspection by automating some of the activities. Drury and Sinclair (1983) identified two types of inspection activities which can be possibly automated: monitoring, where inspector acts as a monitor observing a continuous process to identify any deviation and measuring, where inspector uses instruments and measuring tools to give numerical measures. Patrolling, which involves checking and organizing work of other inspectors, is solely for humans unless machines check human performance, a socially unacceptable proposition at this time. Examining, wherein inspector has to search items or array of Items for defects without numerical measurement, is receiving much attention these days from designers. In the study, Drury and Sinclair compared human and machine performances using small steel cylinders varying from 7 to 11 mm in length and diameter. The fault types considered were: nicks, dents, toolmarks, scratches, and pits. They found that neither humans nor machines gave an outstanding performance, in particular for low-contrast faults such as nicks and dents. Inspection device could locate most faults but was not able to classify them as acceptable or rejectable as consistently as humans. In general, humans did better than the machines because of their more sophisticated decision-making capabilities and possibly also because of very high motivation of inspectors as indicated by longer than normal times for inspection.

It is well known that comparative judgement is more accurate than absolute judgement. By providing physical examples and specifications of good or bad items, which are readily available, inspection performance can be improved (Harris and Chaney, 1969). There are two ways of providing opportunities for comparative judgement to a inspector: (1) using a static overlay which is placed on top of the item to be inspected; any difference between the overlay and the item is shown in a contrasting manner and (2) using a temporal alternating of the item to be inspected with a known perfect item, both items being registered on the same visual field; any difference between two items will appear to blink on and off, while rest of the field remains steady.

Teel et al. (1968) evaluated the photomask overlay for the inspection of microelectronic circuits and concluded that for some defects the performance improved significantly. Harris and Chaney (1969) also reported that with the use of negative and colored overlays the number of missed defects reduced as compared to without overlays.

The second method has been used by astronomers for a long time for detecting planets and changing stars against constant background of starts. In fact, the Blink Microscope was used in 1930 to detect the planet Pluto (Liuzzo and Drury, 1980). Smith and Goodwin (1971) found shorter search times with blinking using alphanumeric characters. They observed less improvement when the number of background Items in the search field were lower and suggested no improvement for a single target with blinking. Liuzzo and Drury (1980) also observed improvement in search time with blink inspection but the degree of improvement was not equal for different defects. They also indicated that for a blank field inspection task, blinking gave a significantly worse performance than without Winking. They further mentioned that the heart rate measures did not indicate that task was stressful.

In an another study of inspection of printed circuit boards, with the commercially available blink comparator, Drury and Kleiner (1984) found that the difference between blink aided inspection and manual inspection was minimal. Error rates for both modes were also closely comparable, although for missing components the blink comparator was superior to free manual inspection. Goldberg and O’Rourke (1987), using a programmable sliding table, observed that the defect detection ability was dependent upon the size and probability of the defect.

The review indicates that, in general, automated equipment tends to aid manual inspection.

AUTOMATED INSPECTION

It is not possible to review all the technological developments in vision systems, pattern recognition and image processing to date in order to make judgements about the feasibility of automation in the short space here. However, it can be stated that technological developments are still long ways from making a major portion of inspection automatic in most routine situations. Wherever technically feasible, the decision to automate inspection is based on economic considerations (e.g, the cost of inspection itself, cost of faulty inspection, etc.). Even though automated visual inspection (AVI) systems have been around for more than a decade, the number of installed systems is small due to its high cost of customization: design of optics, and lighting systems, complex configuration, and programming of the vision system.

Scott (1982) has outlined the reasons for automated inspection. He states that products should fulfill at least one of the following conditions in order to justify automated inspection: inspection time and number of inspectors are very large, inspection is a part of automated assembly process, products are produced in very large number or are extremely complex, high cost penalties apply If products deviate from standard, quality standards are objective criteria and are readily definable, calculations are needed to determine the good or bad status, and products are produced in large number and 100 % inspection is a must but cannot be performed manually. The primary reason for shifting to computer vision based inspection are slow and error-prone performance, subjectivity involved in decision, and appreciable waste of manual inspection.

The inspection of printed circuit boards using the specially designed machines, primarily vision systems, for detection of defects such as breaks, cracks, overlaps, change of widths, and soldering defects is now routine (Jarvis, 1980; West, 1984; Mandeville, 1985; Ahluwalia and Sitaraman, 1989). Bose and Kim (1989) have developed vision algorithms for identifying defects of chip-bonding process such as missing chip, misregistration of the chip, scratches, edge cracks, surface contamination, misorientation, poor eutectic flow, and carrier damage.

Harned and Holcman (1987) present an overview of robotic gauging and inspection systems, particularly in the context of flexible manufacturing systems. They describe two applications: first, in the tube assembly inspection where the measurement of tube end locations is performed and second, in the chassis rail inspection where inspection is performed off-line. The inspection is carried out by both optical and vision sensors. The optical sensors measure coordinates at selected surface locations, whereas vision sensors measure radii, hole location and diameters. In an another example defects on the sheet metal such as dings, dents, scratches, and paint defects are identified by robot vision (Pastorius, 1987). A white light source or laser source is directed at the surface to be inspected then the reflected light is sensed and digitized and with complex algorithms scanning to detect such defects is performed.

Toutant (1987) describes another application of robot inspection applied to microwave cavity inspection for sampling cavities from assembly and weldline, and to monitor dimensional tolerance specifications. Unfortunately, the reason for selecting robot inspection method was not very convincing.

It Is worth mentioning here that some inspection activities involve examination of properties and cannot be performed by humans. There are various methods that can be applied for such applications (Robinson and Miller, 1989).

The prominent applications of automated inspection systems used in automobile industries include: checking the number of holes, sorting castings, checking the presence of valve-spring retainer keys, inspecting cylinder heads, timing gears, and valve ring retainers, checking precombustion chambers, measuring, identifying, and inspecting flywheel, cylinder block, crankshaft, etc., inspecting stampings for cracks, breaks, and tears in certain areas due to stresses induced during drawing operation, etc. Engine casting is another example where the vision system is being used by the automobile industry. Film manufacturing industries are using vision systems for checking film cartridges. Vision systems are also finding applications in pharmaceutical industries to identify the absence of product, broken tablets, presence of foreign objects, and wrong products. This list simply emphasizes that there are applications where automated inspection systems perform better and are more desirable than manual inspection because of the size, shape, volume of the product, need to avoid any possible contaminations, extremely high litigation costs, and slow and boring human inspection process.

In short, the primary application of automated inspection is in the area of measurements and gaging and some in examining (e.g., PCBs) type of inspection activities. With advancements in technology, it is clear that inspection activity is going to be automated provided it is economically justifiable.

CONCLUSIONS

Inspection taxonomy classifies inspection activity into four general categories: measurements, monitoring, examining and patrolling. With the current technology, measurements and monitoring and some classes of examining can be automated. However, manual inspection is still required for examining and patrolling. The factors which favor automated inspection are high production volume, need for 100% inspection, large inspection time, large products, and higher litigation costs if faulty product is placed in the hands of customer. The manual inspection performance depends upon job-related factors, such as pacing, task complexity, defect rate, defect frequency, type and number of defects to be inspected, and available inspection time, environmental factors, such as lighting and magnification, organizational factors, such as self-inspection, multiple inspector, working in pairs, and organization of material, motivational factors, such as knowledge of results or feedback, payoff structure, and training, and personal factors, such as individual differences, visual acuity, age and sex.

Since it is difficult to achieve 100 % error-free performance in manual inspection and automated inspection may not be technically feasible or cost effective, designers must strive to improve manual inspection performance. The review of pertinent literature, provided here, can assist in improving inspection performance.

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THE APPLICATION OF PRODUCTION STANDARDS, PERFORMANCE FEEDB ACK AND MONETARY INCENTIVE TO IMPROVE WORKER SATISFACTION AND JOB ATTITUDES IN INDUSTRY

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The provision of assigned normal, assigned hard and participative standards with feedback improved worker satisfaction significantly in a repetitive production task in industry, when compared with the control condition with no standard and no feedback. The participative standard with feedback proved to be significantly superior to other experimental conditions when worker satisfaction was measured by the modified Job Diagnostic Survey (JDS) scales. However, no significant difference was found among the standards and feedback conditions when worker satisfaction was measured by the Job Descriptive Index (JDI) scales. Only the provision of a participative standard with feedback had a significant positive effect on worker job attitudes. Monetary incentive added no incremental satisfaction or job attitudes gain.

INTRODUCTION

Researchers in the past have studied the effects of goal setting and performance feedback on worker satisfaction and job attitudes. Research studies in goal setting have demonstrated that (1) hard goals generate less satisfaction and overall acceptance of task than easy goals, and (2) specific hard goals produce more interest and less boredom than "do your best" goals (Locke 1968). Another study showed that the hardest goal produced the highest performance but also produced the lowest degree of satisfaction (Locke et al. 1981). Performance feedback has often, but not invariably, elicited positive responses from operators that tasks are more interesting and less tiring when feedback is present (Ammons 1956). When a specific goal was provided with feedback, worker satisfaction improved significantly (Kim and Hamner 1976).

Goals could be either assigned to the operators or set participatively with the operator. It is believed that participation in goal setting has a positive impact on worker satisfaction and job attitudes. White et al. (1977) found that goal setting had no direct or positive effect on worker satisfaction. Ivancevich (1976) reported that participative goal setting was not superior to assigned goal setting in terms of worker satisfaction. Some studies have reported a decline in worker satisfaction in both assigned and participative goal setting conditions (Latham and Yulk 1976, Latham et al. 1978). When an assigned hard goal was provided with feedback, worker satisfaction and job attitudes improved significantly compared to the provision of an assigned hard goal or feedback alone (Das 1982). Often the combined effects of goal setting and feedback on worker satisfaction produced mixed results.

Monetary incentive is believed to have a positive effect on worker satisfaction and job attitudes. However, in the laboratory setting, monetary incentive had no effect on worker satisfaction and job attitudes (Das 1982).

Worker satisfaction is an emotional reaction which reflects value responses. It is a function of the perceived relationship between what the worker wants from his or her job or what he or she perceives it as being offered (Locke 1969, 1970). Differences in the nature of jobs or work situations cause differences in worker satisfaction. It is believed that both job content and context factors affect worker satisfaction on the job (Vroom 1964). Task satisfaction appears to be directly related to task success. Hamner and Harnet (1974) found that the subjects who exceeded their reference operators' outcome or performance were more satisfied than those who did not.

Worker job attitudes affect the way a worker functions in a task or work situation; consequently, an improvement in worker job attitudes will benefit industry. The terms "worker job attitudes" and "worker satisfaction" are typically used interchangeably in the literature, since both allude to effective worker orientation towards the job. Vroom (1964) has argued that positive attitudes are conceptually equivalent to worker satisfaction, and conversely, that negative attitudes are equivalent to worker dissatisfaction. Hackman and Lawler (1971) have identified four worker job attitude factors: (1) experienced work motivation, (2) job involvement, (3) general job satisfaction, and (4) specific job satisfaction.

Improving worker satisfaction and job attitudes especially in repetitive production tasks is a major concern for management. Often such tasks are perceived as monotonous, boring and fatiguing. This in turn, may result in reduced worker satisfaction and job attitudes. A considerable amount of research on goal setting and performance feedback was performed in the laboratory, only a limited number of studies were performed in a field setting. For most of the field studies with goal setting, the researchers had either omitted or discounted the possible effect of goal setting with feedback and monetary incentive. Often data were not collected objectively. Measured standards and repetitive tasks were never used in such studies. The main objective of this research was to investigate alternative application methods of production standards, performance feedback and monetary incentive that would produce a high level of worker satisfaction and job attitudes in a repetitive industrial production task.

METHOD

The details of the experimental method were described elsewhere (Shikdar 1991). The essentials of the experimental method relevant to the present research are stated below.

A large fish processing industry was selected to conduct the research. The selected task was a perch fish trimming operation, a highly repetitive production task. The task involved trimming and/or sorting perch fillets into four different product sizes. The work cycle time varied from 3 to 5 minutes. The cycle time comprised of processing one pan of incoming fillets of about 20 lbs. The workers were unionized.

The existing method of operation was standardized for the purpose of the research, Methods-Time Measurement (MTM) was used to determine the normal (100%) production standard. The hard standard was set at 140% of normal. The participative standard (above 100% normal) was set by the workers individually in consultation with the experimenter. Performance feedback was provided in terms of production output (lbs/hr., % of normal standard) every two hours on a feedback card in graphical form. Monetary incentive was based on a company policy (1:0.6).

The research was conducted on 48 industrial workers (male/female), having at least 6 months job experience and a minimum of 7th grade education. They took part in the investigation on a voluntary basis. The exact method of operation to be followed was explained to them. Operators were trained for one day to familiarize them with the standardized method. The workers/subjects were randomly assigned to six experimental groups, consisting of eight subjects in each group.

The groups received the following experimental conditions with respect to production standards (PS), performance feedback (PF) and monetary incentive (MI): (1) No PS/PF (control), (2) PS: Assigned 100% (normal)+PF (quantity and performance level), (3) PS: Assigned 140%+PF, (4) PS: Participative+PF, (5) PS: Assigned 140%+PF+MI, and (6) PS: Participative+PF+MI. The subjects worked under the experimental conditions for ten days over a ten-month period.

Worker satisfaction and job attitude scores were measured through questionnaires or subjective scales at the end of both training and experimental work sessions. Worker satisfaction scores were determined by employing two measures: (1) modified Job Diagnostic Survey (JDS) scales (Hackman and Lawler 1971, Hackman and Oldham 1975), and (2) Job Descriptive Index (JDI) scales (Smith et al. 1969). The second measure was used to compare or confirm the results obtained by the first measure. Worker job attitudes were measured by using JDS scales (Hackman and Lawler 1971, Hackman and Oldham 1975).

The modified JDS scales included the following job or work dimensions: (1) skill variety, (2) task identity, (3) task significance, (4) autonomy, (5) production standard, (6) performance feedback, (7) working conditions, (8) pay, (9) promotion, (10) supervision, and (11) co-workers. Each subject was asked to answer the questionnaires. It consisted of 24 questions on seven-point Likert-type scales regarding his or her perception of the various job attributes that were actually present.

The JDI scales measure worker satisfaction in terms of five aspects of the job: (1) work, (2) pay, (3) promotion, (4) supervision, and (5) co-workers. The work, pay, promotion, supervision and co-workers scales consisted of 18, 9, 9, 18 and 18 adjectives or phrases, respectively, with regard to each particular facet of the job. The subject was asked to put Y (or yes) beside an item if the item described the particular aspect of the operator’s job, N (or no), if the item did not describe that aspect, or ? if the operator could not decide. The following weights were used for direct scoring of JDI items: (1) 3 for Y to a positive item, (2) 3 for N to a negative item, (3) 1 for ? to any item, (4) 0 for Y to a negative item and (5) 0 for N to a positive item.

The JDS scales measure worker job attitudes in terms of four job attitude factors: (1) experienced work motivation, which is composed of both the amount of intrinsic motivation and the focus of worker motivation, (2) job involvement, (3) general job satisfaction, and (4) specific job satisfaction. For determination of worker job attitudes, each subject was asked 17 questions on a seven-point Likert-type response scale.

RESULTS

Both training and experimental data for worker satisfaction and job attitudes were summarized. The Statistical Analysis System (SAS) computer program (Ray 1982) was used to analyze the following experimental data: (1) worker satisfaction as measured by the modified JDS scales, (2) worker satisfaction as measured by the JDI scales, and (3) worker job attitudes as measured by the JDS scales.

Statistical Analysis of the Worker Satisfaction as Measured by the Modified JDS Scales

The results of the analysis of variance (ANOV A) showed that the differences among the six groups were highly significant ($F=3.97$, $p\leq 0.01$). It is believed that the individual differences in the perception or feeling of satisfaction might condition the outcomes of the experiment regarding the perceived worker satisfaction. To equalize the variation, an analysis of covariance (ANOCOVA) was performed with the experimental data using the corresponding training data as covariate. The results of the ANOCOVA showed that the differences among the groups were highly significant ($F=4.79$, $p<0.01$). Thus, the ANCOVA confirmed the results of the ANOVA. The covariate was also highly significant ($F=9.67$, $p<0.01$), a finding which indicated that the subject’s satisfaction score obtained after the training work session had a direct bearing on the subject’s score obtained after the experimental work session. The Student-Newman-Kuel’s (SNK) range test was then employed for a comparative analysis of worker satisfaction among groups. Adjusted group means were used for this purpose. The results of the SNK range test are presented in Table 1.

A comparison between Groups 2 (100%+Feedback) and 1 (control) showed that the provision of an assigned normal production standard and feedback had a highly significant positive effect on worker satisfaction. The specific standard made it clear to the operator what was expected of him or her, and feedback helped to reorient his or her action to meet the standard. These task attributes probably had contributed to the positive effect on worker satisfaction. Past studies have shown that task success causes improved satisfaction (Locke 1969).

Table 1. Student Newman-Kuel's (SNK) range test of worker satisfaction (modified JDS scales)

Groups	Groups/Differences in adjusted means between groups[a]→					
	1 (Control)	5 (PS: 140% +PF+MI)	3 (PS: 140% +PF)	6 (PS: Participative+PF+MI)	2 (PS: 100% +PF)	4 (PS: Participative+PF)
1	–	3.49**	4.02**	4.35**	4.93**	8.10**
5		–	0.53	0.86	1.44	4.61**
3			–	0.33	0.91	4.08**
6				–	0.58	3.75**
2					–	3.17**
4						–

[a] Groups in order of increasing differences in adjusted mean worker satisfaction score. Note: The adjusted mean score of Group 1=39.73.

The provision of an assigned hard standard (140%) with feedback (Group 3) was significantly better than Group 1. No significant difference was found between Groups 3 and 2. Stated otherwise, an assigned hard standard with feedback did not improve worker satisfaction over an assigned normal standard and feedback.

A comparison between Groups 4 (participative+feedback) and 1, showed that the provision of a participative standard with feedback improved worker satisfaction significantly. Highly significant differences were found between Groups 4 and 2 and Groups 4 and 3. Worker satisfaction for the participative condition was signficantly better than the assigned normal (100%) or assigned hard (140%) standard conditions. Participation in setting a standard or decision making probably lead to a higher level of worker satisfaction.

As disclosed by the comparison of Groups 5 and 1, the provision of monetary incentive in conjunction with an assigned hard standard and feedback had a highly significant positive effect on worker satisfaction. However, no significant difference was found between Groups 5 and 3. Consequently, monetary incentive had no effect on worker satisfaction. A comparison between Groups 6 (participative+feedback+monetary incentive) and 1 showed that worker satisfaction improved significantly as a consequence of a participative standard with feedback and monetary incentive. There was a significant negative difference in worker satisfaction between Groups 6 and 4. Stated otherwise, monetary incentive had a significant negative effect on worker satisfaction when provided with a participative standard and feedback. The most likely reasons for such a result were the perception that the monetary incentive was inadequate and the subjects felt the pressure to produce at a high level in a monetary incentive condition. Indeed the performance was maximum under this condition (Group 6). Past research results have shown that the highest performance produced the lowest degree of satisfaction (Locke et al. 1981).

Statistical Analysis of the Worker Satisfaction as Measured by the JDI Scales

This analysis will highlight the main results obtained by the JDI scales and any departure from the observations already made regarding worker satisfaction as measured by the modified JDS scales.

The ANOVA revealed that the differences among the six groups were not significant ($F=1.56$, $p<0.19$). This was contrary to the ANOVA results obtained from the modified JDS scales. However, the ANOCOVA showed that the differences among the groups were

Table 2. Student Newman-Kuel's (SNK) range test of worker satisfaction (JDI scales)

Groups	Groups/Differences in adjusted means between groups→					
	1 (Control)	6 (PS: Participative+PF+MI)	3 (PS: 140% +PF)	5 (PS: 140% +PF+MI)	4 (PS: Participative+PF)	2 (PS: 100% +PF)
1	–	12.83**	13.28**	16.60**	17.33**	22.74**
6		–	0.45	3.77	4.50	9.91
3			–	3.32	4.05	9.46
5				–	0.73	6.14
4					–	5.41
2						–

Note: The adjusted mean score of Group 1=99.12.

significant ($F=2.65$, $p<0.04$). Thus ANOCOVA reversed the conclusions derived earlier from ANOVA. Furthermore, the covariate was highly significant ($F=30.40$, $p\leq0.01$).

The results of the SNK range test are presented in Table 2. A highly significant difference was found between Groups 2 (100%+feedback) and 1. The provision of a normal standard and feedback had a significant positive effect on worker satisfaction. A similar result was found from the use of modified JDS scales.

A comparison between Groups 3 (140%+feedback) and 1 showed that the provision of an assigned hard standard with feedback had a significant positive effect on worker satisfaction. No significant difference was found between Groups 3 and 2. Again, similar results were found from the use of modified JDS scales.

The positive difference in worker satisfaction found between Groups 4 (participative+ feedback) and 1 was highly significant The provision of a participative standard with feed back had a significant positive effect on worker satisfaction. No significant difference was found between Groups 4 and 3 and Groups 4 and 2. A participative standard with feedback did not improve worker satisfaction over an assigned normal or hard standard and feedback. Significant differences were found between Groups 4 and 3 and Groups 4 and 2, when worker satisfaction was measured by the modified JDS scales.

A comparison between Groups 5 (140%+feedback+monetary incentive) and 1 and Groups 6 (participative+feedback+monetary incentive) and 1 revealed that worker satisfaction improved significantly as a consequence of the provision of an assigned hard or participative standard with feedback and monetary incentive, when compared to the control group. However, no significant difference was found between Groups 5 and 3 and Groups 6 and 4, indicating that monetary incentive had no incremental or beneficial effect on worker satisfaction. When modified JDS scales were used to measure worker satisfaction, no significant difference was found between Groups 5 and 3, but a negative significant difference was found between Groups 6 and 4.

Statistical Analysis of the Worker Job Attitudes as Measured by the JDS Scales

The ANOVA showed that the differences among the six groups were significant ($F=2.51$, $p<0.04$). The ANOCOVA revealed that the differences among the six groups were highly significant ($F=5.36$, $p\leq 0.01$). Furthermore, the covariate was highly significant ($F=48.84$, $p<0.01$).

Table 3. Student Newman-Kuel's (SNK) range test of worker job attitudes

Groups	Groups/Differences in adjusted means between groups →					
	1 (Control)	5 (PS: 140% +PF+MI)	6 (PS: Participative+PF+MI)	3 (PS: 140% +PF)	2 (PS: 100% +PF)	4 (PS: Participative+PF)
1	–	0.06	0.62	0.88	1.08	2.28**
5		–	0.56	0.82	1.02	2.22**
6			–	0.26	0.46	1.66**
3				–	0.20	1.40**
2					–	1.20**
4						–

Note: The adjusted mean score of Group 1=15.02.

The results of the SNK range test are presented in Table 3. No significant difference was found between Groups 2 (100%+feedback) and 1. The provision of a normal production standard with feedback had no significant effect on worker job attitudes. Worker satisfaction had improved as a consequence of assigning a normal standard with feedback.

A comparison between Groups 3 (140%+feedback) and 1 showed no significant difference between them. The provision of a hard standard with feedback had no effect on worker job attitudes. There was no significant difference between Groups 3 and 2, in terms of worker job attitudes.

A highly significant difference was found between Groups 4 and 1, Groups 4 and 2, and Groups 4 and 3. The provision of a participative standard with feedback had a highly favourable effect on worker job attitudes, much better than an assigned normal or hard production standard with feedback.

No significant difference was found between Groups 5 (140%+feedback+monetary incentive) and 1 and Groups 6 (participative+feedback+monetary incentive) and 1, in terms of worker job attitudes. Stated otherwise, monetary incentive when provided with an assigned hard or participative standard and feedback had no impact or effect on worker job attitudes. Further, a comparison between Groups 5 and 3 revealed that monetary incentive had no effect on worker job attitudes. A highly significant negative difference was found between Groups 6 and 4. Monetary incentive hard a significant negative effect on worker job attitudes. The probable reasons for such results were that the subjects experienced the pressure to produce at a high level in a monetary incentive condition and they perceived that the monetary incentive was inadequate.

CONCLUSIONS

In summary, the conclusions reached by the research conducted with a repetitive industrial production task are:

1. The provision of an assigned normal (100%) standard with feedback improved worker satisfaction significantly compared to the control group with no standard and no feedback. This experimental condition had no significant effect on worker job attitudes.
2. The incorporation of an assigned hard (140%) standard with feedback improved worker satisfaction significantly compared to the control group. This experimental condition was not superior to assigned normal standard with feedback in terms of worker satisfaction. Also this experimental condition had no effect on worker job attitudes.
3. Worker satisfaction improved significantly as a consequence of the provision of a participative standard with feedback. This condition was significantly superior to assigned normal or hard standard with feedback when worker satisfaction was measured by the modified JDS scales. However, no significant difference was found among the assigned normal, assigned hard and participative standards with feedback conditions, when worker satisfaction was measured by the JDI scales. The provision of a participative standard with feedback improved worker job attitudes compared to the control, the assigned normal standard with feedback and the assigned hard standard with feedback conditions. In fact, only this condition had a significant positive effect on worker job attitudes.
4. Monetary incentive had no significant effect on worker satisfaction when provided with an assigned hard standard and feedback. Monetary incentive when provided with a participative standard and feedback had no significant effect on worker satisfaction when measured by the JDI scales but had a significant negative effect on worker satisfaction when measured by the modified JDS scales. Monetary incentive had no incremental gain on worker job attitudes.

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DECISION AID CRITERIA TO INTEGRATE A TELEMAINTENANCE TOOL INTO THE MAINTENANCE MAN-MACHINE SYSTEM

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This article aims at helping the decision to integrate a telemaintenance tool into the maintenance man-machine system. Indeed it is possible to classify the decision criteria into four main classes for which the telemaintenance factor is (i) possible, (ii) appropriate, (iii) justified, (iv) acceptable. After the presentation of the telemaintenance notion, this article will make a census of such decision criteria.

INTRODUCTION

The growing level of automation in industrial processes—continuous or not—breeds a particular interest for telemaintenance problems. Indeed this field is of paramount importance to insure the best possible productivity of the equipments. Consequently, a huge number of tools and methods have been developed to optimize maintenance, to insure a better availability of technical means and thus to have falling coasts. Among these methods, one has appeared in the 80s: the telemaintenance approach. It consists in a maintenance at a distance of the installations.

Our article aims at helping the decision to integrate a telemaintenance tool into the maintenance man-machine system. Indeed it is possible to classify the decision criteria into four main classes for which the telemaintenance factor is (i) possible, (ii) appropriate, (iii) justified, (iv) acceptable. Respecting the four classes all together allows us to recommend the integration of a telemaintenance tool (Kolski, Gambiez, 1991). After the presentation of the telemaintenance notion, this article will make a census of such decision criteria.

THE TELEMAINTENANCE

The telemaintenance consists in carrying out at a distance some operations ensuring the different forms of maintenance.

This is a particularly interesting technique to optimize “the after-sales service” of an automated installation. It appeared at the end of the seventies in order to maintain computers. Gabriel and Pimor (1985) present one of the first applications in this field: Digital Equipment put a telediagnosis center into service first in the States in 1977, then in France in 1980. Realizing the interest of such a maintenance approach for both the constructor and the user, the firm integrated a specific micro-computer into every system installed by the customer. This micro-computer behaved as an intermediary between the system to diagnose and the diagnosis center calculator. The specialized console and the modem were installed free of charge at the customer’s. The telephone calls communication were chargeable to Digital and the maintenance contract amount was reduced by 10%. The telediagnosis system was first used for the corrective maintenance. The percentage of success was equal to 90% without the intervention of a technician on the site. Nevertheless, when this person had to go on the site, it was most of the time with the right components. Then, it turned to the preventive maintenance which consisted on the one hand in storing technical faults in the telediagnosis center and on the other hand in controlling these information regularly with a goal of prevention.

At present, more and more telemaintenance systems are studied and progressively installed on industrial sites. They are particularly interesting in the fields constituting some risks for the human beings, those fields where the human interventions are very expensive (off shore, nuclear power plants, chemical processes…). We can find some operational systems in domotics (repairing of lifts, adjustment of steam generator…).

PROBLEMATIC ISSUES CONCERNING THE HUMAN FACTORS

The telemaintenance notion leads to problematic issues concerning the human factors which are particularly interesting. Indeed, the expert in telemaintenance uses a computing system from a site which is different from the production site, figure 1. So the computing system always consists of a dialogue software and a console. It also integrates communication means.

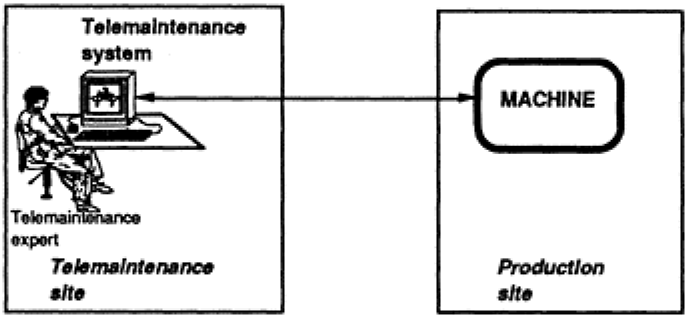

Figure 1: The basic telemaintenance principle

Of course, an operator or a maintenance technician can be present on the production site. But the maintenance technician has less knowledge than the expert. In this case, a connection must be foreseen between them. In most cases this connection is insured by the use of a telephone, figure 2. This is not a general case, but it is at the moment the most classical for the telemaintenance systems.

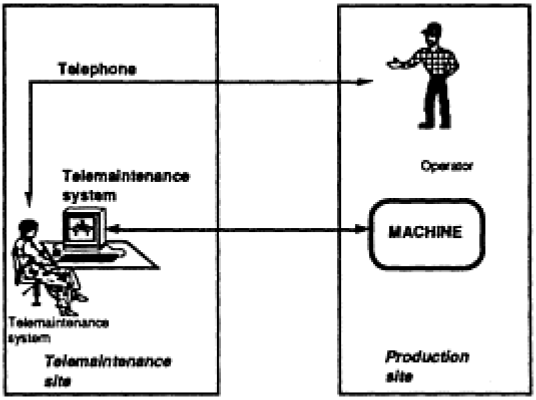

Figure 2: Collaboration by telephone between the telemaintenance expert and an operator

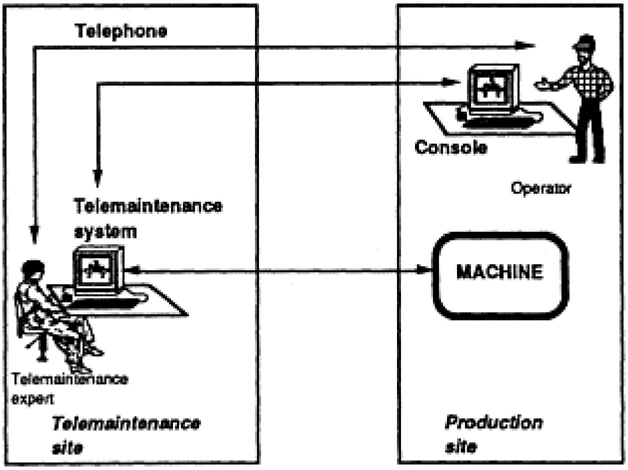

Figure 3: Collaboration by telephone and computing system between the telemaintenance expert and an operator

According to the competences and/or to the functions of the operator who is present on the production site, he may also access to some functionalities of the telemaintenance computing system, and collaborate with the expert by telephone together with a console, figure 3. This last case is very rare, but is today the subject of research outlooks.

The operator who is present on the production site is likely to perform some maintenance actions on the machine, by following expert instructions. Nevertheless, for certain repairs, the expert will probably have to move on the production site, or to send a specialist.

CRITERIA TO AID TO THE DECISION TO INTEGRATE THE TELEMAINTEN ANCE FACTOR

Aiming at helping to the decision to integrate the telemaintenance factor, it is possible to classify the criteria in four classes for which the telemaintenance factor is (i) possible, (ii) appropriate, (iii) justified, (iv) acceptable. Respecting the four classes all together allows us to recommend the integration of a telemaintenance tool (Kolski, Gambiez, 91). Of course, this list of criteria is not exhaustive. Since each firm has its proper constraints and objectives. Nevertheless, these criteria will provide the potential designers with a base of reflection.

Each of these criteria is briefly examined below and explained in a synthesis diagram (see the figure 4).

Criteria of possibility to integrate the telemaintenance factor

In this class, we put together all the criteria which are essential to the setting up of a telemaintenance system. It considers four subclasses which correspond to the four entities (figure 4): (i) the telemaintenance operator (also called telemaintenance expert), (ii) the expertise this operator has to use, (iii) the operator on the site, (iv) the information the telemaintenance operator needs to manipulate at a distance.

About the telemaintenance operator: First at all, he must exist, that is to say that he might be able to intervene at the right time in maintenance operations at a distance. Then he has to be able to answer his informational needs, either by the way of the computer (by telemeasures) or by asking the operator who is present on the site complementary information. Finally, if the telemaintenance operator concludes that it is necessary to intervene physically on the site, he may be able to guide the operator in the actions to undertake.

About the telemaintenance expertise: The expert's reasoning process must be possible at a distance. For this reason, his reasoning must be essentially cognitive and does not require too many manipulations. To design a telemaintenance system, the knowledge used must be previously validated, and perfectly mastered. This knowledge may not be retained -consciously or not- by the telemaintenance expert and has to be accessible by the designer.

About the operator present on the site: This operator may be contacted in case of need by the telemaintenance operator. The fact that he is free must be sufficient. In other words, an operator present on the site may be permanently able to answer the informational needs of the telemaintenance operator. Aiming at an efficient co-operation between themselves, the operator may be able to formulate his observations. His competence and/or training levels have to be sufficient. So, in each case, the operator must be able to understand the telemaintenance operator and to answer his informational and action needs.

About the telemaintenance information: All the measures useful to the telemaintenance operator may be instrumented, and therefor accessible at a distance: indeed the operator telemaintenance may quickly access the information without worrying about their reliability. Thus the information have to be essentially of these two following types: objective "signs" (taking the form of measures) and "symbols" (interpreting the information: too high, too low…) (for this notion, see Rasmussen, 86). The information must not be of the subjective "signs" type such as smokes, smells, and so on. In this case, they have to correspond to well-known and explainable at a distance (for instance by using a telephone) by the operator present on the site.

Criteria of adaptation to integrate the telemaintenance factor

The subject of the criteria which are put together in this class is to estimate if a telemaintenance system is better than a classic maintenance approach. These criteria are divided in two sub-classes corresponding to two steps of the maintenance: (i) tele-supervision and tele-diagnosis, and (ii) actions of maintenance deduced from the reasoning at a distance.

About tele-supervision and tele-diagnosis: These two operations (the most classical in the field of telemaintenance) have to be faster than if they were performed with a movement on the site. The telemaintenance time has then to be inferior than the displacement time plus the maintenance time on the site. The reliability level of the system has to be as close as possible to the level which is reached when the maintenance operations are performed on the site.

About the resulting actions: The actions resulting from the telemaintenance, and which cannot be directly performed by the telemaintenance operator using his computing system, have to be workable in most of the cases by an operator present on the site. Indeed, if it is not possible, the telemaintenance operator (or a maintenance expert) must systematically move on the site to make the maintenance actions. In this case, the profit-earning capacity of the maintenance approach decreases. Another telemaintenance criterion is to be able to optimize the displacement of the maintenance expert on the site: the expert has to move only if it is necessary and in this case he has to know the type of operation he will have to perform. For instance: a day, a maintenance expert moved on the site only to press an “on/off” button to start a machine. Indeed the inexperienced operator which was on the line was incapable of giving the slightest explanation about the situation!

Criteria of justification to integrate the telemaintenance factor

In this class, economical and strategic criteria related to the company are considered.

About the availability of the telemaintenance operator: If the operator in charge of the maintenance of a machine is not very available, then the telemaintenance is a solution to this problem. For instance, maintenance companies can insure the maintenance of machines for which a displacement on the site may last two or three days because of geographical reasons whereas an intervention at a distance would have lasted just a few minutes.

About temporal constraints of maintenance interventions: For some industrial sites, a day of unavailability of a machine can be disastrous. A telemaintenance system can then optimize the intervention time relating to the maintenance.

About the profit-earning capacity: A telemaintenance system corresponds above all to a service, or even to a product. If this system is sold in a sufficient quantity, the profit-earning capacity is ensured.

About the formation: If it is envisaged to attribute to the telemaintenance system a double function, the second one may concern the formation. For example, operators can follow a course in diagnosis at a distance on the telemaintenance center. Furthermore, it is possible to form some operators present on the site, in a context of exploitation of a new machine.

About the impossibility to send a maintenance expert on the site: It can be impossible to train an expert on the site, for instance when the system is closed or difficult of access (off-shore, nuclear or chemical processes, space…). In such conditions it is necessary to choose a telemaintenance approach.

About the volatility of the expertise: With a more strategic point of view, a maintenance expertise could disappear. This situation may influence the design of a telemaintenance system.

Criteria of acceptability to integrate the telemaintenance factor

The level of acceptability for choosing a telemaintenance approach is centered on the human factors linked to this new technique.

About the evolution of the work: It must be possible to insure the valorization of the tasks of the operators present on the site. This is true if we try to exploit as often as possible the dialogue between the two operators. Of course, this dialogue has to be possible and must not come down to actions asked by the telemaintenance operator to the operator present on the site. Furthermore, the operator present on the site has to find an interest due to the pedagogical aspects of the operations in which he is involved.

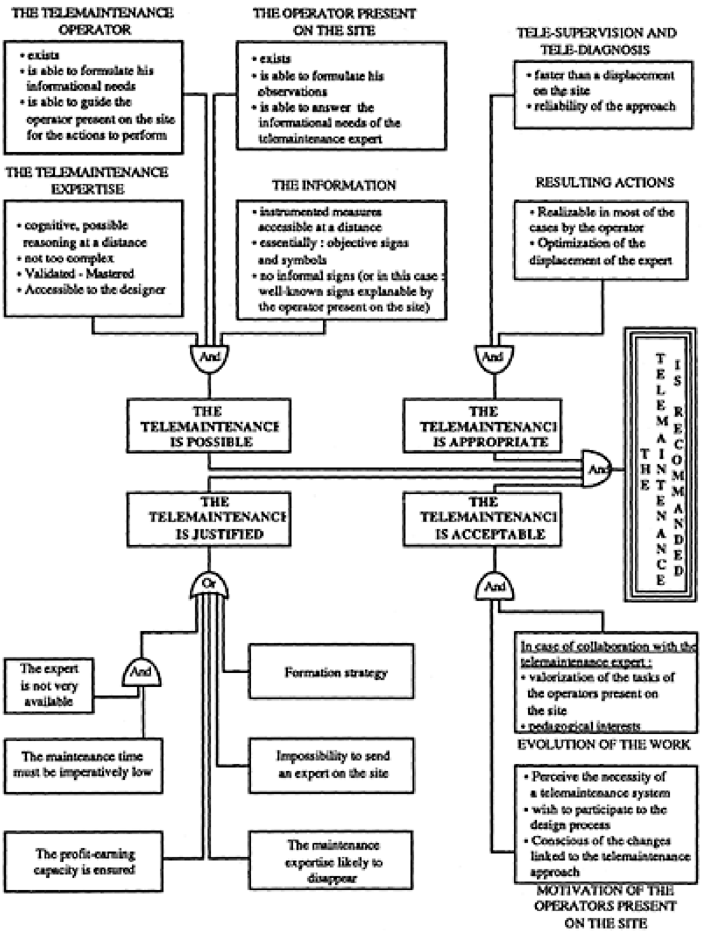

Figure 4: Criteria for helping the integration of telemaintenance factor

About the motivation of the operators present on the site: The telemaintenance system must not be integrated from the opposite direction in the company's culture and of course it must not involve problems relating to the confidential aspect of certain information which are accessible on the site by the telemaintenance operator. Moreover, the operators present on the site may perceive the necessity of such a maintenance approach. More and more, the integration of such a system implies a participation of the end users to the design process (Gould, 88). If the operators present on the site wish to take part in this process, it is a sign of the "human" success of the integration. Nevertheless, a telemaintenance approach involves changes in the work methods, the different operators must be conscious of this situation. Specific sessions organized to prepare the telemaintenance integration will here find their usefulness.

CONCLUSION

This article has first dealt with the telemaintenance notion and its problematic issues concerning the human factors. According to these problematic issues, it is evident that the telemaintenance system is integrated in a man-machine system in which the characteristics and the tasks of the telemaintenance expert will have a direct influence on the successful result of the project concerning the telemaintenance system design.

The designer of such telemaintenance systems will need to consider such notions. It is in this purpose that our article has make a census of criteria helping the decision to integrate the telemaintenance factor.

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INTEGRATING ERGONOMICS INTO THE MODERNIZATION OF A SLAUGHTERHOUSE: THE IMPLEMENTATION OF AN APPROACH BASED ON AN ANALYSIS OF THE REAL WORK

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Integrating ergonomics into the modernization process can be an effective means of preventing health and safety problems. In the modernization of a poultry slaughterhouse, ergonomists collaborated with the users of the plant and with the designers from the first stages in design, in order to improve future work situations. The approach that they used is presented and discussed here. It is an overall approach in which work analysis is important. Although the results of this integration of ergonomics into the project cannot be analyzed in-depth here, interest in developing this approach continues.

BACKGROUND

A specialized poultry slaughtering and processing company decided to modernize its turkey slaughtering facilities. The project is part of an effort to reduce production costs and involves a desire to act at source to prevent occupational health and safety problems. It is in this context that the ergonomists were invited to take part in defining future work situations.

The literature on ergonomic interventions during design is growing. There are two main trends. On the one hand, the ergonomist is called on as a consultant for the designers (Evans and Chaffin, 1986). On the other, he plays a role as catalyst in a process where the users are directly involved (Wilson, 1990, Eklund, 1990). The approach adopted here is this second type (Daniellou, 1987).

Furthermore, the analysis of the actual work, as practiced by French-speaking ergonomists (De Keyser, 1991) is the basis for this ergonomic intervention in the design process. The work activity is defined as the mobilization of the person in carrying out his task. The activity depends (Leplat and Cuny, 1984) on internal variables, involving the person performing it (for example, his physical characteristics, experience and training) as well as external variables (for example, the objectives, the means supplied, the constraints imposed). The performance of the activity in turn has an impact on the individual himself (his health, his physical integrity, his degree of fatigue) and also on the production system (quality, quantity). By watching actual work situations, the observable part of the activity can be described, with the verbalizations of the operators about their own activity enriching the analysis (Guérin and al, 1991). The diagnosis resulting from this analysis is a key element in the success of the changes that will be made (Wilson and Grey, 1988; Bussi and Helander, 1990; Leppanen, 1990).

METHOD

The company, specialized in poultry production, has several slaughterhouses and processing plants. The one to be modernized is specialized in slaughtering turkeys and large chickens. Three hundred people work there, mainly in 4 departments: reception-slaughtering, evisceration, fresh packaging and frozen packaging.

The project—content and structure

The project consists of enlarging the existing building to produce a new reception area. The means of transporting the live birds will be changed: instead of arriving in cages that are unloaded and placed on a conveyor, the birds will be removed directly from liners attached to the trailers. The evisceration department will also be affected: some mechanized equipment will be introduced to perform operations that are now performed manually.

The plans for the future facility were produced by 2 people from the company’s engineering department, in direct collaboration with the plant manager and his chief engineer. The company’s operations manager acts as project promoter, in collaboration with the human resource director. The modernization was the subject of an agreement between the union and the company, mainly guaranteeing that the workers would continue working.

Employers and union representatives agreed that task forces be created involving the users of the future plant. A task force was formed in each department involved in the modernization. Each contained, in addition to 2 ergonomists: 3 workers with a good knowledge of the different workstations, the foreman, the production manager, and the plant’s chief engineer. The participants have clear guidelines to the effect that the contribution of each be related to his abilities rather than to his role within the company. The joint health and safety committee is regularly informed of progress in the project and the activities of the task forces.

Ergonomists' activities

The ergonomists, after analyzing the project, analyze the existing situation. Observations are made and interviews with the operators and foremen are carried out. At the same time, reference sites are chosen which are also the subject of analyses. They are plants that already operate under the planned conditions: 2 plants that have adopted the new method of transportation, 5 poultry plants using the planned equipment (2 of which slaughter turkeys).

Activities of the task forces

The first phase of the work consists of validating and enhancing the work analyses performed by the ergonomists in the actual plant. Video recordings of the work situations under study, as well as plans, are used to promote discussion. At the end of this phase, a collection of information is available for the designers, namely, what difficulties are encountered at the present time in the work, and what factors must be taken into account in the design of new working situations.

The second phase begins with the designers' presentation of plans of the future facility. The groups then examine the proposed installation by attempting to anticipate the future work activity, taking into account what has been proposed.

The meetings last two hours and are conducted by one of the ergonomists, while the other summarizes them. The group meetings are recorded on audio tape.

PRELIMINARY RESULTS

Analysis of the work in the actual situation has revealed that the variability in the material to be processed is a major determinant in the activity and must be taken into consideration during design. The analysis also reveals the individual and group strategies developed to ensure production quality and to regulate the work load. What also emerges is that the actual spatial arrangement is a major constraint which often limits these strategies.

Variability in shipments

The poultry arrives from the producer in shipments. Each shipment normally consists of birds of the same sex whose weight is similar. A certain percentage of the birds often do not have the characteristics of the remainder of the shipment. The mechanized slaughtering equipment is however adjusted to these characteristics. Operators must then compensate for all inadequacies in the mechanized work. Often, these operations have not been planned in the layout of the premises, which increases the difficulties encountered by the workers: they adopt constraining postures and have difficulties with access.

It is also planned that the birds will arrive at the slaughterhouse without having recently eaten. This measure makes evisceration easier and decreases the risk of contamination. Nevertheless, complete shipments of birds sometimes arrive, in which the birds’ intestines are full or even filled with water because the period without food has not been respected.

Other factors affect the condition of the birds, and consequently, the slaughtering and evisceration operations: conditions during poultry production, climatic factors during delivery, the way in which the birds are caught, etc. The negative consequences of variability can be avoided if conditions are planned for dealing with them, particularly the possibility of detecting this variability, of temporarily assigning additional resources, and the development of a workstation to make manual operations easier.

Individual strategies to regulate the work load

Most of the work stations found in the slaughtering and evisceration departments have short cycles, with the work carried out in a standing position. The workers implement strategies to regulate their own work load. The detailed analysis of the video recordings shows, for example, that in order to hang the birds after slaughter, a worker will alternate between several operating methods. The workstation to be designed can be considered from the following perspective: it must allow the worker to adopt different operating methods.

The work analysis also reveals that the workers use, in order to reduce their postural load, components of their workstation that are there for other purposes. For example, workers rest their backs on a safety railing in order to reduce the effort required in removing the crop. Such observations can be collected and translated directly in the design of future workstations.

Group strategies

People assigned to the same production line are a working group in the sense that the operations carried out at one location have impacts on those that are carried out farther along. The company has implemented a 2-hour rotation system, and the result is that the workers in one department know each of the workstations. When a worker is carrying out his task at one workstation, he can make the work of the people at the other workstations easier. Training is one means of improving future work situations.

Observations also reveal that the operators, in addition to the “official” rotations, make other rotations in order to better balance their work load. For example, the workers performing the same operation on two production lines with different speeds will change lines every 30 minutes. From the design standpoint, this cooperation can be made easier, mainly by retaining a flexibility in work organization and by arranging the space in such a way as to allow rapid movement between the two workstations.

Spatial constraints

In addition to the spatial constraints previously mentioned, analysis of the actual situation reveals the difficulties encountered during the movement of people and carts. Traffic areas cannot be distinguished from working zones, which compromises safety during displacements and also leads to frequent handling when objects that are blocking the carts are moved and then put back.

Furthermore, the work space on the production line is often completely occupied, making it impossible to add another person when the situation requires it, as for example when a shipment is of poor quality. An inventory of the problem situations observed provides scenarios that allow the displacements in critical situations to be simulated and their consequences to be evaluated. The plans can often be revised on the basis of the results of these simulations.

DISCUSSION

Although it is too early to assess this intervention, some aspects deserve to be emphasized.

The advantage of user participation

By involving users in the task forces, the ergonomists' assessments could be complemented. The video recordings viewed during work meetings proved to be an effective means for the workers to enhance the analyses by drawing from their experience and know-how. Furthermore, the fact that these meetings were recorded gave the ergonomists access to information which could not be noted immediately, or whose pertinence was demonstrated later. For management personnel, these meetings were an opportunity for adopting a different viewpoint on the workers' activity which leads to solutions that had not yet been extensively explored (making the organization of the work more flexible, training).

In addition, this analysis-validation process carried out in the working groups resulted in several immediate modifications to existing work situations. This outcome, although unexpected at the beginning, is interesting in that it reinforces the idea with the users that their participation can have a real impact in changing their work.

A prior analysis of the modernization project allows the ergonomists to orient the analysis of the actual situation. The operations that were going to disappear (for example, the unloading and loading the cages in the trucks) were not considered. However, operations that were going to be mechanized were analyzed. In fact, it seems important for the future to understand how the variability in shipments affects each of the operations and what the workers do to maintain product quality.

The importance of the reference sites for the designers

The plants chosen as reference were visited by the ergonomists and designers. Although it was impossible to carry out detailed analyses, except in one case where filming was possible, these visits allowed certain problems normally not mentioned by equipment suppliers to be visualized. As well, these visits were an opportunity for the ergonomists to point out to the designers that mechanization does not necessarily eliminate actual problems. For example, in a mechanized facility, the inspector regularly stops the production line to allow an operator to unhook the birds that do not meet standards. Each stoppage leads to extra handling at the first workstation in the production line, where the birds continue to arrive but cannot be hung. The accumulation must be controlled by placing the birds in containers so that they can be hung later. This situation and the problems that it causes are well known by the users. However, until the designers had seen the stoppages in a mechanized plant, they answered that there would be no production-line stoppages in the future facility and that it was irrelevant to discuss the way in which the accumulation would be managed. If production-line stoppages themselves are a problem, this is magnified because everything is designed as though they never occur. This example clearly illustrates that the ergonomist contributes to design through his knowledge and analyses, but must also be persuasive at certain times.

CONCLUSIONS

In modernization projects, ergonomists are often involved at the end of the process, when the margins of maneuver are limited. Due to a delay in the start of construction, the actual situation could be covered in depth with the users, which provided detailed information for the designers. This reflection, which was part of the ergonomic intervention, changed the perspective of the modernization project by focusing on aspects that have a continuity with the actual situation rather than those which are changing. Although it is premature to arrive at a conclusion on the impact of the entire procedure applied here, it appears promising. At the present time, the changes that the companies are forced to make due to the economic situation, as well as the more extensive use of participatory management methods, create a favorable context for implementing this type of ergonomic approach.

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CHANGEOVER TOWARDS SMALL GROUP PRODUCTION IN A CLOTHING COMPANY AND ITS IMPACT ON EMPLOYEES' WELL-BEING, MOTIVATION AND PARTICIPATION

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Ageing and health problems are adding to the difficulties of managing the clothing industry at a time when attempts are being made to increase the flexibility of the manufacturing process. One approach is to change over from assembly line production to small group production. This study attempts to observe such a process in a Finnish clothing company. It follows up employees involved in assembly work during the organizational restructuring process and focuses on their evaluations of their jobs, work environment, and motivation. To support the employees' own activity, a program for self-managing work-related problems (ergonomic hazards, stress, etc.) has been initiated.

INTRODUCTION

The pressures of international competition have been affecting Finnish industry for more than ten years now. However, the clothing industry was driven into serious economic difficulties only by the total collapse of Soviet trade. This has resulted, albeit rather sluggishly, in the striving to adopt new technology, to develop personnel policy and the organization of the work, and to establish subcontract networks and to develop training. One of the central ideas has been to increase flexibility and to improve the product quality, thereby adjusting production to the accelerating cycles of marketing and the requirement of smaller, increasingly specialized batches (personal communication with a production manager in 1991). The high turnover and illness rate of workers, the difficulties in recruiting young labour, old-fashioned management methods, piecework pay, low work motivation and ergonomically harmful working postures exemplify the problems of the old-fashioned assembly line work. Accordingly, it has been necessary to look for new technical and organizational solutions which take cognizance of the changes in employees' values, educational level and expectations about their working conditions (cf. Emery 1977, pp. 132–137).

The purpose of this study is to follow up a clothing company in which work has been reorganized from assembly lines to small work groups. Inquiries and interviews are made about the content of work and the work environment, and the personnel is encouraged to develop their jobs, working conditions and strategies of maintaining their performance level. Of particular interest is the question if the individual's prior work experience and age differentiate the strategies or means of coping with the changed situation.

RESTRUCTURING THE PRODUCTION PROCESS

Techniques of work design (job enlargement, job enrichment, self-steering) have provided means of alleviating some of the problems related to tayloristic production line work. However, in the clothing industry these have been largely unknown or refuted until recently. In some cases entrepreneurs experimenting with small work groups have disposed of the old conveyor belts and transfer lines. As any change in real setting, this kind of fundamental reorganization of assembly work may entail a great deal of difficulties in both production and workers' interaction, as well as fears and anxiety among some employees. It is generally assumed that older employees find it more difficult to adjust to new situations than do their younger counterparts. This statement might be plausible generally, but when focusing on a particular workplace or a particular group of employees, the evidence remains rather weak. Instead, the manner in which the individual attempts to control the new situation may be interpreted as part of his or her life strategy and as the way in which the group collectively understands and accepts or rejects the new organization.

The models of increasing self-steering and autonomy are by no means new (Buchanan 1979, Emery & Thorsrud 1976). Although these models have been experimented with in the Nordic countries, the experiments have been mainly carried out in the metal industry, in which it has been possible to automate the production processes. In addition, metal industry is traditionally male-dominated and occupies a strong position in the market. In it conditions have been more favourable for experimentation than in female-dominated fields. The assembly work (sewing) in these fields has also been difficult to automate. Old work techniques and the qualification structure of the workers have presumably slowed down the introduction of new models of work organization.

ACTION RESEARCH

The idea threading through this research and development project is the participation of the workers in the improvement of their working conditions. Apart from investigating this process, the researchers also act as agents of activity by providing support without, however, acting as consultants. From this follows a need for cooperation between the different parties, which presupposes common learning. This in turn requires a sufficiently long timespan.

The research project has been designed to conform to the classic model of action research, in which the researchers closely follow up a process and also attempt to affect a specified area or group in the overall process (Lewin 1946, Rapoport 1970). In the present study the task is to follow the change primarily from the viewpoint of the assembly workers, the subjects of the change. Furthermore, data on the whole personnel (for example, evaluations of working conditions and perceptions of the work climate) is collected to facilitate comparisons. At the same time the workers' interest in the development of work and working conditions is stimulated by providing them with provisional information about the research results. One of the goals is to encourage the personnel to initiate one or more development projects of their own (*cf.* Rapoport 1970 and Town 1973). This kind of approach was, for example, used in the planning of a large mail center (Gustavsen, Hart & Hofmaier 1991).

In this study emphasis is placed on the so-called interactive logic, in which research progresses in accordance with the results of the discussions between the participants, as against the so-called linear logic, in which research proceeds stepwise according to a predefined model. Therefore, this study cannot be unambiguously placed into a "pure" category of research approaches (*cf.* the categorization presented in Wilson 1991). An attempt is made to apply a number of different strategies simultaneously: questionnaires ("remote"), interviews and discussions ("direct" and "discrete") as well as users' own development projects ("direct" and "continuous"). In fact, at its best the application of action research requires that a variety of methods are used simultaneously. This is, of course, a principle established long ago in ergonomics research.

COMPANY AND STUDY TEAM

The study focuses on a manufacturer of children's clothing. The biggest part of its products are sold in the Nordic countries. The factory employs about 200 people, most of whom are women. The proportion of office workers is 30 per cent of the entire staff. The proportion of workers under 30 years of age is 25 per cent, between 30 and 40 years about 30, between 41 and 50 years about 38, and over 50 years about 7 per cent. A couple of years before the beginning of the study, a change of ownership had taken place. Following it, there was a decision to reorganize production. The company also moved into a new factory building. The idea was not only to adopt new technology in a new work environment, but also to introduce innovations into the assembly work proper. Thus, some of the old machinery was replaced, new adp-technology was introduced, and assembly lines were removed. It was decided to organize the manufacture of clothes in small groups (with about 8 people per group), each of which was given numerous machines at its disposal. When the reorganization was under way we got to hear about it, contacted the management and proposed cooperation. Our proposal was accepted.

As soon as the financial backing for the research project was secured, a cooperating team was established, including (from the company's side) the production manager, representatives for all employee groups, a doctor, a public-health nurse, and two researchers. The team has the task of going through and accepting the plans, schedules, questionnaires and other measures related to data collection and other activities in the factory.

DATA COLLECTION

Data refer here to minutes, memoranda, interviews, observation, picture material etc., including survey data on the workers' views concerning the restructuring process. As one of the purposes of the study is to encourage the workers' initiative, a great emphasis is placed on the material which they produce themselves. Also, the data collected by means of conventional research methods are placed at the workers' disposal. This paves the way for discussions about matters which are felt to be important. As the present stage of research does not permit a detailed analysis of the results gained thus far, we must restrict ourselves to giving a few examples.

Working conditions and motivational aspects

Two surveys of the employees' evaluations of work and working conditions were carried out in December 1990 and in June 1991. The response rates were 65 per cent (N=143) and 47 per cent (N=87) respectively. The economic depression and its strong effects on markets forced the company to resort to lay-off and even to give notice to some employees during the spring season, which considerably lowered the response rate in the latter case. However, the data can be utilized for certain comparisons. The questionnaire dealt with following aspects of work: challenges, feedback, organization, motivation, supervision, peer relations, compensation, work load, health status and psychosomatic symptoms.

In Figure 1 the distributions of choices are shown concerning the question: "Are the jobs in your department well organized?" Highly interesting is the change towards opposite directions in the responses of seaming workers (positive direction) and office staff (negative direction) between the dates of inquiry. The former might reflect firsthand experiences of the small groups. On the other hand, the latter might be an indication of frustration or even anger resulting from the heightened mental pressure due to the current economic depression.

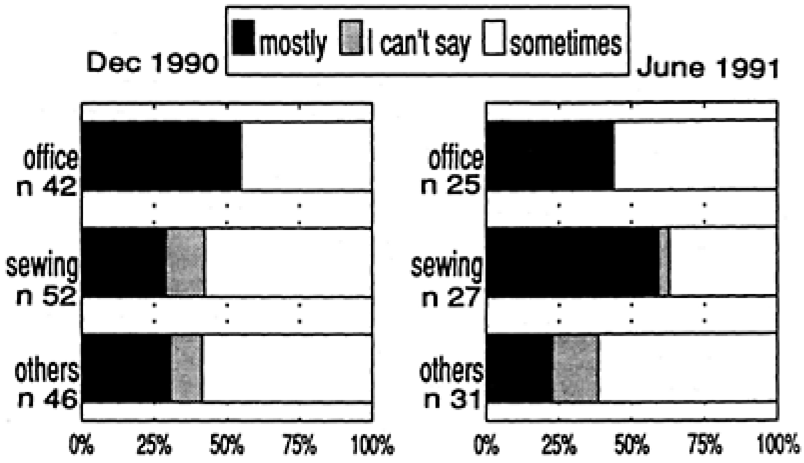

Figure 1. The jobs are well organized.

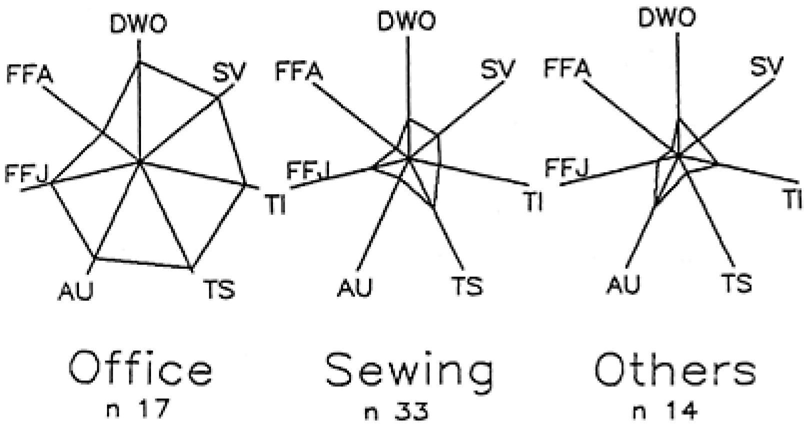

Figure 2. The motivational structure of work among employees in June 1991.

Figure 2 represents the motivational structure of work among three groups of employees in June 1991: office staff, seaming workers and other blue-collar workers. Each of the diagrams represents the seven JDS-core job dimensions for each employee group: skill variety (SV), task identity (TI), task significance (TS), autonomy (AU), feedback from the job (FFJ), feedback from agents (FFA), and dealing with others (DWO) (Hackman & Oldham 1975). Seaming workers and other blue-collar workers evaluated their jobs as less rewarding on each dimension than did the office staff. It is an observation which reflects consistently the strong contradiction between the job content of white-collar and blue-collar workers, also confirmed by other comparative studies.

The work conference

In order to facilitate communication within a company and to establish links to other companies operating in the same production area, we organized a “work conference” (*cf.* Gustavsen 1991). In a work conference the personnel of a number of companies meet, the main idea being to provide a neutral arena for “democractic” dialogue across organizational boundaries. A more concrete purpose of the meeting is to set up a participatory development project in each company participating in the conference (in order to enhance small group production). Generally, the group meetings are divided into four stages. The groups are formed by mixing companies and people during the first three stages, and the final meetings take place with participants only from the same company (Gustavsen & Engelstad 1986; Gustavsen 1991).

Our work conference took place in November 1991. Three other Finnish clothing companies were invited to participate. Common to all these companies was the fact that they had some experience of small group production. The conference group from our target company decided to start a project for improving the “know-how” for small group production, e.g. by organizing a training and education program for all the employees involved in the manufacture of clothes. We are now writing a preliminary draft of the conference account and will distribute it to all participants in order to receive comments for the final report.

FURTHER STEPS

We will carry on the research project in three ways:

1. by supporting workers’ own development projects:
   – “learning at the workplace” (an in-company education program)
   – preparing video material for ergonomic considerations
2. by collecting comparative data by means of questionnaires and interviews
3. by organizing a “Good Feeling” program
4. by supporting other activities, such as producing information material for “Company news”, tapes, etc.

The study started in January 1991 and will finish in June 1993. The study is supported by a grant of The Finnish Work Environment Fund.

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APPLICATION OF ERGONOMICS IN INDUSTRIAL ENGINEERING

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This paper is concerned with the contributions of Industrial Engineers to ergonomics. The weaknesses of work measurement and motion economy are presented. A methodology for incorporating ergonomics and methods analysis into the design of the production system is presented.

INTRODUCTION

Human performance in Industrial Work has been studied for approximately 120 years. The Industrial Engineering pioneers F. W.Taylor and F.B.Gilbreth approached the problem from different perspectives, Taylor using work measurement and Gilbreth developing methods analysis. Up to this time there had been no systematic approach to analyzing work and improving human performance. Operating methods had developed by evolution and by learning how to use machines and scant attention was paid to the health and safety of workers.

Taylor was probably the first person to use a systematic method to determine a sustainable working pace. With his cohorts, the experiments on shovelling showed that the optimal load for a shovel was 21 1/2 lbs (4.75 kgs) and therefore the size of the shovel would depend upon the density of the material being moved. He also understood the physical and physiological needs of operators. The effect of fatigue depended upon the size of the load as an operator moving pigs of iron (92 lbs or 20.3 Kg) would work 43% of the time and rest for 57% and for half pigs (46 lbs) the corresponding figures were 58% and 42%. In another case involving women inspecting ball bearings, the working day was reduced was reduced by 2 hours and it was recommended that the women be allowed to take two consecutive days off with pay in each month whenever they chose to do so.

Gilbreth placed a total emphasis upon designing the work method. His interest was aroused when he was an apprentice bricklayer. He observed that there were three ways of laying bricks:

one set of motions when the operator worked fast,
2nd set of motions when he worked slow, and
3rd set of motions when he was teaching how to lay bricks.

These observations led Gilbreth to to develop a better system for laying bricks.

Gilbreth invented a scaffold which could easily be raised a short distance, keeping it near the most convenient working level. The scaffold was also equipped with a bench for holding bricks at a convenient height for the workmen, thus saving the tiring task of bending to pick up bricks from the floor of the scaffold. The bricks were inspected, oriented and placed on packets, which located were on the bench so that the bricklayer could pick up a brick with one hand and a trowel full of mortar with the other hand at the same time. In addition, the mortar was kept at the proper consistency so that the brick could be showed into place on the wall with the hand and eliminating the motion of tapping the brick in place with the trowel. The number of motions was reduced from 18 to 4 1/2. For a particular type of wall, the average production was 350 bricks/man/hour whilst the previous record was 120 bricks/man/hour.

Gilbreth, unlike Taylor, never timed an operation. He believed that a good method would lead to a low time. However, he must have had a good concept of time, because as a contractor he constructed quality buildings on time, within budget and at a lower price than competitors. Because of his emphasis upon methods and the use of micromotion techniques including filming of operations, it could be said that Gilbreth was the first practicing ergonomist.

Later Industrial Engineers continued the techniques developed by Taylor and Gilbreth. Management benefited by increased productivity and the operators received increased earnings. However, as one problem is solved, other problems emerged, for which there are two main reasons. First, one is usually concerned with making a living today and not with the long term effects of injuries twenty years in the future, e.g., professional athletes taking steroids. Second, as a result of increased life expectancy, increased emphasis on the quality of life and continuous repetitive motions under poor operating conditions, cumulative trauma disorders have become important. Repetitive Motion Injuries are not restricted to industrial situations, e.g., hand injuries caused by playing video games.

Although the pioneers and subsequent Industrial Engineering researchers have made significant contributions in the field of ergonomics, the greatest emphasis has been placed on work measurement and methods engineering, which are often lacking in an ergonomic approach. For example, time and motion studies often do not take into consideration the work physiology issues (sex, age, health, etc.) and cumulative trauma disorders resulting from repetitive motion tasks. The objective is to show how ergonomics and methods engineering can be merged in the design of a production system with particular reference to workstation design and materials handling.

METHODS ENGINEERING

Methods engineering involves the design, creation and selection of the best methods to manufacture a product or to deliver a service. In order to have an optimal effect, methods engineering should be included in the planning, pre-production and production stages of the system. In this way all the factors of the Person-Machine-Environment system can be considered. Thus work measurement and methods analysis can be considered as two subdivisions of methods engineering.

Work measurement and methods analysis are the two most common techniques used in analyzing existing processes. As work measurement does not in itself involve ergonomics, a good method needs to be developed before the basic time to perform the operation is determined The physiological needs are considered to be met by adding an allowance, usually 15%, to the basic time to yield the standard time. The application of a predetermined motion time system can be used to develop a good method.

Methods analysis is concerned with developing the best method under the prevailing circumstance. Usually an existing operation is to be improved. It operates on a philosophy of "Work Smarter not Harder". The improvement technique is based upon six questions: Who?, What?, When?, Where?, Why?, and How?. The good points of this technique is that it eliminates unnecessary effort, avoids awkward movements, provides smooth flow of materials and a balanced workload.

Table 1. Principles of workplace layout: Ergonomic approach (Corlett 1988)

1. The worker should be able to maintain an upright and forward facing posture during work.
2. Where vision is a requirement of the task, the necessary work points must be adequately visible with the head and trunk upright or with just the head inclined slightly forward.
3. All work activities should permit the worker to adopt several different, but equally healthy and safe postures without reducing capability to do the work.
4. Work should be arranged so that it may be done, at the worker's choice, in either a seated or standing position. When seated, the worker should be able to use the backrest of the chair at will, without necessitating a change of movements.
5. The weight of the body, when standing, should be carried equally on both feet, and foot pedals should be designed accordingly.
6. Work activities should be performed with the joints at about the mid-point of their range of movement. This applies particularly to the head, trunk and upper limbs.
7. where muscular force has to be exerted it would be available by the largest appropriate muscle groups and be in a direction co-linear with the limbs concerned.
8. Work should not be performed consistently at or above the level of the heart; even though in occasional performance force is exerted above heart level, rests for the upper arms are a requirement.
9. Where a force has to be exerted repeatedly, it should be possible to exert it with either of the arms, or either of the legs, without adjustment to the equipment.
10. Rest pauses should be allowed for all loads experienced at work, including environmental and information loads, and the length of the work period between successive rest periods.

The weakest point of method analysis is that the guidelines developed were mainly aimed at motion economy and neglected the physiological needs of the operator and failed to establish a relationship between the operator's limitation and the workstation (Corlett, 1988). In order to avoid building up of static muscular effort, Corlett suggested a set of principles based upon ergonomic considerations, see Table 1. The use of these principles although limited in scope, in the design of methods with a repetitive task could lead to a dramatic improvement in productivity and a reduction in the incidence of musculoskeletal disease.

WORKSTATION DESIGN

A workstation is generally a small working area in the plant where the operator is confined to perform an assigned task. The term workstation usually includes regular and protective clothing, lighting, climate, chairs, machines tools and materials, but seldom the worker. Even small changes in workstation dimensions can have a considerable impact on worker productivity, safety and health (Tichauer, 1975).

Industrial workstation design should ideally be capable of satisfying the systems performance requirements as well as the needs of the human user. Operator performance capabilities and limitations must be considered in designing an ideal workstation. The design should enable the operator to see the working area, posture must be adequate and comfortable, and controls must be within reach to minimize error.

The design of the workstation has three groupings:

1. Use of the Human Body.
2. Arrangements of the work place.
3. Design of tools and equipment.

Barnes (1980) used the above groupings in developing his Principles of Motion Economy. These principles give guidelines for the development of the work area but do not give any dimensions. The basic outline of the work area is shown in Figure 1

The first requirement in the design of the workstation is the determination of the working envelope. Maynard (1934) presented the concept of normal and maximum working areas in the horizontal and vertical planes. Subsequent research showed that one standard area was not suitable for everyone.

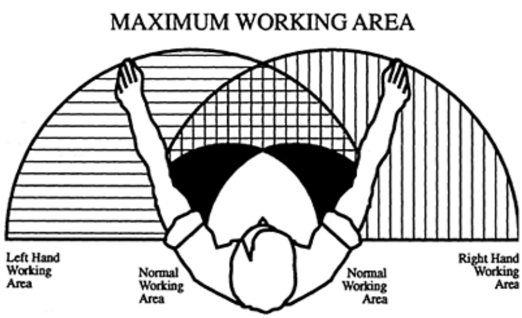

Figure 1. Hand and arm movements in the workplace.

Das and Behara (1989) have shown that the magnitudes of reach distance vectors of an individual in the work space were not constantly proportional to his or her arm length. The body dimensions which were dominantly related to reach distances were: stature, slump eye height and thigh clearance. The other dominant body dimensions were popliteal height and forearm-hand length for the male and shoulder height and slump shoulder height for the female. The 5th, 50th and 95th percentile horizontal work areas and three dimensional work spaces were found to be smaller than their conventionally determined values.

The second stage in the design is that all materials, tools and equipment which require manual operation be located inside the working envelope in such a manner that they can be reached and operated efficiently by all workers. Corlett's set of principles for workstation design based on ergonomic principles (Table 1) form the basis for the design. The final design of the workstation is based upon biomechanics and anthropometric measurements. Das and Grady (1983) give a good description of the use of ergonomics employing anthropometric measurements in the design of workstations. Because of the wide variation in size of the population, the workstation has to be designed for use by people of varying sizes. It is suggested that the range be from the 5th percentile for women to the 95th percentile for men.

There is still some leeway for the location of materials and tools. Konz (1983) has proposed that parallel motions rather than symmetrical motions (Figure 2a) for the hands should be used. However, by placing easily grasped objects at the extremities and less easily grasped objects in front of the operator, a combination of symmetrical and parallel motions can be used (Figure 2b). Also as the preferred hand is about 10% faster for reach motions, more accurate in movement and 5 to 10% stronger, using a tool in the preferred hand is 20 to 30% faster. Therefore, if possible, the workstation should be designed so that it can be set up as a mirror image to allow tool use by the preferred hand.

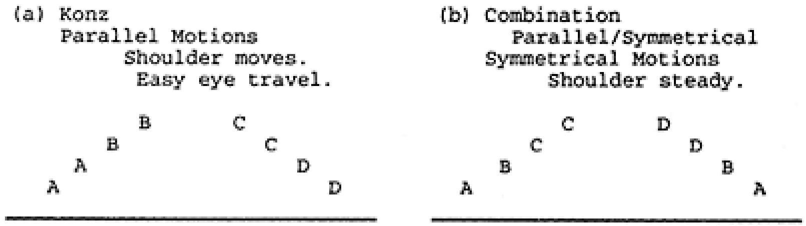

Figure 2. Basic designs for workplace layout.

Materials Handling

In spite of modern technology, there is still a considerable amount of manual materials handling (MMH). Manual materials handling is a major source of injury in industry. The injuries are caused due to slipping and falling, dropping a load, and lifting, carrying and lowering a load. Lifting injuries include lower back strain, hernias and slipped discs. In many cases these injuries cause partial or total permanent disability. About 50 to 60% of lifting injuries are due to lifting objects beyond the workers physical capacity. The financial costs are immeasurable and the injuries also cause suffering and anguish to victims and families. Despite their importance poorly designed MMH tasks are commonplace in industry.

In order to minimize the risks and severity of the MMH over exertion injuries, an ergonomic approach to the design of MMH tasks should be pursued. In the design of these tasks, the utmost consideration should be given to the human anatomical, physiological and psychological capabilities and limitations. Therefore, the design of the job is concerned with matching human capabilities with the requirements of the MMH job, so that it can be performed efficiently and at the same time it will not create safety and health problems for the worker.

The factors contributing to MMH hazards are identified as: worker characteristics, material/container features, work practices and task characteristics (Herrin 1976). Worker characteristics include age, sex, anthropometry, psychomotor skills, training and health. Material/container features include load, dimensions, location of the unit center of gravity with respect to the worker; couplings or handles and stability of the load. Work practices include posture and lifting techniques, administration and organization of the safety and hygiene functions. Task characteristics include the movement distance, frequency, duration and pace of movement, foot and trunk rotation and work environment. The hazards caused by the interaction between the factors is not known sufficiently to permit the development of standards.

The design of a workstation is different to designing a MMH task. In an MMH task, the objects being handled are usually bulkier and heavier and transported over longer distances than at a workstation. There are two main components in MMH tasks to analyze, viz., lifting and carrying.

There are no comprehensive rules for “safe” lifting. In MMH, there is a complex combination of moving body segments, changing joint angles, tightening muscles and loading the spinal column (usually the weak link in the chain). The following points can assist in preventing injury:

1. Design manual lifting and lowering out of the task. If this is impossible, the task should be performed between the knuckle (hip height) and shoulder height.
2. Movement of material should be horizontal. People should push and pull rather than lift and lower.
3. If people must move material, it should be light, compact and safe to grasp. A solid object with good handles is preferable to pliable material.
4. Material should not have sharp edges, corners or pinch points.
5. People should only tackle difficult lifting and lowering tasks if they are in good physical shape and used to lifting and vigorous exercise.
6. Material should be placed conveniently within reach with lifting aids available and sufficient cleared space. The Operator should think before acting.
7. The operator should get a good grip on the load and should test the weight before moving it. If the load is too heavy or bulky, assistance from either another operator or a mechanical lifting aid or both should be obtained.
8. The operator should place the body and feet close to the load with the feet pointing in the direction of movement. Lifting should be done mainly by straightening the legs.
9. The operator should not twist the back, bend sideways, lift or lower awkwardly or with the arms extended.

10. The operator should not continue heaving when the load is too heavy.

The energy expended in lifting and carrying in an MMH task has to be considered in determining the relaxation allowances. A formula has been developed for estimating the energy costs in kilocalories per hour (Frederick 1959)

$$\text{kcal/hour} = \frac{f \times a \times w \times c}{1000}$$

where f=number of lifts/hour, a=lifting height in feet, w= weight in lbs. and c=energy in grams per foot pound. The energy expended can be used to calculate the rest required using a formula developed by Murell (1965):

$$R = \frac{T(k-s)}{k-1.5}$$

where R=rest required in minutes, T is the total working time in minutes, k is the average kcal/min or work and s is the kcal/min adopted as standard (e.g. 5 kcal/min) and the constant 1.5 is the approximate resting level in kcal/min. MMH tasks can be performed optimally if the workers are allowed to take frequent short breaks and vary the weight handled.

ANALYSIS OF THE PRODUCTION SYSTEM

In facility layout the relative locations of facilities to facilitate easy movement of materials between them are determined. Materials handling is concerned with the method of moving materials from one workstation to another or to storage locations. Ergonomics considerations are often omitted. The most common method used is Systematic Layout Planning (SLP) developed by Muther (1969). The effect of the layout on the operator is seldom fully considered. The materials handling method has also been selected prior to starting the layout.

A systematic way to evaluate the production system is as follows:

1. Describe the whole material movement process from receiving to distribution.
2. Break the whole process into its separate functions.
3. Within these functions, chart and tabulate the activities to determine manual operations and handling details.

The best approach to design or improve a production system is to use a method based upon the “four keys” system as proposed by Kroemer (1984):

1. The initial layout of facilities contributes essentially towards safe and efficient material transfer. What process is selected and how the flow of material is organized and designed in detail, determines the involvement of people and how they need to handle material.
2. Job design determines the stress imposed on the worker by the work. Initially, the engineer must decide whether to assign certain tasks to a person or a machine. The layout of the task, the kind of material handling motions to be performed, the organization or work and rest periods, and many other engineering and managerial

techniques determine whether a job is well-designed or not; whether it is safe, efficient, and agreeable for the operator.

3. Selection, use, and improvement of equipment, machines and tools, affect material handling requirements. Human engineering principles, e.g., concerning operator space requirements, control design, visibility and color and sign coding, must be considered.
4. This concerns people as material handlers, particularly with regard to body size, strength, and energy capabilities. People are the king pins of manual material handling; they are critical because they supervise, control, operate, drive, and actually handle material. If people are not needed in the system, then it should be automated. If they are needed, the system must be designed for them.

CASE STUDIES

In spite of the knowledge available for industrial work, there are many cases where it is not used. In one recent case involving operators working on overhead powerlines, the tools were poorly designed. The youngest operators were generally approaching middle age and the effects of using a poorly designed wire cutters are showing up in injuries to the hand and wrist. In addition, the operators often preferred to use the more manoeuverable lighter cutter in situations where the heavier tool should be used.

In order to develop an appreciation of ergonomics, the author assigns a design project in his Work Study Course. The students have to design a work station to assemble a simple product, e.g., a gate valve. All the students have the same project. The students build the workstation and demonstrate the method of assembly. A critique of the demonstration is then given. The students are able to see the wide range of alternative ideas and to see situations which should be avoided.

CONCLUSIONS

In spite of the great technological developments that have been made, the design of processes involving humans often leaves a great deal to be desired. Some of the factors involved in the design of production systems has been presented. A suggested procedure for the analysis and improvement of a production system has been presented. The progress in designing and installing ideal working conditions will be long and arduous.

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AN INTRODUCTION TO TRANSFORMATION DYNAMICS: THE LAW AND THEORY OF TRANSFORMATIONS

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Transformation dynamics theory studies not only monotonous processes like traditional learning theory but also wavy-like processes of transformations of complex systems structures. Transformation processes were found in training, operator performance in emergency situations, in automated control systems, technological machines, industrial environments. Yuri Venda's newly discovered Law of Transformations is fundamental and practically useful for ergonomic, psychological and engineering studies on transformation dynamics in all types and components of human-machine-environment systems, and improvement of their safety, quality, and productivity.

PREFACE AND DEDICATION

With this paper I am starting the publication of previously unpublished manuscripts by my son Yuri Venda. While he was critically analyzing and generalizing my 20-year experimental data on transformation learning processes, Yuri discovered The Law of Transformations. He wished to prove that the law is very general and applicable for all dynamic systems with changeable structures like individual development, dynamic manufacturing, non-linear control systems, economics, business and management, adaptive human-machine-environment systems, etc.

We had planned with him studies on transformation dynamics in psychology, engineering and ergonomics. He worked very hard in the summer 1991. He was very tired and went to the Moscow University student summer camp just for several days to see his friends.

Yuri was tragically killed August 9, 1991 in the camp during a tornado, that had never happened there before. Yuri was only 22. He was an extremely bright and talented person.

This paper and other studies on Yuri Venda's Law of Transformations and Transformation Dynamics are dedicated to the memory of Yuri.

Val Venda

MONOTONIC DYNAMICS IN OLD LEARNING THEORY

Studies on learning always were a central problem in world psychology. Systematic experimental research on learning processes were started by H.Ebbinghaus (1885). His numerous experiments led him to identify the existence of monotonic (actually exponential) regularity in learning dynamics. E.L.Thorndike (1898), C.L.Hull (1943) confirmed that regularity. Many subsequent experimental studies and mathematical models of learning and development processes confirmed the same monotonic shape of the dynamic curves (Estes, 1950, 1959; Bush & Mosteller, 1955; Luce, 1959; Bower, 1961; Atkinson & Crothers, 1964; Greeno, 1967, etc.).

Monotonic learning curves became the only one type officially accepted in science. For example in the handbook on experimental and design techniques in engineering psychology, published by Johns Hopkins University Press in 1959, the former President of International Ergonomics Association Dr. Alphonse Chapanis recommended to proceed with monotonic exponential approximations to any kind of experimental data on individual training. On this basis the authors of the Introduction to Ergonomics (Zarakovski et al., 1977) proposed to compute learning curves based on three or even two empiric points. As a result all authors in the last 50 years considered dynamics in development as very simple: monotonic and exponential. The experiments by Brian and Harter (1896) on training of operators using telegraphic code where intermediate plateaus had been found, were almost fully ignored because no theory or regularity was given for these unusual phenomena. A short explanation with a hypothesis regarding the plateaus as the indicators of changes of the subject's strategies was given by Woodworth (1938).

Hence only two types of learning dynamics curves have been identified during more than 100 years: monotonic exponential and monotonic with intermediate plateaus. Only monotonic exponential dynamics of development was recognized as being classic and universal.

MONOTONIC STATICS AND MONOTONIC DYNAMICS: DANGEROUS SIMPLICITY

Monotonic exponential models were widely used not only in analysis of individual learning processes, but in many other areas of science and practice. For example, many economists tried to predict dynamics of the financial state of companies and industries as monotonic exponential processes. They found that long term predictions up to 30 years or more could be more or less modeled with this type of progress curves. However attempts to use traditional monotonic curves for prediction on shorter periods were unsuccessful. Yanch (1971) named middle term prediction periods as “difficult periods”. One could imagine how many companies fell into bankruptcy with this primitive modeling and prediction of firm dynamics by monotonic processes. Monotonic learning theory has made many people unhappy. Teachers and coaches were always expecting steadily increasing academic and athletic success. Any declines in results led to dramatic conclusions with removal of “non-performing” people. Wrong theory led to wrong decisions. The same troubles were also common in science and industry. We shall show that temporary declines of efficiency are inevitable and play a positive role in the development of the individual, firm, technology, science and every complex human-machine-environment system. Why has the monotonic development dynamics so hypnotized people during such a long time?

We already explained an experimental basis for the phenomenon. A theoretical basis of monotonic exponential theory of dynamics is provided by Fitts’ law (1954) as illustrated by the left side of Fig. 1. The monotonic influence of the volume of information perceived by a subject on his efficiency of information processing was stated by Fits. Thus static characteristic of the influence is monotonic. It is very easy to understand (monotonic theories are very attractive because one should not think much to get it quickly), that dynamics also will seem like monotonic. Indeed a learning process is always based on gradual increasing of information displayed and perceived by the individual. According to Fitts’ law the efficiency of the performance studied should also increase gradually. Zarakovski et. al. (1977) have drawn this simple logical conclusion shown by the right side of Fig. 1. After reaching the single maximal level of efficiency (Qmax) determined by Fitts’ law further learning will not affect the efficiency. The same authors fell into a total euphoria of simplification of the learning theory leading to approximations of the monotonic learning curve with only three and then just two experimental dots.

We shall show how far this simplification is from real learning and development dynamics in individuals and human-machine-environment systems.

FROM FITTS’ LAW OF MONOTONY TO YURI VENDA’S LAW OF TRANSFORMATIONS

T.B.Sheridan (1992, p. 123) notices that despite Fitts’ model fitting experimental data of a number of the relatively simple studies, “like so many elegant models for human behavior, Fitts’ model breaks down for more complex manipulations”.

In the very beginning of this century Yerks and Dodson (see Woodworth, 1938) and Taylor (see Freivalds, 1987, and Konz, 1990) have found that every human or animal performance has some optimal condition when performance efficiency is maximal. That means that if efficiency of information processing (understanding of texts, decision making, diagnosis, etc.) is a bell-like shape function of the information volume perceived, it can not be constant when information volume surpasses some certain, optimal level for maximal efficiency. Further increasing of information volume will lead to decreasing of performance efficiency. Hence performance efficiency dynamics for gradual information volume increases will also have a bell-like shape (see Fig. 2).

Yuri Venda proposed several experiments to prove non-monotonic behavior of the efficiency of human performance:

1. The subjects were asked to identify the words of 8 letters' length. Different, randomly (for static characteristics) and gradually (for dynamic) increasing numbers of letters were displayed: from 0 to 90. The probability of correct answers changed shown in Fig. 2. This bell-like shape of the Q(I) function means that Fitts' law is not correct for volumes of information greater than optimal. In Y.Venda's experiments the optimal volume was equal to the length of the word—consisting of 8 specific letters. If more then 8 letters were displayed, the exact word became masked. And masking was higher with further increasing of the number of letters. After 15–17 letters the probability of a correct answer was practically equal to zero.
2. The subjects were asked to read words with the same length of 8 letters. All letters were displayed, but with special fonts making reading more or less difficult, so that the subjects were reading by separate letters, by syllables and by whole words. Eye movements were recorded. In another series of experiments text by separate letters, syllables and words was displayed on the computer screen. In addition text moving on the screen with different speeds was displayed for reading by letters, syllables and words.

The static characteristic curves for three strategies of reading as a results of the experiments are shown at Fig. 3 (left side). The right side of Fig. 3 shows learning curves with changing strategies Sa into Sb and then into Sc or directly Sa into Sc.

> Let us explain, why we name characteristic curves as static. The curves do not display changing of process in time. The characteristic curves were obtained by selecting data (Q and F) for different performance strategies. For example, analysis of eye movements during information perception helps to classify strategy of reading.

FUNDAMENTALS OF TRANSFORMATION DYNAMICS THEORY

There were four important findings:

1) The same human performance could be accomplished with different strategies, and every strategy has its specific characteristic curve—correlation between performance efficiency (or other criteria) and ergonomic (psycho-physiological) factors of performance.
2) If an ergonomic factor is being increased gradually, monotonously, and the performance has only one strategy, the dynamics of efficiency ("learning curve") will have bell-like shape.
3) If an ergonomic factor is being increased gradually, monotonously, but different strategies are used in the performance, efficiency changes as a wavy-like process, with

monotonic, exponential phases of development of every concrete strategy, and efficiency decreasing when previous strategy has to be transformed into a new one.

4) So in addition to monotonic exponential learning curves discovered by Ebbinghaus in 1885 and learning curves with intermediate plateaus discovered by Brian and Harter in 1896 (see Woodworth, 1938) we found wavy-like learning processes. Woodworth suggested that the phenomenon of plateau arises because subjects changed their cognitive strategies for executing the task. The same explanation can be used in our case, but the difference between strategies (distance between their optimal values of factor F) should be bigger to have a wave.

5) We found that transformation of one strategy to another depends on the level of efficiency and value of factor common to both strategies. In Fig. 3, transformation states are displayed as the crossing points of the characteristic curves of the strategies Sa, Sb, and Sc.

6) We suggested that psycho-physiological structures which are the bases of the respective strategies of performance have some common parts. So when transformation is starting, that part which is specific for the structure is eliminated. Only the common part remains. Obviously the efficiency of this part is lower than that of the whole structure. Subsequently on the base of this common part a whole new structure is synthesized and the efficiency becomes higher.

7) Some times performance structures include many different levels of the human organism. Barabash et. al. of the Novosibirsk Branch of the Russian Academy of Science showed that training of astronauts affects not only the psycho-physiological level but also biological and cell levels of their organism.

Transformations of structures could be some times very fast (in our experiments it some times took only minutes) and some times very slow. It is well-known that training of athletes takes many years. We suggest that transformation strategies are important not only in the direction of ever-increasing complexity, efficiency and achievement, but also in the reverse case of reduction in complexity, efficiency and achievement such as in factory downsizing, de-automation to meet reduced demands and “retirement” of highly motivated and skilled staff. It is important not to slide down too fast on the left side of the curve. We all know situations when previously challenged individuals met untimely illness, depression or even death once the challenge was removed (e.g.: retirees from executive levels or athletes).

5) Yuri Venda found many examples of such wavy-like processes in physics, chemistry, engineering, non-linear control theory, metallurgy, optics, electricity, social processes as well as in economics. He conjectured that all those processes have similar mechanisms.

YURI VENDA’S LAW OF TRANSFORMATIONS

Yuri Venda worded his Law of Transformations as follows:

“Transformations of structures of any system go through states common to the previous and following structures”.

By "system" we mean a complex unit with constant components and energy-material resources.

By "structure" of the system we mean the regularity of mutual adaptation processes between inner components of the system. The regularity could be displayed as a technological scheme (technological structure), scheme of organization hierarchy (management structure), sequences of operations (algorithm structure), structure of the control system (dynamic links between parameters, transferring equations), and the tree structure of work operations.

By "strategy" of the system we mean the regularity of mutual adaptation of the system with its environment (the characteristic curves at the left sides of Fig. 2–5 display different strategies). Hence, strategy depends on interaction between internal structures and external conditions.

TRANSFORMATION DYNAMICS IN DECISION MAKING

Yuri Venda was interested in testing his Law of Transformations in many different systems and conditions. He proposed to study transformations in learning as a long-term psychological and decision-making process. He started to analyze my old experimental protocols. Yuri was especially interested in natural, field and industrial experiments.

Many years ago I have organized special emergency experiments at Moscow's fossil power plant #21. At that time I designed and implemented new complex equipment for the control room of the plant (Venda, 1982). Moscow Power Plants Headquarters gave me special permission to conduct emergency experiments for more objective studies of efficiency, reliability and safety of control room equipment and analysis of the performance of human operators under normal and emergency situations. Ten emergency situations were organized during night time (between 2 and 5 A.M.—that was a condition of the permission). My assistants suddenly and secretly, without the knowledge of the operators, turned off important technological equipment like working feed water pumps, air and dust fans, fuel lines, etc. Operators were supposed to recognize, diagnose, locate and eliminate these emergencies with information obtained from annunciator flashing labels, mnemonic schemes and computer displays. Five operators participated in the experiments, each operator two times. All commands, comments, inquiries, operations, motions and eye movements were recorded with movie cameras, computers and telemetric psycho-physiological instruments.

Three cognitive strategies of operators were found: Sa—perception of information by separate elements, Sb—perception of information simultaneously by small chunks (2–11 functionally connected elements), Sc—perception of information simultaneously by big chunks (20–50 functionally connected information elements). Characteristic curves of these strategies and their transformations during decision making processes are shown in Fig. 4.

TRANSFORMATION DYNAMICS IN SYSTEMS SAFETY

It was found in those real emergency experiments that it is especially important to teach operators not only to perform main control strategies but to quickly and easily transform one strategy to another, for example to transform their strategy and psycho-physiological state adequate to normal control situation into ones which are adequate for suddenly occurring emergencies. Fig. 5 shows processes of transformations of a normal strategy Sn into an emergency (alarm) strategy Sa and back into Sn. Fk is the relative level of psycho-physiological strain as a complex parameter of electrical brain activity (in alpha, beta and delta intervals, average number of eye movements per minute., angle of movement and fixation duration of eyes) (Venda, 1975, 1982).

To consider the multilevel character of human structure it is important to explain some phenomena:

1. For human individuals (as well as any other complex system) structures and strategies in their explicit representations in the processes of mutual adaptation are plural. Human performance can be achieved with several different structures and strategies. Effective and safe performance should be based on adequate structure and strategy

2. Human structures and strategies are discrete. There are essential intervals between values of every factor of mutual adaptation efficiency-complexity optimal for different structures-strategies. This explains why the same individual can respond very differently to the same information in normal and emergency situations.

TRANSFORMATION DYNAMICS IN INFORMATION SYSTEMS ERGONOMIC ANALYSIS AND DESIGN

The higher level of efficiency of strategy Sc than Sa and Sb, Sb than Sa in the emergency experiments (Fig. 4) could be explained with simple information measures. Higher efficiency means (in this case) lower response time and corresponding task complexity. The natural question is: How does a change in strategy make it possible. Let us analyze the following example. Suppose a subject is taught to identify, i.e. diagnose, 16 states of an object which is described by binary values on a total of 30 dimensions. Each binary value may be thought of as representing either the normal or pathological state for that dimension.

There are two important consequences for practice: a) strategy Sc with more narrow range of factor F values than Sa: (Fcmax−Fcmin)<(Famax−Famin) usually has higher maximal efficiency: Qcmax>Qamax. We say in this case that Sc is more specialized and Sa more universal. Obviously, that reading by words is more effective in optimal environmental conditions (light, size and style of the fonts, etc.) than reading by letters. But the same deviation from optimal conditions will cause greater decreases in efficiency of Sc than of Sa.

In the experiments on reading (Fig. 3) as well as in the emergency experiments (Fig. 4),, the strategies used by operators were usually in the sequence Sa, Sb, Sc. Some times after short and unsuccessful trials to use strategies Sc and Sb operators made reverse transformations back to Sb and Sa, and later again to Sb and Sc. That means that decision making processes include using and assessing different cognitive strategies, using various methods of combining ("chunking") of information elements as well as direct and reverse transformations of the strategies.

ERGONOMIC MICROANALYSIS OF PERFORMANCE TRANSFORMATIONS

In another series of experiments we used a power plant training center where similar emergency situations were modeled. 25 engineering students participated as the subjects with 10 trials each. They were supposed to make decisions, carry out operations and give commands like operators at the power plant. The experiments showed the same dynamics of human performance during learning processes as those observed in the previous experiments. The main difference wa that learning processes include reverse transformations as well as transformations from Sa directly to Sc, were found in only two students out of 25.

In addition to studying decision making we investigated learning on tracking control—another typical human operators function. It was even easier to find transformations of the strategies in those functions (Venda, 1986).

CONCLUSIONS

Yuri Venda's Law of Transformations is very general and can be profitably used in many areas of science and practical activity.

This law is especially important for ergonomic analysis and design of dynamic, productive and safe human-machine-environment systems.

Transformation dynamics can be an area of effective collaboration between different specialists: psychologists, ergonomists, engineers, physicists, economists, etc. Yuri wished to participate in that collaboration and organize an International Journal on Transformation Dynamics. Maybe such a journal could become a fitting memorial to him.

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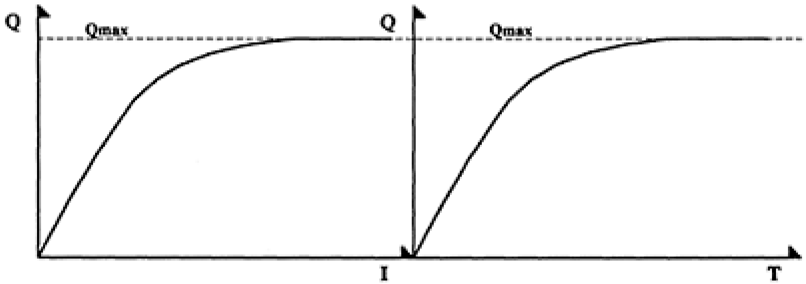

Fig. 1. Illustration of the Fitts' Law (left side) and monotonic dynamics as its consequence (right side). Q-efficiency of performance, I-information volume perceived, T-time.

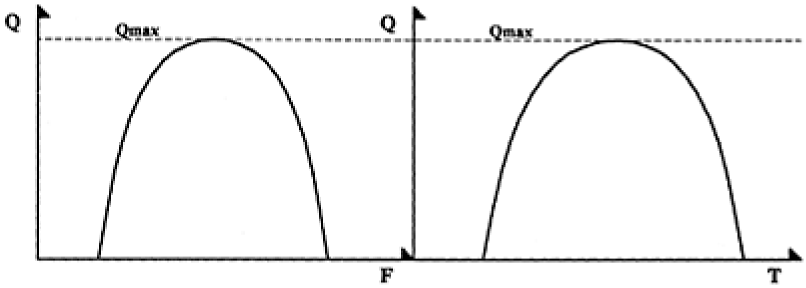

Fig. 2. The law by Yerks-Dodson and Taylor (left side) and its consequence as a bell-like shape of performance

efficiency dynamics (right side), Q-efficiency, F-ergonomic factor, T-time.

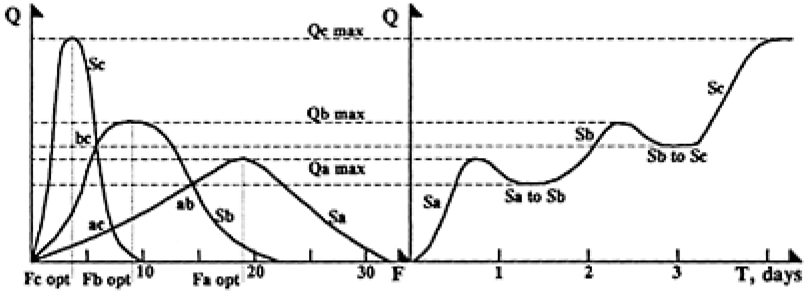

Fig. 3. Transformation dynamics in information perception: characteristic curves of reading strategies Sa-readng by letters, Sb-by syllables, Sc-by words (left side) and transformations of the strategies (right side), Q-efficiency (probability of successful trial divided by time spent), F-ergonomic factor (number of eye movements during perception), T-time (Venda, 1990)

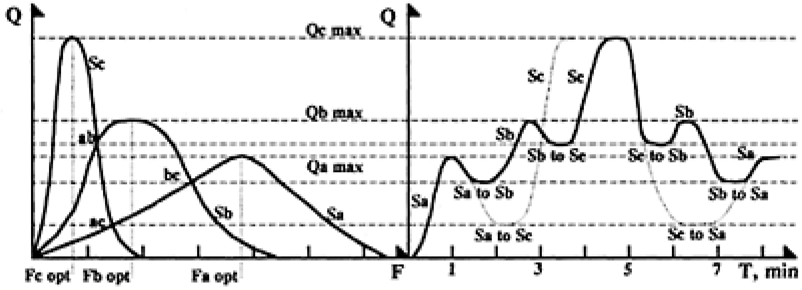

Fig. 4. Transformation in human operator performance under real emergency: characteristic curves of operators’ information perception strategies (Sa-by separate elements, Sb-by small chunks, Sc-by whole

technological units) under emergency at the power station (Venda, 1982)

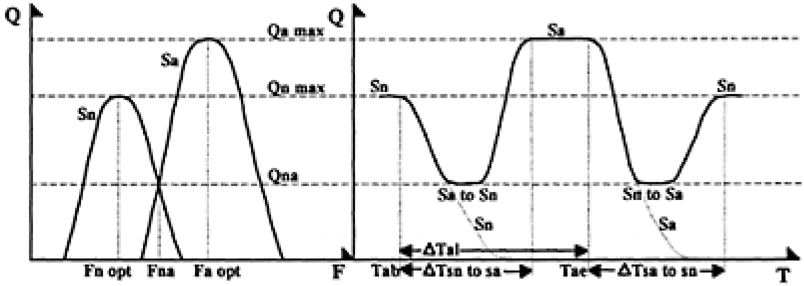

Fig. 5. Transformation dynamics of operator’s strategies at the start and end of emergency situations, Sn-strategy in normal situation, Sa-strategy in alarm situation, Q-efficiency, T-time.

APPLICATIONS OF TRANSFORMATION THEORY IN BIOMECHANICS

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As with any other complex system, the human body allows for a plurality of its structures and respective strategies of behavior. In changing the structures/strategies, their transformations are based on human evolution and on individual development of abilities for mutual adaptation with environment, machines and other people. Such plurality of mental and physical structures/strategies is particularly important when employees are requested to adapt to new technologies, workplaces or to develop work skills. In accordance with Yuri Venda's Law of Transformations that adaptation will be made through states common to the individual's previous and new mental and body structures or strategies. In physical terms, this law may refer to the transformations of specific motor groups used to accomplish certain tasks.

DEDICATION

This paper, as well as all our studies in transformation dynamics, is dedicated to memory of Yuri Venda (1969–1991) who discovered and started to actively to study the general nature of The Law of Transformations, which can be very useful in prospective studies of structural dynamics in all kinds of complex systems.

INTRODUCTION

The human body is a redundant system and thus allows for a plurality of strategies, both mental and physical, to be developed to accomplish a particular goal. Such pluralities are particularly important when employees are requested to adapt to changes in methods and physical movements in the workplace. The law of transformation states that adaptation will be made through states common to both the new and the old strategies (Venda, Yuri, 1991). In physical terms Yuri Venda's law of transformations may refer to the implementation of specific motor groups used to accomplish certain tasks. In order to adapt to a new activity, the first level of adaptation will involve the coordination of muscle groups used previously for familiar activities. As the mind and body adapt to the new activity, new strategies and new muscle groups are incorporated in the task and error rate and effort are reduced through a natural process of optimization. By recognizing the general law of transformations, training programs can be made more effective and training time reduced. The major benefits of recognizing and using transformation theory are not confined to simple cost efficiencies; the reaction of the physiological system to external stimulus is such that proper adaptation to change can reduce the incidence of stress-related death (such as heart attack) as well as to reduce absenteeism in the work place. Since all adaptation is essentially the process of adopting new operational strategies, and all new strategies are adopted through a behavior compatible both with the old and the new strategy, it is thus apparent that when the degree of change requested of an individual or of a system is such that very little is in common, then drastic failure of the system is imminent.

The purpose of this paper is to demonstrate the ways in which the law of transformation is manifest and to indicate specific parameters that may be monitored to predict the probability of successful adaptation.

METHODOLOGY

The law of plurality of complex systems structures and strategies was proposed by V.Venda (1980, 1985) and used as a preliminary basis for transformation theory (Venda, 1980, 1981, 1986) before Yuri Venda worded original law of transformations. The law of structural plurality insists that "Every complex system may have a number of different internal structures and respective external strategies of behavior. Each structure/strategy is described by a specific characteristic curve (or hyper-surface if multi-factor analysis is used)." It was shown that characteristic curves are U-shaped for complexity criteria and bell-shaped for efficiency criteria (Venda, 1986). It is well-known that bell-shaped curves describe efficiency. A single-strategy curve was experimentally found by Yerkes and Dodson (see Woodworth, 1938) and Taylor (see Frievalds, 1987) in the beginning of this century. Yerkes-Dodson studied the performance of rats related to stress which was induced by an external (exogenous) stimulus. Figure 1 is a qualitative representation of performance related to exogenous stimulation, or level of arousal, in humans (Hasset and White, 1989). As human interest in performance increases (stimulation), the quality

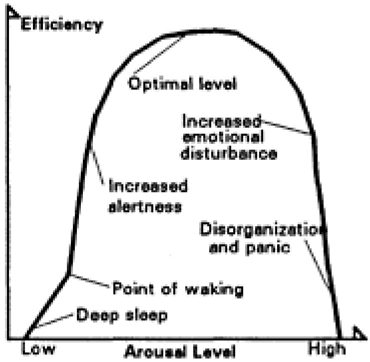

Fig. 1 Efficiency of performance as a function of arousal (Hasset and White, 1989)

of the work done increases, reaches a peak, then begins to decline as the individual becomes overly concerned with the performance itself. This performance curve would change quantitatively if a right-handed individual were asked to perform the task with her left hand. The individual would revert to a very slow pace while learning the operation of the motor units associated with the left-handed movements, then increase the speed of repetition of the motions, thus developing the qualitative curve of Figure 1. The transformation in this case is a biomechanical one as well as a mental one. The mind must image the actions of the right handed system, encode the firing sequence of the motor units of the left hand and increase the speed of the repetition of the sequence. Eyesight is the general sensor used for feedback to ensure correct encoding and sequencing.

CHARACTERISTIC CURVES OF STRATEGIES

In the above, we assumed a successful adaptation and an ability to reduce the demand for performance during the learning or re-learning period. In other words, we dealt with neither the case of under-stimulation nor over-stimulation. Figure 2 is a qualitative performance versus stimulation curve which incorporates the effects of both under-stimulation and over-stimulation on human performance. These ranges of stimulation were studied by P.V. Simonov (1962) and he noted periods of negative performance resulting from too little or too much stimulation. We see that when the stimulation or motivation to

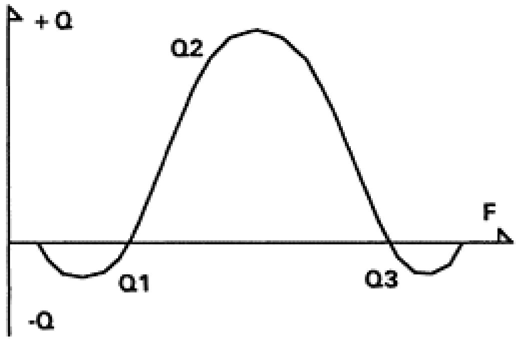

Fig. 2 Three phases of organism response Q to different intensities of stimulation F (Simonov, 1962)

perform a task is too low, the individual pays so little attention to the task that organization is disrupted and additional work would have to be done to restore the possibility of acceptable accomplishment. Such a phenomena is often seen in the work place when individuals feel that the task is unimportant and that errors are not important and need not be corrected. If our operator of the previous paragraph had other tasks to perform and was required to attend to the slow delivery of a stream of parts to be assembled while attending to a second more stimulating task, then parts may pass unnoticed and dis-assembled. These conditions arise from understimulation of the individual. On the other hand, if we require our operator to switch to her left hand and do not reduce the rate at which we expect the repetitive motions and insist inadequate performance will result in highly undesirable consequences for her, she is apt to be suffering from over-stimulation and increase error rate to the point where incorrectly assembled unit are passed as well as dis-assembled parts. Thus both too little stimulation and to much stimulation cause not only a reduction in performance, but may also cause a negative performance. After a period during which the inability to cope is experienced, the usual reaction of an organism is to cease to attempt to perform. Too high a stress level is not a good thing. Optimal stress is the greatest benefit. Neither a lack of concern nor an active hostility or high level of anxiety are beneficial in the work-place. Both task design and training programs must take these variables into account.

Based on the two qualitative performance curves shown in Figure 1 and Figure 2, any new task assignment can be seen to change the level of stimulation. What must also be recognized is that when the approach to the task is re-designed it represents a change in task strategy. The individual's performance will drop to a level compatible with both the old and the new strategy envelopes as shown in Figure 3. As the individual attempts to adapt to the new strategy, the stimulation level rises and performance drops. The new method begins to be understood, the new motor units and firing sequences become trained, the stimulation level drops and the individual increases performance reaching a new, hopefully higher. level of productivity.

In the above discussion we have dealt primarily with exogenous stimulation; the presentation of work-pieces or the external demand for a change in sequence or positioning involved in simple mechanical tasks. It is important, however, to consider also the stimulation occurring as a result of the cognitive functions of the brain. The physiological response of an organism is not a response to the physical reality of the individual's situation, but is a response to the organism's to its perceived situation. Our reality is our perception of the world, which is not necessarily the true or complete situation. Emotional and psychological stress have physiological responses which must also be

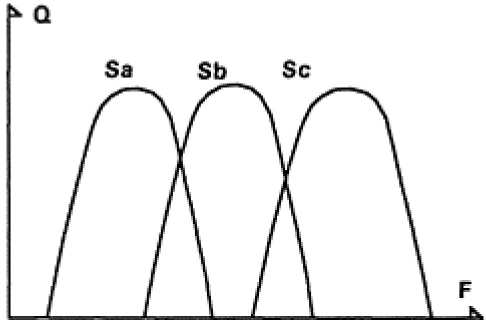

Fig. 3 In mutual adaptation with machines and environment an individual may use different strategies Sa, Sb, Sc (Venda, 1980, Frankenhauser, 1981)

reflected as stimulation level on the performance curve. However, such stresses, their origins and their relationships to perception will be the topic of future presentations. The purpose of this presentation is to establish the basis of measurements of biomechanical and biochemical parameters that may be used to monitor the level of adaptation of an organism to new states.

WORK, TRAINING AND RETRAINING AS THE PROCESSES OF TRANSFORMATIONS

When a task is re-organized or a new job or level of job is attained, there is an associated stress to which the physiology must adapt. In industry, the purpose of re-organization is to increase productivity and often is predicated on an increase in performance of the individuals. Figure 4 is a qualitative portrayal of the performance benefits of four possible strategies S_1, S_2, S_3, and S_4 and the expected performance Q of each strategy. If the task is currently employing strategy S_1, then it is obvious that we would like to go to strategy S_4 in order to elicit the highest productivity. However, the law of transformation requires that the new strategy will be adopted and adapted to through a performance level not greater than that common to both strategies. Figure 4 indicates that such a performance is extremely low. The intersection of the strategy curves is at a performance level of one-fifth the normal performance using the current strategy. A corporation attempting to introduce new technology without having the personnel to comprehend it may be in exactly the position described above. It is obvious that the possibility of financial disaster is great under these circumstances, particularly if our performance measure is taken to be goods produced. However, the focus here is on the human factors and the stimulation level F associated with performance. We note that F is indicated as increasing with each new strategy and thus the individual worker must adapt to the new task environment, the biomechanical motion requirements of the new task environment and to the new biochemical environment both the exogenous and endogenous stimulation produces.

If we wish to adopt new work strategies, we must accept that planning to reach the most lucrative strategy is necessary. Referring again to Figure 4, we see that by using the two intermediate strategies S_2 and S_3, we could reach the S_4 strategy without the loss in productivity associated with a direct attempt to go from S_1 to S_4. As we move from S_1 to S_2, the value of performance Q drops to the value of the intercept of the two curves, but performance is much higher than that at the intercept of curve S1 and either S_3 or S_4 and thus productivity is maintained. A similar observation is made of the transfer from S_2 to S_3 instead of attempting the transfer to S_4. The productivity saved is the difference of the performances integrated over the time period of the projected strategy changes.

The curves of Figure 4 also have a second meaning; a more human meaning. As the stimulation level rises, the emotional and psychological stress levels are kept lower if personal productivity can be maintained. Therefore, by approaching the goal through intermediate strategies, the stress-related occupational diseases are minimized and the skills of the work-force are retained. The element of time is important in any adaptation process. The denial of time can result in the stimulation level rising to the point of over-stimulation as shown in Figure 2 but forms of biomechanical adaptation also require time and a programmed approach. While such biomechanical adaptations are often not considered in industrial situations, almost every new executive notices that his clothes begin to feel tight as he puts on weight from days and nights at a desk. The point is, the physiology adapts to the level of physical activity such that it becomes dangerous to exert oneself at levels that once were a normal part of a job. It is from this observation and from athletic training programs that we may draw information on the biomechanical adaptation process and demonstrate conformance with the law of transformation.

The energy supply system for man’s motion is multi-partite. A runner may draw his energy from creatine phosphate (CP) as a result of energy release from a phosphate bond as a result of the decomposition reaction. He may also gain energy from glucolysis, as glucose is lysed to lactic acid. A third source of energy is the aerobic oxidation of proteins, fats. and carbohydrates which at the same time replenish the reserves of adenosine triphosphate (ATP) What is important here is the rapidity with which the energy can be accessed and the level at which the activity can be maintained. In training, the runner forces his physiological processes to increase the rate of energy release due to decomposition of creatine phosphate as well as the rate at which glycolysis takes place. Each individual has a different potential for the upper limit of this activity and so not all can be good sprinters, but the physiology responds according to the qualitative behavior shown in Figure 6.

Due to the time period of the events a sprinter takes part in, the primary energy reserves he uses are the creatine phosphate (CP) shown as curve Q_1 in Figure 6 and glycolysis shown as curve Q_2 in the same Figure. The adaptation of a runner to sprinting may be monitored by measuring the energy reserves used from these two sources after the subject has performed the event for which he is being trained. Since creatine phosphate has three times the total energy of the glycolysis system, the rate of release of CP is of extreme importance in adapting to sprint events. For long distance runners, the third energy source, oxidation of fats, proteins and carbohydrates, becomes important. Since the oxidation source has four and a half times less energy than glycolysis, it is the last source of energy to be switched on during locomotor activity. Indeed, in sedentary people it may never operate at a high rate. In this latter case, physical exhaustion sees an early onset and the stimulation of the organism moves into the negative performance region on Simonov's curve in Figure 2. In the case of a runner in training, if the exercises he undertakes are changed to utilize new muscle groups, the energy release targets are changed, representing a change in strategy for the physiology thus an erosion of performance in sprinting would be seen prior to the hoped-for increase in performance. Such changes are observed in coaching.

A more common situation in which the Law of Transformation can be seen to apply is in the biomechanical adaptation to a knee injury. In such a case, the phase relationship of the locomotor muscle firings is changed for both the injured and the uninjured limb. The amplitude and duration of the firing of the muscle groups also changes. The reasons for such changes are primarily the attempt of the two nearest uninjured joints to alter activity to compensate for the injured joint, but also may be a pain-

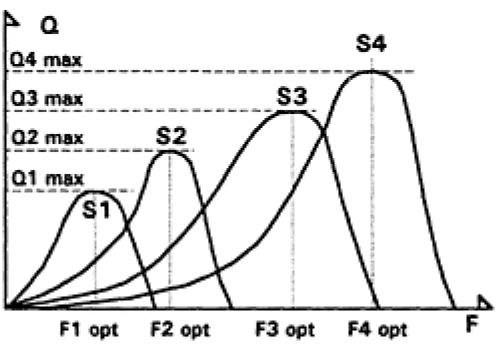

Fig. 4 Efficiency Q of different structures/strategies S1, S2, S3, S4 could be very different for different environment parameters F.

avoidance mechanism. The results of the motion restriction and of the phase changes in muscle group activity are to cause the speed of normal locomotion to decrease and to change the floor reaction force record such that the Fourier components of that record are changed in magnitude and in phase relationship. A graphical display of such a record is shown in Figure 7. The adaptation to the new firing sequences and durations can be measured in terms of the changes in these Fourier components and in terms of normal walking speed. Adaptation to regained function can be monitored by observing the slow return to symmetrical behavior of the two limbs.

CONCLUSIONS

Yuri Venda's Law of Transformations is seen to be valid for many biomechanical and psycho-physiological processes and should be applied in the design of training programs when changes in work-place are such that new sequences of movement, levels of movement or new groups of tasks are required of the individual. Parameters can be developed and measured to assess the adaptation level of the individuals and to determine training programs appropriate to the ability to adapt.

Productivity can be maintained at a higher level during transition in strategies if intermediate strategies are used. By designing transitions recognizing the Law of Transformation, both corporate and individual health can be best served.

Of primary significance in the changing of strategies is the recognition of the fact that new strategies can only be adopted through the elements common to both the old and the new strategy. It is through the recognition of this, the Law of Transformations, that a more reliable basis of the estimation of costs involved in adoption of new work skills can be established.

Using Transformation theory leads to many practical observations. For example:

1. The longer the time an individual remains at a stable level (plateau) of strategy Si, the longer will be the time needed for transformation of Si into Si+1;
2. Individual learning capacity, creativity, adaptability, mutual adaptation with new machines, and environment are dependent on an ability to transform the strategies, especially distant ones (with big differences between Fi-opt.);
3. It is necessary to teach human operators, pilots, sportsmen not only different effective strategies (such as normal and emergency operative conditions) but also to transform those strategies for appropriate mutual adaptation with the environment; effective transformations in both directions, forward and reverse, are needed in many types of human performances;
4. In the learning, training and retraining processes, no exams, tests or competitions should be organized during periods of transformations of structures, strategies or skills.

Studying of transformations in the biomechanics of work skills is planned to be an important part in the Human Factors Engineering and Ergonomics Program at the University of Manitoba.

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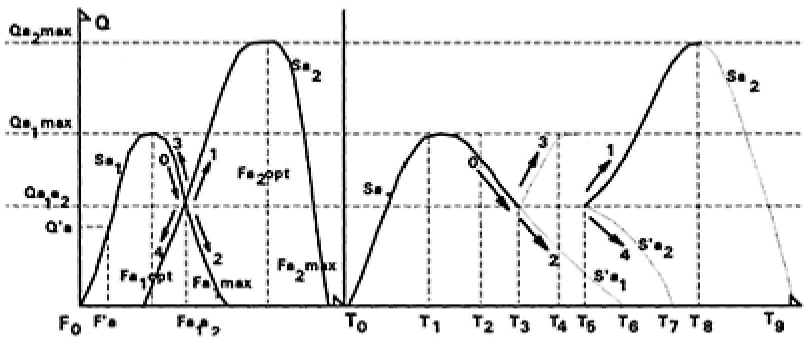

Fig. 5 Yuri Venda's Law of Transforamtions allows one to explain, predict and practically organize different kinds of transformations between structures and strategies of humans, human-machine systems, technologies, firms, and other complex systems.

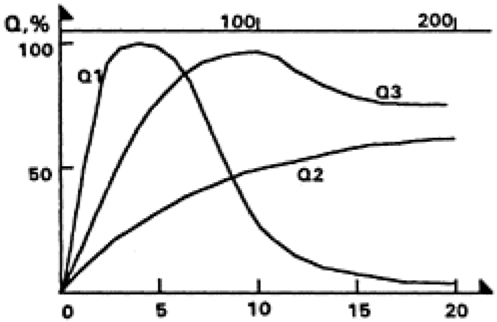

Fig. 6 Locomotor energy sources for a runner, Q1=CP; Q2-glycolysis, Q3=Total energy release rate

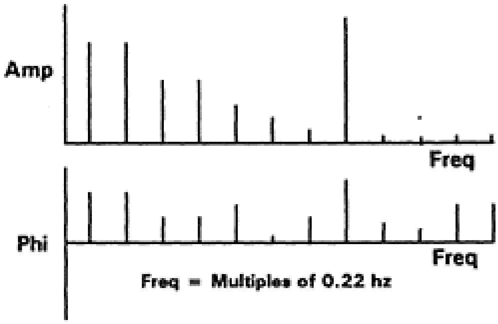

Fig. 7 Amplitude and phase shift of Fourier components of reaction forces of human gait (Thornton-Trump and Suzuki, 1991)

HUMAN FACTORS AND TRANSFORMATIONS OF MANUFACTURING TECHNOLOGIES

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The main ergonomic requirement and methodological principle in the design of productive, reliable and safe technology is mutual, multi-level adaptation between all components of the human-machine-environment system (Venda, 1975). This requirement can be satisfied relatively easily in "constant technology" condition. Companies with "constant technology" are quickly becoming uncompetitive. Only companies with the ability to quickly and often change technologies and products will be able to survive in difficult times. This paper describes a new theory for predicting, analyzing and managing transformation in manufacturing technologies and human factors. The theory is based on Yuri Venda's Law of Transformations.

DEDICATION

We dedicate our paper to the memory of Yuri Venda, (1969–1991) who discovered the Law of Transformations, which could be useful in many studies in human factors, ergonomics, system theory, industrial engineering, dynamic manufacturing and professional education and training.

INDUSTRIAL ERGONOMICS AS A SCIENCE FOR MUTUAL MULTILEVEL ADAPTATIONS AND TRANSFORMATIONS IN HMES

Human Factors and Industrial Ergonomics are considered here as a multidisciplinary, fundamental and applied study and design of human-centered processes of mutual adaptation and structural transformations in human-machine-environment systems (HMES).

Studies of human-machine-environment interaction in dynamic advanced manufacturing facilities means that the features of machines (workstations, assembly lines, computers, telecommunications, control rooms, etc.,) and industrial environments (working space, shifts, light, noise, micro climate, etc.) are being analyzed and designed in connection with dynamic psychological, physiological, and biomechanical characteristics of human beings.

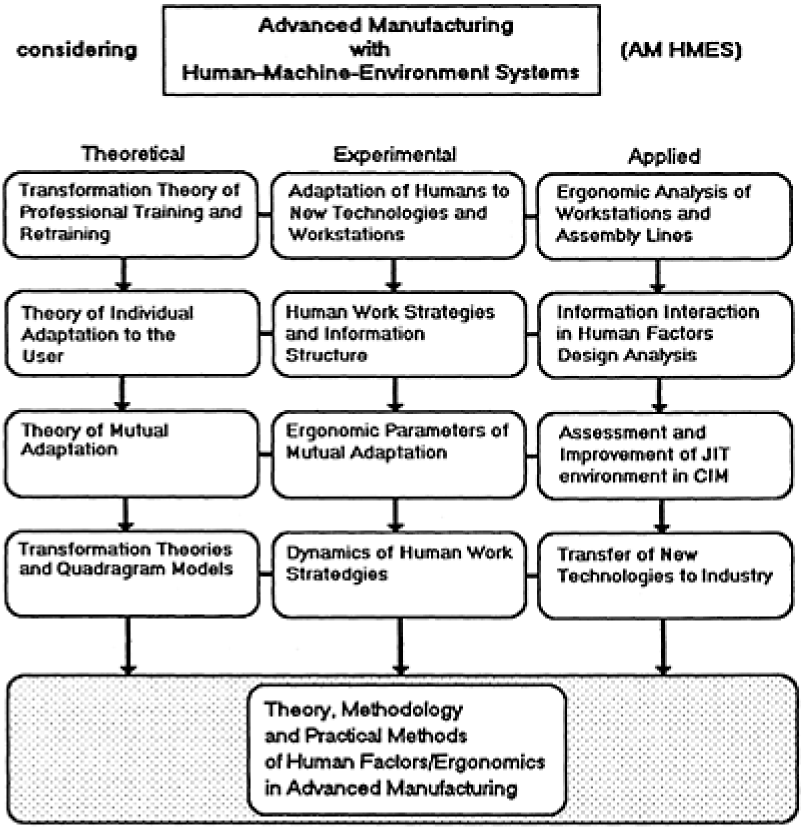
Study of mutual adaptation and transformations is of particular importance in the implementation of new technologies, advanced manufacturing, management, flexible team work, shifting of work places and worker's functions, professional training and retraining, etc. Yuri Venda's Law of Transformations can become a new basis for theories of professional training and retraining, multi-level mutual adaptation in dynamic industrial human-machine-environment systems.

There is no general theory or methodology for the analysis and synthesis of the structural dynamics of advanced manufacturing human-machine-environment systems in contemporary world human factors and ergonomics. Therefore, analysis and design of all such systems always start almost from the beginning, with each design having its own individual character, making such studies very expensive and time consuming and slowing the pace of progress. This is especially visible in the time and effort spent by ergonomists at the Winnipeg plant of Northern Telecom Ltd. during their implementations of CIM, Just In Time, the Total Quality Management (TQM) Philosophy and Team Owned Processes.

We believe that the principles of Mutual Adaptation and Transformations are fundamental and generally applicable to all kinds of systems and to every component of the manufacturing system, i.e. human beings, machines, working environment, and to the system as a whole in its mutual adaptation with other manufacturing, trade, supply, communication, control and management systems.

Fig. 1 The Tree of Goals of

BASIC AND APPLIED RESEARCH IN HUMAN FACTORS ENGINEERING/ERGONOMICS



MAIN GOALS AND STAGES OF THE RESEARCH

The general structure and goals of our research are displayed in Fig. 1. It also shows the various areas of research and development and how they relate to each other.

The main aim of our research is to work out the theory, methodology and practical methods of human factors engineering/ergonomics in dynamic Manufacturing Systems. This aim can be achieved by conducting in parallel a wide range of theoretical, experimental and applied research.

The theoretical part of the research includes the following stages:

1/ The Transformation Theory of learning, professional training and retraining (Venda, 1986) is a basis of optimal individual adaptation of humans to new technologies, machines and environment.

The theory of mutual adaptation in human-machine-environment systems is oriented toward synthesis of two main and traditionally separate directions in psychological and human factors/ergonomics studies: 1. adaptation of humans to new machines, environment, functions and tasks by using the methods of learning, education, professional and physical training, etc.; 2. adaptation of machines and technological, educational environments to people by using the methods of ergonomic analysis and design. Our proposed methodology of mutual adaptation helps to combine possibilities of both previous tendencies, to make human-machine-environment systems more productive, effective, reliable and safe. In the books by Venda (1975, 1982, 1990) and the paper by Yufik, Sheridan, and Venda (1992) the principle of mutual adaptation and the transformation theory are used for improving the methodology of analysis of decision making processes, design of information display systems and decreasing of intellectual complexity of human operator functions.

2/ The theory of individual adaptation of machines to the user describes in what way machines need to be designed to fit various types of machine users (Venda, 1977, 1990).

3/ The Theory of Mutual Adaptation of humans with machines and the environment describes how the best trade off of adjusting the human to the machine and environment, and reworking the machine and the environment to the human can be derived. The theory is being implemented to human factors design, usability testing, interface design and innovative hardware and software solutions for future terminal and user interface design.

4/ The Quadragram Models of the HMES structural transformations (Venda, 1988) describe how a human changes cognitive strategies as learning progresses, and shows how this learning may be sped up.

The following experimental studies are planned to be conducted in parallel and in connection with the theoretical studies:

1/ Adaptation of humans to new technologies and workstations. The experiments will be based on the transformation theory of learning, training and retraining and connected with the analysis of human working skills, strategies of information perception, thinking and decision making, and change of the strategies if a new technology or workstation is implemented in the experiments with the same subjects.

2/ Mutual adaptation of human cognitive strategies and adequate information structures. The influence of information on human decisions is studied at facilities and with laboratory simulation of human performance in computer integrated manufacturing. In addition to the previous stage of experimental studies, an opposite direction of adaptation, the adaptation of a machine to the human individual, will be studied as a second stage. Instead of changing human knowledge, skills, and work strategies, at this stage the local optimum of human-machine system efficiency will be found experimentally by using wide changes of machine characteristics in design, and operative adaptation of information displays, workstations, control rooms, assembly lines, etc.

3/ Studying ergonomic parameters of mutual adaptation which relate to HMES in dynamic manufacturing. The parameters include criteria and factors of human performance efficiency, complexity, reliability and safety. The third stage of experimental studies on mutual adaptation in human-machine systems will include searching for the global optimum of the systems with co-ordinated adaptation of human to machine and machine to human. Mutual individual adaptation in human-computer interactive systems will be studied especially intensively in the experiments. Recording and computer analysis of a subject's self report on psychological factors of decision making will be used in the experiments in combination with recording of psycho-physiological parameters. Fundamental methods of searching for the factors of human operator work complexity and efficiency were described by Venda (1975, 1982)

4/ Experimental study of the dynamics of human work strategies when criteria and factors may be changed not only quantitatively but also qualitatively. Fast and effective implementation of new technologies in the manufacturing environment can be organized only on the base of mutual adaptation of workers and industrial facilities with dynamic ergonomic criteria and factors of the human-machine-environment system efficiency. the experiments will be based on the transformation theory of learning, training and retraining and the principle of mutual human-machine adaptation. They will be oriented to synthesis and analysis of new types of human-machine-environment-systems dynamics models as the quadrigrams. Industrial experiments will be done on the transferring of new technologies to assembly plants of Northern Telecom.

Fig. 1 shows that every experimental research stage is connected with the theoretical as well as with the applied stages.

APPLIED RESEARCH AND DEVELOPMENT

Ergonomic analysis, industrial design and improvement of work stations, should facilitate human-centered processes in mutual multi-level adaptation of human-environment systems. Research is underway at Northern Telecom will concentrate on information display at assembly lines and workstations in Computer Integrated Manufacturing (CIM) and Just-In-Time (JIT) environments. The objective will be to increase the productivity and reliability of individuals, teams and systems working under these conditions through the use of the principle of mutual adaptation.

Ergonomic analysis and improvement of the assembly workstation will involve the evaluation of current methods in designing modular quickset workstations that are product specific. The present method of manufacturing is on long flow line workstations. Current problems with the straight line process are: decreased communications, fewer opportunities to solve immediate problems and difficulties with smooth KAN-BAN operation.

Research and development on the human-human, human-machine information interaction processes is very important for Human Factors/Ergonomics Design in the transfer of new technologies. Concrete studies include the transfer from experimental robotics to mass production, the introduction of new technologies into automated control systems, and the introduction of new control or organization technologies.

From the point of view of the Transformation theory, ergonomic aspects of the process of changing of old technology to new could be analyzed with the Q(F, S, T) diagram and then modeled on the Quadrigram. (Fig. 2, Venda, 1988)

In Fig. 2, working professional strategies for the S1 and S2 technologies are displayed at the left side of the Q(F, S, T) diagram. If a worker uses strategy S1, but the working environment and its subjective perception (F) change from Flopt to F2opt, the efficiency (Q) of the worker's performance (see right side of the diagram) will decrease very fast and very quickly go to zero. Hence, transformations of technologies should be synchronized with the transformations of the worker's strategies. That means that mutual adaptation in human-machine-environment systems during transferring of technologies is very important, and is a complicated problem of human factors engineering/ergonomics. This problem is very typical for advanced manufacturing. For example, at the Northern Telecom Winnipeg Plant, a new project involves evaluating current methods of assembling and testing of DNX Bays. The old method was to perform the operations in a vertical manner. Problems encountered in the old method included those of extended reaches leading to muscle fatigue and possible repetitive strain injuries (RSI). One other division within the company (Calgary Wireless Systems) performs similar Bay assembly and testing operations in a horizontal position. Special fixtures and platforms were designed to allow the Bay to be maneuvered from a vertical to horizontal position when it was received from the preparation stages. To assess and implement these changes in the DNX Bay, multi-factor ergonomic methods revision is being used.

Ergonomic analysis of job rotation schedules is very important for dynamic manufacturing. The problem with job rotation is that not all of the jobs that the operator will rotate through will use different muscle groups and cognitive systems. A well defined analysis of Job Rotation Schedules is very important for dynamic manufacturing. A problem of transformations in biomechanics is discussed by V.Venda and A.Thornton-Trump (1992).

We are interested in the process of developing a new multi-parameter Quadrigram to permit the study and documentation of multi-factor production organization problems involving humans.

EFFECTIVE TRANSFORMATIONS OF TECHNOLOGY: THE ONLY WAY TO SUCCEED IN COMPETITION, ESPECIALLY DURING A RECESSION

The Transformation Theory could be applied not only to research on individual learning but also to the study of the dynamics of manufacturing systems. Let us illustrate this with a hypothetical example:

A manufacturer is faced with a problem of survival. The techniques of manufacturing and distribution are changing very quickly, and to stay with or ahead of his competition, he must change quickly and smoothly. Any change first involves assessment of the change direction, which is in itself very difficult, but once he has made the decision, the problem is to make the change successfully. A well-known example involves the cash flow during the transition period. A less obvious, but very real problem, is the manufacturer's ability to successfully adjust to the change that he has brought upon himself. This ability or lack of ability is the subject of the discussion in this example.

The manufacturer must improve his manufacturing effectiveness, in this case, create more product with more variety, and of better quality, and/or for less cost. The answer is to use the existing machines and processes as effectively as possible, or predict when and how to change them. The manufacturer can proceed in three different ways to make the change of technology. Let us analyze the possible ways with transformation diagrams.

1/ He can build a new plant somewhere else, using new workers. When the new plant functions properly, terminate the workers at the old plant and sell the old plant and land. (see Fig. 3)
2/ He can enter a change carefully in one part of his plant, using volunteers to work in this changed area. If the introduction is successful, introduce the change in other areas which require the same type of improvement. (see Fig. 4)
3/ He can introduce changes on a continuing basis as a part of the manufacturing routine, just as product changes are usually part of the manufacturing routine. (see Fig. 2)

Changing the process costs money, effort and time, so the typical manufacturer—to make as much money as possible from his investment—changes his manufacturing process as little as possible, which often means no change at all for many years. Part of the justification he may use is that he requires a one year payback to justify the change. When change is finally required for survival, the manufacturer does not have the ability to change the outlook of the managers and workers, so he starts all over again somewhere else, with great pain, expense and loss of time. One critical problem with this approach is that sometimes skills that are special to this particular type of manufacturing are still required, and the only people with the skills are those in the old plant. Some new plants have died because these required skills could not be developed in the new plant before the money ran out.

If the manufacturer decides to change his present plant, he meets stiff opposition from everyone. This problem has caused many plants to go bankrupt while on the road to change. A risky route around the problem is to find the people in the plant most interested in change, and have them run a pilot line to test the new equipment or technique. If the technique is successful, it can be introduced into the rest of the plant, with opposition. If the effort is unsuccessful, the more conservative people will gain ground and reduce the chance of any new techniques being introduced in the near future.

A route for introducing new methods which seems to be more successful is creation of an atmosphere of constant improvement. Total Quality Management" is the name of one of the most successful techniques and philosophies. The aim is to convince everyone that the plant will survive only if everyone works toward constant improvement, and if the plant sets up and maintains continuous retraining for everyone. A management style which allows everyone to be involved to some level in the decision making is also required.

Of the three approaches, the third is certainly the most humane, and has been shown to be effective. The second approach of gently introducing technology onto an unwilling group has been much less effective, while the first approach of running a plant into the ground, then closing it and opening a new one somewhere else has been generally as effective as the humane approach from the manufacturer's point of view. The major questions to be answered are: What process is going on when techniques like TQM are used? How can this process be measured and predicted to make it as effective as possible? How cost and time effective is it compared to the competing scorched earth policy?

The transformation diagrams along with human factors analysis are very effective in prediction of processes, consequences and accomplishing the best results of transformations of technologies in dynamic manufacturing.

Using the same Transformation Theory and principle of mutual adaptation for modelling the dynamics of the whole facility and every individual working in it is very important and effective for complex ergonomic and engineering study to improve the manufacturing facility and technology in it, as a multi level adaptive human-machine-environment system.

CONCLUSIONS

Now, let us list some of the properties of the transformation process in dynamic manufacturing human-machine-environment systems.

1/ The longer the time that the manufacturing facility (firm, human, operator, etc.) remains on the plateau of the Si th structure, the longer will be the time for a transformational plateau for the transition from the Si th to the Si+1 th structure: Si goes to Si+1.

2/ The longer the time that the manufacturing facility (firm, human operator, etc.) remains on the plateau of the i-th structure, the shorter will be the time for retransformational plateaus with the back transition from novel strategies Si+1 back to the Si: Si+1 goes to Si.

3/ The learning capacity and potential for creativity (innovation) of a system, i.e. its mobility, is determined by its ability to execute direct (forwards) and reverse (backwards) transitions from one distinct strategy to another, and to adopt the most effective strategy in the mutual adaptation of the system with its dynamic environment.

4/ The learning efficiency with respect to a range of rapid changes of conditions, at which a system can perform ("survive"), depends on the batch of mastered strategies and on the rates of their action during the transformational period.

5/ An increase in the learning time may result in the deterioration of efficiency criteria; the learning process should not be stopped during transformational shifts.

6/ A subject's motivation during learning depends on his personal assessment of prospects and on the degree of mutual adaptation with his environment.

7/ The learning rates increase in case of an optimistic forecast for the efficiency dynamics. In this sense the transformational periods impose particular difficulties. More often than not, both the student and his teacher lose all hope and give up exaonditions are equal: the components of the system; the time of some other specific strategy has been in use; the frequency of transformations and retransformations; etc.)
8/ the learning process ought to be so planned as to exclude all kinds of examinations, tests, competitions or responsible assignments during transformational periods.
9/ The cognitive strategies, amenable to transformation are called associated ones, and the methods of thinking predicated thereupon as associative ones. A process of thinking, especially a creative one, is based on the transformations of thoughts, images and the like.
10/ The quantitative estimates of the fields of events, images and decision making are the target of studies of various transformations.
11/ In many practical cases the initial direct (forward) and the subsequent reverse (back) transformations differ in that the former are clearly of an exploratory, searching character and are performed by the trial-and-error method.
12/ A direct and reverse transformation of structures and strategies of the complex system proceed under the same conditions and state of the system. The law and theory of transformations are general and applicable to any system. This last consequence of Yuri Venda's Law means in application for example to the former USSR, that contemporary reverse transformation of socialism to capitalism should be in its main aspects as difficult and as similar to the direct transformation which occurred in 1917. These transformation processes are described in more details in my book (Venda, 1989).

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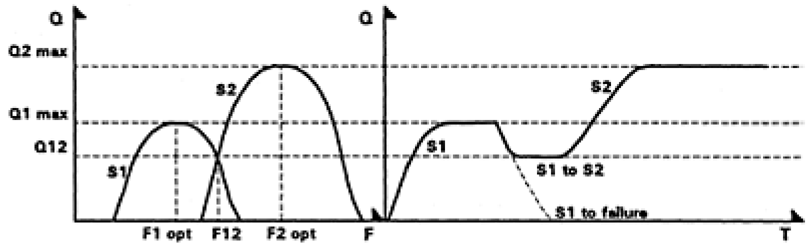

Fig 2. Intorducing new technology S2 by continuous Transformation of work stratedgy S1 into S2 or introducing new technology S2 by continuous transformation from old technology S1.

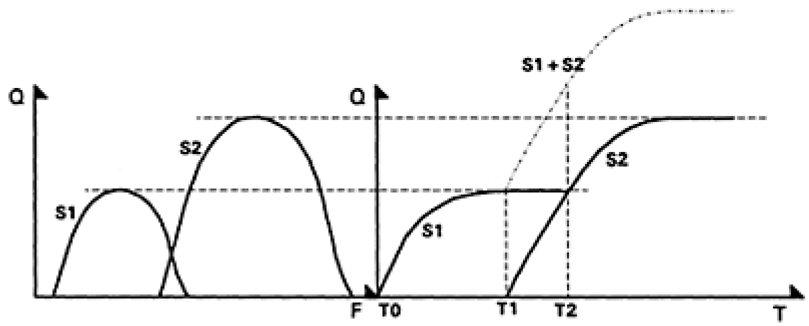

Fig. 3 Changing of manufacturing technology by replacing old plant S1 with new one S2. Q-productivity, F-level of technology, T-time, T0-starting time of S1, T1-starting time of S2, T2-terminating point of S1.

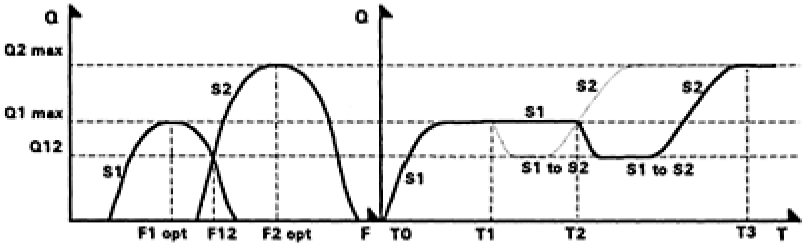

Fig. 4 Changing of old manufacturing technology S1 to S2 (S1 goes to S2) in some part of facility (see dash-line from time moment T1 to T2), then of entire facility (T2–T3). Q-productivity, F-level of technology, T0-start time of initial technology S1.

RISKS, ACCIDENTS, AND ACCIDENT PREVENTION

ASSESSING ERGONOMIC RISK: A COMPREHENSIVE APPROACH TO ERGONOMIC TASK ANALYSIS AND HAZARD CONTROL

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This paper describes a step by step methodology for gathering and analyzing data, in order to identify ergonomic problems within a facility. An initial assessment, including the completion of an Ergonomics Checklist and a review of medical records, is performed in order to classify jobs as low, medium, or high priority. Jobs that are of low priority are periodically monitored; jobs that are of medium or high priority are further analyzed using a series of techniques. Through engineering and administrative controls medium and high risk jobs are redesigned to reduce the risk score to "low".

INTRODUCTION

According to the Bureau of Labor Statistics, Cumulative Trauma Disorders (CTDs) accounted for more than half (52%) of all occupational illnesses reported in 1989. The figure below illustrates the sharp increase in the number of reported CTDs from 1981 to 1989.

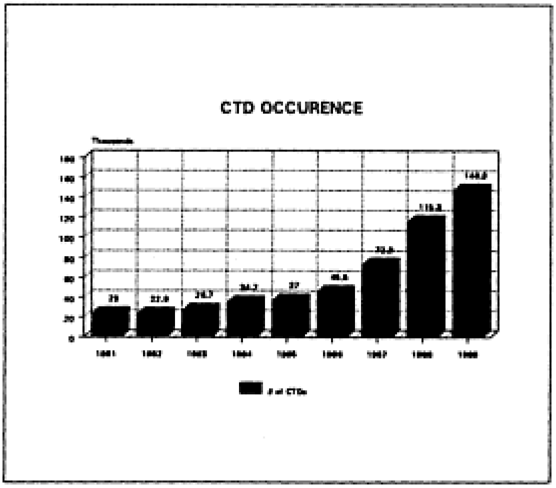

FIGURE 1—CTD occurrence from 1981 to 1989

An effective ergonomics program consists of the following steps: commitment/organization/plan, worksite analysis, hazard prevention and control strategies, solution implementation, and documentation/monitoring.

This paper will focus on worksite analysis methodology for gathering, quantifying and tracking ergonomic hazards associated with various jobs or work areas in an industrial or office setting. The end results of the analysis would be to reduce job related risk to a low rating category through ergonomic redesign of the job.

METHODOLOGY

A systematic approach is recommended by OSHA as a means of identifying hazardous jobs and correcting ergonomic problems. Figure 2 is a flow diagram describing the methodology that is needed for identifying ergonomic hazards, quantifying hazard, redesigning the job, and continuously monitoring change.

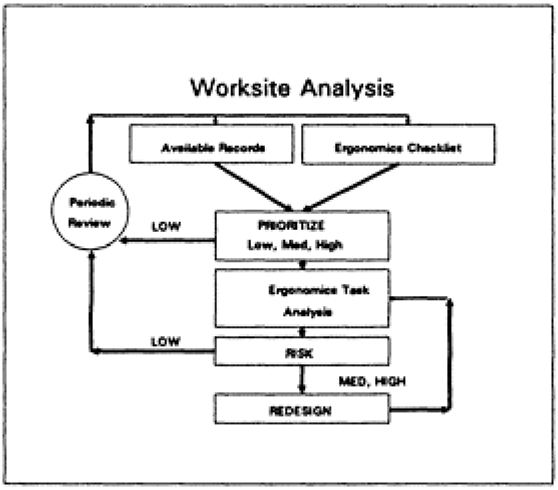

FIGURE 2—Flow diagram describing analysis methodology

The following is a step by step description of the recommended approach:

Step 1: Review of existing records

A first step for identifying CTD problems is to review all the available medical, safety and insurance records for evidence of injury or disorders associated with repeated trauma. A review of such records will indicate the frequency of CTD occurrence associated with a job/task or department (Anderson, 1988).

Although a review of the existing records is essential in any investigation of CTDs, often these records do not provide the analyst with the essential information needed to accurately assess the extent or potential for CTD occurrence. A major problem has been that CTDs are not always recognized as work related and hence go unreported. Therefore, plant or group statistics compiled for CTD often fail to identify those jobs or workers who may be experiencing symptoms or who may be future candidates for Cumulative Trauma Disorders. In general a review of records should be considered as a starting point for a more comprehensive worksite analysis.

Step 2: Perform an Ergonomics Checklist

Since a review of medical and safety records alone will not describe the extent of ergonomic hazards, it is necessary to perform an initial task analysis as a means of evaluating the potential for ergonomic hazards throughout a facility. The task analysis is in the form of an Ergonomic Checklist which gathers information on the job components listed in Figure 3.

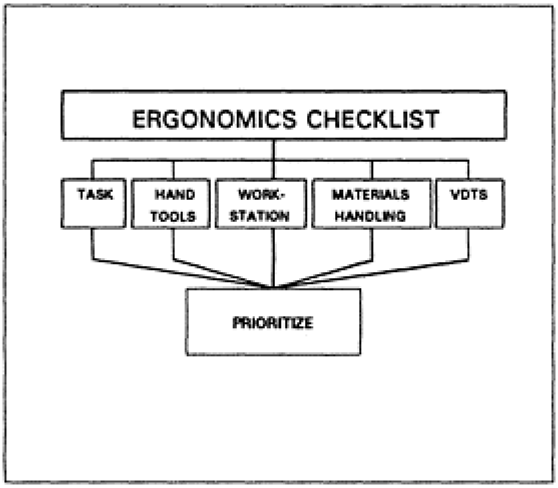

FIGURE 3—Ergonomics Checklist

One or more of the job components checklists may have to be completed depending on the nature of the job. There are four basic types of jobs:

• A job that is upper limb intensive and requires tool use
• A job that is upper limb intensive and does not require tool use
• A job that requires manual materials handling
• A job that requires working with a Visual Display Terminal (VDT)

If a job is upper limb intensive and requires tool use then the workstation, task, and hand tool checklists need be to completed. If a job falls in the second category then a workstation and task checklist need to be completed. For jobs that requires materials handling, only the materials handling checklist need to be completed. For jobs that require the operator to work with a VDT only the VDT checklist need to be completed.

Completion and analysis of the Ergonomics Checklist will result in the jobs or work areas being assigned one of three hazard classifications. These classifications and their respective descriptions are illustrated in Figure 4.

PRIORITY	DESCRIPTION
Low	Exposes the operator to minimal degree of risk for potential development of CTDs, and is considered to be safe for the majority of the population.
Medium	Considered to be safe (“low” risk) for some and hazardous to the others. Would require administrative control and close monitoring.
High	Considered to be hazardous to the majority of the working population and will most likely contribute to the development of CTDs.

FIGURE 4—Description of risk

Each of the aforementioned job components (i.e. workstation, task, etc.) will be assigned a priority of low, medium, or high. A combined priority category will be assigned to each job/task based on the analysis of the checklist. Jobs that are of low priority will have to be monitored and periodic checklists will have to be completed. Jobs that are of medium or high priority will have to be analyzed further for better identification and quantification of hazard.

A computer software has been developed for analyzing a large number of jobs/tasks within a facility. This software will allow the user to assign a priority category to a job/task, produce a report, and assist in continuous monitoring of the jobs/tasks. The software will also make recommendations as to the type of detailed analysis (Step 3) that will be needed for medium and high priority jobs/tasks.

Step 3: Perform an Ergonomics Task Analysis

Jobs that have been identified as medium or high priority in the previous step will need to be analyzed in greater detail. A more detailed analysis will not only determine the extend of hazard but also assist the engineers in redesigning the job effectively. A redesigned job would result in a risk factor of “low”.

The various types of detailed analysis will once again vary depending on the type of job (the four basic types mentioned in the previous step). The following is a suggested method of analysis based on the type of job:

1. JOBS THAT ARE UPPER LIMB INTENSIVE AND REQUIRE TOOL USE

An elemental task analysis is recommended for jobs that involve manipulation of the upper extremity and use of a hand tool (hand/wrist, arm, shoulder). An elemental task analysis consists of breaking the job into sub-tasks and identifying undesirable postures of the upper extremity, measuring the amounts of forces used and the amount of vibration (if any). This technique will result in quantification of the total undesirable positions and excessive forces. Total number of undesirable positions and excessive forces are weighed against a pre-determined criterion. The comparison will result in a risk category assignment of low, medium, or high. If a job is determined to be of medium or high risk, engineering measures will have to be taken to reduce the associated risk to a ranking of “low” (TJI Training Design Team, 1991).

2. JOBS THAT ARE UPPER LIMB INTENSIVE AND DO NOT REQUIRE TOOL USE

For jobs that are upper limb intensive but do not require tool use (i.e. prolonged standing or seating postures), a postural analysis is recommended. This type of analysis consists of evaluation of the operators posture during work. The analyst would measure seven postural angles. These angles are:

- Trunk
- Upper arm
- Elbow
- Head

- Upper leg
- Lower leg
- Foot

The measured angles are weighed against a predetermined criterion. The comparison of the actual angles and recommended angles (criterion) will result in a risk category assignment of low, medium, or high for each of the seven postural angles (TJI Training Design Team, 1991).

3. JOBS THAT REQUIRE MANUAL MATERIALS HANDLING

There are three different types of analysis that would result in a risk factor assignment of the job. These types of analysis are:

- Biomechanical analysis
- NIOSH lifting analysis
- Physiological energy expenditure analysis

a. Biomechanical analysis

This type of analysis is recommended for materials handling activities that are of low frequency. By performing a static biomechanical analysis (Chaffin & Anderson, 1984) the analyst would be able to determine operator's Disk Compressive Force (DCF) based on operator posture (trunk, upper arm, and lower arm angles), subject weight and stature, and object weight. The DCF is weighed against a predetermined criterion and the materials handling activity is assigned a risk factor of low, medium, or high.

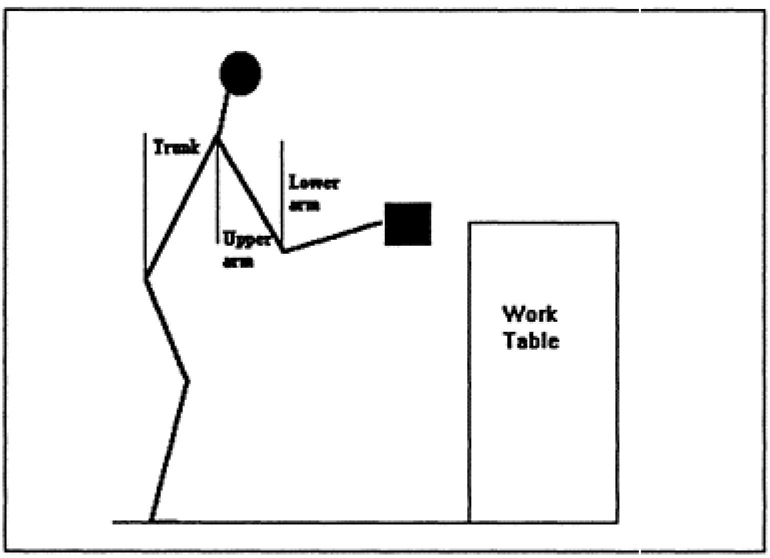

FIGURE 5—Biomechanical model

b. NIOSH lifting analysis

This type of analysis is particularly useful for frequent lifting activities. Five parameters need to be measured for this type of analysis. These parameters are:

- The horizontal location from the midpoint between the ankles to the center of the load at the origin of lift (H)
- Vertical location of the hands at the beginning of lift measured from the floor to the hands (V)
- Vertical travel distance from the origin to the destination of load (D)
- Frequency of lift in lifts per minute

Measurements and analysis of these parameters will result in the calculation of an Action Limit (AL) and a Maximum Permissible Limit (MPL). The object weight is compared against the AL and MPL, and the manual activity is assigned a risk factor of low, medium, or high (U.S. Dept. of HHS, 1981).

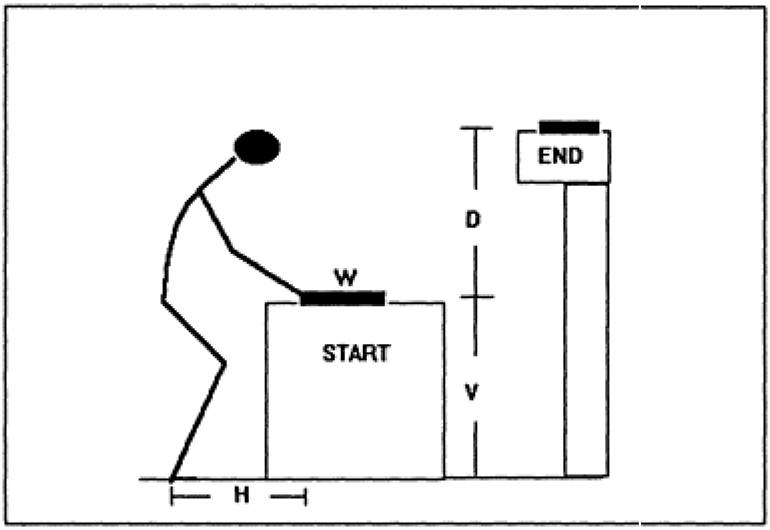

FIGURE 6—Illustration of the NIOSH AL and MPL parameters

c. Determination of physiological energy expenditure

The metabolic energy expenditure could be estimated based on the various elements of the task (Garg Chaffin & Herrin, 1978). These elements are:

- Operator posture
- Type of lift (i.e. stoop, squat, semi-squat)
- Type of lower (i.e. stoop, squad, semi-squat)

- Type of carrying and distance to carry
- Push/pull forces
- Types of hold

Analysis of these elements would result in a metabolic energy expenditure calculation. The amount of energy expenditure is weighed against a recommended criterion and the job is assigned a risk factor of low, medium, or high.

4. JOBS THAT REQUIRE WORKING WITH A VISUAL DISPLAY TERMINAL

For these type of jobs both a postural and an elemental task analysis of the operator is required. The technique for performing a postural and elemental task analysis for VDT users would be the same as for jobs that require static seated or standing postures (previously described).

A computer software has also been developed for performing an Ergonomics Task Analysis using the above methodology and techniques. The software enables the user to assign a risk factor to a job, produce a report for OSHA purposes, and assist in continuous monitoring of a large number of jobs.

Step 4: Periodic review

Redesigning the job by itself is not sufficient. To ensure the success or impact of the ergonomically driven changes, the Ergonomics Checklist in conjunction with a review of the available records must be performed on a regular basis in order to effectively monitor jobs/tasks and be able to measure results. Analysis of the job/task using the aforementioned methodology will enable the ergonomics coordinator to produce documentation describing the need for continuous implementation of ergonomics and thereby be able to secure management commitment.

DISCUSSION

In summary, federal regulations and increased focus on ergonomic related health issues are driving organizations to implement effective and results orientated programs. To adequately address the areas of concern, jobs must be analyzed for their potential risk factors. This is achieved most effectively through computerized worksite analysis procedures. The impact of this type of analysis results in having the data to make necessary engineering changes which would in turn result in reducing the causes of injury to workers.

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AGE, SHIFTWORK AND INDUSTRIAL ACCIDENTS—A LONGITUDINAL STUDY

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This paper is an extension of the earlier paper by the authors as reported at the 1991 Annual Conference. A new severity index, to determine the effects of age and shift on accidents, has been proposed. It is observed that accident potential is higher over the middle age groups (30–45 years) as compared with the younger and older age groups, across all shifts. Further investigations on the refinement of the index are in progress.

INTRODUCTION

Recent efforts by many companies to increase productivity and resource utilization have focused on extending their manufacturing activities to 24 hour work days, six days a week. Simultaneously, the population in North America is aging significantly; in the next 40 years, the number of Canadians 65 years and older will more than double to 7.5 million. The number of aging “baby boomers” is so large that even substantial immigration will not change those figures very much, according to statisticians. The total population of Canada will also not exceed 30 million over this period.

These considerations therefore reflect changing scenarios within the workplace from a human factors perspective. More and more older people will be expected to work on rotational shifts to meet the changing patterns of the workplace. The question that is often posed is: How does this affect the health and well-being of the older worker? Is it necessary to adopt specific personnel placement policies to accommodate such shifts in work regimens?

In a recent report in the business columns of “The Windsor Star” (20th January, 1992), it was noted that there has been a 13% drop in compensation claims registered in 1991 as compared to 1990, i.e., 412,000 cases in 1991 versus 473, 100 cases in 1990. This 60,000 drop in registered claims does in fact reflect the lowest total number of claims since 1984 in the Province of Ontario. However, interestingly enough, compensation costs have risen over the same period; the Workers’ Compensation Board spent $200 million (Canadian) more in 1991 as compared to the amount spent in 1990. Simultaneously, employer contributions dropped by $300 million (Canadian), which, when added to the shortfall of $500 million in the Board’s funds in 1990, has led to a total deficit of about $1 billion, over a non-funded liability of about $10 billion.

The drop in the number of compensation cases can be attributed to the severe recession which has hit the Province of Ontario over the last one-and-a-half years, leading to a loss of nearly half-a-million jobs. Recessions of this type hit construction and manufacturing the hardest; these sectors are the largest contributors to the fund and so there has been a concomitant drop in revenue. However, further analysis shows that on the one hand, the death rate has decreased, while there have been fewer accidents per person, i.e., those who have jobs adopt safer working habits. So why do costs tend to rise, even when the number of claims have been reduced?

Part of the answer may perhaps lie in remarks by Wagner (1988), who states that, “… point to the need for more extensive human factors research on the possible interaction between shiftwork, temporal factors and age in relation to work performance decrements and accident risk.” The paper also points to the need for normalization of accident data to account for population sizes in various age groups and injury profiles. There is, however, reason to believe that safety records of older workers are distinctly different from those of younger workers, especially when the effects of shift are accounted for. It is, therefore, important to explore these relationships in greater detail and determine the hazard potential for workers under different cross-sections of activities, given a variety of age group and shift combinations.

The present paper is an extension of the preliminary findings on the subject reported by the authors at the 1991 Conference on Advances in Industrial Ergonomics and Safety Research (Dutta & Barsky, 1991). The effects of injury type on variability in severity of accidents is now examined.

METHODOLOGY AND EARLIER RESULTS

The paper reports on a longitudinal study carried out in six large automotive related industries in South Western Ontario which, between them, employ over 8000 workers. The nature of work extends from light assembly tasks to heavy machining and fabrication. All these industries work on three shift schedules under varying rotational schemes. Workers employed range in age groups from 20 years to 65 years. Detailed daily accident records for 3 years (1987–1990) have been collected in all cases and correlated with sex and age of the workers, the shift in which the injury occurred, the body part involved, the nature of the injury and the corresponding severity in terms of dollar value of lost time due to the accident.

Data have been collected from all these industries. However, at the time of preparation of the paper, complete analysis has been carried out on two of the companies. Company 'A' represents a unit with approximately 1000 workers on the shift system and is involved in the manufacture of various types of automotive engines. The nature of the work is therefore heavy, with a fair number of lifting tasks. Company 'B' is larger, with about 2300 employees on shiftwork. It is engaged in the production of upholstery and automobile body interiors. The nature of the work is therefore relatively light, with a preponderance of repetitive stress on small muscle groups within the upper extremities of the body.

The injury profile based on the raw data collected in all the companies is shown in Fig. 1. Figures 2 and 3 indicate the specific profiles for companies 'A' and 'B'.

It is interesting to note that these profiles show similar patterns of distribution over the ranges of age group from 20 years to 65 years for all three shifts. Given that these data need to be normalized to account for population sizes in the various age groups, our earlier paper (Dutta & Barsky, 1991) has presented the results of the first stage of the normalization process. The normalization index was as follows:

$$\text{normalized number of injuries/100 employees in a specific age category} = \frac{\text{number of injuries/shift}}{\text{number of workers/shift} \times \text{\% of workers in age category}}$$

Figure 4 shows the normalized injury profile for all companies combined. A negative exponential pattern emerges, which seems to indicate that the normalized number of injuries is higher for lower age groups, and then decreases for higher age groups for all shifts.

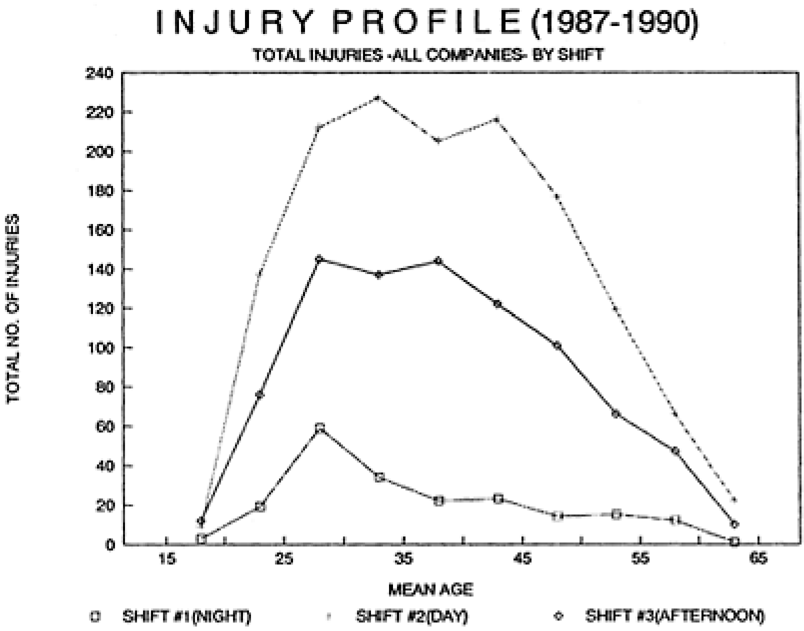

Fig. 1 Total injuries—all companies—by shift.

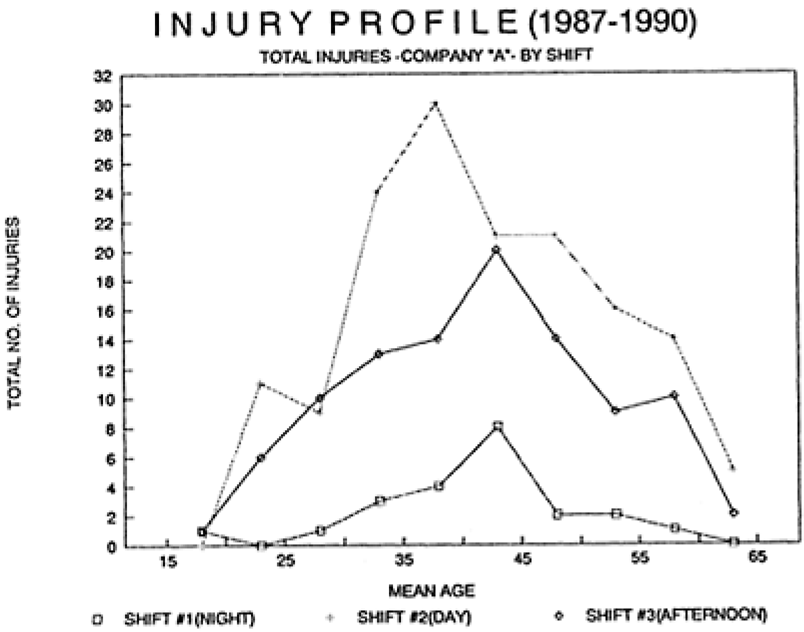

Fig. 2 Total injuries—Company "A"—by shift.

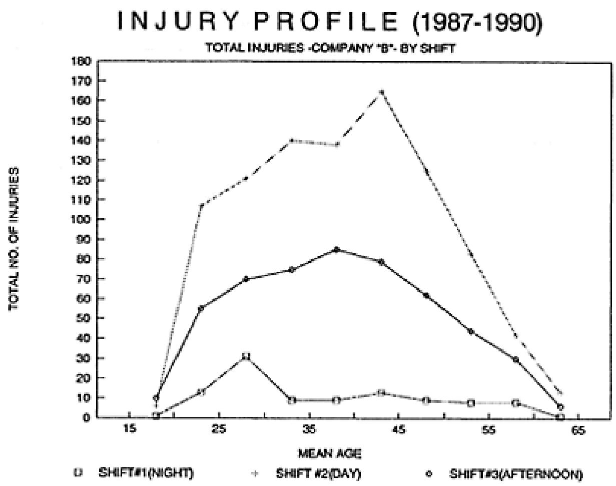

Fig. 3 Total injuries—Company "B"—by shift.

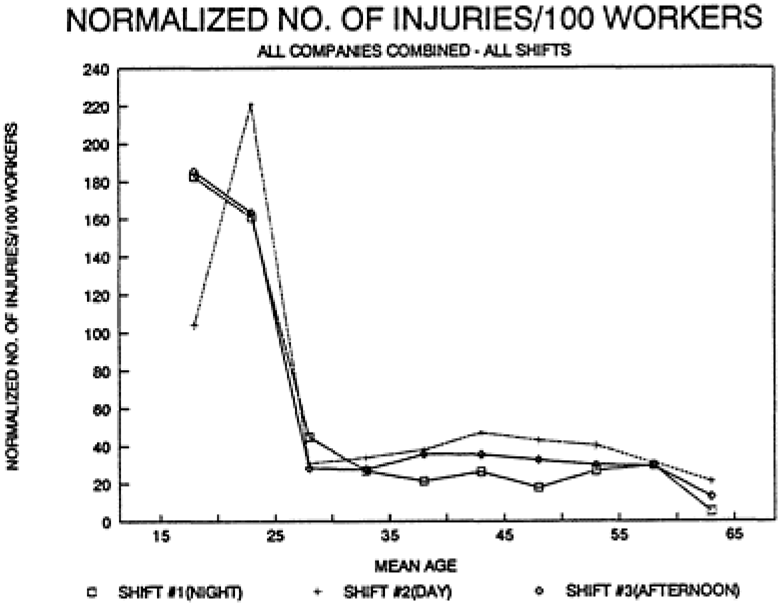

Fig. 4 All companies combined—all shifts.

In order to examine the problem in greater detail, and study the effects of other related factors on the hypothesis, “Older workers in rotating shift systems are better adjusted as compared to younger workers,” the effects of the severity of the injury, i.e., the nature of the injury, the body part(s) affected and the corresponding cost in terms of dollar value of lost time, have now been considered. The normalized index has thus been modified as follows:

$$\text{Weightage for type of injury} = \left[\frac{\text{\$ equivalent for each injury type}}{\text{Highest (Maximum) \$ value for all categories}}\right]$$

$$\text{Revised "Severity Index"/shift/age group} = \frac{\frac{1}{30}\,[\text{Average \$ value}]\,[\text{Weightage for injury type}]\,[\text{no. of injuries}]}{\text{number of workers/shift} \times \text{\% of workers in age category}}$$

The division by a factor of 30 represents the cost ($30) of each lost hour, a figure used by all the companies from whom data have been collected. As stated earlier, the paper presents the results of this analysis for two companies only.

ANALYSIS & RESULTS

Over thirty categories of injuries were recorded for the three-year period by the two companies. After some deliberation, it was decided that these would be clustered into 14 representative groups based on the affected anatomical region. The results of this classification, and the corresponding injury (severity) weightage factor for each cluster for companies 'A' and 'B' are shown in Table 1. As indicated earlier, each weightage has been calculated by taking the ratio of the cost of the injury to the maximum cost associated with

Table 1. Severity (injury) weightages for companies "A" and "B".

Anatomy Group	Company "A"			Company "B"		
	Cost of Injuries ($)	% Cost	Weight Factor	Cost of Injuries ($)	% Cost	Weight Factor
Undetermined	0	0.00%	0.00	390,060	17.21%	1.00
Abdominal	20,784	3.50%	0.10	4,380	0.19%	0.01
Upper Extremities	58,286	9.83%	0.29	547, 170	24.15%	1.00
Fore Arm-Elbow	31,415	5.30%	0.16	226,200	9.98%	0.41
Hand-Wrist	42,866	7.23%	0.22	286, 770	12.66%	1.00
Ankle-Toe	28,877	4.87%	0.15	16,770	0.74%	0.03
Lower Leg	63,472	10.70%	0.32	64,140	2.83%	0.12
Hip-Back	198,978	33.54%	1.00	443, 640	19.58%	1.00
Groin Area	0	0.00%	0.00	1,650	0.07%	0.00
Chest	3,162	0.53%	0.02	25,200	1.11%	0.05
Head-Face	46,195	7.79%	0.23	45,120	1.99%	0.08
Finger	99,143	16.71%	1.00	103, 380	4.56%	0.19
Multiple	0	0.00%	0.00	86,790	3.83%	0.16
Other	0	0.00%	0.00	24,570	1.08%	0.04
	593, 178	100.00%		2,265,840	100.00%	

all (unclustered) injury categories. The nature of the work is reflected in maximum weightages for hip-back, upper extremity and hand-wrist injuries in the case of company 'B', as opposed to maximum weightages for hip-back and finger injuries for Company 'A'. These weightages have been used to determine the severity index for both companies, as shown in Table 2. From these indices, the severity profiles for both companies were then generated (Figs. 5 and 6).

The apparent fluctuations in the values of the severity index from one age group to another seems to be inconsistent with the pattern in the raw data. This could be due to the effects of the shift on which the injury occurred. It was then decided to cluster the data into three age groups to see whether there were any significant differences between age groups and the shifts on which they worked. The results of the analysis of variance for companies “A” and “B” with the nested data vis-a-vis age groups is shown in Table 2.

Table 2. Weighted severity indices for Companies “A” and “B”.

Mid-Point Class	Severity Index by Shift No. Age (A)”				Severity Index by Shift No. (“B”)			
		1	2	3	1	2		3
18		1.00	0.00	3.04	28.04	9.18		3.59
23		0.00	35.27	6.11	4.43	15.66		16.84
28		1.22	2.30	9.83	33.54	4.75		2.65
33		15.89	14.05	10.70	2.66	29.22		6.44
38		8.58	22.23	10.46	9.79	17.89		19.20
43		14.03	4.33	13.73	11.42	44.74		7.29
48		33.01	22.09	13.40	3.73	12.65		3.45
53		11.88	20.31	2.13	3.37	41.48		6.40
58		3.15	30.08	19.04	6.43	13.98		10.98
63		0.00	12.33	2.78	0.00	5.46		1.29
Factor	TWO-WAY ANOVA (“A”)				TWO-WAY ANOVA (“B”)			
	SS	df	VAR	F Ratio	SS	df	VAR	F Ratio
Age	387.53	2.00	193.77	2.29	91.92	2.00	45.96	0.43
Shift	355.47	2.00	177.73	2.10	746.27	2.00	378.13	3.53*
Age×Shift	350.00	4.00	87.50	1.03	983.51	4.00	245.88	2.30
Error	1778.77	21.00	84.70		2248.10	21.00	107.05	
TOTAL	2871.77	29.00			4079.81	29.00		

* significant at 5% level.

DISCUSSION AND CONCLUSIONS

The INJURY PROFILE graphs exhibit a “bell-shaped” pattern for all shifts and for all companies being studied (Figs. 1, 2 and 3). This general trend is expected since there are more workers in the middle age group. Removing the effect of unequal age group size is shown in the negative-exponential type curve patterns of Fig. 4, and which are again homogenous with respect to shifts and age. However, the introduction of the severity or cost of injury factor tends to skew the pattern relating shift and age. Nevertheless, it can be reasonably argued that the Severity Profile graphs (Figs. 5, 6) both indicate a higher severity or cost value among the middle age group and a lower value for the afternoon and night shifts—both of these phenomena being consistent with the previous graphs.

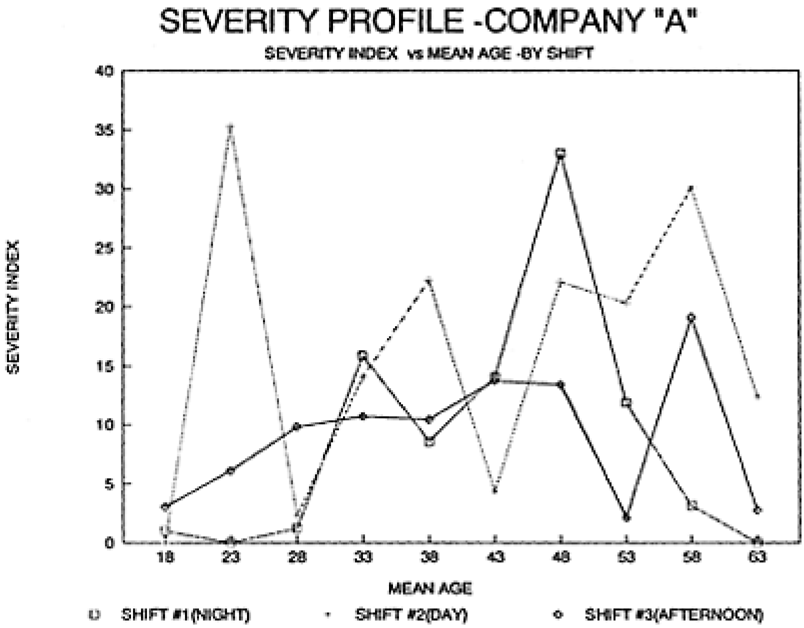

Fig. 5 Severity index vs. mean age—by shift.

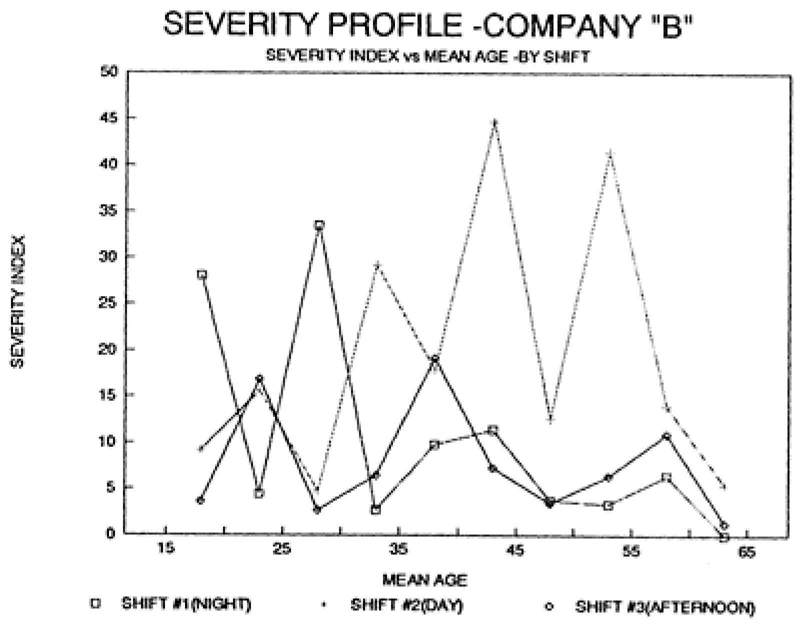

Fig. 6 Severity index vs. mean age—by shift.

It is distinctly possible that the higher WCB costs, while number of injuries is dropping as reported in the introduction, could be due to older workers retiring earlier and leaving a large middle age group who have a greater potential for increased injury severity. Also, as production capacity is reduced, later shifts are being discontinued again increasing the severity potential.

The difference between Company "A" and Company "B" is more a matter of distinction than degree. Both seem to average approximately 20 lost hours/injured person with Company "B" displaying a greater variation in values. This probably is due to the large number of RSI injuries in Company "B" compared to high number of back injuries at Company "A", since workers with back injuries can return to work more easily than those with RSI type injuries.

This study, thus far, has developed a Severity Index which might be useful to industry and regulating bodies as a standard against which other similar industries might be compared. This standard is still not sufficiently refined to be of universal value and additional work will continue to study the effect of other factors on this Index as well as determining the influence of treating the Index as being non-linear.

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AGRICULTURAL-RELATED FATALITIES: 1986–1988

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Data collected and analyzed by Division of Safety Research, National Institute for Occupational Safety and Health, indicate that agriculture is among the more hazardous U.S. industries with a traumatic fatality rate of 15.1 deaths per 100,000 workers, for years 1986 through 1988. For the same period, the fatality rate for all U.S. industries was 6.1 deaths per 100,000 workers. Data analyses reveal that crop production and agricultural services accounted for 39% and 13% of agriculture deaths. In crop production, the leading cause of traumatic occupational fatality was machine-related incidents, and struck by falling object was the leading cause of death in agricultural services.

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) has recently expanded its agricultural research program. Agriculture is among the four most hazardous industries in the United States. Actual fatality rates for agriculture vary depending on the source of data. Analyses indicate the occupational injury fatality rate ranges from 2.6 times (Bell et al., 1990; Myers, 1990) to 5 times (Elliot, 1989) the national average for all industries.

The industry division agriculture, forestry, and fishing (A/F/F) is composed of five sectors according to the Standard Industrial Classification (SIC) Manual (Office of Management and Budget, 1972). The major sectors in A/F/F are crop production (SIC 01), livestock production (SIC 02), agricultural services (SIC 07), forestry (SIC 08), and commercial fishing, hunting, and trapping (SIC 09). Logging is a manufacturing activity and is not included in this analysis.

Surveillance of occupational injuries and fatalities is important in determining the requirements to improve the overall safety of the nation's workforce (Myers, 1990). In the United States, there is no national surveillance system for monitoring injuries and deaths among farm owners, farm family members, or the hired workforce. In 1985, the Division of Safety Research (DSR) of the National Institute for Occupational Safety and Health (NIOSH) initiated a surveillance project directed toward quantifying occupational deaths due to trauma occurring in the U.S. (Myers, 1989). This effort is known as the National Traumatic Occupational Fatality (NTOF) surveillance project.

METHODS

The NTOF data base is a death certificate-based census of occupational injury deaths in the U.S., and can be used to calculate work-related injury mortality rates (Bell et al., 1990). Data collection began with deaths that occurred in 1980 and continues as an on-going DSR project (Jenkins and Hard, 1992).

There are 52 separate vital statistics reporting units in the U.S.—one in each of the 50 States, New York City, and the District of Columbia. Each reporting unit submits to DSR copies of death certificates for persons 16 years or older who died from an external cause of death, and for whom the certifier responded positively to the "injury at work?" item on the certificate (Bell et al., 1990). External cause-of-death codes (E-codes) are assigned according to the International Classification of Diseases, Ninth Revision (ICD-9), Supplementary Classification of External Causes of Injury and Poisoning (World Health Organization, 1977).

Cases were selected for this analysis if the industry of employment, according to the SIC code designation discussed previously, was agriculture, forestry, and fishing and the death occurred during 1986 through 1988. Fatality rates for industry division and geographic region were calculated using employment data from the County Business Patterns data files, which are based on an annual census of establishments (U.S. Dept of Commerce, 1987). Fatality rates for age groupings were calculated using employment data from the Bureau of Labor Statistics Employment and Earnings Annual Averages (U.S. Dept of Labor, 1987–1989).

RESULTS

During the period 1986 through 1988, a total of 2,127 individuals died of occupationally related injuries in the A/F/F division. These incidents represented 12.2% of all work-related deaths contained in the NTOF data base for the 3-year period. Table 1 provides a percentage distribution of the fatalities in the A/F/F division, by major sector.

Unfortunately, due to the lack of detail on death certificates, 30% of the fatalities were unclassified as to specific sector. Of the remaining 70%, crop production and agricultural services accounted for three-quarters of the fatalities. Of the remaining one-quarter of the fatalities, the majority occurred in commercial fishing, hunting, and trapping and in livestock production. Very few fatalities occurred in the forestry sector of A/F/F.

Table 1. Agricultural-related fatalities, by major sector, during 1986–1988, n=2, 127.

Crop Production (SIC[1] 01)	**Livestock Production (SIC 02)**	**Ag Services (SIC 07)**	**Forestry (SIC 08)**	**Fish, Hunt, and Trap (SIC 09)**	**Unclassified**
38.8%	7.9%	12.6%	1.6%	8.9%	30.1%

[1]Standard Industrial Classification code.
(Total does not add to 100% because of rounding).

Table 2 presents a geographic distribution of the fatalities, by U.S. Bureau of the Census regions. An equal number of deaths occurred in the north-central and southern sections of the U.S. The fatality rates for these two geographic sections were very similar. The western section accounted for 22% of the fatalities and had a slightly lower fatality rate. Although a minimal number of fatalities occurred in the north-east section, the fatality rate was comparable to the other sections of the country.

Table 2. Geographic distribution of agriculture fatalities, 1986–1988, n=2, 127.

Region	**Frequency**	**Percentage**	**Fatality Rate[1]**
North-central	766	36.0%	17.9
Southern	765	36.0%	17.4
Western	459	21.6%	14.3
North-east	137	6.4%	12.4

[1] Deaths per 100,000 workers

Fatality rates for the four U.S. industry divisions with the highest risk of work-related traumatic death, during the period 1986 through 1988, are displayed in Table 3. These can be compared to the fatality rate for all U.S. industries combined, for the same time period. NIOSH has recently established and commenced research initiatives for safety and health problems in the construction and agriculture industry divisions.

Fatalities in the A/F/F industry division, by age groups, for the 3-year period of interest, are presented in Table 4. The fatality rates increase with an increase in age, especially in the oldest grouping. Workers 65 years and older have more than twice the risk of workers 45 through 54 years, and almost four times the risk of those 16 through 24 years.

Table 3. Comparison of the four U.S. industries with the highest traumatic occupational fatality rates, and all U.S. industries combined, 1986–1988.

Industry Division	**Fatalities**	**Fatality Rate[1]**
Mining	587	25.4
Construction	3,421	23.6
T, C, & PU[2]	3,119	20.4

Agriculture	2,127	15.1
All Industries	17,387	6.1

[1]Deaths per 100,000 workers
[2] Transportation, Communication, and Public Utilities Division.

Table 4. Work-related traumatic deaths and fatality rates, by age groups, 1986–1988, n=2, 127.

Age Group (in yrs)	Total Deaths	Fatality Rate[1]
Unknown	5	–
16–24	275	14.3
25–34	418	18.2
35–44	311	18.2
45–54	299	21.5
55–64	368	32.1
65 and older	451	53.4

[1] Deaths per 100,000 workers.

Table 5 provides a percentage distribution of the 11 leading causes of occupational death, according to E-code rubrics, for the A/F/F industry division, during years 1986 thru 1988. Machinery, which includes farm tractors, was the leading cause of death. In fact, of the 681 machine-related fatalities, a total of 431 (63.3%) involved farm tractors. Transportation (motor vehicle, air, rail, and water modes) accounted for a combined 24% of all A/F/F fatalities.

The three leading causes of occupational traumatic death for the SIC 01 sector (crop production) of A/F/F are shown in Table 6. The leading cause of traumatic death for this major grouping was machine-related incidents, followed by motor vehicle incidents and electrocutions. These three causes of death accounted for almost two-thirds of all the fatalities reported (in the NTOF database) to have occurred in the crop production sector.

Table 5. Work-related traumatic deaths in the agriculture, forestry, fishing industry (A/F/F) division, by cause of death, 1986–1988.

Cause of Death	Frequency	Percentage[1]
Machine	681	32.0%
Motor Vehicles	332	15.6%
Other Transportation	175	8.2%
Struck-by falling obj	154	7.2%
Electrocution	130	6.1%
Falls	100	4.7%
Natural & Environmental	100	4.7%
Suicide	70	3.3%
Homicide	64	3.0%
Drowning	52	2.4%
Suffocation	45	2.1%

Other (5 categories)	140	6.6%
Unknown	84	3.9%
[1](Total does not add to 100% because of rounding)		

Table 6. Work-related traumatic deaths in the crop production (SIC 01) major grouping of the A/F/F industry division, 1986–1988, n=826.

Cause of Death	Frequency	Percentage
Machine	363	43.9%
Motor Vehicle	120	14.5%
Electrocution	52	6.3%

The distribution of the three leading causes of occupational traumatic death for the SIC 07 sector (agricultural services) of the A/F/F industry division is provided in Table 7. The leading causes of death for this major grouping were struck by falling object incidents, followed by motor vehicle and electrocution incidents. These three causes of death accounted for more than half of all the deaths that were reported (in the NTOF data base) to have occurred in the agricultural services sector.

Table 7. Work-related traumatic deaths in the agricultural services (SIC 07) major grouping of the A/F/F industry division, 1986–1988, n=268.

Cause of Death	Frequency	Percentage
Struck by falling object	74	27.6%
Motor vehicle	38	14.2%
Electrocution	25	9.3%

DISCUSSION

Previous analyses of the NTOF data base for agriculture covered the period 1980 through 1985 (Bell et al., 1990 and Myers, 1990). The present analysis was limited to the years 1986 through 1988. NTOF data for 1989 are still not complete for the entire United States, and could not be included in the analysis. The fatality rate for agriculture, forestry, and fishing (A/F/F) during the 6-year period previously analyzed averaged 20.7 deaths per 100,000 workers, and was trending steadily downward from 1980 through 1985 (Bell et al., 1990). For the 3-year period, 1986 through 1988, the fatality rate for A/F/F averaged 15.1 deaths per 100,000 workers, and was also trending downward during the three years. Despite this steady decrease, the fatality rate for A/F/F is 2.5 times the national average for all U.S. industries. In addition, one of the objectives of the Public Health Service in its Healthy People 2000 document (Department of Health and Human Services, 1990) is to reduce the traumatic fatality rate for farm workers to 9.5 deaths per 100,000 workers by the year 2000.

Of the death certificates that included an entry to designate the sector of agriculture in which the worker was employed, 56% of the fatalities occurred in crop production (SIC code 01) and 18% occurred in agricultural services (SIC 07). The distribution of occupational traumatic fatalities by age group revealed that an almost equal percentage occurred in each of the six groupings. However, when the fatality rate for each age grouping is considered, a different trend emerges. The first four groups showed some consistency in their rates, ranging from 14 to 21 traumatic deaths per 100,000 workers. The last two groupings, however, showed dramatic increases in the fatality rates: 32 deaths per 100,000 workers in the 55–64 year age category, and 53 deaths per 100,000 workers in the 65 and older age category. This is consistent with the NTOF data analysis for 1980 through 1985 (Myers, 1990).

Data analysis of the cause of death for A/F/F workers indicated that machine-related fatalities accounted for 32.0% of the deaths, and motor vehicles and other types of transportation (air, rail, and water) accounted for 15.6% and 8.2% of the deaths, respectively. These data compare quite closely with analyses conducted by Jenkins and Hard (1992) for the period 1980 through 1986.

Of the 681 machine-related fatalities, 431 involved farm tractors. Farm tractors contributed to 20% of the total fatalities, more than any other single cause-of-death category. These data are comparable to an analysis conducted by Etherton et al. (1991) on the NTOF data base for the years 1980 through 1985 on agricultural machine-related deaths across all U.S. industries.

SUMMARY

While the data presented in this paper do not reveal any newly emerging problems in the A/F/F industry division, they reiterate the need to continue to design and implement intervention strategies aimed at machinery safety, especially tractors. Despite available engineering prevention techniques (e.g., roll-over protective structures, guarding of power take-off units) fatalities continue to occur.

Additional research may be necessary to determine if the age of the equipment (for machine-related incidents) has any effect on increasing worker traumatic fatality rates. Improved identification and characterization of fatal incidents involving the use of motor vehicles in A/F/F work also merits further attention. Finally, additional research efforts are definitely needed to address the elevated fatality rates for the older agricultural workers.

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ERGONOMIC FACTORS IN THE WORK SITUATION FOR AI-TECHNICIANS ON ANIMAL FARMS

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AI-technicians work with artificial insemination on a number of different farms each day. They do a lot of dangerous driving between farms, but most problems occur during the insemination and other treatments and examinations of cattle. Pain in the musculoskeletal system and injuries due to accidents are common. Females reported a significantly higher frequency of symptoms in the neck, shoulders and shoulder joints, wrists and hands and in the neck. Preventive measures are suggested such as: improvements in the livestock buildings, new implements and tools, physical training and further education

INTRODUCTION

AI-technicians is a profession working with artificial insemination (AI) on animal farms. They were earlier called veterinary assistants. In Sweden there are more than 800 people working with this type of job. AI is performed in almost the same way all over the world. Most of the work is connected with dairy farming, but many technicians are also doing AI-jobs on pigs and horses. The AI-technicians organisation and the National Livestock Association (SHS) together with the Farmers Safety and Preventive Health Association found that some of the personnel reported serious injuries from their field work with artificial insemination and other work operations. Our Department was asked to make an in-depth study of the working conditions with special attention to the ergonomic factors. The Swedish Work Environment Fund supported the project and a reference group was formed with representatives from the organisations and authorities involved (Lundqvist and Pinzke, 1992).

According to the report of the Health Risks Study Group to the Swedish Commission on Working Conditions (1990) female agricultural and livestock workers demonstrate a raised frequency of serious accidents, including loss of limb and disorder of the musculoskeletal system. Male agricultural workers have an increased risk of fatal accidents. Work in agriculture and farm buildings has been considered to be highly demanding (Lundqvist, 1988). The common accident risks are also considered a major problem (Gustafsson et al., 1991). Studies about the working conditions for AI-technicians are very few. According to Swedish statistics (SHS, 1991) the insemination of cattle, interior fittings in farm buildings and slippery surfaces cause a number of work related accidents each year. A Norweigian study (Natvik, 1969) showed that each insemination operation took in average 34 minutes of which 60 % of the working time was spent in the car driving from one farm to another. The Department of Farm Buildings made a study in the 70ties (Nilsson, Gustafsson and Swensson, 1979) in order to find out the best ways of restraining the cattle during the insemination. Despite the importance of the problem there seem to be very few scientific publications in this area.

MATERIAL AND METHODS

A questionnaire survey was carried out among all Swedish AI-technicians who primarily did AI-jobs on animal farms. It comprised 233 men and 286 women, a total of 519 persons, with a respons rate of 81%. Before this survey was done, we pretested the questionnaire among 20 persons working in this profession. The questionnaires was partly designed by us, but we were also using the standardised Nordic questionnaires for the analysis of musculoskeletal symptoms (Kuorinka et al., 1987).

RESULTS

Personnel

The women were younger (mean 40, 7±9, 4 years) then the men (mean 49, 9 ± 10, 9 years). Mean figures for weight and length were for the women: 64, 2±9, 7 kg and 166, 8±5, 4 cm and for the men: 79, 9±9, 9 kg and 178, 1±6, 7 cm.

The women exercised regulary (2–3 times/week) more frequent (60%) then the men (45%). The women spent their spare-time with agricultural work, household work and pet animals. The men reported the same interests but were often also interested in fishing and hunting. It was significantly more common to be a smoker among the women. Less than half of the AI-technicians had their meals on regular times.

Most of the men worked full time (40 hours/week) or more. It was quite common that the women worked part time. Most of the AI-technicians were satisfied or very satisfied with their work, although sometimes they thought they had too much to do.

The distribution of work times indicated that there were four main work operations: driving cars between farms, treatment of cattle (artificial insemination and pregnancy control), office work and production control/advisory work.

Driving

Driving the car between the farms took about 30–35 % of the working time. The women thought that the driving was a working environment problem to a higher extent (57 %) then the men (44 %). The problems that were considered hazardous included the weather/part of the year, the quality of the roads, the accident risks and long time and distances to drive. Problems related to the car were mainly: driving posture, the climate and the general comfort More than 6 % noticed the risk of falling asleep during driving (figure 1).

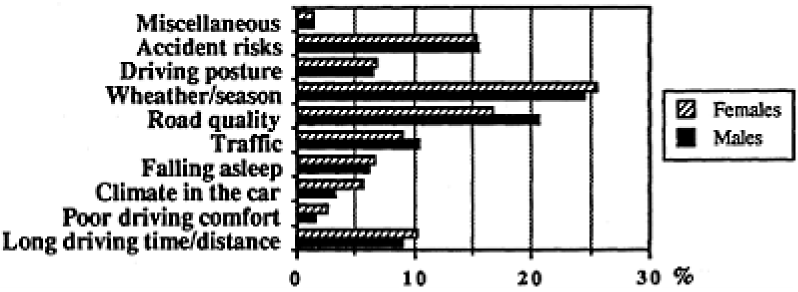

Figure 1. The working environment problems related to driving of cars according to the AI-technicians. Percentages.

The equipment and tools

The equipment and the tools used in the work caused problems during transport (most often with respect to carrying) and to extra work (cleaning), and were often constructed so that poor working postures were necessary with their use (figure 2).

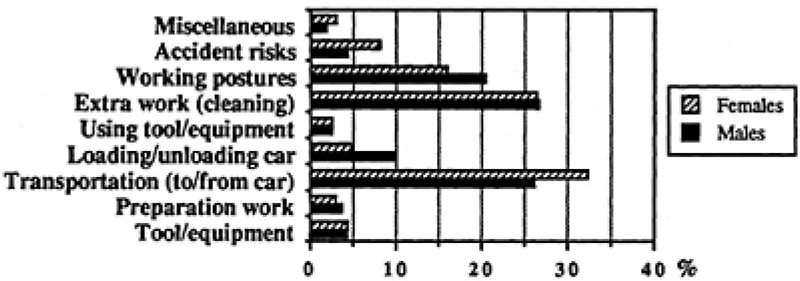

Figure 2. The working environment problems related to the use of equipment and tools in the work

according to the AI- technicians. Percentages.

The artificial insemination of cattle

The artificial insemination of cattle appeared to present the greatest problems with respect to the working environment. These problems included poor or lack of insemination bridges over the dung channels, poor working postures, slippery surfaces, poor lighting and lack of isolation possibilities for individual animals. Other problems are poor fixation of animals and risk of accidents (figure 3).

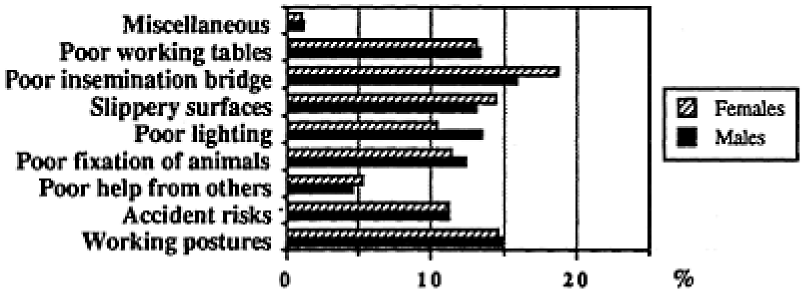

Figure 3. The working environment problems related to the artificial insemination of cattle according to the AI- technicians. Percentages.

Other work operations

During the artificial insemination of pigs, the working postures, poor possibilities for isolating animals and poorly tied animals were the main working environment problems.

Production control services were considered to be the most difficult during the winter, when the climate and cold in the barns, and especially in the milk room, were taxing. Control measurements of cattle were also considered hazardous and involved poor working postures.

Taking feed and dung samples often meant that it was necessary to climb ladders to hay lofts and feed silos, which was also regarded as being perilous. Udder health care often necessitated poor working postures and involved accidents.

When testing milking machines, propblems with cold and damp milking rooms were noted. In addition, the poor location of service and control points on the milking equipment were remarked.

Musculoskeletal symptoms

The frequence of musculoskeletal symptoms among the AI-technicians were studied by using the standardised Nordic questionnaires (Kuorinka et al., 1987). Figure 4 shows the ditribution by sex of symptoms among the AI-technicians during the last 12 months.

The body parts having the most problems were shoulders/shoulder joints both for males (47, 2%) and females (62, 7%). Also the lower back (46, 3 and 47, 4% respectively) and the neck (33, 8 and 46, 3% respectively) were noted as problematic body parts. Significant differences were found between males and females for the neck (X=8,326**), shoulder/shoulder joints (X=12,388***), wrists/hands (X=20,454***) and upper back region (X=7,926**). In all these body parts the female AI-technicians had a higher frequency of problems than the males.

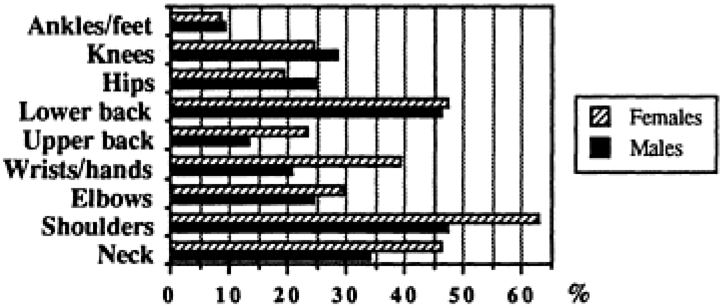

Figure 4. The distribution of musculoskeletal problems occuring during the last 12 months for the AI-technicians. Percentages.

Another question was related to if they had been unable to work during the last 12 months due to musculoskeletal problems. The results in figure 5 show that this type of problems among the AI-technicians were most frequent in the lower back (males 14, 2 % and females 10, 5 %) and in the shoulders/shoulder joints (9, 9 and 13, 6% respectively). Significant differences were found between males and females for the wrists/hands (X=4,226*) and the upper back region (X=5,078). Because of troubles in these body parts the female AI-technicians had a higher frequency of times when they were unable to work.

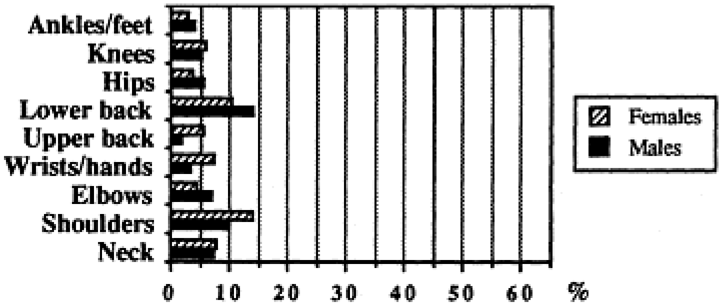

Figure 5. The distribution of musculoskeletal problems occuring during the last 12 months for the AI-technicians causing absence from work. Percentages.

Accidents

Artificial insemination and other treatments/examination of cattle represented jobs that caused many accidents. Injuries occurred primarily due to kicking and crushing by the animals and being caught between the animal and the equipment. Many serious injuries occured when the AI-technician's arm was inside the animal during treatment and examination. Other common injuries in the cattle house environment were falls on slippery surfaces and falling into the dung channels.

DISCUSSION

The results of the study have shown that the AI-technicians are satisfied with their work situation, but are exposed to significant occupational risks, primarily with respect to the development of difficulties with the locomotor organs and accidents. Females have significantly more musculoskeletal disorders. This confirms the findings of other studies within the agricultural sector. Lundqvist and Gustafsson (1988), Gustafsson (1989) as well as Stål and Pinzke (1991) reported higher frequency of troubles in the locomotor organs for females. It is well known from several professions that women suffer in working environments that are primarily designed for men with larger body dimensions and stronger muscles. Efforts have to be made to design and develop working environments that are adjustable to the individuals. According to the Swedish standard for working postures and working movements (The Swedish National Board of Occupational Safety and Health, 1983) new workplaces should as much as possible be individually adjustable.

Measures ought to be taken to improve the working environment conditions in the cattle houses by:

- arranging methods for confining/fixing the animals for treatment, as well as increasing the requirement for assistance.
- require insemination bridges over dung channels when inseminating in stanchion barns
- arranging better animal isolation pens and treatment areas
- improving the climate conditions in the milking room.
- improving the lighting and preventing risks of falling

Measures to be taken when driving should be aimed at evaluating which type of vehicle is suitable for this type of work, that is, one with good possibilities of loading /unloading, transport, entering and leaving, climate regulation, driving comfort and accident security.

Other types of improvements ought to involve better tools and equipment as well as possibilities for physical training and further education. It would also be of great value if the AI-technicians could have their own mobile telephone, which would ease the communications at work and make it possible to call for help if needed.

Most of the suggested measures can be made easily and at low costs. Improvements in the livestock building will also benefit the owner and other employees, especially other workers such as temporary help, veterinarians and family members.

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ERGONOMICS AND ACCIDENT RISKS IN A NEW TYPE OF POULTRY HOUSE

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This paper deals with the ergonomical factors and the accidents risks which can occur during work in a new type of rearing system for laying hens in Sweden. Keeping laying hens in loose housing in a large scale production involves new types of problems compared with caged animals. Ergonomical problems are common during the collection of mislayed eggs on the floor, manual cleaning of interior fittings to get rid of mites and during the collection and transportation of the hens at the end of the rearing period. Accidents are most likely to occur during the close contact with the animals, climbing on the interior fittings and during the operation of the manure handling system.

INTRODUCTION

The new Swedish animal welfare act, which took effect on the 1 st of July 1988, stated that there will be a total ban on caged laying hens from the 1st of January 1999 (SFS, 1988). It is therefore necessary to develop alternative rearing systems which satisfy the rules in the new law. It is also important to study the working environment and the consequences for the workers in these new systems. The Department of Farm Buildings at the Swedish University of Agricultural Sciences has carried out ergonomical and accident studies in a new type of poultry house for laying hens supported by the Swedish Work Environment Fund. The study also included air quality (Mårtensson and Lundqvist 1991), which is a big problem in poultry houses. This paper will only deal with the ergonomical factors and accident risks from that study.

Work in agriculture and farm buildings has been considered to be highly demanding (Lundqvist, 1988, Gustafsson et al., 1989). Accident risks are also considered to be a major problem (Gustafsson et al., 1991). According to the report of the Health Risks Study Group to the Swedish Commission on Working Conditions (1990) female agricultural and livestock workers demonstrate a raised frequency of serious accidents, including loss of limb and disorder of the musculo-skeletal system. Male agricultural workers have an increased risk of fatal accidents. Within the group as a whole, there is a higher than average reporting of lung disease, for example asthma and allergic alveolits. Very few studies have dealt with ergonomics and accidents in poultry farming. Brazelton et al. (1984) made an accident study in the poultry industry in California. They found no fatal accidents during the study but the main events when the occupational accidents occurred were: 1. Overexertion of body part, 2. Struck by falling or flying objects, 3. Back injuries from lifting and carrying, 4. Pressing injuries from feed barrows. doors etc and 5. Slipping and falling accidents caused by tripping over objects in the alleys or falling from a higher level. These injuries are closely related to ergonomical and accidental problems in the farm buildings. They also tried to calculate the accident rate in poultry farming and found that the rate was twice as high as in general farming.

It has not been possible to get any detailed information from official Swedish statistics about the rate of injuries among those working in poultry farming. The Swedish National Board of Occupational Safety and Health made a small investigation of the official materials. The results were poor but indicated that the injuries that had been reported were often related to ergonomical factors such as manual egg handling. Injuries related to accidents seemed to be connected with close animal contact (Lindé, 1992). In the process of developing new types of rearing systems is it important to point out and correct the weak points at an early stage, to comply with the animal welfare regulations prior to the commercial use.

MATERIAL AND METHODS

The hen house in the study was built in 1977 for laying hens in cages. The hen house have been rebuilt in 1988 for loose laying hens, with a total of 4 400 hens (17, 5 hens/sqm). The interior design of the hen house means that the hens can move freely on the floor, three levels of net floors and into the laying nests.

The two experienced workers which are included in this study were females: 51 and 36 years of age, righthanded, with a length of 167 and 160 cm and with a normal body constitution.

The work operations with special interest were: collecting misslayed eggs on floor level, collecting eggs from coveyor belts, manual cleaning work to get rid of mites, operating the manure handling system and the collection and transportation of the animals at the end of the rearing period.

Ergonomical studies

The method used for ergonomical studies of body postures and body movements, was the WOPALAS method (working posture analysing system), an observation method developed from the Finnish OWAS method (Ovako working posture analysing system) which has been described by Karhu et al. 1977, 1981 and Heinsalmi, 1986.

The OWAS method has been used in several studies within the construction industry (Hellsten, 1982), forestry (Almqvist, 1983) and animal husbandry (Lundqvist, 1988).

The WOPALAS method described by Hellsten (1985) is based on work sampling which provides the frequency of and the time in each posture. The method has been used in several studies (Lundqvist, 1990). The main parts of the body are registered by number for each posture. Each posture are described by a number for the back, the arms, the legs and for the head. It is also possible to register the weight or force that is acting externally on the body. In the present study the work has been videotaped, and the videofilm was stopped for registration of the body posture every third second.

The following four-point rating scale is used to determine action categories or operative classes used in the WOPALAS analyses:

A. Normal postures with no discomfort and no effect on health, need no special attention except in some cases (A, %)
B. Postures which must be considered during the next regular check of working methods (B, %)
C. Postures which need consideration as soon as possible (C, %)
D. Postures which need immediate action (D, %)

In the present study, the results according to the four-point rating scale have been transformed into one figure, for each part of the body, one for the weight factors and one figure for the whole body (degrees of difficulty), according to an approach suggested by Hellsten (1982). This means that a locomotor load factor or index, here called the L factor has been determined as follows:

$$L=(1\times A)+(2\times B)+(3\times C)+(4\times D)$$

An L index of 100 means an optimal work situation. Every index value over 100 gives an indication of how urgent it is to introduce corrective measures.

Studies of accident risks

The studies of the accident risks were made by three methods:

1. Examining the poultry house/work place with a checklist (interior design, machinery, etc)
2. Risk analysis through in-depth studies of videotapes from ergonomical studies
3. Interviews with the personell

RESULTS

In all studies related to working environment it is also important to study the time exposure for different types of work operations in order to make the right priorities when it comes to countermeasures. The average working time during variable production in the poultry house during the studies and preliminary calculated values for the following production bath are shown in table 1. The results indicate that collecting eggs from the floor etc are quite time consuming. The number of eggs on the floor was found to be around 7, 5 % of the total. The rest of the eggs were laid in the nests, as intended. Through different measures in the rearing system it was concluded that a reasonable level of floor eggs would be around 2 % in the next production bath. This would mean a substantial reduction in time, without any other change of production system.

Table 1. Average working time during variable production in the poultry house during the study (I) and preliminary calculated values for the following production bath (II) (minutes per day). Source: Tauson (1990).

Work operation	Production bath	
	I	II
Collecting eggs on floor etc, Inspection, Collecting dead birds	85	45
Collecting eggs from coveyor belt *	110	120
Handling manure/cleaning	25	25
Handling eggs in containers	10	10
Total	230	200

* Introduction of complete automatic egg handling would also include an elevator, a cross coneyer belt and possibly a farm packer. These figures might then be reduced by 10–25 %.

The ergonomical studies indicate that there are three work operations that cause considerable work load during the work. Collecting eggs on floor level, manual cleaning of the interior (against mites) and the collecting of the birds and transportation of cages in that work seem to involve the most serious ergonomical problems. Collecting eggs from conveyor band and handling of the manure system are generally less troublesome. An overview of the results from the ergonomical studies with the WOPALAS method is presented in table 2.

Table 2. Work load on different parts of the body during different work operations in the poultry house, according to the WOPALAS study. Relative values (100=optimal level)

Part of the body	Work operation				
	Collecting eggs (floor)	Collecting eggs (conveyor)	Manual cleaning (mites)	Manure handling (machinery)	Collect & transport (hens)
Back	133	110	139	102	103
Right arm	107	101	153	107	114
Left arm	124	133	137	102	111
Legs	173	115	154	107	118
Weight	100	100	121	118	147

The collection of mislayed eggs on the floor involved working postures with the back bent >20° in 42% of the working time, twisted (7%) or in a combination of bent and twisted (21%). The work under the birds nests was the worst from the back positions point of view. The positions of the arms were very often in angles between 30–90° from the body (32%), more than 90° in 7% of the time with the right arm and 28% of the left. The most awkward positions of the legs were those with both legs bent (54%) when reaching for the eggs at the floor. Some of the time (4%) was also spent climbing on the interior fittings to inspect the animals, looking for other mislayed eggs etc. The loading factors (L) in table 2 shows that the legs (173), the back (133) and the left arm (124) were the most affected body parts during this work. The figures point at an obvious need for improvements.

The manual cleaning of the nests and other interior fittings to get rid of the mites was also a hard work. The back was bent, twisted or both during 80% of this work, that could be quite time consuming depending on the amount of mites there could be. The arms were quite often in positions >90° (22% for the right arm and 17% for the left), but the legs were also a great deal in awkward positions (standing on knees during 49 % of the weorking time). In table 2 it is shown that the loading factors are high for all body parts and that also the weight is quite high.

At the end of the rearing period the whole house must be empty from animals and the hens are then collected manually and put into transportation cages and carried to a lorry that brings them to the slaughter house. That job was done by 6 persons during 5 hours (30 manhours). This work is seldom performed but is demanding in different ways. Table 2 shows that it involves heavy weights in combination with awkward working postures, including climbing on the interior fittings and carrying heavy transportation cages in narrow alleys and through narrow door ways.

The accident risks were not very frequent, but since this type of housing system is new, is it important to document the risks involved, to enable future improvements. According to table 3 the close contact with the animals and climbing on the interior fittings have the two highest ranking and therefor represent the type of risks that are most likely to occure during work in this type of poultry house.

Table 3. Accident risks in the poultry house. Ranking.

Type of accident risk—Ranking	Comments
1. The close contact with the animals	Sharp claws, bites
2. The climbing on the interior fittings	The inspection of animals, water and feeding system and the collection of birds
3. The handling of the manure system	Risks for accidents during the handling of the involved machinery
4. The design of the poultry house	Narrow alleys and doorways, only usable doors in one end of the house
5. The location of the poultry house	Location at the top of a pig house (a higher level of risks when working alone, fire risks, transportation problems—stairs-elevators)

DISCUSSION

The study shows that a new type of rearing system for laying hens with a loose system instead of caged animals involves not only new types of work operations, but also new types of accident risks and ergonomical problems. Having caged laying hens gives the possibilities of fully automated egg collection. In loose housing systems the hens are supposed to lay their eggs in nests, which can be automatically handled, but there will also be a number of mislayed eggs—mainly on floors. Laying hens in cages makes it also more easy to keep the animals and the environment in the house free from illnesses (like coccidios) and noxious animals (like mites). Loose animals also mean closer contacts between the animals and the workers, which can make the work more interesting, but also more risky. This study has shown a series of ergonomical problems including poor working postures and high work load when collecting mislayed eggs on the floor, during the manual cleaning of the interior fittings and at the work with the collection of the birds.

According to the Swedish standard for working postures and working movements (The Swedish National Board of Occupational Safety and Health 1983) new types of jobs should not be designed were it is necessary to regularly work with your hands under knee level or over shoulder level, which is necessary at the egg collection procedure. If this type of system should survive it has to be supplemented with a device for the collection of eggs on the floor.

Other desirable improvements of the working conditions include: arranging wider alleys and doorways, installing transportation devices (hanging rails or some kind of carts) and designing of interior fittings that meet the requirements with respect to ergonomics, vision and accident risk prevention. This presumes that working environment experts have possibilities to participate in the future development of these new types of rearing systems. It is also important that the natural habits of the animals are considered. It is a real challenge to create an environment which is acceptable for both the animals and the workers at an acceptable level of costs.

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PREVALENCE OF MUSCULOSKELETAL DISORDERS AND RELATED JOB FACTORS IN 900 NEWSPAPER WORKERS

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INTRODUCTION

Repetitive tasks are common in the newspaper industry and may be associated with cumulative trauma disorders (CTDs) (Silverstein et al. 1987). The prevalence of CTD symptoms among editors, writers, and sub-editors at a European newspaper ranged between 17 and 54% (Buckle, 1991). At a large American newspaper 40% of workers using computer keyboards reported symptoms consistent with upper extremity CTDs (NIOSH, 1989).

The purpose of this cross-sectional study was to determine 1) the 12-month period prevalence of job-related musculoskeletal disorders and the prevalence of missed work due to those disorders, 2) whether specific job factors were perceived by the workers as being problematic in their work, and 3) the association between various job factors and missed work due to musculoskeletal disorders in specific anatomical areas. The long term goal of this prospective study is to investigate the predictive value of the survey tool in identifying workers at risk for developing CTDs.

Although the prevalence of CTD symptoms in newspaper workers using computer keyboards and other inputting devices has been reported previously (Buckle, 1991; NIOSH, 1989), there are no studies reporting the prevalence of musculoskeletal disorders in pressroom and mailroom workers. The “production” workers (mailroom and pressroom) perform more physically demanding work than “office” workers (editors, reporters, advertising, classified, data processing, general office) and may have a higher prevalence of musculoskeletal disorders. This study, therefore, includes symptoms, job factors, and the association between lost work and job factors in office workers as well as production workers.

METHODS

In August 1991, 1250 self-administered questionnaires were sent to three medium-size (90,000 circulation) U.S. newspapers. The questionnaire was divided into three sections: 1) demographic survey, 2) symptom survey, and 3) job factors survey. The symptom survey was a checklist of anatomical areas that the respondent either checked as “yes” or “no” if they had a musculoskeletal problem in that area that was work-related in the preceding 12 months. A musculoskeletal problem was described as an “ache, pain, discomfort, numbness, etc…”. If they checked “yes”, they were instructed to indicate if the problem had prevented them from performing their daily work (missed work). The job factors survey was a description of 15 job factors where the respondent indicated whether the specific factor was or was not a problem for them during their work (Table 1).

Table 1. Description of job factors.

JOB FACTOR	DESCRIPTION
1.	Performing the same task over and over.
2.	Working very hard for short periods (lifting, grasping, pulling, etc.).
3.	Having to manipulate or grasp small objects.
4.	Not enough rest breaks during the work day.
5.	Not enough stretching before or during work.
6.	Having to work in the same position for long periods (standing, bent over, etc.).
7.	Bending or twisting in an awkward or uncomfortable way (hand, elbow, back).
8.	Having to work so fast your muscles start to cramp or get sore.
9.	Reaching for something that is over your head or away from your body.
10.	Uncomfortable conditions (heat, cold, vibration)
11.	Workstation not adjusted to fit you (too high, too low, too small).
12.	Workstation not organized for easy use of materials and tools.
13.	Work scheduling problems (over-time, irregular shifts, too long of a work day).
14.	Tools/machines that are uncomfortable to use (too heavy, poor design).
15.	Not enough training on how to do the job.

The respondents were guaranteed that their questionnaire would remain confidential and not be available to the newspaper management. Questionnaires were collected after a one-week period.

Twelve-month period prevalence rates were calculated by dividing the number of workers indicating that they had a musculoskeletal disorder in a specific anatomical area during the past year by the total number of participants. A prevalence rate was calculated for each anatomical area. The percentage of workers with missed work in the preceding 12 months due to a musculoskeletal disorder in a specific anatomical area was calculated in the same manner. Odds ratios (Mantel-Haenszel) were used to estimate associations between perceived exposure to job factors and missed work for each body part. A Fishers exact two-tailed statistic was used to determine the level of significance for the odds ratios.

RESULTS

Nine hundred questionnaires were returned for an overall response rate of 72%. No attempt was made to contact workers on vacation, sick leave, or disability leave.

The mean age of the questionnaire respondent was 36.8 years (range 17 to 77). Mean height and weight were 170 cm and 75 kg., respectively. The mean length of employment at the newspaper was 7.25 years (standard deviation 8 years). Females accounted for 46.8% of the questionnaire respondents.

Overall, the participants had the highest 12-month period prevalence rates for musculoskeletal disorders in the low back (53%), neck (46%), and the right hand/wrist (30%). The highest prevalences of musculoskeletal disorders were reported by workers in the production sectors (mailroom and pressroom) of the newspapers. The 12-month period prevalences of missed work in office and production sectors due to musculoskeletal disorders are listed in Table 2 by anatomical area.

Table 2. Prevalence of missed work due to musculoskeletal disorder in the preceding 12 months by anatomical area.

ANATOMICAL AREA	OFFICE	PRODUCTION
NECK	5.5%	4.8%
SHOULDER	3.3	8.1%
HAND/WRIST	2.6%	4.5%
LOW BACK	10.5%	12.9%

The purpose of the job factors survey was to identify the workplace conditions that may contribute to musculoskeletal disorders. The job factors survey data reflects the workers' perceptions of whether the specific factor was a problem during their work.

For all newspapers and departments combined, the factor that was reported most frequently as being a problem was prolonged positions. There were differences among the three newspapers in the proportion of workers who reported that specific job factors were a problem. Some job factors also appeared to be department specific. For example, newsroom workers sited prolonged positions and repetitive tasks as the most frequent problem in the workplace. Pressroom and mailroom workers reported the largest percentage of problems with prolonged positions and awkward postures.

Associations between four of the most prevalent problematic job factors and missed work as a result of four of the most prevalent musculoskeletal disorders are presented in Tables 3, 4, 5 and 6. The greatest association between job factors and missed work occurred with the hands/wrists for office workers and with the neck for production workers, Tables 3 and 4, respectively.

Table 3. Association between specific job factors and missed work due to musculoskeletal disorders in the **HANDS/WRISTS**.

HANDS/WRISTS	OFFICE WORKERS	PRODUCTION WORKERS

		Missed Work				Missed Work			
Job Factor		no	yes	O.R.*	p**	no	yes	O.R.*	p**
Repet. Task	no	424	6	6.8	.0001	192	8	4.4	.001
	yes	135	13			92	17		
Prolong. Position	no	395	5	4.0	.008	134	3	6.6	.001
	yes	230	14			150	22		
Awkward Postures	no	448	12	1.9	.242	211	4	15.2	.0001
	yes	111	6			73	21		
Work Station Adjust.	no	430	9	3.7	.006	202	11	3.1	.011
	yes	129	10			82	14		

* Odds Ratio
** Fishers exact p (two-tailed)

Table 4. Association between specific job factors and missed work due to musculoskeletal disorders in the **NECK**.

NECK		OFFICE WORKERS				PRODUCTION WORKERS			
		Missed Work				Missed Work			
Job Factor		no	yes	O.R.*	p**	no	yes	O.R.*	p**
Repet. Task	no	394	19	1.8	.128	190	1	29	.0001
	yes	124	11			85	13		
Prolong. Position	no	311	12	2.3	.036	130	0	26	.0001
	yes	205	18			145	14		
Awkward Postures	no	419	21	1.8	.157	198	5	4.6	.007
	yes	99	9			77	9		
Work Station Adjust.	no	401	16	3.0	.007	195	5	4.4	.013
	yes	117	14			80	9		

* Odds Ratio
** Fishers exact p (two-tailed)

Table 5. Association between specific job factors and missed work due to musculoskeletal disorders in the **SHOULDERS**.

SHOULDER		OFFICE WORKERS				PRODUCTION WORKERS			
		Missed Work				Missed Work			
Job Factor		no	yes	O.R.*	p**	no	yes	O.R.*	p**
Repet. Task	no	425	5	6.2	.001	196	4	4.9	.007
	yes	138	10			99	10		
Prolong. Position	no	331	3	5.7	.003	137	0	25	.0001
	yes	232	12			158	14		
Awkward Postures	no	453	8	3.6	.018	211	4	6.2	.001
	yes	110	7			84	10		
Work Station Adjust.	no	431	8	2.9	.060	208	5	4.3	.014
	yes	132	7			87	9		

* Odds Ratio

** Fishers exact p (two-tailed)

Table 6. Association between specific job factors and missed work due to musculoskeletal disorders in the **LOW BACK**.

LOW BACK		OFFICE WORKERS				PRODUCTION WORKERS			
		Missed Work				Missed Work			
Job Factor		no	yes	O.R.*	p**	no	yes	O.R.*	p**
Repet. Task	no	385	30	3.3	.0001	173	21	1.7	.145
	yes	108	28			83	17		
Prolong. Position	no	302	20	3.0	.0001	123	8	3.4	.002
	yes	191	38			133	30		
Awkward Postures	no	409	31	4.2	.0001	191	17	3.6	.0001
	yes	84	27			65	21		
Work Station Adjust.	no	388	30	3.4	.0001	185	19	2.6	.008
	yes	105	28			71	19		

* Odds Ratio

** Fishers exact p (two-tailed)

CONCLUSIONS

There were minor differences in prevalence rates and missed work rates among the three participating newspapers. Greater differences in prevalence rates were found among the departments. The higher prevalence rates of musculoskeletal problems in mailroom and pressroom workers demonstrate the need to further evaluate these workers and their work methods. This is a group that has not been studied previously, yet had a large proportion of musculoskeletal disorders.

The association between repetitive tasks and missed work due to neck problems was demonstrated by an odds ratio of 29 in the production workers and 1.8 in the office workers. This indicates that if the production workers perceive repetitive tasks as being a problem in their work, they are 29 times more likely to have missed work in the previous year than someone who does not perceive repetitive tasks as a problem. The difference in the odds ratio between the production and office workers indicates that the production workers are more likely to have missed work due to neck problems if they perceive problems with repetitive tasks. It may also suggest that office workers can continue working despite musculoskeletal disorders in the neck.

Caution should be used when comparing the data in this study with other studies because of differences in case definitions and methodology. The results of this study may have been influenced by survivor bias due to the cross-sectional design. Cross-sectional studies may miss those who have left their jobs because of health problems and this may result in an underestimation of the actual prevalence of musculoskeletal problems. Another limitation of the study may be due to the questionnaire format of the data collection which relies on self-reported symptoms and conditions. A prospective study of these workers is planned to further validate the variables and determine the predictiveness of the questionnaire. Additional analysis, including the development of logistic regression models, may be useful in more specifically identifying the combination of job factors which helps predict from the questionnaire those individuals who are most susceptible to miss work.

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ACCIDENT PREVENTION IN STEVEDORING—A NEW APPROACH

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INTRODUCTION

In Finland the labour protection administration has sought new ways to meet the challenges encountered in controlling working enviroments and to reduce occupational accidents. One undertaking is the accident prevention project being carried out in stevedoring, which has adopted a totally new approach to safety work.

The study was started in the end of 1987. The main objective was accident prevention in stevedoring by developing a method, for appraising the safety level of an organization and arranging safety work in an enterprise. The other goal were to develop a safety program for enterprises and a new point of view to inspect enterprises and to improve occupational safety.

An outline of the study is shown in figure 1.

1987	Planning
1988	Safety anlysis of the accident records of all stevedoring enterprises Report and conclusions Choice of six enterprises Questionnaires and interviews conducted in the enterprises
1989	Analysis and conclusions; report and feedback Support of development work
1990	Support of the development of occupational work safety programs
1991	Safety analysis and measurement report

Figure 1. Schedule and implementation of the study.

Six stevedoring firms were selected as target enterprises. Four ports with high accident rates were included in the study, and two ports with low accident rates.

METHOD

Stevedoring

In Finland, some 4000 people are implyoed in stevedoring, of whom about 600 are foremen. Ten largest stevedoring companies account for 85% of those employed in stevedoring. Figures on stevedoring workers and accidents in Finland are shown in table 1.

Table 1. Stevedores, foremen and accidents in 1990 (and in 1987).

Stevedores	Foremen	Accidents	Accident ratio Acc./1000 employee
3409	521	575	146
(3431)	(596)	(670)	(166)

Stevedoring is dangerous work, as the accident rates clearly indicate. The safety level and conduct in the ports vary widely.

Accident

In Finland, every employer must file a report to the insurance company on each occupational accident causing disability to that lasts more than three days. The accident reports investigated in this study concerned accidents which occured in 1987 and 1990.

Assessment of the operations of the enterprise.

Work climate measurements can be carried out by either interviews or questionnaires. Different climates can be measured in an enterprise (Brown and Holmes, 1986, Diekemper and Spartz, 1970, Seppälä 1988, Zohar, 1980). For the study, a questionnaire (with 73 questions) was posted to stevedores, and the replies from each enterprise were analyzed separately.

The line management and safety experts play an important role (Grimaldi and Simonds, 1984, Johnson, 1980). The line management were interviewed in the target enterprises. The base of the interviews comprised questions on normal work routines and occupational safety activities. The interview included 20 questions, presented primarily to supervisors. The replies were analyzed and compared with an expected ideal situation.

The workers assessed the level of safety operations in their enterprise through the questionnaire. One part of the questions were given to foremen in the end of interviews, too. The assessments are summarized in figure 4. These methods were applied in 1988 and repeated exactly three years later in 1991.

After the analyzing stage, the results were presented to each target group separately. After this special efforts were made to get the enterprises involved in the development work and committed to the project. In some enterprises, more advanced experiments were made in an attempt to influence the line management attitudes towards safety matters.

Table 2. Guestions concerning the safety level

1)	Work guidance
2)	Safety training
3)	Safety inspections
4)	Safety aspects taken into account during the planning of work
5)	Housekeeping
6)	Safe working methods encouraged
7)	Attitudes towards proposed improvements
8)	Initaitive in proposing improvements
9)	Safety surveys
10)	Investigation of accidents
11)	Action of the supervisors in safety matters
12)	Action of the higher management in safety matters
13)	Action of the workers in safety matters
14)	Supervision of safety
15)	Flow of information on safety matters
16)	Consideration of safety aspects in purchases
17)	Preventive safety work
Scale of values	5=excellent
	1=very poor

RESULTS

The safety level and conduct in the ports vary widely. Typical accidents include falling, sprains, squeezing of the leg,that causes leg or back injuries, and squeezing of the hands or fingers. The figure 2 shows the accident rates in the target ports.

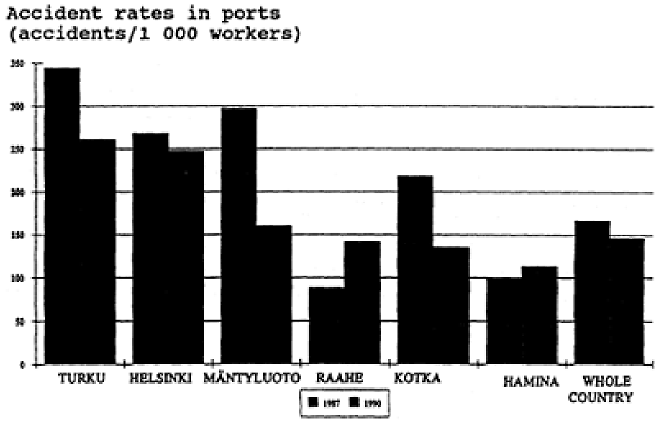

Figure 2. Accident rates for the target ports.

Target enterprises for futher investigation and development were selected on the basis of the first accident survey. These were four ports with high accident rates: Turku, Mäntyluoto, Helsinki and Kotka; and two ports with low accident rates: Raahe and Hamina. During the project, the number of accidents in the target ports dropped from 468 to 375, a fall of 20%. The number of serious accidents were declined from 50 to 19, a fall of 37%.

In Mäntyluoto accidents decreased by 44%. The trend was quite positive in Turku where the accident rate fell by about 25%. In Kotka the reduction was 30 %, and no serious accidents occurred there in 1990. In Hamina serious accidents were cut by 75%, serious accident is a disability of accident more than 30 days. Hamina has a low accident rate, and the trend there remained nearly unchanged. The accident rate rose in Raahe, but there the total number of accidents was rather small (16). In Helsinki the situation remained nearly unchanged, and one fatal accident occurred there in 1990.

The questionnaire findings indicate that the safety personnel encourages workers to act safely. Stevedores appreciate safety instructions. They can discuss safety issues with their foremen, who have positive attitudes to safety. The risk of accidents worries stevedores. Wrong attitudes are experienced as a serious problem.

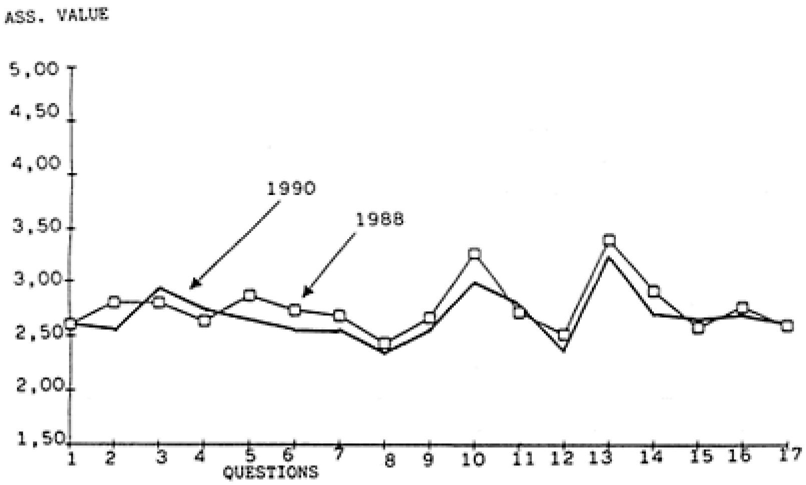

Figure 3. The workers' estimate of the level of the safety operations in 1988 and 1991 (N=185/228).

<u>The level of safety operations</u>

The f igure on the next page (figure 4) summarizes the workers and supervisors' estimates

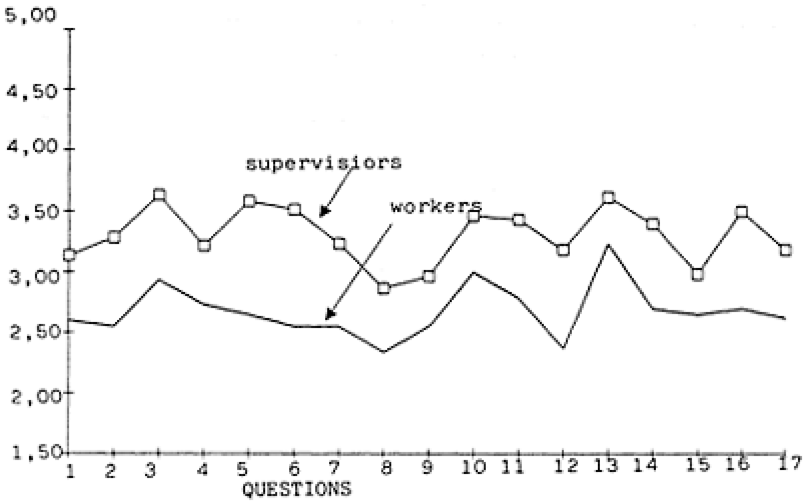

Figure 4. The level of safety operations in the target ports as estimated by supervisors and workers in 1991.

Supervisors generally see the function more positively than workers. The two groups do not have the same assessment value for in any question. They disagree most in questions concerning housekeeping, whether safe working methods are encouraged, and actions of the upper management in safety matters.

The results for interview questions were summarized for each enterprise. The results are shown in figure 5.

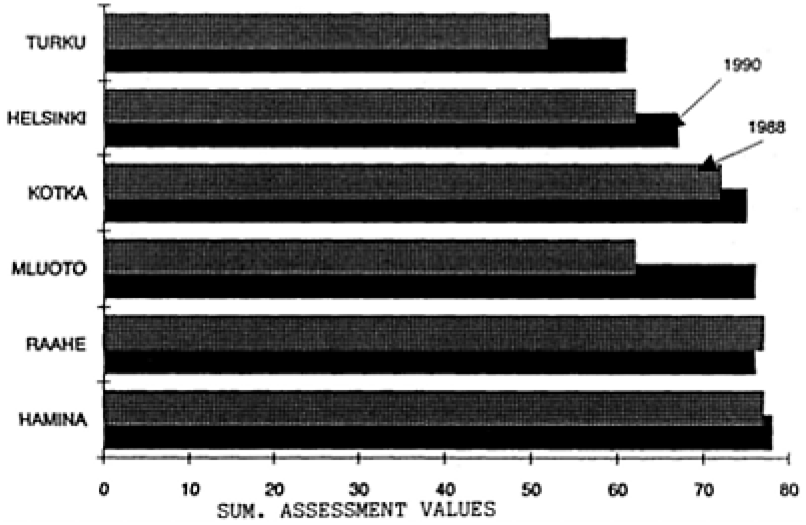

Figure 5. Assessments from interviews made in six ports in 1988 and 1991.

The greatest changes have taken place in Mäntyluoto and Turku. The development has also been positive in Helsinki and Kotka. Only a slight change is discernible in Raahe and Hamina.

The interviews clearly revealed how safety objectives are recognized in the enterprises, how accidents are investigated and how aware the enterprises are of safety matters and their safety level. The interviews also give information about the following: the the management system, accident follow-up, accident research, guidance of new workers, supervisors' attitudes to safety work, etc.

On the basis of the interviews, the enterprises can be ranked in the same order as their accident rates, with the minor exception of Mänytluoto.

CONCLUSIONS

The explicit objective of the study was to reduce accident figures, and in this the study succeeded.

The study succeeded in stimulating safety work. Interest in safety activities increased, and the enterprises set more goals in their operations.

The study distinctly revealed that the safety knowledge of the line management needs to be improved. Wrong attitudes still emerge in the development of safety operations.

Management was found to be more management by results the closer one gets to the top of the hierarchy, and management by rules the closer one gets to the bottom of the hierarchy.

The best way to reduce accidents is to get the enterprise interested in improving its accident situation and the level of its safety operations. It is very important for an outsider to understand what is possible and reasonable to carried out in a specific enterprise and who are the right persons in the organization to do so. Positive results are achieved by follow-up of accidents, by information on them and by general consciousness of the whole situation.

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AN EPIDEMIOLOGICAL AND ERGONOMICS ANALYSIS FOR THE LAUNDRY INDUSTRY—A CASE STUDY

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The injury and illness records from a local linen and uniform service company were reviewed and analyzed to identify the high risk operations. An ergonomics risk analysis was also conducted to identify and quantify the severity of occupational hazardous factors via the physical investigation. A correlation analysis was conducted to identify the relationship between the predicted injury rate from Job Severity Index and the actual injury rate. A positive relationship was established. A similar analysis was also conducted to compare the predicted injury rate and the actual loss workdays and a similar result was obtained. These results showed that the predicted injury rate is reliable.

INTRODUCTION

Historically, Manual Materials Handling (MMH) has been recognized as a major source of injuries and lost workdays in manufacturing industries. Consequently, the reduction of such injuries has been of prime interest to researchers and practitioners of occupational safety and health. A large portion of activities in the industrial laundries are composed of various types of manual materials handling (e.g., loading/unloading from/to route trucks, soil separation, loading/unloading of linens from/to washers and dryers) that have been recognized as major hazards to linen service industrial workers. The primary objective of this study was to improve the working environment and reduce the injuries for the high risk operations in linen service industry via the injury and illness record investigation and the ergonomic risk analysis.

THE INJURY AND ILLNESS RECORD INVESTIGATION

The analysis of past accident and injury data has been proved to be an effective method in identifying high risk operations in manufacturing industry. Genaidy (1990) conducted an extensive study on the computation of basic epidemiological measures on the basis of the data collected from the medical records. 271 occupational accident and injury data during the past 3 years were collected, reviewed and analyzed based on the number of injury cases, lost workdays, and average lost workdays per injured employee for different operations and different demographic factors (e.g., age, gender, length of service, part of body injured, nature of injuries, and accident type) to identify the jobs that had the high risk of injury. The jobs that have the high risk of injury were identified by the number of cases and the number of lost workdays. Table 1 shows that the flatwork worker, maintenance engineer, presser, route salesman, soilroom worker, warehouse worker, and the washroom operator have the highest number of recordable medical cases, with the route salesman topping the list. Furthermore, these operations also caused more lost workdays than other activities in the company.

Table 1. Incidence and severity of different operations.

Type of Occupation	Number of Cases	Number of Lost Workdays*
Checker	1	0
Clerical	2	1
Counter Sales	1	0
Data Entry Clerk	1	2
Dry Cleaning Worker	1	0
Engineer	6	77
Extractor	5	28
Flatwork Worker	21	652
Fleet Manager	2	0
Fleet Shop Mach.	3	4
Folder	5	10
General Manager	1	0
Hot Shot Driver	2	34
Janitor	2	27
Laundry	6	9
Linen Control	1	0
Maintenance Engineer	22	347
Marker	1	0
Mending Operator	1	0
Net Assembly	1	0
Packout Operator	8	74
Plant Supervisor.	1	60
Presser	16	99
Production Manager	1	0
Q.C. Inspector	4	0

Route Salesman	65	938
Service Supervisor	13	6
Shipping (Loading Dock)	1	0
Silk Finisher	1	1
Soilroom Worker	30	184
Supervisor	2	0
Tumble Operator	1	1
Warehouse Worker	19	88
Warehouse Supervisor	1	0
Washroom Worker	20	164
Washroom Supervisor	2	0
Others	1	0
Total	271	2806

* The number of lost workdays includes compensable injuries and illness for days away from the work and days of restricted work activity due to injury.

Table 2 shows the severity of injuries increased gradually with an increase in age and decreased in ages over 40. The age group of 30 to 39 years recorded the highest average number of lost workdays away from work. The severity of injury cases and lost workdays for male employees were significantly higher than that for female employees, although the female employees constitute the majority (63%) of the workforce. There were more average number of lost workdays per injured employee for female workers than for male workers as compared to the number of injury cases. This is because most male employees work in the higher risk operations such as maintenance, washer operation, warehouse operation, and route sales.

The number of injury cases for those employed in the company for less than 1 year was higher than the rest. On the other hand the average number of lost workdays per injured employee in the case of senior employees (experience of more than five years) was higher than the other groups. The necessary safety training is recommended for the junior and senior workers.

The severity of injuries for the different body parts indicated that the trunk including back and the total lower extremities accounted for the highest number of injury cases and lost workdays. Eye irritations caused by foreign objects in the case of maintenance and soilroom operator were also high. From the results of nature of injuries, it was evident that sprain and strain had significantly higher number of injury cases and caused more lost workdays among all the injuries. The fractures of body parts was responsible for the highest average number of lost workdays per injured employee, although the number of injury cases due to fractures was low. This can be attributed to the time taken for recovery in such cases. The average number of lost workdays due to accidental falling and over exertion was also high. Sprain and Strain are closely related to back injuries. When a person complains of back pain, it can be classified as sprain and/or strain.

The route sales workers suffered most of the severe injuries. These injuries occurred mostly in the parts of back, upper extremities, and lower body resulting in sprain and strain injuries. These disorders were mainly due to repetitive motions or inappropriate working postures, inaccurate lifting technique, or overexertion when handling load.

Almost one-fourth of the analyzed accidents were classified as physical overexertion which indicates the manual materials handling in linen industry has potential risk of overexertion injury to the workers. Once the high risk of operations were identified, task analysis was performed through video recordings and observations in order to identify the various elements of each job as well as the risk factors associated with them. After reviewing and justifying with the company's safety committee, a set of safety equipments were then recommended and implemented (Table 3).

Table 2. Severity of injuries by various factors

Factor	No. of cases (% of total cases)	Lost workdays (% of total lost workdays)	Avg. no. of lost workdays per case
Age [% work force]			
19 & below [3.0]	2.7	0.7	2.57
20–29 [40.9]	32.6	27.6	8.87
30–39 [27.0]	39.4	49.1	13.0
40–49 [20.0]	17.8	21.4	12.6
50 & over [9.1]	7.5	1.2	1.6
Gender			
Male [37.0]	64.3	67.0	10.8
Female [63.0]	35.7	33.0	9.58
Length of Service (Yr)			
less than 1 year	47.5	48.7	10.7
1 year to 2 year	27.5	28.0	10.6
3 year to 4 year	8.7	4.6	5.52
5 year or more	16.3	18.7	12.09
Part of Body Injured			
Head (Eye, Face, etc.)	14.8	6.0	4.6
Neck, Shoulder	5.5	0.4	0.66
Total Upper Extremities	(31.4)*	(12.2)	(3.85)
Arm	8.1	5.5	6.6
Wrist	3.0	0.3	1.13
Hand	10.0	5.6	5.57
Finger	10.3	0.8	0.76
Trunk (Including Back)	18.8	41.5	26.7
Total Lower Extremities	24.0	19.4	7.8
Multiparts (e.g. arm & leg)	4.8	20.5	43.5
Others	0.7	0.0	0.0
Nature of Injuries			
Burn (by heat)	4.4	5.2	10.7
Crushing and Bruise	16.2	8.8	5.3
Cut, Laceration,	14.8	4.7	3.2

Puncture			
Joint Inf lammation or Irritation	11.0	0.0	0.0
Scratches, Abrasions	4.4	0.1	0.33
Sprain, Strain	39.1	54.9	14.1
Fractures	7.0	21.7	34.5
Others (e.g. Dermatitis)	13.0	4.6	3.73
Accident Type			
Struck against or by	27.2	13.0	4.85
Fall	17.7	35.2	20.2
Caught in, under, etc.	10.6	7.3	7.0
Overexertion (sum)	(26.9)	(25.4)	(9.61)
Lifting	10.6	16.5	15.9
Pulling/Pushing	7.2	2.9	4.11
Other Materials Handling	9.1	6.0	6.6
Others (e.g. auto accident)	17.6	19.1	11.0

DEVELOPMENT AND VALIDATION OF THE INJURY RATE PREDICTION MODEL

The job demands and employee capacity were then measured to compute the severity of each job. The job demand parameters involves the job exposure time and the job components such as weight of lift, frequency of lift, and range of lift. There are several methods available in measuring employee capacity. Generally, these methods fall into four categories: psychological, biomechanical, physiological, and psychophysical. The psychophysical approach developed by Ayoub et al. (1978) was selected for determining employee capacity. The weight, arm strength, shoulder height, back strength, abdominal depth, and dynamic endurance were measured for selected employees to fit into the lifting capacity prediction model. With these data, the Job Severity Index (JSI) for each operation was derived (Table 4). These JSI value were then proportionated to predict the injury rate for each different operation. The actual injury rate and actual lost workdays were the ratio of the number of cases/lost workdays for each department to the total number of cases/lost workdays. A correlation analysis was conducted to identify the relationship between the predicted injury rate from Job Severity Index and the actual injury rate. A positive relationship (r=1.0) was established. A similar analysis was also conducted to compare the predicted injury rate and the actual loss workdays and a similar result (r=0.898) was obtained. These results showed that the predicted injury rate is reliable.

The physical stress job analysis according to the NIOSH Lifting Guideline Limits was also performed for each type of operation. Table 5 shows the Action Limit (AL), Maximum Permissible Limit (MPL), and optimal lifting frequency for each operation.

The current measurements were then simulated by changing the value of variables to get optimal weight of lift, frequency of lift, and work station dimensions.

CONCLUSIONS

The above case study illustrates the potential applications of the Epidemiological Measurement, JSI, Psychophysical Lifting Capacity Prediction Model, and NIOSH Lifting Guidelines in controlling of MMH problems for the laundry industry.

More research is needed to develop job severity index norms with respect to a specific injury prediction rate for both males and females that could be used as *a* basis for establishing a policy for the job placement.

It should be noted that an epidemiological study can be used as the good predictor for the future injury occurrences.

Table 3. Safety recommendations.

Department	Safety Equipments Recommended
Extraction	Safety belt, helmet, ear plug, waterproof boots
Maintenance	Safety glasses, safety belt, safety gloves, helmet, safety shoes
Mat Roller	Safety belt
Packout	Safety belt, safety shoes
Route Sales	Safety belt, safety shoes
Soilbelt Sorting	Safety glasses, safety gloves
Soil Separation	Safety glasses, safety gloves
Towel Folding	Mask, safety glasses
Tumble Drying	Safety belt, helmet
Washroom	Safety glasses, ear plug, safety gloves, safety belt, helmet, safety shoes, clean floor

Table 4. Lifting capacity, JSI, predicted injury, actual injury, and actual lost workdays comparison

Type of Occupation	Lifting Capacity	JSI	Predicted In jury	Actual Injury	Actual Lost Workdays
Checker	5.53	0.91	0.497	0.740	0.030
Counter Sales	6.34	0.78	0.248	0.370	0.000
Dry Cleaning	17.8	1.12	1.745	2.600	0.000
Engineer	37.3	0.54	1.477	2.200	2.700
Extractor	30.6	1.32	1.007	1.500	1.000
Flatwork Worker	20.1	0.27	6.443	9.600	23.600
Hot Shot Driver	29.2	1.40	0.497	0.740	1.200
Maintenance Engr.	25.9	0.94	6.174	9.200	12.500
Marker	4.31	1.16	0.248	0.370	0.000
Mat Roller	30.3	0.66	0.497	0.740	0.030
Material Handler	24.0	1.67	1.007	1.500	0.900

Mending Worker	13.9	0.36	0.497	0.740	0.000
Packout Worker	24.0	0.83	2.953	4.400	2.600
Presser	19.9	0.50	3.960	5.900	3.500
Route Salesman	23.5	3.01	16.107	24.000	33.400
Service Supery.	30.8	0.65	3.289	4.900	0.200
Silk Finisher	6.9	0.72	0.248	0.370	0.015
Soilroom Worker	24.5	0.85	7.383	11.000	6.600
Supervisor	16.8	0.91	1.678	2.500	2.100
Tumble Operator	24.1	1.70	0.248	0.370	0.030
Warehouse Worker	27.7	0.72	4.966	7.400	3.100
Washroom	24.9	1.70	5.436	8.100	6.200

Table 5. The comparison of AL, MPL, and optimal lifting frequency for different Occupation.

Occupation	Current Object Weight (Max)	AL (kg)	MPL (kg)	Optimal Lifting Frequency (task/min.)
Checker	2.0	6.89	20.67	5.00
Counter Sales	2.0	7.99	23.97	2.00
Dry Cleaning Worker	12.0	10.12	30.36	0.06
Extractor	35.6	10.08	30.24	0.05
Flat Work	2.0	0.71	2.13	11.00
Hot Shot Driver	30.0	11.91	35.73	0.10
Marker	2.0	13.22	39.66	2.00
Mat Roller	6.8	8.25	24.75	2.00
Material Handler	27.0	12.53	37.59	0.05
Mending Worker	2.0	11.41	34.23	2.00
Packout Worker	7.0	6.60	19.80	3.00
Presser	2.0	11.81	35.43	1.00
Route Salesman	36.3	10.91	32.73	0.06
Silk Finisher	2.0	12.60	37.80	0.20
Soilroom Worker	12.1	9.10	27.30	0.10
Tumble Operator	28.0	12.27	36.81	0.05
Warehouse Worker	20.0	8.58	25.74	0.15
Washroom Worker	30.0	11.73	35.19	0.05

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SAFETY AND SURVEILLANCE

AN ATTRIBUTIONAL MODEL OF THE SAFETY MANAGEMENT PROCESS IN INDUSTRY

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The present paper argues that causal attributions represent an important link between workplace safety problems and the actions that are taken to control them. With this as a starting point, an attributional model of the safety management process is proposed that describes the formation of safety-related attributions and the various individual and organizational factors that are likely to limit and/or bias these causal inferences. Several safety program recommendations are offered based on this analysis.

INTRODUCTION

Attribution theory is the area of social psychology concerned with how people process information in arriving at inferences of causality for the events around them. Attributional processes are inexorably linked to safety management at the worksite. Individual workers, supervisors, managers, and safety specialists are all involved in making inferences of causality or attributions for various safety-related events. These causal inferences, in turn, broadly determine the actions that are taken or not taken to correct hazards and prevent injuries. Attributions of causality are certainly part of the formal analysis of hazards and accidents, but many other safety-relevant attributions occur informally as part of normal workplace interactions and job activities.

The present paper proposes an attributional model of the safety management process that draws upon basic attribution theory work (e.g., Kelley, 1967, 1973; Weiner, 1985), as well as previous applications of attribution theory to organizational behavior (e.g., Brown, 1984, Ford, 1985; Green & Mitchell, 1979) and occupational safety (e.g., DeJoy, 1985; Hale & Glendon, 1987). Within this model, workplace participants are viewed as processors of information or decision makers. While safety-related events provide the stimulus for attributional thinking and for subsequent behavior, the process is far from simple or direct (DeJoy, 1985; Green & Mitchell, 1979).

CAUSAL ANALYSIS

In workplace safety, causes are generally “things” that increase the probability of injury; they are, however, seldom sufficient by themselves to produce injury each and every time they are present. There is almost always a certain degree of ambiguity about what constitutes an accident cause (Woodcock, 1989); in many situations, the analyst is faced with multiple causal candidates, as well as with causes that have causes of their own. Situations high in causal ambiguity are fertile grounds for attributional errors and biases.

At its most basic level, the process of reporting and investigating accidents revolves around the making of internal (e.g., unsafe behavior) and/or external (e.g., unsafe conditions) attributions of causality. Unfortunately, in most work settings, causality is closely associated with the assignment of blame, fault, and responsibility. Indeed, the search for causal understanding is often dominated by the desire to fix responsibility, which often translates to avoiding responsibility. The task of assigning responsibility certainly has the potential to bias attributional thinking, to favor certain causal explanations over others, or to truncate the entire causal search process.

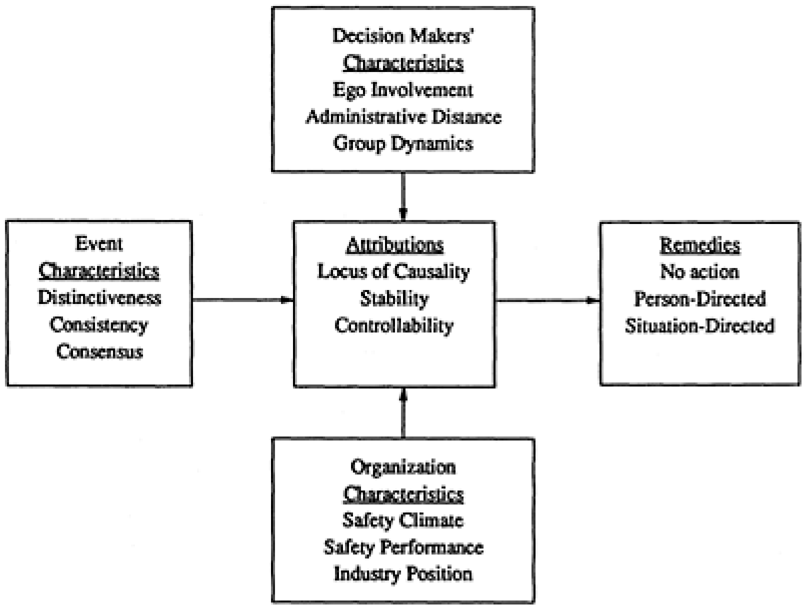

Figure 1. Attributional model of safety management process

PROPOSED MODEL

The model depicted in Figure 1 is similar in structure to Ford's (1985) model of corporate performance. Moving from left to right in the figure, the occurrence of some safetyrelated event provides the stimulus for causal thinking on the part of the worker, supervisor, or other workplace participant. The individual then "collects" information about the event to facilitate causal understanding. Attribution theory proposes several types of informational or outcome-related cues that are important at this stage. Continuing along the mid-line of the figure, attribution research suggests that causes are typically categorized using three major dimensions: locus of causality, stability, and controllability. The manner in which causes are categorized plays an important role in the types of remedies that are pursued.

The total process becomes more complicated because causal information is often ambiguous and incomplete, and workplace participants are seldom unbiased, unconstrained processors of information. To reflect this reality, two categories of moderating factors are included in the model. The first category focuses on the "decision-maker" and the types of bias that often exist in organizational settings. The second category pertains to various organizational characteristics that may influence or place boundaries on how individuals process causal information and select remedies.

Event characteristics

Kelley (1967, 1973) argues that the primary attributional task facing the individual is to classify the causes of behavior into three categories: person, entity, or context. In most instances of poor safety performance, the observer tries to determine whether the event or outcome was caused by the worker (person/actor), the task (entity), or by some set of circumstances related to the event (context). The individual examines covariations between causes and effects in arriving at attributions. Three types of information appear to be particularly important in forming attributions.

a) distinctiveness—Whether the worker has performed safely on other tasks.
b) consistency—Whether he/she has performed safely on this task in the past.
c) consensus—Whether other workers have performed this task without incident.

Affirmative answers to questions a and b, combined with a negative answer to c, should lead to the conclusion that the worker is a safe worker and that the event was caused by something related to the task or the environment. In contrast, negative answers to a and b, especially in combination with an affirmative answer to c, would focus causality on the worker. Of course, not all patterns of data yield such unambiguous attributions, and decision-makers are often confronted with conflicting information.

Attributional dimensions

Weiner (1979) proposes that causes can be categorized along three major dimensions: locus of causation, degree of stability, and controllability. Table 1 portrays this three-dimensional classification scheme.

Table 1. Dimensional structure of safety-related attributions and illustrative examples

	Internal		External	
Controllability	Stable	Unstable	Stable	Unstable
Uncontrollable	Ability	Fatigue	Inherent hazard	Chance
Controllable	Typical effort	Immed. effort	Incentive system	Co-worker action

Locus of causation locates the cause as internal or external to the person or persons involved in the event. Stability is essentially a continuum that varies from temporary (variant) to permanent (invariant). Referring to Table 1, fatigue is classified as unstable because it can vary over time; ability, on the other hand, is a more enduring or stable factor. Controllability is also a continuum that reflects the degree to which the cause is controllable. Effort is typically perceived as controllable and ability as uncontrollable. The controllability dimension is somewhat problematic (Weiner, 1979), specifically, in terms of when external causes are perceived as controllable. In occupational safety, almost all causes are viewed as controllable by someone at some point. Whether external causes are controllable appears to depend on how far back one goes in the causal chain and whether controllability is only from the perspective of the worker or also from that of supervisors, managers, safety specialists, equipment designers, and so forth.

Remedies

The selection of particular remedies is strongly influenced by the dimensional structure of the decision-maker's attributions. In selecting remedies, there are three basic options: 1) do nothing, 2) change something about the worker (person-directed), or 3) change something about the environment/situation (situation-directed). As a general rule, internal attributions produce worker-directed responses, while external attributions produce situation-directed responses. However, in most instances, attributions involve more than a single dimension. For example, attributing an accident to poor worker effort brings in both the locus of causation and controllability dimensions (internal/controllable) and is likely to result in punitive actions by the supervisor or manager. On the other hand, an accident due to an inherent hazard in the manufacturing process (external/stable) is likely to result in an situation-directed response involving engineering or source control measures. However, if this same hazard is perceived as being controllable through additional operator training or heightened vigilance, then some type of person-directed response might be the preferred course of action.

Remedies often involve multiple actions, some of which are directed at the worker and others which seek to change various aspects of the situation. still, the specific actions chosen and relative mix of worker and situational actions are likely to reflect the dimensional structure of the decision-maker's attributions.

Decision makers' characteristics

Workplace participants are seldom totally objective, unbiased processors of information. Ego involvement can often bias attributional thinking in organizational settings (DeJoy, 1985; Green & Mitchell, 1979). In particular, self-serving or self-protective biases are likely to be involved given people's tendency to readily accept responsibility for their successes and to deny responsibility for their failures (Bradley 1978). Supervisors are motivated to attribute the good safety performance of their departments to good management skills, while poor performance may be explained in terms of worker carelessness or lack of effort. Attributing poor performance to factors internal to the worker tends to absolves the supervisor from direct blame and may also obviate the need for complex and costly engineering or other situation-directed actions. Some evidence exists suggesting that those in supervisory roles may be biased toward making internal attributions about workplace accidents (DeJoy, 1987; LaCroix & DeJoy, 1989; Mitchell & Wood, 1980).

Workers are also subject to self-serving biases but their biases are likely to be opposite from those of supervisors or managers. Workers will most often favor external causes in explaining their own workplace safety problems. Attributional differences between supervisors and workers can be an important source of organizational conflict and they undoubtedly contribute to the adversarial relationship that often exists between management and labor in the safety arena (DeJoy, 1985).

Supervisors, managers, and safety specialists typically interpret safety events from the perspective of an observer rather than an actor. The attribution literature suggests that people tend to explain the behavior of others in internal or dispositional terms, whereas they attribute their own behavior to situational or environmental factors (Jones & Nisbett, 1972). The tendency of observers to underestimate situational factors is so pervasive that it is often referred to as the "fundamental attributional error" (Ross, 1977). Actor-observer differences predict that those involved in accidents and those charged with analyzing them are likely to have different views of causality and needed corrective actions.

This bias toward internal attributions among observers is likely to be exaggerated with increasing administrative distance (Brown, 1984). Upper level managers are often farremoved from the actual work situation and have considerable difficulty appreciating external or situational factors. In addition, lack of direct experience in performing the worker's job makes managers less knowledgeable and less able to empathize with the worker (Mitchell & Kalb, 1982).

Group dynamics can also influence attributions. For example, groupthink (Janis, 1983) can impact safety-related decision-making and receptivity to advice and input. In general, the social/personal relationship between actor and observer, as well as the personal characteristics of those involved, also influence attributions in the workplace (Green & Mitchell, 1979).

Organization characteristics

Zohar (1980) defines safety climate as the coherent set of perceptions and expectations that employees have regarding safety in their organization. While it is difficult to precisely define what constitutes a positive safety climate, studies have been able to identify the elements of good safety programs (e.g., Cohen, Smith, & Cohen, 1975; Cohen & Cleveland, 1983, Simonds & Shafai-Sahrai, 1977). In general, good safety performance is associated with active management support and involvement, a balanced view of accident causation, and full acceptance of safety as an integral part of the management system. Having a balanced view of accident causation means that emphasis is given to controlling situational and environmental factors as well as worker behavior. The safety climate of an organization, at least as reflected by the above characteristics, has the potential to influence the causal thinking of all workplace participants; in particular, the safety climate may serve to limit causal thinking and/or "favor" or "endorse" certain types of casual ascriptions and types of corrective actions.

The overall safety performance of an organization and its relative position among its competitors may also influence attributions. Poor safety performance at the organizational level would seem to represent a situation of high consensus that should yield external attributions (see Kelley's covariation model discussed earlier). However, the reverse is often true in organizational settings (Brown, 1984). For one thing, intra-group consensus may be relatively unimportant because companies are often interested in comparing their performance against that of their competitors. In addition, self-serving and self-other biases are both likely to favor the making of internal attributions in the face of poor group performance.

Green and Mitchell (1979) argue that when managers use consensus information in decision-making, it tends to be self-based rather than sample-based. Instead of making inferences on the basis of actual group performance, they infer what others could do in terms of what they think they could have done. Many managers also believe that safety is a worker-oriented problem and that the firstline supervisor is responsible for poor safety performance. As such, supervisors may be singled out for responsibility, especially when poor group performance is chronic (DeJoy, 1985).

Economic conditions and the relative position of the organization within its industry may also influence and/or place boundaries on attributions. In many respects, safety is seen as overhead, with costs that ultimately must be passed on to the consumer or purchaser. The idea that safety efforts actually save money is not as pervasive as we might wish.

CONCLUSIONS AND IMPLICATIONS

The model presented in this paper is not intended to be a comprehensive model of accident causation or accident investigation; rather, its purpose is to illustrate the role of attributional processes in safety management and to argue that attributions represent an important link between safety problems and the actions that are taken to control them. The cognitions and motives of workplace participants are clearly central to the detection, appraisal, and amelioration of workplace safety problems. In a very real sense, actions to manage safety derive from attributions rather than actual causes.

Perhaps the most general recommendation that can be offered from this paper is that efforts should be made at all levels of the organization to promote balanced attributions concerning workplace accident causation. Several somewhat more specific recommendations are presented below.

1. Employees at all levels need to be made aware of eventattribution—remedy linkages and the limitations and biases involved in perceiving and responding to safetyrelated events.

2. Toward the goal of establishing positive safety climates and comprehensive safety programs, special efforts should be directed at managers to reduce administrative distance and to increase the salience of environmental factors in accident causation.
3. Accident reporting forms and procedures and investigative strategies should be examined for their objectivity and ability to detect valid causes. Wherever possible, the results of formal analyses should be disseminated to supplant the informal and often flawed attributional analyses that inevitably occur.
4. Supervisory safety training programs should highlight sources of attributional bias in supervisor-subordinate interactions as well as the importance of making accurate diagnoses of safety problems.
5. Aggressive efforts are needed to promote open and two-way communication between labor and management on safety matters. Better decision making is possible if attributional perspectives can be shared and if the adversarial relationship between workers and managers can be mollified.

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CONSUMER PERCEPTIONS OF SAFETY OF CONSUMER PRODUCTS

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Two studies examined how hazards represented by specific terms as applied to commercial products are understood. College students were asked to indicate how much danger was posed by different products, all having the same hazard designation. In both experiments large differences were found among products associated with the same hazard. The results are discussed in terms of top-down versus bottom-up processing of safety information. It was tentatively concluded that information about individual products outweighs general knowledge of hazard characteristics.

INTRODUCTION

Interest in good ergonomic development of consumer products has blossomed in recent years, and this has given impetus to further research on ergonomic characteristics of consumer products. Much of this effort has been directed toward ease and comfort in operation of the products. Advertising has been a prominent factor in shaping the ergonomic interests. Touting the "ergonomic design" of the product appears to have merit in the eyes of the advertisers.

Advertising has largely neglected an important feature of the ergonomic approach which is the safety of operation. Perhaps less attention has been paid to this aspect of consumer products, because it is not considered a good basis for advertising to indicate that any undesirable events might be associated with a product. However, it is clear that safety must be paramount in design of consumer products, and the manner in which a product is used affects its safety. Warnings and instructions are important in influencing proper use. The attention paid to warnings by consumers tends to vary with the perceived risk associated with a hazard (Wright, et al., 1982; Godfrey, et al., 1983). It is reasonable to assume that two factors might influence the perceived risk of a product, knowledge about the nature of the product and information found in warnings on the product. Thus, if either of these factors indicated a serious risk was associated with the product, the user might be more inclined to read the instructions for safe use. Similarly, in industrial settings we should expect workers to attend more closely to information that indicates greater risk.

Recent studies (e.g., Leonard, Creel, & Karnes, 1991) have shown that many individuals are not familiar with the meanings of some terms that are used in warnings both in the workplace and on consumer products. A significant result of such lack of knowledge could be unsafe behavior resulting in serious injury or materiel damage or both. This could occur because the individual dealing with the hazardous substance failed to take appropriate precautions, or by virtue of producing hazards by inappropriate actions. Inasmuch as some warning signs contain limited information, for example merely stating that a substance is an oxidizer, those exposed to the signs must have some prior knowledge if they are to take adequate precautions.

Knowledge about hazards may be developed in two ways, often characterized as top-down and bottom-up. The top-down knowledge would be represented by one's knowledge of the characteristics of different substances and the hazards related to those characteristics. For example, a textile manufacturer might know that a certain class of textiles would melt when exposed to flame, and knowing that a particular textile fit in that class would not use it for fire-fighters' suits. The bottom-up approach involves the knowledge of particular hazards and use of that information may be incorporated with other specific information to arrive at conclusions about a particular situation. One might combine the knowledge that sparks can cause gasoline vapors to explode with the recognition that a particular set of tools can cause sparks and decide not to use those tools to work on a gas tank. The top-down system has several advantages. The usual features associated with an adequate warning are 1) a signal word to call attention to the hazard, 2) a description of the hazard, 3) information about consequences associated with the hazard, and 4) responses to be made to overcome problems associated with the hazard. If one has prior knowledge of the nature of the hazard, the last two features of the warning should be known in advance. One disadvantage of the top-down approach is that not all hazards fit neatly into a particular category. From a practical standpoint a more serious problem is that not all users of hazardous substances are knowledgeable about their characteristics. Further, many hazardous substances may impinge on the public, even though the public does not use them. For example, hazardous substances are transported on the public streets daily, and on occasion they are involved in mishaps that may bring them into contact with the public.

One feature of the bottom-up approach to knowledge that has been demonstrated in some situations is that given several cases of a particular type, one may generalize to other similar cases, thus ultimately achieving the capability of the top-down approach. The type of experience that one has with different cases may influence the extent to which one is able to generalize among them. Experiences of a physical sort could affect generalization differently from cognitive experiences.

The present research was undertaken to determine the extent to which prior and current information influence an individual's perception of risk associated with different substances having the same hazardous properties. Specifically, subjects were asked to rate the dangers associated with a number of consumer products within groupings by type of hazard. It was assumed that if subjects were using a top-down approach, they would tend to assign similar values to products having the same characteristics. It was also considered possible that subjects might readily generalize on a cognitive basis across products having the same characteristics. An alternative possibility considered was that subjects would respond primarily on the basis of their prior knowledge about specific products.

Two procedures were used to evaluate the risk perceptions of the subjects, a ranking procedure and a rating procedure. For purposes of explication we shall treat the two as separate experiments.

EXPERIMENT 1

In this experiment subjects were asked to rank order the products within subgroups based on a particular hazardous characteristic in terms of the amount of danger they posed to the user. A comparison was made of the influence of different sorts of instructions on the willingness of subjects to use tied ranks.

Method

Subjects were volunteers from undergraduate courses in psychology at the University of Georgia (UGA) and at Metropolitan State College of Denver (MSCD). Some received research participation credit in their courses for their cooperation. A total 85 subjects, 38 males and 47 females were used in the experiment.

Based on the characteristics stated in the warnings on the products, four lists of commonly used products were constructed. The characteristics were: flammable, combustible, corrosive, and irritant. The specific items are shown in Table 1. The lists were reproduced along with instructions for rank ordering the items (a rank of 1 for most dangerous and higher numbers for less dangerous items). The instructions were repeated for each set of characteristics, and the rank ordering was done among products having the same characteristic. Two sets of instructions were used. The standard instructions simply described the ranking procedure as it is commonly done. The enhanced instructions contained a statement that items which were considered equally dangerous should be given the same rank. General instructions presented at the beginning of the session mentioned that hazardous substances existed in the environment and the experiment was designed to evaluate people's perceptions of the risks involved. Subjects were asked to read the instructions on the sheets provided them and follow those instructions. Subjects given the enhanced instructions were run at a later time than those with the standard instructions.

Results

As seen in Table 1, subjects overall did tend to rank the items differently within the subsets having the same characteristics. Thus, it seems that processing of this sort of information is performed largely in a bottom-up fashion. That is, the subjects responded in terms of their knowledge of specific items, rather than the category information.

Although the difference in the number of subjects who used tied ranks in the enhanced instruction group (19 vs 3, $2_{(1)}$=17.45, P<.01) was significant, most subjects used tied ranks in only one or two categories of hazard. Examination of the instances suggested that they may have resulted from lack of knowledge about items in a subgroup rather than of recognition of their hazard similarity. The differences in average ranks were quite small. To evaluate the generality of the rankings, correlations were obtained between males and females within each group and between the totals of the standard and enhanced instructions groups. All of the correlations were greater than .88. Thus, the rankings presented in Table 1 are for all cases combined.

Our original assumption that prior knowledge about specific products could influence the perception of risk was supported by the differences found between different products. In addition, one specific hypothesis was developed about differences among subjects having different experiences. In examining preliminary data it was noted that many subjects failed to assign a very high rank to a rather noxious product in the category of corrosive substances, the oven cleaner. It was assumed that a possible explanation for this was that the mainly 18–20 year old subjects had no experience with this type of product. It was predicted that older subjects might assign it a higher rank. In one subset of subjects having the same instructions 31 subjects were under 25 years old and 14 were 25 or older. The mean ranking assigned by the younger subjects was 3.61, while the mean ranking by the older subjects was 1.86. This difference was statistically significant, $t_{(43)}$=4.82, P<.01.

EXPERIMENT 2

The rank ordering procedure has the advantage that it essentially forces the subject to compare items with each other. Thus, items judged different by a subject may be presumed to have some difference in the perception of that subject. However, there is also the possibility that even though the differences are real, the size of the differences may be masked by the technique which uses a difference of one in rank order no matter how small or large the perceptual difference might be. Further, the scale values assigned to the items are necessarily a function of the set in which the ranking is done. It is possible that the results obtained in Experiment 1 could exaggerate the differences among items in each hazard characteristic set. Therefore, in Experiment 2 a rating procedure was used to obtain scale values for the perception of risk involved in dealing with the substances examined in Experiment 1.

Method

As in Experiment 1, subjects were volunteers from undergraduate courses in psychology at UGA and at MSCD, and some received course credit for participating. In all, 36 males and 62 females were used in the experiment.

The four lists of products from Experiment 1 were

TABLE 1 Mean ratings and rankings for products by hazard designation.

Hazard	Ranking (N=86)	Rating (N=98)
Flammable		
Furniture polish	3.79	2.66
Gasoline	1.13	4.62
Fingernail polish remover	2.99	2.85
Air freshener	4.12	2.56
Hair spray	2.42	3.30
Combustible		
A lubricant	3.35	2.50
Car polish	3.76	2.49
Paint thinner	1.21	3.81
Liquid kitchen wax	3.80	2.49
Oil-based paint	2.45	2.92
Corrosive		
swimming-pool algae killer	2.61	3.13
Tire cleaner	4.05	2.50
Weed killer	2.54	3.57
Septic tank cleaner	1.80	3.94
Oven cleaner	3.15	3.01
Irritant		
Dog shampoo	4.32	1.57
Hair permanent solution	2.86	2.51
Rust remover	1.75	3.24
Moth balls	3.65	1.99
Ammonia cleaner	1.62	3.34

presented with instructions to rate them on a five-point scale of danger extending from little or no danger to highly dangerous.

Results

As may be seen in Table 1, the differences in scale values obtained with the rating procedure were comparable to those found with the ranking task. The data in Table 1 represent the combination of data from all subjects. Correlations between results for males and females and between results obtained at different colleges were again at the level of .88 or greater indicating generality of the results. In addition, the correlation between the ratings and the rankings was −.88. This correlation was negative because a low rank indicated high level of risk perception.

It might be noted that while the stated hazards for the substances in different groups varied in seriousness, the ratings within groups tended to be similar across groups. One possible explanation for this result is that the subjects anchored their judgments on the set having the particular characteristic. Another possibility is that despite the hazard description presented with each set, the prior knowledge (right or wrong) of the subjects has a strong effect in determining their risk perceptions.

GENERAL DISCUSSION

The results of these experiments have implications for both theoretical and practical notions about the use of warnings in the workplace and in the marketplace. Further, they raise some questions about the information processing that may be performed with information about hazards.

Although top-down processing of warnings is desirable from many standpoints, our data suggest that it may not occur with a substantial percentage of the population. Generalization to the population at large from our sample is somewhat tenuous, because of its higher educational level, but it is not unreasonable to assume that college students would be at least as capable of processing information as those with less education. Indeed, the knowledge needed for top-down processing might be obtained through the educational process. Although the majority of our subjects were in the 18 to 25 year age group, the comparison with those in the older age group showed no substantial difference in the pattern of responding despite the one case of the oven cleaner. Further, we must recognize that many of the entry level workers who may be directly exposed to hazardous materials would be in the 18 to 25 year age group.

Models of information processing have typically included some description of how information is stored. Both network models (e.g., Collins and Loftus, 1975) and feature models (Rips, Shoben, and Smith, 1973) use location analogies in which items having similarity or relationships are in close proximity with one another. The propositional model suggested by Anderson (e.g. Anderson, 1990) involves semantic connections based on relational statements. In all of these cases the presumption is that information about two concepts may be encoded together or may be extracted from the memory through a chain of concepts related to one another. Ideally a top-down approach to understanding the warning that a substance was flammable would first include the relation “product <---> flammable” which could trigger the relation “flammable <---> spark ignites at 100°F” and result in the relation “product <---> ignited by spark at 100°F.” The assessment of the danger associated with the product would be based on the resultant relation.

The data from our experiments indicate that connections between the concepts of the characterisitcs of hazards and the substances that provide instances of them are at best limited. That is, given the assumptions of the preceding paragraph, a link between a hazard term and any substance might be expected to produce similar levels of risk perception for all substances. From the experimental procedures used it might have been possible to form such links in a simple cognitive equation, but the data do not indicate that happened.

One factor involved in the failure to indicate similarly high risk perceptions for products involving the same hazard is that the subjects were likely unaware of the relative uniformity of the meaning of a term across substances. Thus, the terms might be linked but the danger associated with the hazard is not tied to the generalized concept but to an individual’s perceptions about the specific product. This view is supported by the inability of many subjects to describe adequately the meanings of several hazard identifiers (Leonard, et al., 1991). A question raised by this explanation is how different perceptions of danger become attached to the substances. It seems probable that these differences arise from differential experiences (real or vicarious) with the substances. Although most individuals may never directly experience them, often when gasoline fires occur they are documented graphically by the media. However, we seldom hear of someone's hair burning up because of lighting a cigarette while spraying the hair, unless that individual is known by us personally. Apparently the simple joint presentation of the different substances with the hazard is not sufficient to induce the notion that all have the same characteristics. The literature on memorial structure does support the notion that frequency of joint occurrence facilitates the retrievabilty of one concept from another (e.g. Conrad, 1972).

One other explanation for failure of associating the substance with the potential result indicated by the hazard is that the names given for the products were generic and some subjects may have had experience with instances of that sort of product that did not have the hazardous quality. Thus, experience might have contradicted the stated hazard. This explanation does not seem very likely in view of the fact that substantial differences were found among several products in each hazard category. Most cases that we found of the products selected warned against the hazard of the category in which they were listed.

There is a modest amount of evidence for the experiential factor in the development of understanding of hazard qualities in the finding that older subjects ranked oven cleaners higher than younger ones did. More substantial evidence could be obtained by providing demonstrations of the particular characteristics associated with the hazard designation for the separate products and comparing ratings of those who witnessed the demonstrations with those who did not. Another means of achieving the top-down analysis by users of products would be to give specific instructions about the generality of the meanings of the hazard terms. If an individual had explicit knowledge about the meanings of the hazard terms, it might be possible to transfer that characteristic to any substance involving that hazard.

From a practical standpoint the results of these experiments indicate that without some changes in the topics covered in our educational system we cannot expect a top-down approach to be effective in presenting warnings. it is possible that over time some individuals who are exposed to many substances labeled flammable, combustible, and so forth could develop the generalizations that would allow them to use a top-down procedure for assessing hazards. Unfortunately, the number of events necessary to develop such generalizations might include some in which injuries or property damage or both could occur. Thus, it seems imperative that warnings continue to provide some explicit descriptions of the consequences of their hazards and the steps to be taken to avoid those hazards. Obviously, within an industrial organization it will be useful to include training that will facilitate top-down appraisal of hazards by the employees, but it should be recognized that individuals outside of an organization may also be exposed to substances produced or used within an industry. Because these individuals are likely not to have the knowledge prevalent within the industry, they must be fully warned. This means the warnings should include statements of consequences. Unfortunately, these are lacking on some standardized warning materials. Therefore, it is necessary to add them to the hazardous objects.

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Stress Management Based on the Catastrophe Model for Creative Processes

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The purpose of this paper is to illustrate the relationship between human stress and creativity. Both are vital ingredients of modern contemporary society. They affect our health, social and economic wellbeing and determine, to a large extent, our standard of living. This paper extends and modifies King's catastrophe model for creative processes and provides a new model for understanding and managing occupational stress. For this purpose, first, stress-strain concept is presented and it is clarified that the catastrophe model for creative processes considering psychological stress becomes the theoretical basis for stress management in the creative activity.

INTRODUCTION

Working form for labor who work in computerized manufacturing system changes from the manual work in the conventional factory in which the waist or hand-arm is used to the brain work in which the five senses or brain. Thus, as automation of production system progress, workers have been needed creativity namely ability of human. As the change of working form progress, the problem of human stress has been discussed (Salvendy and Sharit, 1982, Brod, 1984). Stress at work, especially psychological stress becomes important problem. So, the relation between creativity and psychological stress has been attracted considerable attention.

If psychological stress exceeds the limit, it brings to maladjustment conditions, but optimal stress is desirable. Also, stress is what worker cannot avoid. Therefore, it is important how to manage the stress. For this purpose, it is important to grasp how workers are changed by the environment surrounding him, that is, the relation between stressor, stress and strain. So, in this paper, by means of the model (Kume at al.) for creative processes constrained based on the catastrophe model for creative processes proposed by R.G.King (1986), the relationship between stressor, stress and strain in the creative processes is considered and the methodology for stress management is presented.

STRESS—STRAIN CONCEPT IN HUMAN STRESS PROBLEM

The relationship between stressor, stress and strain is described by many researchers. But these definitions are various ones. The theory of stress-strain concept indicates that strain cannot be determined wholly by a consideration of the specific work load (Rohmert, 1987). Now, comparing human stress with stress in mechanics, its relation may be shown as Fig. 1. First, the relationship between stressor and stress is discussed. Humanbody is subjected to various stimuli, namely stressors. By these stressor equivalent to external force in mechanics, various stresses occur. For example, these stresses are physiological stress, psychological stress, etc. Therefore, the strength of physiological stress or psychological stress depends on the intensity of each stimulus, that is, stressor. At

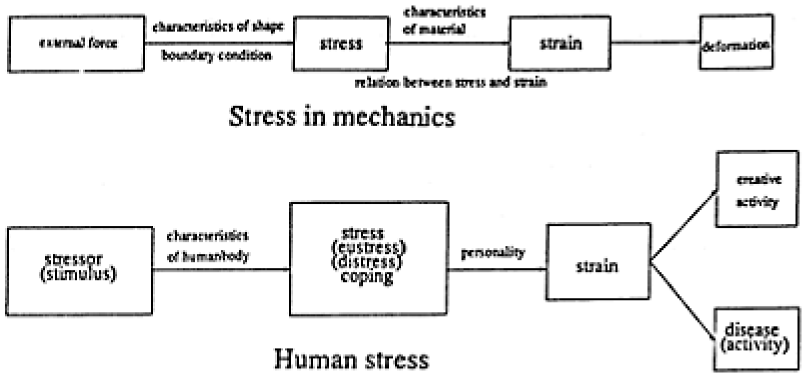

Fig.1 Comparison of human stress to stress in mechanics

any situation of stimuli, various aspects can be thought. The strength of the stress for these aspects depends on characteristics of human body, namely physiological characteristics, anatomical characteristics, etc. This is a specific subjective behavior of person. The effects of stress cannot only be found objectively and on a bottleneck basis, that is, from physical and biochemical data or from personal experience, but also, they must include data of performances and efforts. Stress is found in a performance—specific work analysis to be merely relevant to working objects and situations.

The combined stresses are classified along ergonomically defined kinds of stresses, which actively coped with or passively put up with, depending on the specific subjective behavior of the working person. The active case involves activities directed toward the efficiency of the working system, whereas the passive case induces reactions (voluntary or involuntary reactions) that are mainly concerned with minimizing stress. Relationship between stress and stimulus (stressor) is shown in Fig. 2. Also, the relation between stress and activity is decisively influenced by individual characteristics and needs of the working person. The main factors of influence are those determining performance from the field of

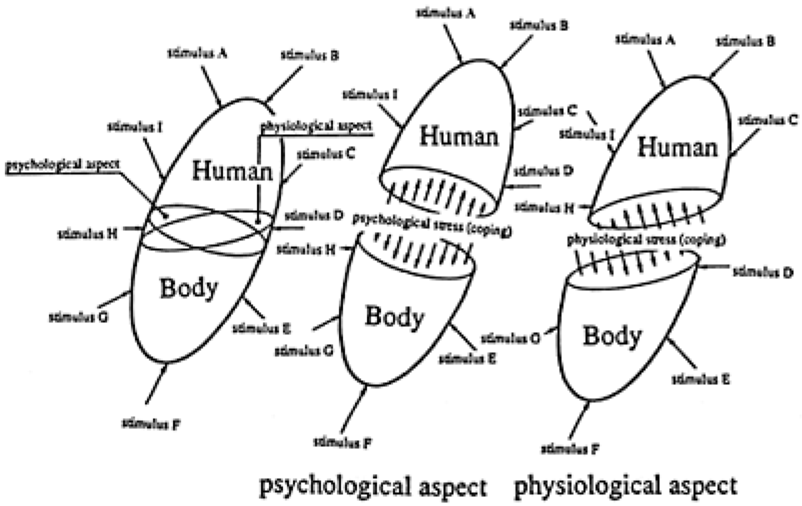

Fig. 2 Relationship between stress and stimulus (stressor)

motivation and concentration, and those from the field of disposition, which are mostly referred to as abilities and skills. In addition, if the stress exceed the limit, worker's healthy disorder occurs (Rohmert, 1987). Also, the relationship between stress and strain in mechanics is important. This relationship is determined by characteristics of material. In the problem of human stress, the relation between stress and strain depends on personality as shown in Fig. 1 The personality consists of individual characteristics and intelligence. Therefore, strain depends on the individual characteristics, abilities, skills and needs of the working person. On the basis of the stress—strain relation mechanics, the relationship between stress and strain in human stress problem can be shown as Fig. 3. In addition, strain is transformed to activities. The activities are classified into creative activity and disease. Thus, the stress generating creative activity is eustress and the stress resulting disease is distress from Fig. 1.

As mentioned above, in the stress, human is just like material about various factors. So, they can be summarized as Table 1 which is important in human stress problem and in creative activity.

CATASTROPHE MODEL FOR CREATIVE PROCESS
CONSIDERING PSYCHOLOGICAL STRESS

In King's model, control factors are divergent thinking and convergent thinking, and state variable is creativity. In other words, the information for creative activity is collected by divergent thinking and unified a logic system by convergent thinking. Consequently, the creativity becomes catastrophic jumping phenomenon. For this purpose, conventional logic system is dissolved and the information which are the materials for building a new logic system are collected. This information cannot be unified by the conventional logic system. It seems that the condition of complication which result in operating divergent thinking is the condition of psychological stress. And the information which cannot be unified by the conventional logic system is unified to a new logic system by operating the convergence thinking. This is equivalent to the operation of coping function by which a

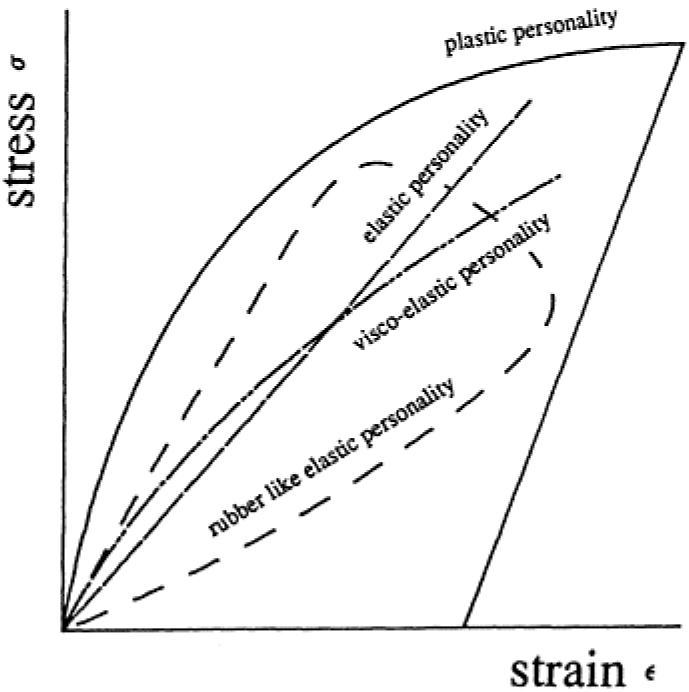

Fig. 3 Relationship between stress and strain in human stress problem

Table 1 Comparison of Material to Human being

factor	solid material	human being
external factor	external force	stimulus (stressor)

internal resistance correspond to external factor	stress	stress
external factor strain generated by	strain	strain
heat cycle	f fatigue by heat cycle	(disease by air-conditioning)
factor cyclic external	metal fatigue	fatigue for pressure and depression
application of constant external factor for longitude	creep deformation with time	creative activity or disease
constraint of external factor for longitude	relaxation stress decrease with time	adaptation stress decrease with time controlling environmental conditions
characteristic strength	strength	limit of homeostasis
elasticity	elastic deformation	homeostasis
plasticity	plastic deformation	plasticity of cerebrum memorizing, learning, self-organization

new logic system is formed in the view point of coping for psychological stressor. In the new logical system, one does not cling to conventional logic system by means of the strain of activity due to defense function, namely suppression or illogical thinking, but the information under the condition of complications can be unified and comprehend by the logic system. From consideration mentioned above, in our previous paper (Kume at al.), a catastrophe model for creative processes considering psychological stress shown in Fig. 4 in which control factors are psychological stressor and coping was proposed. In order to have generality in this model, state variable is creativity of self—actualization in the basis of creativity. As a result, the level of creativity may be estimated by psychological stressor and coping in the new model propose on our previous paper, and the effect of psychological stress on creativity becomes clear. Therefore, King's model may be used as the management of the information which diverges and converges in creative activity and the new model as the management of human factors in creativity.

STRESS MANAGEMENT BASED ON THE CATAS TROPHE MODEL FOR CREATIVE PROCESS

The worker who is engaged in creative activity at work performs creative operation under leading his superior and associating group. Therefore, it seems that stress condition of worker depends on his superior or leader of group. Thus, the PM theory for leader ship can be aided to stress management in creative activity and its validity is investigated. Also, an experiment for the relation of the effect of posture and leadership is performed by Fujita (1984). In this experiment, four types, namely P, M, PM and Pm of superintendent activity are introduced. This experiment was performed by the subject under a manager in these specific types. The type of superintendent activity was confirmed by the test of questionnaire after experiment. The subject who judges manager for PM type, that is, the subject who experiments under PM type manager is called PM type and the subject who experiments under the other type manager is called similarly (namely, the subject is divided into four groups; P, M, PM and pm type). Besides, in this experiment, the degree of internal insecure of subject is measured, and the groups of four types subjects are divided into two groups. Standing the group of high insecure for suffix H and the group of low insecure

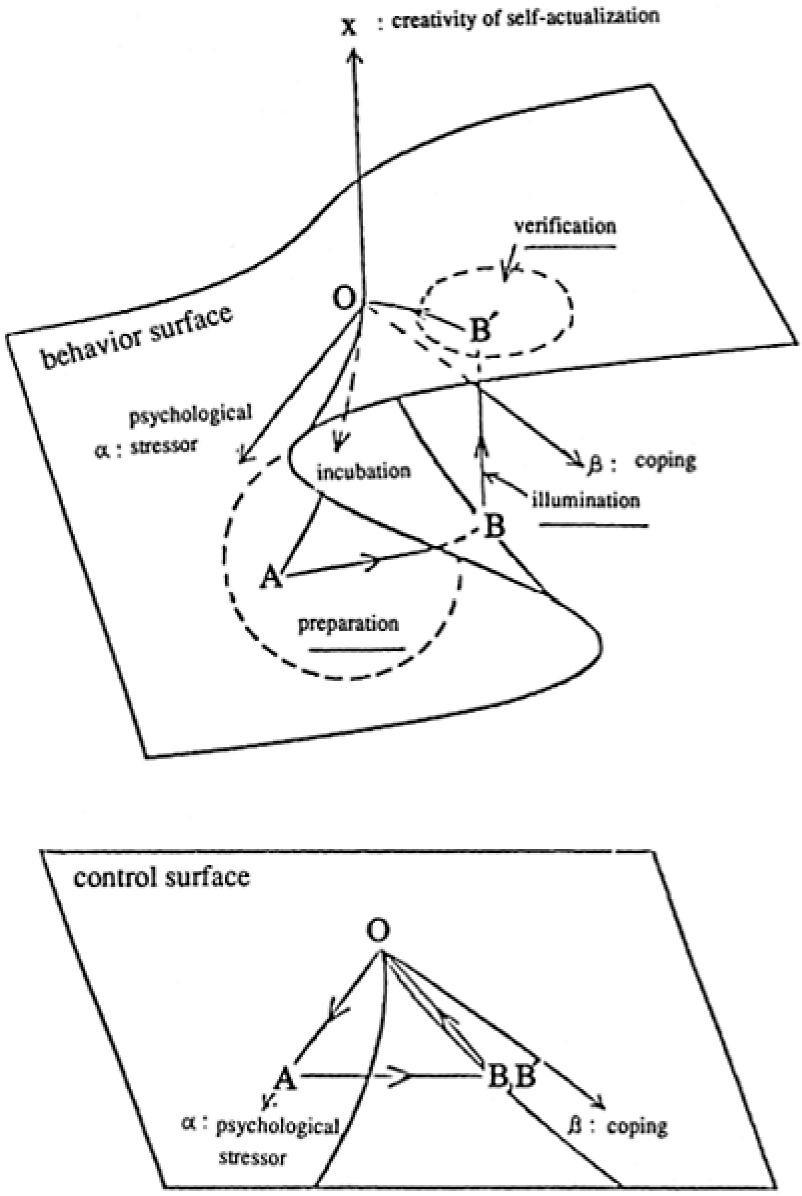

Fig. 4 Cusp catastrophe model for creative processes considering psychological stress

suffix L, subjects are divided into eight groups as follows.

P_H: the group of subjects with high insecure which experiments under the manager of P type (the type attaching importance to group performance function for problem).

P_L: the group of subjects with low insecure which carried out experiment under P type manager.

M_H: the group of subjects with high insecure which carried out experiment under manager of M type (the type attaching importance to group maintenance function).

M_L: the group of subjects with low insecure which carried out experiment under M type manager.

PM_H: the group of subjects with high insecure which carried out experiment under manager of PM type (the type with P and M type).

PM_L: the group of subjects with low insecure which carried out experiment under manager of PM type.

pm_H: the group of subjects with high insecure which carried out experiment under manager of pm type (the type with weak P and M functions).

pm_L: the group of subjects with low insecure which carried out experiment under manager of pm type.

On the whole, it shows that P type has a higher effect of posture than PM and M types. In the group of subjects with low insecurity, P type has higher effect of posture than pm type. Also, the significant difference between M and pm type is not discriminated in the effect of posture.

In the groups of subjects with low insecurity, the significant difference between P and pm type was not discriminated in the effect of posture. In addition, the significant difference between PM and M type was not discriminated, and M type showed a lower effect of posture than the P type. From the result mentioned above, the low effect of posture, namely the high possibility of creative thinking becomes as follows; in the group of low insecure:

$PM_L > pm_1$, $M_L > P_L$,

in the group of high insecure:

PM_H, $M_H > P_H$, pm_H.

Now, still more, internal strain of subject is grown by P type leadership. However, in the degree of strain roused for subject, there is optimal quantity. In the group of high insecurity, the significant difference between pm type and P type is not discriminated. When immanent or external high level strain is in subject, M type leadership decreases the effect of posture. As a result, followings may be assumed;

1. Psychological strain is generated by P function.
2. Coping function is performed by M function.
3. The subject with high insecure recognizes experimental conditions in itself to stress condition.

The result drawing each group of subjects on the control surface in the model proposed by us is shown in Fig. 5. The groups of PM_H and PM_L with the lowest effect of posture seems to be in bifurcation set, and the model mentioned above is consistent with each group of subjects.

From discussion mentioned above, PM theory can be aided to stress management in the creative activity and the training of leadership can be based on the theory for the model proposed in this paper.

CONCLUSIONS

In this paper, it is clarified that the catastrophe model for creative processes considering psychological stress becomes the theoretical basis for stress management in the creative activity. The summary of results is as follows:

1. The relationship between stress and activity is influenced by the individual characteristics and needs of the working person.

2. The operation of the coping function by which a new logic system is formed in the view point of coping for psychological stressor is generated. In the new logic system, one does

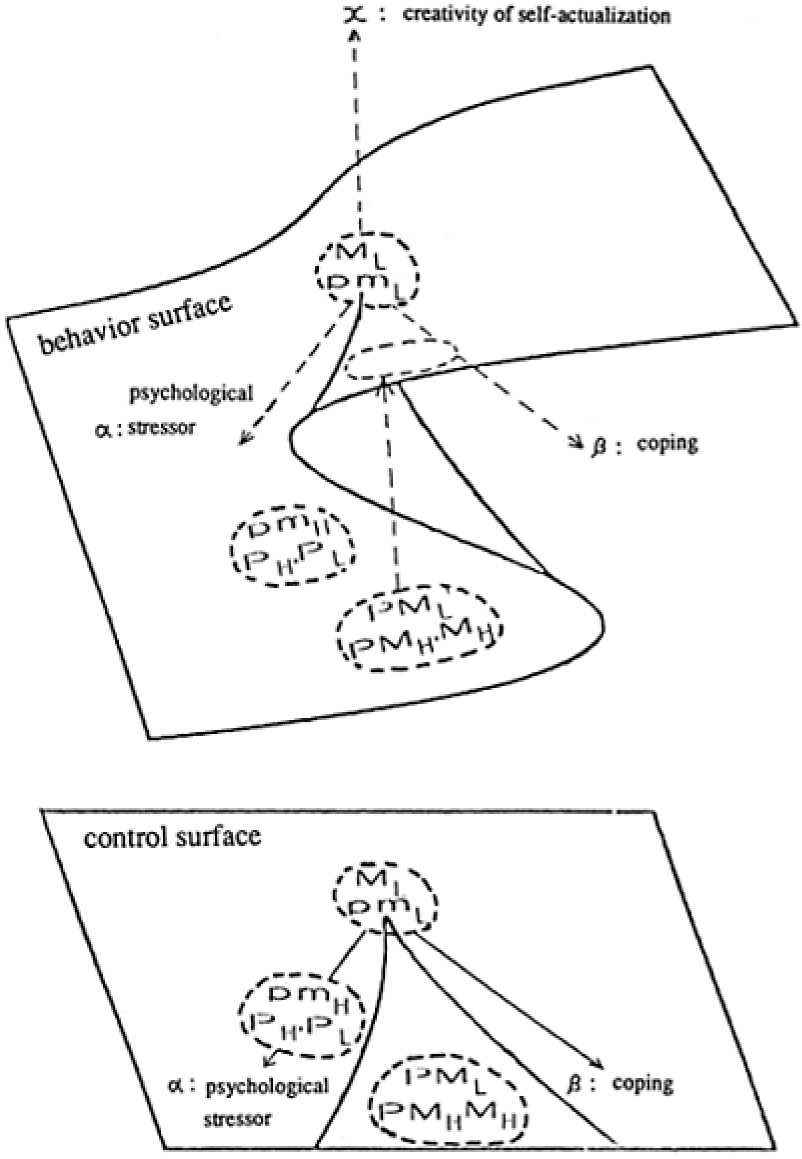

Fig. 5 The result of Fujita's experimental results on the proposed model

not cling to the conventional logic system by means of the strain of actuality due to defense function, namely suppression or illogical thinking, but the information under the condition of complications can be unified and comprehended by a logic system.

3. The validity of the proposed model was investigated by Fujita's experiment. Also, the PM theory can be applied to stress management in the creative activity and the training of leadership can be based on the theory for the proposed model

4. King's model may be used as the management of the information which diverges and converges in creative activity and the new model as management of human factors in creative activity.

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MLSD: A MEDICAL LOGGING AND INJURY SURVEILLANCE DATABASE SYSTEM

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A Medical Logging and Surveillance Database was created to simplify OSHA recordkeeping requirements, and to allow flexible analysis of safety and health records by a broad range of users. The system can log daily injuries and illnesses, create required reports, and can compute periodic statistical analyses to better characterize and predict injuries. The package interface makes extensive use of menus and dialogue boxes, and does not require extensive statistics knowledge by the user. The program has been in place at a local poultry processing plant for one year, and has been extremely well-received.

INTRODUCTION

OSHA Violations and Record Keeping

The U.S. Occupational Safety and Health Administration (OSHA) requires employers to maintain records of occupational injuries and illnesses, with stiff penalties for failure to maintain, falsification, or inadequacies in these records. Companies incur high labor costs for maintaining the escalating number of injury/illness records, which are usually overseen by medical management departments. Personnel involved with record-keeping include those from nursing/ medical, safety, personnel records, worker's compensation, and other management staff. Some provide routine day-to-day record-keeping, others may send or post periodic reports, while others may conduct annual workplace safety evaluations. An integrated, easy-to-use record-keeping system is required to satisfy all of these parties, with their varying needs.

Employers now receive OSHA citations in difficult to manage areas such as close medical management of Cumulative Trauma Disorders (CTDs), timely return-to-work, and appropriate placement of medically restricted workers using functional job descriptions. Accurate record keeping is also dependent on final injury diagnoses, which can take several months for CTDs. Of specific assistance to ergonomics efforts are a good job record from each worker, detailed medical diagnoses which can be related back to job design, and statistics for surveillance in the workplace.

Occupational Safety and Health Records

Occupational safety and health records provide an important source of information for medical/safety/management staff in industry, and government policy makers/enforcers. Maintenance of these records can: (1) provide baseline health status of workers, (2) meet requirements of OSHA and workman's compensation regulations, (3) protect the employer, physician, nurse, and employee in litigation, (4) aid supervisory and peer audits for quality assurance, and (5) accumulate statistical data for epidemiological research (Ossler and Lister, 1988).

Companies must maintain OSHA logs, as well as other records. OSHA Form 200, Log and Summary of Occupational Injury and Illness, classifies occupational injuries/illnesses with their outcome, and OSHA Form 101 contains more detailed information for each of these cases (DOL, 1986). Both must be completed within 6 working days of the time the employer learns of the work related injury/illness, and must be kept for the duration of employment plus an additional 30 years. The employer must provide access to an employee's own records, as well as to analyses derived from these records (DOL, 1988). In addition to OSHA logging and reporting requirements, companies maintain health records of individual and family demographic data, health history, occupational history, medications, emergency contact information, prior workman's compensation claims, health problems and their management, and health progress (Ossler and Lister, 1988).

Computerized Record Keeping

Medical management, an important component of industrial ergonomic programs, can greatly benefit from computer packages to aid with timely recording and analysis of occupational illness and injury. Recently reported software includes Risk Control Plus™ (Control Software Group, Inc., Columbus, OH), Safety Trax™ (Safety Management Systems), Accusafe™ (National Safety Council, Chicago, IL), and Gupta and Genaidy (1990). All have menu driven interfaces with shortcut keys, and can print OSHA 200 logs and supervisor accident reports. Some have password protection, automatic case numbering, data backup, online help, and maintenance of other personnel records.

The analysis and report generation capability of these packages vary. Some can print OSHA From 101, employee case history details, drug testing results, and lost/restricted workday summaries. The packages also have varying injury and cost analysis capabilities, including multiple criteria search for injury types, plots by time, day, or month, incidence rate computation, and billing information. The existing packages cannot plot time series graphs, perform department scheduling, compute regressions, or forecast future cyclic events.

MLSD INTERFACE

This paper details the capabilities of new computerized database package for medical logging and surveillance in industry. The Medical Logging and Surveillance Database (MSLD) is in extensive use at a poultry processing company. It was iteratively developed and evaluated in this environment to ensure the greatest possible usability.

System Requirements

MLSD currently requires an Apple Macintosh computer with 4–8 MByte of RAM, a 19-in. monitor, extended keyboard, mouse, floppy drive, and hard drive. High density data backup capability and a laser printer are recommended. Unless using a compiled version, 4th Dimension™ database software (Acius Software, Cupertino, CA) is necessary.

Menu System Overview

All screens use an Apple Macintosh style of menus, mouseclicking, scrolling, and form fill-in to enhance flexibility of use by a broad range of users. The program simplifies work methods by using common, relational databases for employee/job information, billing information, and employee case records. On-line, context sensitive help is always available. Password-controlled access levels for users and automatic backup to a tape drive ensure data security. The system was designed for easy, safe exploration by untrained users. More advanced users have keystroke item abbreviations for added speed. In all screens, employee/case database information is pre-entered, so little typing is required.

Several open menus are displayed in Figure 1, and further described below. The File menu contains access to the on-line help facility, plus additional program and password setup utilities. Via hierarchical password protection, user read/write access to personal records is carefully controlled. The Employees and Departments menus allow addition and deletion of employees/departments/jobs, as well as Department scheduling for modifying base exposure hours.

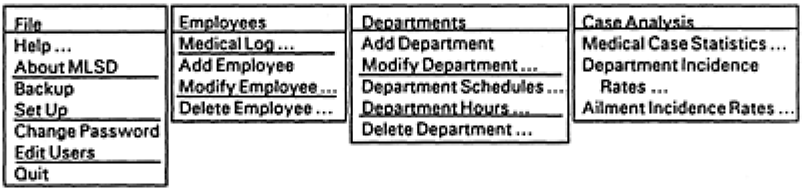

Figure 1. File, Employee, Department, and Case Analysis Menus

The Case Analysis menu allows more extensive statistical regression, forecasting, and incidence rate modeling and plotting of cases. Independent and dependent variables are chosen by mouse pointing and clicking. Possible independent factors include gender, recordable vs. non-recordable OSHA cases, active vs. terminated employees, injuries vs. illnesses, active vs. inactive cases, day of week, month of year, year, time of day, department, type of injury, and affected body part.

The Reports menu (Figure 2) allows easy generation of OSHA 200 and 101 logs, and provides other company-specific reports. The OSHA 200 only prints cases over a specified time interval, and the OSHA 101 prints for specified cases. All employee logs initially call up a scrolling list of employees, and

Reports
OSHA 101…
OSHA 200…
Employee Information…
Employee Medical Log…
Employee Case Progress Note…
Employee Case Ref erral…
Employee Case Bills…
Acti ve Case Log…
Supervisor Report of Cases…
Department Schedules…
Department Hours…
Voucher Log…
Outstanding Bills…
Sup. Accident Invest. Rpt….

Figure 2. Reports Menu from MLSD.

choices are made by mouse click. The Active Case Log provides information on open cases. The Supervisors case report and Accident Investigation report prints cases within a department, and provides follow-up accident investigation forms. Department Schedules prints those days deviating from the default department schedule, and Department Hours prints the number of hours worked by Department. The Voucher Log report prints current information on prescription drug vouchers, while Outstanding Bills prints a summary of still outstanding insurance claims.

MLSD FEATURES

Employee Medical Logs

The Medical Log is the most frequently accessed screen for routine day-to-day operations. After selecting an employee from a scrolling list, a medical log with prior case history appears. A new case number is automomtically assigned when requested, and scrolling lists appear for entering injury/illness, affected body part, company location, and job when injured (see Figure 3 for an example list). Entries are easily added and deleted from these lists, ensuring error-free spelling and searching. To facilitate rapid entry, the list of jobs is drawn only from those jobs currently assigned to the employee in a case. A discharge date on the log is required to consider a case closed. Entering 'N' (non-recordable) under a case ensures that OSHA reports will not contain that case. Text messages, entered and linked to a case, are also reported on the OSHA 200 log. Direct transfer to employee Progress Note, Referral, or Bills screens are also made from the employee log. These screens provide additional case information, lab tests, prescriptions, and bills or payments received.

Employee Medical History Form

Adding or modifying an employee in the Employees menu leads to a five-screen medical/personal history form. Scrolling lists are used for many inputs, such as allergies, city, and medical problems. Again, through mouse clicks, menus, and lists, entering information is fast and well controlled, and spelling and other common database problems are eliminated.

MLSD Case Analysis

The unique and powerful Case Analysis menu allows extensive description, modeling, and forecasting of injury/illness statistics. These allow extensive research into the nature and cause of injuries and illnesses, and are epidemiological tools for solving recurrent or cyclical injury trends. Selecting Medical Case Statistics displays a statistical criteria screen, which limits subsequent statistical analyses to an intersection of independent variables via mouse clicking and scrolling (Figure 4). Through an overlaid dialogue box, the type of statistical analysis is chosen. Choosing Descriptive

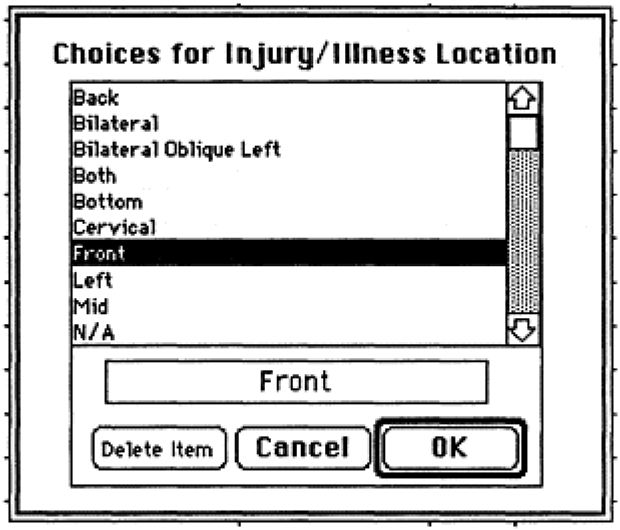

Figure 3. Example Scrollable List for Location of Injury/Illness on Body.

Statistics will print number and average number of cases, lost workdays, restricted workdays, OSHA recordable, nonrecordable, and uncategorized cases for both injuries and illnesses. Choosing Statistics by Type of Injury/Illness prints a listing of all ailments in the database, showing numbers, percentage of cases, lost days, restricted days, and percentages for these days. Averages are also printed by ailment for time between incidents, length of employment of affected workers, ages, years on job, and hours on shift. These listings provide an important epidemiological starting point for more detailed analyses. A list of those cases matching the selected criteria can also be printed.

Regression or forecasting analyses are selected with mouse clicks within dialogue boxes. A dependent variable is chosen by clicking either Number of Cases, Lost Workdays, or Restricted Workdays. For regression, independent variables and desired 2-factor interactions are chosen from Time of Day, Day of Week, Month, Year, Recordable vs. Non-recordable Cases, Department, Affected Body Location, Type of Injury/Illness, Sex, Age, and Length of Employment (Figure 5). The regression model is then displayed and/or printed, including term and model significance, ANOVA, and sequential sums of squares. Forecasting, programmed from code presented by Seitz (1984), starts by clicking a dependent variable as above, then selecting parameters from a dialogue box. These include Time Period, Number of Periods per Cycle, and desired Number of Periods. Default location, trend, and cycles are can be modified; MLSD computes model standard error for all combinations of weights and selects the lowest standard error set of parameters. The output includes a bar chart showing present and forecast data over the specified time interval.

The Case Analysis menu also contains extensive plotting and incidence rate computations utilities. The analysis selection screen allows pie, bar, line, or scatter plots of Number of Cases, Lost Workdays, and Restricted Workdays by Time, Day, Month, or

Day of Month, depending on desired information. Incidence rates can be computed for numbers of Recordable Cases, Lost Workdays, Lost Workday Cases, Restricted Workdays, and Restricted Workday Cases by mouse clicks. Exposure hours are extracted from department schedules, and base hours may be defined (a default 200,000 manhour base is standard). These may be tallied by department, or by type of injury/illness,

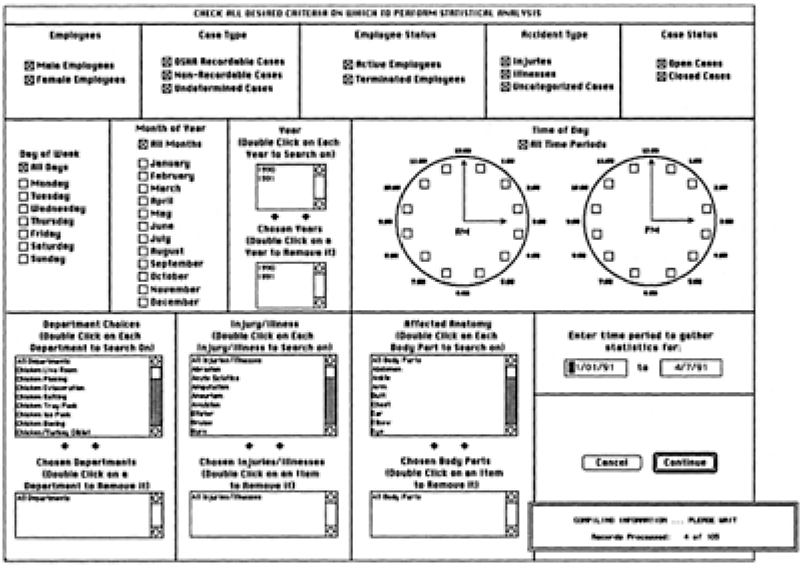

Figure 4. Statistical Criteria Screen for Limiting Subsequent Analyses.

and allow comparison with other industries or facilities.

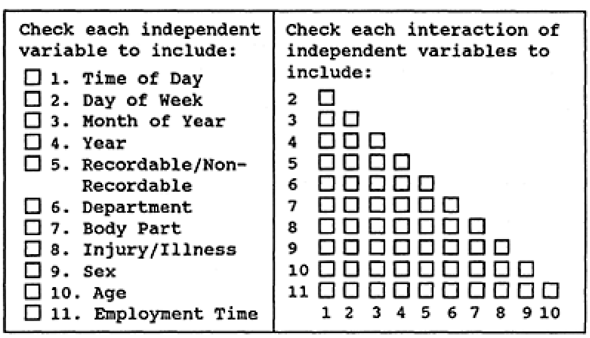

Figure 5. Regression Independent Variable Selection Screen

Consistency in Medical Records

Accurate record keeping is difficult if diagnoses change or are slow to evolve, as with CTDs. Several features of MLSD prevent inconsistencies of medical records. Cases are recorded as open or closed so accuracy can be checked before the case is closed. A “Don’t Know” category can assist with tracking unclear cases. Case notes allow for important annotation to cases which can print on the OSHA 200 logs, such as date of termination of employment. Diagnosis, affected anatomy and location on the body are separate fields, ensuring that no details are neglected. This is important for determining trends of physical stress from poor design—traditionally, logs are poorly completed, with no indication of side of the body or insufficient specifics on the affected body part. Accuracy of restricted and lost work days is also required. Lost work days are often viewed as a measure of severity and certainly are costly to the company. Department scheduling in MLSD permits entering workdays so department hours, restricted, and lost workdays are accurately counted.

SYSTEM USABILITY

MLSD provides a local, highly usable system to accomplish the extensive tracking and accuracy required to address time consuming medical management issues. Close medical management entails documentation to show protocols are being followed, such as follow-up every two days for CTDs. Open cases are easily tracked, with medical progress notes.

Usability is enhanced by maintaining personnel records in the database. When an injury occurs, little information has to be retyped to generate a case. Advance work scheduling by department allows accurate computation of exposure hours for incidence rates, which may be further modified for individual employees. Unique to MLSD, computation and plotting of incidence rates, regression, and forecasts are useful for describing and predicting trends in injuries. Seasonal, daily, and monthly trends can be discovered through these forecasting models.

Physician referral is rapid, as pertinent patient information is automatically transferred to a referral form. An important feature of the form is the work status and the anticipated date for change of status. The physician immediately sees the work status history for the case and is requested to update the information. Such good, clear communication expedites return-to-work and ensures close follow-up of cases which may otherwise be overlooked. Most importantly, such a system helps move patients through restricted or modified jobs back to their previous jobs so that modified jobs are not inappropriately used. Anticipation of length of disabilities or restrictions also assists management planning.

Jobs are entered with ease by selecting the appropriate job number and title from the system’s list. The job list is easily modified, on-line, as jobs or systems change. An extensive job and hobby history gives clear indication of risk exposure, which can be combined with the extensive medical history section. The next stage of the system development will include functional descriptions of the jobs. The data base could be used to help medical personnel select the range of jobs which could be done by an employee with certain functional limitations.

Summary printouts of medical cases by supervisors or departments are useful for management to help with staffing and anticipation of specific placements. They also provide descriptive feedback of problem areas—statistics help in quantification and prioritization of these.

FUTURE DEVELOPMENT

Future modifications and additions are planned. The package will be modified to run on smaller, 9-inch screens. Several systems will be networked for more efficient simultaneous use by personnel. A database of job characteristics will be added, allowing analyses of incidence rates by such characteristics as lifting or repetitive motions. Improved cost analysis modules will allow determinations of cost-benefit for job modification decisions. Continued iteration of development and user testing will ensure maintenance of a high level of usability from a broad range of personnel.

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EFFECTS OF INDIVIDUAL CHARACTERISTICS, CONTEXT AND WARNINGS ON HAZARD AWARENESS AND SAFETY COMPLIANCE

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The objectives of this study were to investigate the effectiveness of posted warnings on noticing, recognizing, and recalling safety messages in a chemistry experiment. The warning messages were directed to the use of protective devices. A total of 134 subjects participated. Prior exposure to a chemistry demonstration had significant effects on both safety intent and compliance. Participants who were exposed only once to a chemistry demonstration benefitted most from the posted warnings. Noticing the posted warnings doubled the safety intent and for all protective devices. Participants who were risk aversive were more likely to read warning messages than those who were risk takers.

INTRODUCTION

The design and effectiveness of warning messages as a safety measure have been studied frequently (Dorris & Purswell, 1977; Gill, 1987; Godfrey, 1983; Horst, 1986; McCarthy, 1982; Wogalter, 1985). Two criterion measures have been frequently used in these studies, the first being a subject's preference for a given warning design, and the second being the subject's response to a warning message in a research setting that attempts to duplicate the actual use condition for the product. In several studies, the research paradigm has been based on the use of some form of chemistry experiment, with the safety measures related to the use of the materials in the experiment and/or the use of protective equipment. This paradigm has been criticized by some researchers as being too situation specific to be useful in extrapolating the results to other types of warnings designs for products. The pupose of this study was to investigate the variables within such a research paradigm for warnings, focusing on individual characteristics, the context of the task and the posted warnings.

METHOD

The goal of this research was to study variables related to warning effectiveness for attending to posted warning signs and complying with their messages. The experiment consisted of two sessions of testing administered at least one week apart. The first session consisted of solving a set of visual pattern matching problems and answering four questionnaires. The purpose of the first session was to document individual characteristics. The second session was a chemistry demonstration that subjects were to perform. The session lasted an average of 30 minutes and specific subject responses to the instructions and warnings were observed.

Subjects

A pool of 134 students taking introductory classes in psychology participated in this experiment. There were 43 male and 91 female subjects, with 53 percent being first year students and the remainder being higher level students.

Equipment and Procedures

The first testing session for subjects gathered information about their personal characteristics. A series of questionnaires was administered to collect the following information:

1. Understanding of the meaning of pictorial warnings, two of which were selected for the second part of the study.
2. Attitudes about risk taking behavior.
3. Ability to solve visual pattern matching problems related to core intelligence.
4. Past exposure to severe injuries.
5. Frequency of exposure to common activities with some injury potential such as driving, swimming, skiing and ladder climbing.

During the second experimental session, subjects were asked to perform a chemistry demonstration. General instructions as shown in Figure 1 were placed at the work station along with a report sheet for results and specific instructions for the mixing of chemicals. Two warnings were posted on the wall immediately facing the work station used for the demonstration for the experimental group. The warnings are shown in reduced format in Figure 2, while the actual warnings were in 8–1/2 by 11 inch format, with black characters on a white background. No warnings were posted for the control group.

The work station had ten containers or vials for measuring and mixing chemical substances, two of which were labelled “Contaminated. Do not use.” A small hammer was provided to crush dry ice into small pieces and filter paper was available for filtering later in the demonstration.

Instructions were provided for the specific demonstration, consisting of 15 steps in three groups. The first part was intended to lead the subject to a violent reaction of dry ice when dropped into a greed liquid, with abundant white fumes produced. The principal hazards which the subject was expected to perceive were frostbite when handling dry ice, splashes of liquid that could get into the eyes and on the skin and fumes that would require the use of a respiratior.

Safety measures to be taken included the use of heavy gloves (to prevent frostbite), rubber gloves (to prevent skin contact with chemicals), goggles (to protect the eyes from fumes and splashes) and a respirator (to protect from breathing fumes). These measures were addressed in the instructions provided and the use of goggles and gloves were also addressed in the warnings for the experimental group.

The second part of the demonstration required subjects to mix acetic acid and bicarbonate of soda. The acid containers were labelled 0.1 M (mole) Acid or 1 M Acid. The violent reaction overflowed the container and required the subjects to clean up the overflow. The subjects were expected to perceive the hazards of skin contact with strong acid, possible splashes of acid in the eyes and perhaps the use of a respirator in when the acetic acid was smelled as it was opened.

Instructions for the Chemistry Demonstration

The task is to make accurate measurements, then combine and mix chemical substances in an environment that is potentially dangerous with poor visibility conditions. Another objective of this task is to evaluate the ability to express verbally your train of thought and how you handle difficulties and indecisions you are faced with. Please raise your voice when explaining what you are doing so that the investigator can hear you.

The preparation of chemical products is a very delicate and precise task. Inaccurate measurements or improper mixing order of substances may result in either (1) hazardous products, or (2) dangerous situations during the preparation process.

This demonstration can be performed without any previous laboratory experience. However, it is important that you treat the materials and substances with care because they are expensive. Read the instructions and operations to the end before starting your demonstration.

Check to make sure that you are provided with a pair of industrial gloves, a package of disposable gloves, two goggles, disposable masks and a roll of paper towels. In front of you are tools and containers of different sizes such as graduated cylinders with labels G, beakers labelled B, Florence volumetric flasks F, plastic bottle L and test tubes. Two solid substances are used: one substance is in the ice chest and the other one in a bottle labelled S. Three liquids are used in bottles labelled L, weak Acid labelled 0.1 M and the strong Acid labelled 1 M.

A divider will be separating you from the investigator. As you perform the demonstration, talk loudly when you have a question or when unclear about an issue and resume your work. Do not attempt to open the divider without prior consent of the investigator. Do not expect the investigator to acknowledge hearing you or to answer your questions, but make your own decisions and proceed with the task. Write down, on the separate result sheet provided, the reasons for taking a course of action. The investigator will intervene if your consultation requires immediate attention. Speak aloud when the following events occur:

1) you smell an odor that did not exist when you first stepped into the room,
2) you burn your skin,
3) you splash chemicals on yourself, or
4) you break any material.

Make sure to abide by the recommendations as follows:

1. Immediately wipe up chemicals everywhere they have spilled/splashed with paper towels.
2. Never return the used tools to their original place. Instead, rest the used tools on the left side of the table on pans or plastic trays.
3. Use only the products and tools that have labels on them.
4. Do not rest containers or tools on instruction sheet or table blanket. Work over pans or plastic trays.

Figure 1. General instructions presented to subjects at the beginning of the chemistry experiment.

Figure 2. Reduced versions of warnings presented during the experiment. Actual size was 8–1/2 by 11 inches.

All of the required safety equipment was present at the work station in plain view of the subjects and consisted of heavy gloves, rubber golves, goggles and a clean respirator.

A concealed video camera was mounted in the ceiling of the area with the work station and all sessions were videotaped for subsequent review. Subjects were also interviewed after completing the chemistry demonstration. The subjects were placed at the work station by the experimenter, told to read the instructions, and the experimenter then closed a flexible partition to separate himself from the subject.

Experimental Design

The data were analyzed using the Statistical Analysis System (SAS) frequency procedure to obtain two-way and three-way contingency tables of frequencies. The null hypotheses for these tables tested the equality of the true response probabilities for the populations examined. Chi-square statistics provided p-values for differences between populations.

Multivariate discriminant analysis was selected to obtain an understanding of the structure of the data on noticing posted warnings, reading and recalling and recognizing the messages as well as using the personal safety devices at the start and during the chemistry demonstration. The predictor variables were either quantitative or rank-ordered by assigning numerical values for qualitative variables such as gender, etc.

Results

One out of every four participants did not notice the warnings that were prominently posted in front of them. Less than half of the subjects claimed to have read at least one of the two messages and one out of four only partially recalled at least one of the messages. Participants who noticed the posted warnings were twice as likely to completely recognize the messages of both warnings as compared to those who did not notice them (i.e., 11.6% for the control group versus 28% for the experimental group who noticed the posted warnings). Neither personal characteristics, familiarity with chemistry demonstrations, perceived hazard and perceived difficulty of the chemistry experiment nor recognition of the messages discriminated well between those who did or did not notice the posted warnings (i.e., 95% of the participants were classified as supposedly noticing the posted warnings). Since the instructions did not mention the wearing of personal safety devices as one of the objectives of the experiment, either the participants just failed to notice or they were more task or performance oriented. Personal characteristics were poor discriminators for predicting whether subjects read the messages but prior exposure to achemistry experiments, perceived hazard and perceived difficulty of the chemistry experiment discriminated for the class Read and Recalled when compared to the classification of participants in the control group (50% versus 38%, respectively). However, safety intent provided a better discrimination for the class Read and Recalled (i.e., 63% versus 23% for the control group). None of the above predictors could discriminate satisfactorily between the classes None or Read Only; participants were classified as not reading the message over 50% of the time. However, the predictor "Recognition of the Messages" improved on the classification of the class Read Only compared to the control group (25% versus 17%, respectively). Personal characteristics were also poor discriminators among classes for "Recognizing the Messages". Noticing the posted warnings improved correct classification among three classes compared to personal characteristics, but the combination of "Posted Warnings" and Safety Intent was a better discriminator over and above the other predictors. The predictor "Posted Warnings was also a better predictor for safety compliance than the personal characteristics, exposure to chemistry demonstrations, perceived hazard and difficulty of the chemistry task.

Tables 1 and 2 give the average safety intent (safety compliance at start and after reading instructions) and safety compliance, respectively, for the four safety devices when the levels of exposure to chemistry demonstrations were collapsed. Posting warnings (experimental group) substantially increased the safety intent for all safety devices compared to the control group, but safety compliance substantially increased only for goggles (from 46% to 84% for the control and experimental groups, respectively).

Table 1. Average safety intent for each safety device (in percent).

Safety Intent	Groups	
Device	Experimental	Control
Disposable Gloves	51	28
Heavy Gloves	40	21
Goggles	69	35

Respirators	19	7

The empirical data generated in this study can be analyzed with respect to the two models of the warning process described by Lehto (1990). If the sequential process model is considered, the data in Table 3 can be generated as an example. The probability of success at each stage can be calculated by multiplying the empirical probability of success at the previous stage by the conditional probability for the next stage. For example, the overall probability of reading a warning (0.45) is the product of first noticing (0.75) and then choosing to read the warning (0.60).

Table 2. Average safety compliance for each safety device (in percent).

Safety Compliance	Groups	
Device	Experimental	Control
Disposable Gloves	71	60
Heavy Gloves	78	77
Goggles	84	46
Respirators	19	14

There are experimental limitations for an acceptable validation of the sequential model. The first limitation is related to the lack of direct observations for noticing the posted warning in this research. It was not possible to verify directly whether a participant had noticed the posted warnings at the beginning, during or at the end of the chemistry experiment. Thus, the effects of the chemistry procedures and those related to the posted warnings on Safety Intent and Safety Compliance could not be separated. The second limitation is related to the dynamics of the interrelationships and recursive process among the stages of the information process. For example, it is possible that a participant had noticed the posted warnings at different points in time with varying degrees of understanding and agreement with the messages. It is also possible that, at times, a participant read a message but failed to store its content in memory: then, later on, the subject assimilated the message when certain steps in the chemistry procedures provided incentives to store and/or recall the message.

Table 3. Probabilities of the sequential information process model.

Sequential Stage	Conditional Probability	Warning Process		
		Notice	Read	Recognize
Notice	–	0.75	–	–
Read	0.60	–	0.45	–
Recognize	0.70	–	–	0.31

The acceptability of the performance model of Lehto (1990) was evaluated by a review of the data for safety compliance for the different groups and different personal protective equipment. Safety compliance with goggles was statistically significant for those participants who were exposed only once to chemistry demonstrations (rule-based or knowledge-based) and those who were never exposed (belief-based). The fact that goggles were statistically significant for those exposed only once to chemistry demonstrations suggests that the posted warnings may have reminded them of the regulations in chemistry demonstrations to wear goggles all the time. The posted warnings of goggles may have also persuaded the participants, who were never exposed to chemistry operations, of the necessity of wearing goggles for safety purposes. Participants in the control and experimental groups of those who were exposed more than once (skill-based) did not differ significantly in their safety compliance for goggles as hypothesized by the performance model.

The other three safety devices (disposable gloves, heavy gloves and respirator were not statistically significant, regardless of frequency of exposure to chemistry demonstrations, suggesting that warnings are most effective when they remind people of previously learned safety practices, but for which there has not been sufficient experience to develop a consistent behavior of either compliance or non-compliance with the warning.

CONCLUSIONS

The following conclusions were derived from the study of the first session of the experiment:

1. Participants who were less familar with an activity perceived it as more hazardous than those who frequently practiced it.
2. Males who were not frequently exposed to a particular activity were less inclined to perceive it as very hazardous compared with their female counterparts.

The following conclusions were derived from the chemistry experiment performed during the second session:

1. Posted warnings doubled the safety intent for all safety devices.
2. Posted warnings doubled the safety compliance for the use of goggles.
3. Participants who read the messages on the posted warnings were more likely to wear safety devices at the start of the experiment than those who did not.
4. Participants who were risk aversive were more likely to read the messages than risk takers.
5. Safety intent is the best predictor of continued compliance with a warning message as the task proceeds.
6. Previous studies of warning effectiveness using the chemistry experiment as the research paradigm should be interpreted with caution unless the previous experience with such an activity is considered.

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A SYMPTOM AND JOB FACTOR SURVEY OF UNIONIZED CONSTRUCTION WORKERS

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A two-part survey was completed by 526 unionized construction workers in eastern Iowa. The survey consisted of a job factors analysis and symptom survey. The low back, neck, wrist/hand, knee, and ankle/foot were the predominant symptomatic areas. Job factors preceived most problematic included prolonged positions, awkward postures, uncomfortable conditions, very hard work and reaching overhead. Examination of relationships between selected symptom areas resulting in missed work and perceived problems with job factors revealed several significant odds ratios.

INTRODUCTION

The workforce in construction is estimated “to be 6,400,000 making it the fifth largest workforce in the country. Construction ranks 3rd highest in death rate, 1st in number of deaths, and 5th in disabling injuries. The national average cost per disabling injury is approximately $23,000. (National Safety Council, 1991)

In 1988 and 1989 the Bureau of Labor Statistics estimates of occupational injury and illness incidence rates by industry division showed the construction industry to be the leading industrial division in the categories of total cases, (14.3 and 14.6 per 100 full time employees (FTE)), lost workday cases, (6.8 per 100 FTE), nonfatal cases without lost workdays, (7.5 and 7.7 per 100 FTE), and lost workdays, (143.3 and 142.0 per 100 FTE). (National Safety Council, 1991)

For the construction industry in 1990, the National Safety Council reported incidence rates (expressed per 100 FTE) as follows: total cases (9.1), lost work cases (3.5), nonfatal cases without lost workdays (5.6), lost workdays (93) and days away from work (77).

The construction industry was second only to either manufacturing or transportation in all of these categories. This data can be further broken down into specific job categories and is available in Accident Facts. (National Safety Council, 1991)

This paper discusses the responses to a job factor and injury symptom survey of persons employed in the construction industry. The construction industry was chosen based upon a joint interest on the part of the university and a joint labor/management construction alliance in determining the types and perceived causes of injuries among construction workers. This interest is driven by the high prevalence of injury in the construction industry and the general lack of knowledge as to the types and causes of these injuries.

The questionnaire used in the study is the first phase of a proposed four part joint project on the reduction of work-related injuries and illnesses through ergonomic intervention.

METHOD

Questionnaires were mailed to the homes of 3,200 union members of the Eastern Iowa Construction Alliance (EICA) representing 15 different building trades. Questionnaires were returned in postage paid envelopes to the EICA office and then forwarded to the University of Iowa for compilation and evaluation. Five hundred and twenty-six union members responded to the two-part questionnaire.

The questionnaire format consisted of a one page symptom survey similar to the Nordic questionnaire and demographic data and a one page job factors survey. The time for questionnaire completion was estimated at approximately 10–15 minutes.

The symptom survey portion of the questionnaire addressed the period prevalence of musculoskeletal problems within the last 12 months, last 7 days and missed work within the last 12 months. Anatomical regions covered in the symptom survey included; neck, upper back, low back, shoulders, elbows, wrists/hands, hips/thighs, knees and ankles/feet.

The job factors portion of the survey addressed issues related to the performance of the job. Each of fifteen job factor descriptions were rated as: not part of the job, part of the job but not a problem, or a problem (described as either mild, moderate or major). The job factors were described as follows;

1. Performing the same task over and over.
2. Working very hard for short periods (lifting, grasping, pulling, etc.).
3. Having to manipulate or grasp small objects.
4. Not enough rest breaks during the work day.
5. Not enough stretching before or during work.
6. Having to work in the same position for long periods (standing, bent over, etc.).
7. Bending or twisting in an awkward or uncomfortable way (hand, elbow, back).
8. Having to work so fast your muscles start to cramp or get sore.
9. Reaching for something that is over your head or away from your body.
10. Uncomfortable conditions (heat, cold, vibration).
11. Workstation not adjusted to fit you (too high, too low, too small).
12. Workstation not organized for easy use of materials and tools.
13. Work scheduling problems (over-time, irregular shifts, too long of a work day).

14. Tools/machines that are uncomfortable to use (too heavy, poor design).
15. Not enough training on how to do the job.

Surveys were compiled and data analyzed for individual trade unions and for the composite group. Summation, graphic representation and visual inspection of the data were done as the initial phase of data analysis. This was followed up by the calculation of odds ratios from two-by-two contingency tables showing missed work in the last twelve months (yes/no) versus job factors perceived as a problem (yes/no). Fisher's exact test was used to test the significance of the odds ratios (Rosner 1986). Relationships evaluated were selected based upon anatomical considerations.

RESULTS

The survey respondents had a mean age of 41 years 3 months (S.D. 11 years), mean height of 179 cm (S.D. 7 cm), mean weight of 85.5 kg (S.D. 13.7 kg), length of employment of 16 years 9 months (S.D. 10 years 8 months), and mean hours worked/week of 41.4 (S.D. 5.2 hours).

Results of the composite survey analysis include responses from brick layers and tenders (14), carpenters (81), electricians (88), glass glaziers (5), insulators (13), iron workers (19), laborers (41), millwrights (49), painters (19), pipe fitters (52), plumbers (20), retired workers (7), roofers (5), and sheet metal workers (47). The results that follow include individual trade group and composite values.

The twelve-month and seven-day period prevalences identified in the composite symptom survey (Figure 1) included; low back (75%, 26%), neck (41%, 14%), wrist/hand (41%, 16%), knee (40%, 14%), and ankle/foot (28%, 10%). The symptom survey data varied by trade group. The carpenters showed an increase in reported problems over all aspects of the symptom survey while the brick layers and tenders showed an increase in only wrist/hand, neck and shoulder problems. The painters, however, showed a decrease in the prevalence of ankle/foot pain (10.5%, 5.3%) relative to the composite group (29%, 10%).

The most prevalent responses in the composite job factors survey (Figure 2) included concerns regarding prolonged positions (69%), awkward postures (69%), uncomfortable conditions (67%), very hard work (44%) and reaching overhead (43%). Grasping small objects (18%) and insufficient training (17%) were the least frequent responses given as reasons for work related pain. Variations were noted in the job factors survey data among specific trade groups. For example, overhead reaching and repetitive tasks were identified as problems for the electricians (39% and 31% respectively) but were not considered problems by the roofers or glass glaziers (0% for all values).

Odds ratios and associated Fisher's exact test values were determined for several relationships between symptoms causing missed work and selected job factors which the workers reported as being at least a minor problem in their work. Data are presented in Table 1.

Table 1. Odds ratios of relationships between symptom-related missed work and perceived problems with job factors.

Job Factors	Anatomical Regions Associated With Missed Work					
	Neck	Upper Back	Lower Back	Shld	Elbow	Hand/ Wrist
Repetitive Tasks	2.1 *	2.0	2.1 **	1.3	1.6	1.3
Working Very Hard	2.1	2.6 *	2.5 **	1.6	1.3	1.4
Manipulate Small Obj.	0.6	1.2	1.0	1.0	0.8	1.3
Prolonged Positions	4.5 **	5.9 **	2.8 **	1.4	1.3	0.9
Awkward Postures	6.8 **	5.6 **	3.8 **	1.9	1.5	1.2
Reaching Overhead	4.0 **	2.7 *	2.8 **	1.5	1.1	1.3
Uncomfortable Conditions	2.1	3.0	1.7	3.5 *	2.1	1.7

* Fisher's exact test $p<0.05$
** Fisher's exact test $p<0.01$

CONCLUSIONS

It should be noted that all but one of the upper extremity Fisher's exact test values were not significant. This result may be explained by compensation for decreased function in the affected upper extremity with increased utilization of the unaffected upper extremity.

It is interesting to note that nearly all of the comparisons of job factors with those reporting missed work due to low back pain showed a very significant relationship. This may be attributed to the severely limiting nature of low back injury. Also of interest is the significant relationship between symptoms of the trunk regions which result in missed work and perceived postural problems. This is as one would expect since the trunk musculature is responsible for the control of posture.

The low back relationships alone appear very significant. However, the initial inspection of the compiled data revealed low back symptoms to have nearly a 2 fold increased prevalence when compared to the other symptom regions. This fact in conjunction with the relationship comparisons should warrant concern on the part of the construction industry.

The information acquired through the use of this survey should facilitate a more directed investigation of specific ergonomic problem areas. Phases three and four of the proposed project should expedite the identification and modification of those job tasks responsible for the problems identified in the survey.

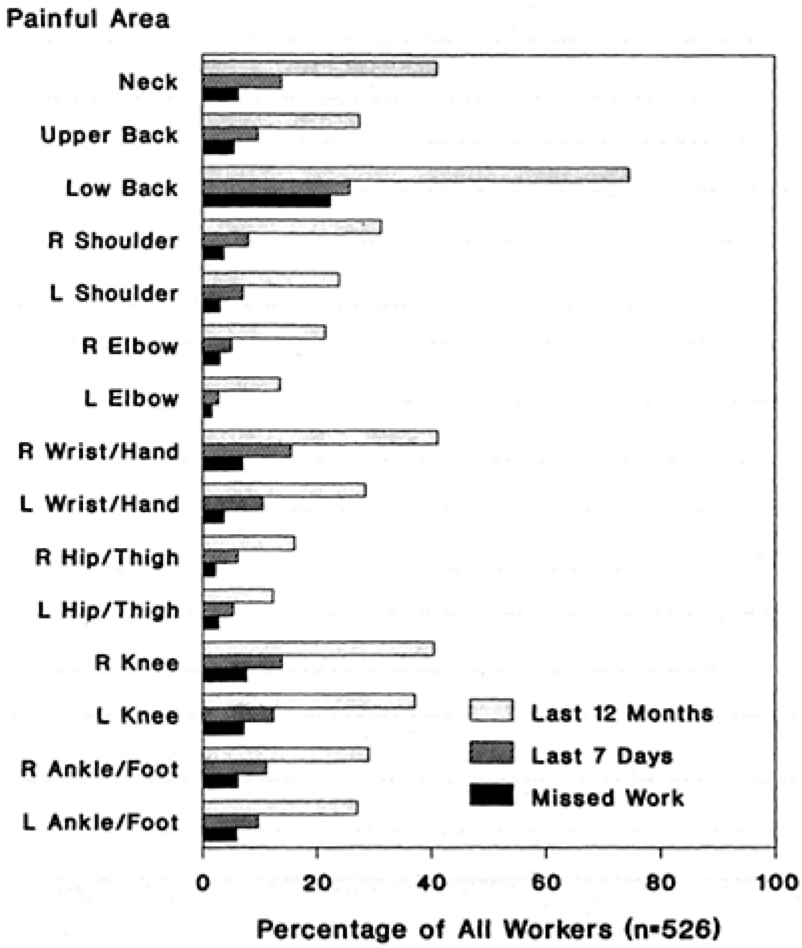

Figure 1: Symptom survey responses of construction workers; including anatomical regions of pain, period prevalence of symptoms and missed work.

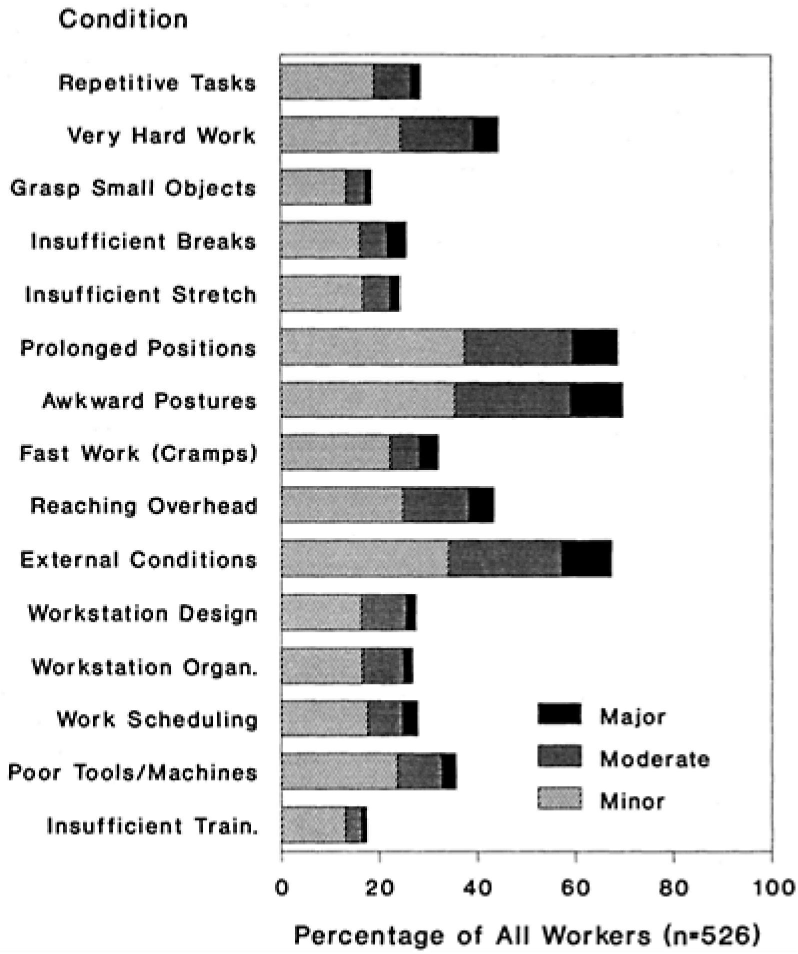

Figure 2: Response of construction workers to job factors survey and their perceived seriousness of problem.

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INDICATORS OF STRESS IN RELATIONSHIP TO INJURY: A HOLISTIC APPROACH AMONG FIRE FIGHTERS.

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The relationship of physical and psychosocial variables to injuries for seventy-six fire fighters was investigated to determine the success of a mandatory fitness program. Physiological variables measured included heart rate, blood pressure, urinary catecholamines, maximum oxygen consumption, body composition and strength measures. Psychosocial stress levels were appraised in terms of identified stressors, cognitive appraisal and coping ability. There was a 23 percent decrease in the injury rate as compared to the pre-implementation period of the mandatory fitness program.

INTRODUCTION

Occupational health is a key feature of the ability to maintain effectiveness and efficiency among certain risk-taking occupations (AAHPERD, 1984). Health promotion and education is a key factor in modern day concern for occupational health and safety. However, the concept of fitness, be it physical, mental, social or spiritual, is an age-old construct inextricably linked with the philosophy of the ancient Greeks. Modern society has converted the fitness concept, primarily physical, into proactive fitness programs. The sequelae effects of physical exercise and endurance in the form of reduced stress and increased productivity are recognized widely by current management executives. The result is an increasing number of non-mandatory fitness programs, often provided as a benefit to employees. Some occupations such as the military, the police and fire fighting often require participation in mandatory fitness programs. The effect of physical fitness programs on the injury rate among fire fighters has been previously researched, but the respective role of psychosocial factors and their relationship to specific injury rates among fire fighters has not been sufficiently examined.

The present investigation was undertaken to examine the relationship between stressors and on-the-job injury to fire fighters; assess which factors could be utilized as predictors of proneness to injury; and to measure selected laboratory values and their relationship to increased levels of stress. In addition, the overall effectiveness of participation in the mandatory fitness program was evaluated.

METHOD

The sample of seventy-six fire fighters was randomly drawn from the population of all three work shifts of a major mid-western metropolitan center. Employer/employee consent forms to the assessment, including personnel record appraisal, were obtained. The subjects were randomly assigned to varying sequences of testing.

For the purposes of this study, stress was measured by the Holmes and Rahe Schedule of Recent Experiences (SRE), State and Trait Anxiety Inventory (STAI), Derogatis Stress Profile (DSP), and urinary catecholamine levels (VMA). Physical fitness was appraised by a fitness level inventory.

Holmes and Rahe (1967) developed the SRE scale to measure a schedule of recent life experiences with a rating determination of the amount of life change units (LCU), and their relationship to the occurrence of illness.

The STAI by Chaplin (1985) is composed of self-report scales that deduce the amount of state anxiety or trait anxiety. State anxiety is defined as a transitory emotional condition, whereas state anxiety is operationalized as a relatively stable predisposition to certain types of stress.

The DSP by Derogatis (1987) is constructed as a multidimensional psychological self-report scale, derived from the interaction of 3 key stress components operationalized as environmental events, personality mediators and emotional responses.

The physlological measurement of stress was assessed utilizing Vanillymandelic Acid (VMA), a urinary metabolite of catecholamines, an indirect measurement of serum levels (Whale Scientific Inc., 1986).

The fitness level inventory by Jackson and Pollock (1985), included measurements of body composition, health posture, trunk strength, flexibility, and estimated maximal oxygen uptake derived from a secondary data source.

Injury was defined as an occurrence that resulted in bodily damage reported on departmental accident reports.

Stress measures were obtained from each subject who received a stress test packet upon entering the test site. Subjects read the test protocol, and then were randomly assigned to begin parts one, two or three of the packet. In collection of the fitness levels, subjects were given the YMCA submaximal bicycle test prior to flexibility and strength measurements. A urine specimen was requested thereafter. VMA specimens were stored at 2–6 degrees centigrade and preserved by sulfuric acid with final pH less than 2.0 until testing was completed.

Data were analyzed using the SPSS-X statistical package on the IBM mainframe computer at The Wichita State University.

Subjects were placed in a low, medium or high level for stress as well as fitness based on their evaluations. Statistical analysis was performed using Pearson Product Moment Correlations, t-tests, multivariate analysis of variance and chi-squares. In the event of statistically significant findings [.05], pre-determination to conduct post hoc analysis was performed.

Overall evaluation of the mandatory fitness program was examined in terms of meeting monetary goals and non-monetary benefits to increased productivity, decreased risk and decreased workman's compensation payments.

RESULTS AND DISCUSSION

The demographic profile of the fire fighters indicated an average age of 35 years with a mean of 11 years of service. Seventy-two percent were married and forty-two percent were employed outside the fire department. Thirteen percent had a BA/BS degree or greater. Fifty-one percent had one or more service-connected injuries between 1986–89.

The SRE found 48% (35) with a LCU of less than 150; 33% (25) had LCU between 150–300; and 10% (16) with a LCU above 300. A LCU over 300 Indicates 80% chance of illness, 150–299 indicates a 50% and less than 150 indicates a 30% chance of illness.

The State Anxiety Inventory found 70% (53) below the mean for working adults and 30% (23) above the mean (M=35.72). The Trait anxiety measure reflected similar results with 72% (55) below the mean and 28% (21) above the mean (M=34).

When the relationship between demographic variables and stress scores was tested, the only significant relatlonship was that between education and stress scores. Subjects reporting the least amount of stress were those with either a two or four year degree while 91% of those reporting higher degree of stress had two years less of college.

In testing the relationship between demographic variables and injuries, the only significant chi-square was found between musculoskeletal injuries and age. The anticipated relationship between stress and injury was not confirmed. However, a significant finding was the relationship between depression and injury. Subjects reporting higher depression scale (M=7.1, SD=3.0) experienced more injuries than those who did not have any injuries (M=5.7, SD=2.8). Relationship between injury and catecholamine levels was not significant. The mean catecholamine levels were higher for the non-injured group when compared to the injured group (M=1.35 and 0.88, respectively), although the relationship was non-significant (p=0.97).

To evaluate the relationship between stress and fitness levels subjects were divided into four age groups with significant relationships found only in the 40–49 year age group. Fire fighters with higher resting heart rates exhibited higher trait anxiety scores, those with higher oxygen consumption sustained more musculoskeletal injuries, and subjects with a lower percentage of body fat demonstrated a lower Total Stress Score. The SRE had a significant correlation with catecholamine levels, i.e. the more life events the subject was experiencing the more catecholamines were being excreted.

The total number of injuries were reviewed by activity. Five years prior to the implementation of the mandatory fitness program (1976–1980) the mean number injured/year was 155; five years post-implementation the mean injuries were 126/year. The average number in the last three years of the study indicated a continuing downward trend decreasing to 120 injuries/year. Even though this trend is positive, other contributing factors must be acknowledged, i.e. OSHA requirements, more restrictive safety standards and improved equipment and fire fighting techniques.

Information regarding service-connected disability retirements was examined to determine the health longevity of personnel and the health status of retiring personnel. During the period from 1971 to 1980 there were 11 service-connected disability retirements. of those 11, 64% (N=7) were due to heart disease; 36% (N=4) were due to fractures, torn ligament, and seizure problem resulting from exposure to heat and chemicals. During the first year (1981) of the mandatory fitness program, there were two disability retirements, one heart disease and one herniated disk. Sixteen service-connected disabilities were granted from 1982 through 1989:19% (N=3) attributed to physical fitness activities, 19% (N=3) to heart disease and 62% to other categories. It is difficult, however, to assess the relationship of the fitness program at this time to the decreased heart disease rate. However, the decrease in heart disease is now replaced by an increase in “low back injuries. The role of the fitness program to low back injuries remains to be determined.

In examining the sample population as a whole, there were, in summary, several individual stress measures that had a significant correlation with fitness indicators, notably cardiovascular measures and strength measures. The impact of life events and catecholamine levels was positively correlated; health posture scores were significantly correlated with several strength measures (push-ups, sit-ups, back extensions, and dips) as well as heart rate and maximum oxygen consumption. The higher the resting heart rate, the more “unhealthy” was the health posture; conversely, the higher the oxygen consumption the more “healthy” the health posture.

Furthermore, the higher scores on strength measures correlated with healthier behavior and habits. Also, increased scores on push-ups and sit-ups correlated significantly with greater satisfaction in the home, work, and health environments collectively. For an interactional analysis, all classes of variables (stress, physiological, and fitness indicators) were found to be non-significant in all cases. However, oxygen consumption, depression, and vocational satisfaction in various combinations approached some significance at (p=.06 to .09).

Lastly, the overall effectiveness of the mandatory physical fitness program were demonstrated two ways: a) demonstration that the program met the goals of providing physical agility, endurance, and mental alertness, and b) a reduction in the total number of injuries by 23% as compared with the pre-implementation period.

The benefits to personnel and to management were reviewed in this study. The undergirding principles in this research postulated that a holistic approach to physical and psychosocial needs of fire fighters by requirement of a mandatory fitness program would prove to be a valuable tool in the promotion of proactive health care/fitness and the reduction of associated costs emanating from injuries. Further research needs to be conducted, especially regarding general stress factors, as well as effects of depression, on injury vulnerability. Physiological propensity for optimal level of “alertness”, thus prevention of injury, could be further investigated through chemical analysis. The study lends thought to further research that would investigate norms for age-dependent fitness programs particularly directed to the prevention of injury on a longitudinal bases, including baseline fitness and physiological norms. Lastly, further research into comparative cost analysis between environments with and without mandatory fitness programs is suggested.

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A SAFETY DIRECTED ERGONOMIC EVALUATION OF THE U.S. POSTAL SERVICE VEHICULAR OPERATIONS: HOUSTON, TEXAS DIVISION

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ABSTRACT

A safety-directed ergonomic evaluation was conducted on the vehicular operations of the U.S. Postal Service Houston, Texas Division Operations. The evaluation concentrated on both the loading and unloading operations required to provide mail service to both residential and commercial locations and on the cabin configuration of the vehicles used by the U.S. Postal Service. Loading and unloading dock area layouts are presented and discussed for both distribution center and substation operations. Detailed process descriptions of the loading and unloading operations are described and critically evaluated, as well. Injury data collected by the U.S. Postal Service from 1986 through 1990 were reduced and analyzed to determine the association of vehicular and operations characteristics with injury data trends. Gender, severity, body part affected, years of experience, object associated with injury, vehicle defect, hours of safety training, work location and cause of accident and/or injury are used to describe the accident and injury trends. Observations of loading and unloading operations were made at the general post office, satellite stations and airport mail facilities. Driver's cabin evaluations were conducted for tractor-trailers, 7-ton trucks, delivery vans and station wagons. Interviews were conducted with delivery personnel operating and conducting operations with each type of vehicle. Weight of lift analyses were conducting using the NIOSH lifting Guide formulas, assessments were made of required push-pull forces during container manipulation and heat stress measurements were made during loading, unloading and vehicular operation. The results of these evaluations provide the background for recommendations presented to the U.S. Postal Service toward abating safety & ergonomic problem areas in the Houston Division Vehicular Operations.

INTRODUCTION

A Safety-directed ergonomic evaluation of the vehicular operations of the United States Postal Service was conducted in the Houston Area Division, Houston, Texas. The evaluation was conducted at the following three distribution centers, Airport Mail Facility, De Moss station and the General Post Office (GPO). The methods of loading of mail onto and the unloading of mail from vehicles were the primary sources of the study. The driver's cabin were evaluated, as well. Four primary types of vehicles are used for transporting mail. (1) eighteen-wheel trucks, (2) seven-ton trucks, (3) delivery/pick-up vans and (4) station wagons. Although the eighteen wheel trucks are used for certain intra-city routes, they are used primarily for long distance handling. The seven-ton trucks are used for postal station delivery within the city. The delivery vans and station wagons are used for local (residential and business) deliveries.

Process Description

The vehicular operations are conducted principally on the dock area of the distribution centers. Dock levelling plates and scissor-lifts for loading/unloading are available. Sorted mail is placed in sacks, mail trays, and totes and then put in containers for transportation. The containers weigh an average 350 pounds. The containers are staged on the dock for loading into the appropriate vehicle for despatch.and pushed into the vehicles manually. The vehicle operator, who is usually helped by another worker, begins pushing the containers from a distance of 5 to 6 feet before the dock levelling plate to generate enough speed and momentum to be able to push the container up an incline of 10 degrees into the vehicle. Some of the docks have a scissors lift, which makes the procedure a lot simpler.

INJURY STATISTICS

The five years of data (1987–1991) was provided by the United States Postal Services for review. During this period 92 injuries associated with loading and unloading operations were reported.

Body Part Affected

The distribution of injuries by body part affected is presented in the Figure 1. As can be seen, back and feet were associated with the majority of the injuries; 15% and 10%, respectively.

Figure 1. Number of injuries by body part affected.

Lost Work Time

As can be seen from Figure 2, sixty two percent of the injuries required first aid while thirty percent of the injuries caused the loss of at least one work day.

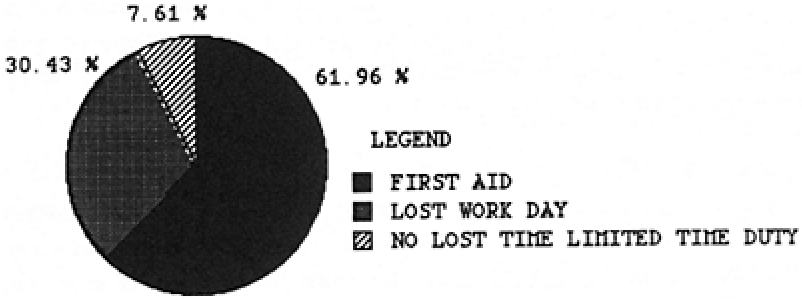

Figure 2. Number of injuries by lost work time.

Work Location

As would be assumed, the major type of injuries (81%) were reported on the dock and platform area. See Figure 3.

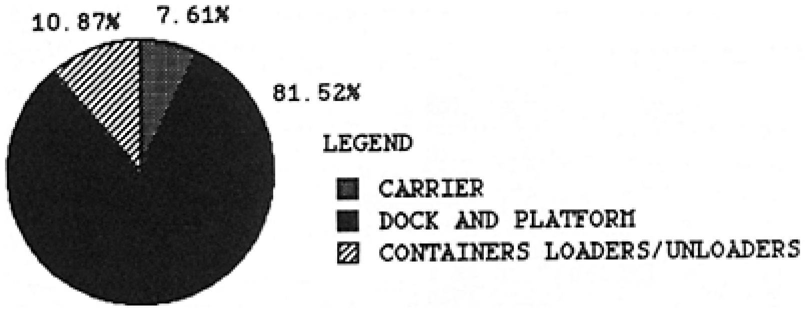

Figure 3. Number of injuries by work location.

Item Causing Injury

The General Purpose Mail Containers (GPMC) were associated with 55% of the reported injuries, while the Bulk Mail Container (BMC) and Over the Road Container (OTR) were associated with 24% of the total injuries. The remaining 21% of the injuries were associated with Mail Trays, Totes and Tubs.

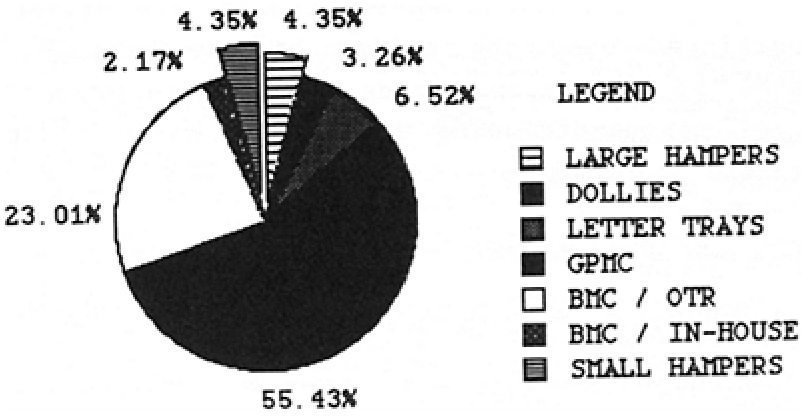

Figure 4. Number of injuries by items causing the injury.

OBSERVATIONS

Loading and Unloading Operations

- The lifting and positioning of the dock levelling plate causes frequent bending of the workers.
- The difference of height of an inch between the dock levelling plate and the dock, causes impact on the wheels of the containers during loading operation.
- Due to the inclination of the dock levelling plate, the worker has to push the container from an average distance of five to six feet before the dock levelling plate to generate enough momentum to push the containers into the trucks, this causes fatigue on the back and shoulders of the worker.
- Insufficient illumination inside the trailer causes difficulty in securing container tow pins into the tow pin holes located in the floor of the trailer and lock the container in place. In addition, The worker has to continually bend to locate the tow pin.
- The dock dumpers are worn out.

Driver's Cabin

- Lack of sufficient legroom between the seat and the brake paddle causes awkward body posture for tall drivers.
- Improperly maintained control panels poses difficulty in monitoring them.
- In eighteen-wheel and seven-ton trucks, the driver's seat is positioned over the engine of the vehicle. This increases the temperature inside the driver's cabin
- Lack of air-conditioning inside the cabin causes high temperature in summer.

ANALYSIS AND DISCUSSIONS

NIOSH

Table 1. provides the various weights handled and the corresponding limits, both the action and maximum permissible, set down by NIOSH (1981).

TABLE 1. NIOSH Lifting and Handling Requirements

ITEM	WEIGHT		ACTION LIMIT		MAX. PERM. LT.	
	KGS	Lbs	KGS	Lbs	KGS	Lbs
MAIL TUBS	18.2	40	1.03	2.26	3.09	6.80
MAIL TRAYS	9.1	20	1.03	2.26	3.09	6.80
ADVO	11.36	25	1.03	2.26	3.09	6.80

Push/pull forces

The push/pull forces for the various items were measured using a force transducer. These measurements are given in Table 2.

TABLE 2. Push/Pull Forces during loading and unloading.

Type of container	Push/Pull Force		Recommended	
	Kg-m	Ft-Pound	Kg-m	Ft-Pound
Bulk Mail Container	**25.39**	56	15	32
GPMC	**17.33**	38	15	32
Hamper	10.33	23	15	32
Levelling Plate	**50**	111	15	32

NOTE:

The recommended values are for the 10th percentile female population. The recommended values have been adapted from Snook (1978). The values that exceed the recommended limits are shown in bold letters in the table.

Heat Stress

The heat stress levels were measured using a Wet Bulb Globe Thermometer (WBGT). The heat stress levels present at the various places and their corresponding limits are specified in Tables 3. (ACGIH 1980)

TABLE 3.

WBGT Readings (in centigrade) and the Recommended Values Vehicle: Eighteen-Wheeler

WINDOW	ENGINE OFF	ENGINE ON	RECOMMENDED
OPEN	29	31.3	26
CLOSED	30	33	26
Vehicle: Seven-Ton (International) Truck			
WINDOW	ENGINE OFF	ENGINE ON	RECOMMENDED
OPEN	29.4	30.1	26
CLOSED	30.7	32.9	26

The values have been recommended considering that the work levels are moderate and the work pattern is 75% work and 25% rest.

RECOMMENDATIONS

- The loading and unloading operations should be mechanized.
- The angle of inclination of the dock levelling plate should be decreased by reducing the length of the chain which is used for movement of the dock levelling plate.
- The dock levelling plate should be aligned correctly with the dock floor.

- Hydraulic or pneumatic mechanism should be used to raise and lower the dock levelling plate.
- The drivers should be assisted by designated workers such as loaders/unloaders or dock workers during loading and unloading operations.
- Hydraulic cushioning should be used instead of the existing rubber cushioning pads to reduce wear and impact while positioning the vehicle.
- The worn out cushioning pads should be replaced.
- The cushioning pads should be periodically inspected.
- The employees should make use of the lights provided inside the trailers while loading and unloading.
- The drivers cabin in the vehicles should be airconditioned.
- Replace the seats of eighteen-wheel and seven-ton truck with the ones similar to those used on the Chevrolet-Grumman delivery vans.
- Provide better cushioning such as pillow for the back support in the seats.
- In eighteen-wheel and seven-ton trucks, the driver's seat is positioned over the engine of the vehicle. The engine should be well insulated to reduce the heat level.

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JOB AND SITE ANALYSIS

VALIDATING A MULTI-FACET APPROACH TO MEASURING HUMAN PERFORMANCE IN COMPLEX SYSTEMS

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INTRODUCTION

Ergonomics research designed to understand human performance in complex systems often requires developing suitable measures of job performance. In complex systems, such as nuclear power plant control rooms, the challenge is to measure the full domain of job performance requirements. When constructing performance assessment instruments, it is important to demonstrate that they yield reliable and valid performance information. The purpose of this paper is to describe an approach used to assess operator performance in simulated abnormal plant operations. Three different performance assessment instruments were designed to measure the full range of operations performance requirements. The primary goal in constructing these performance assessment instruments was to design measures that assess performance at the functional level, assess the generic performance requirements, and to assess performance requirements specific to a particular abnormal condition. The three instruments designed for this study were also subject to a reliability analyses, and performance data were interpreted by examining the correlations between the different types of performance assessment instruments.

METHOD

Three control room operator performance assessment instruments were developed to capture the full domain of control room operations requirements operator job requirements. The procedures followed to construct each instrument, the content of each instrument, and the procedures for scoring each instrument are described below.

Functional Ratings

These rating scales were designed to measure general functional requirements of operating crews. Initial scale development activities involved constructing a list of general performance requirements for operating crews. Research staff then worked with subject matter experts from a simulator training facility to refine the list and develop complete descriptions of these functional performance requirements. A final set of three general crew factors were developed for the Functional performance assessment instrument. Table 1 provides a list and description of these rating factors.

According to the data in the table, the crew is rated on how well they work together, (the senior reactor operator provides adequate instruction, and each crew member understands his own role); how well they perform (follow and understand each accident, recover from the accident quickly); and their enthusiasm as a crew (as indicated by speaking clearly and frequently). All ratings are provided on a seven-point scale ranging from 1 (low or ineffective performance) to 7 (high or very effective performance). Scores represent the mean rating computed across two raters on each factor.

Table 1. Description of functional rating scales

1. How well did the team work together during the scenario?
- SRO provided adequate instruction and RO and TO listen and comprehend.
- Speak frequently to one another.
- Recognize each crew member’s technical expertise and are aware of what each crew member is doing.
- Each crew member understands his own role.
- Group atmosphere is positive.

2. How well did the team perform during the scenario?
- Crew followed and understood the scenario in each accident.
- Little leakage occurs during a pipe break accident (Scenarios 3, 6, and 7).
- Paid attention to all details even in less critical accidents (Scenarios 4 and 5).
- Recovered from the accident early and quickly.

3. How much enthusiasm/team spirit did the team members display during the scenario?
- Crew members spoke clearly and loudly.
- Crew members spoke frequently.
- Referred to written procedures and other materials frequently.
- Moved briskly about the control room.

Evaluation:	1	------------------------	7
	Low Ineffective		High Very Effective

Generic Rating Scales

Under both normal and abnormal control room operations, there are specific behaviors or actions crew members must perform. For example, control room crew members must acknowledge and report the onset of an alarm. Working with subject matter experts, it was determined that operating crews should perform ten generic actions under all operating conditions. It was hypothesized that the more effective crews would perform these actions each time they were required, whereas less effective crews would perform these actions less frequently. Therefore, the evaluation process consisted of determining the number of times crew members actually performed each action in a simulated event, and the number of times crew members should have taken each action. Table 2 presents of list of actions included in the Generic rating scale.

The Generic rating scales also contain one final item, “SRO predicts what will occur next” (Item 11 in Table 2). This item was included to identify the frequency with which the lead operator, the senior reactor operator (SRO), understands plant conditions and anticipates the next activity that occurs in the event. The assumption is that the SRO, who successfully predicts the next activity has a better understanding of plant status and of the abnormal event that is unfolding.

Table 2. Description of generic behavior rating scales

1.	Crew acknowledged an alarm.
2.	Crew reported alarms
3.	Crew monitored alarm-related parameters.
4.	Crew announced a control action before taking it.
5.	Crew announced completion of a control action.
6.	Crew monitored component status related to a manual control action.
7.	Crew monitored process parameters related to a manual action.
8.	Crew monitored component status related to an automatic action.
9.	Crew monitored process parameters related to an automatic action.
10.	SRO provides a verbal acknowledgement.
11.	SRO predicts what will occur next.
Evaluation:	Count of Number of Times Actually Performed and Count of Number of Times Should Have Performed

Scores for the Generic rating scales were calculated for each item (1 through 10), using a the following ratio: Number of Actions Actually Taken versus Number of Actions that Should Have Been Taken. Scores for the last item, “SRO predicts what will occur next,” represent a simple count of those actions.

Procedural Unit Rating Scales

The third performance evaluation instrument was designed to measure crew performance in very specific action terms. For each type of abnormal event presented in simulator training, there are actions that crew members must perform. These specific actions are geared toward diagnosing the problem and taking corrective actions. To construct Procedural Unit rating scales, subject matter experts reviewed each scenario presented in the training simulator; these experts concluded that simulator training offered five distinct events that each requires different actions and procedures to diagnose and correct problems. Therefore, the expert panel developed procedures unit rating scales for each of the following events:

1. Anticipated Transient Without Scram (30 Actions)
2. Loss of Coolant Accident (LOCA) Diagnosis (18 Actions)

3. Confirm Safety Injection (SI) (40 Actions)
4. Reactor Coolant System Depressurization (20 Actions)
5. Safety Injection (SI) Reset (38 Actions)

For each abnormal event, subject matter experts identified the critical actions essential for effective operations. The number of essential actions varied by event, ranging from 18 for the loss of coolant accident (LOCA; Event 2) to 40 for confirm safety injection (Event 3). Table 3 contains the list actions required for loss of coolant accident (LOCA).

Procedures for evaluating crew effectiveness using the Procedural Unit scales involved asking raters to check off each action as a crew member performed it during the event. It is important to note that crew members were not required to perform

Table 3. Description of sample procedural unit rating diagnosis of a loss of coolant accident (LOCA)

1.	Acknowledge “CV Sump Level Hi Rate.”
2.	Acknowledge “CV Sump Level Hi-Hi Rate.”
3.	Acknowledge “Pressurizer Low Pressure BUH On.
4.	Acknowledge “Process Monitor Hi Rate.”
5.	Monitor pressurizer pressure.
6.	Monitor pressurizer lever.
7.	Acknowledge “CV Airlock Area Hi Rad.”
8.	Acknowledge “ICS Airlock Area Hi Rad.”
9.	Acknowledge “CV Operations Floor Hi Rad.”
10.	Acknowledge “CV Airborne Hi Rad.”
11.	Acknowledge “CV Gas Hi Rad.”
12.	Monitor charging flow.
13.	Monitor CV tank level.
14.	Monitor CV pressure.
15.	Monitor CV temperature.
16.	Monitor CV sump level.
17.	Announce occurrence of LOCA.
18.	Report to Supervisor
Evaluation:	Check Performed or Not Performed

each action in the order listed, some variation was acceptable. Scores for the procedural unit rating scales were computed using the following ratio: Number of Required Actions Taken by Total Number of Actions Required in the Event.

Data Collection Procedures

Subjects included 126 reactor operators from several different utilities in a non-western country. These operators were attending a one-week training program held at a centralized training facility. The training facility contained two high fidelity training simulators that mirrored the performance requirements of the control room at each of the operators' home plants. Operators were randomly paired with two other operators to perform as a three-man crew in the training simulator (42 operating crews). During the training event, one operator from the crew served as the senior reactor operator (SRO), one served as the reactor operator (RO), and the other served as the turbine operator (TO). Each crew participated in seven training scenarios; each scenario involved different accidents and emergencies.

For the Functional and Generic performance assessment instruments, each crew was evaluated in each of the seven training scenarios (events). Scores were computed separately for each scenario; mean scores computed across the seven scenarios were used to compare data across assessment instruments. For the Procedural Unit performance assessment instrument, a single ratio score was computed for each of the five critical events. These ratio scores were used to compare data across the different assessment instruments.

Raters providing evaluations differed for the three types of performance assessment instrument. For Functional performance ratings, two experts familiar with control room operations (former operators and trainers), observed crews as they performed during each training scenario (direct observation). Each rater provided an independent evaluation of crew performance on the Functional scales.

For both the Generic and Procedural Unit rating scales, it was determined that raters could not provide accurate counts of actions using the direct observation method. Therefore raters evaluating crews using these rating scales, viewed video-taped performances of crews performance in each of the seven training scenarios. As crews performed in each training scenario their performance was video-taped; these tapes were used by raters providing Generic and Procedural Unit ratings. For the Generic ratings, raters included a group of nuclear engineers experienced in control room operations. For one crew, two different groups of raters provided independent evaluations of the crew's actions in the seven training scenarios; these data were used to compute interrater (group) reliability estimates. For the Procedural Unit ratings, raters consisted of another group of highly experienced nuclear engineers and crew training staff. Two groups of raters were also asked to independently rate performance for a single crew in each of the five procedural unit events.

RESULTS

Table 4 summarizes interrater reliability for the three performance assessment instruments. According to these data, interrater reliability estimates are high for the three instruments. Values are highest for the Generic rating scales, ranging from .93 to 1.00. Estimates are relatively high for the Procedural Unit rating scales (.70 to 1.00) and for the Functional rating scales (.68 to .97). These data indicate that ratings provided by individual raters and groups of raters are reliable and meaningful.

Table 4. Summary of reliability data for three rating procedures

Rating Procedure	Technique for Observing Performance	Raters	Number of Ratings	Ranges of Interrater Agreement
Functional Rating Scales	Direct Observation	2 Independent Expert Raters	35 Crews 7 Scenarios	.68 to .97
Generic Rating Scales	Observe Video-Taped Performance	2 Independent Group of Raters	1 Crew 7 Scenarios	.93 to 1.00
Procedural Unit Rating Scales	Observe Video-Taped Performance	2 Independent Groups of Raters	1 Crew 5 Scenarios	.70 to 1.00

The primary rationale for constructing and using three different approached to performance assessment is to verify that each approach accurately measures effective crew performance and to better understand what is measured in each instruments. To that end, we calculated the correlations between ratings on each instrument. Table 5 present the intercorrelations for Functional and Procedural Unit rating scale, and between instrument correlations for the three performance assessment instruments. Table 6 provides the intercorrelations for the generic ratings.

According to the data in Table 5, correlations between Functional (P1) ratings indicate that the three crew ratings are very similar; these correlations range from .73 to .86. As a results, the Functional ratings yield a similar pattern of correlations with the Generic (P2) and Procedural Unit (P3) ratings. These correlations indicate that Functional ratings are most highly related to monitoring process parameters and component status related to automatic actions (Generic actions 8 and 9). Effective Functional ratings are also significantly related to performing all or nearly all actions in:

3. Confirm Safety Injection (SI)
4. Reactor Coolant System Depressurization
5. Safety Injection (SI) Reset

Further, these correlations indicate that effective Functional crew performance is unrelated to the number of specific actions performed in the Loss of Coolant Accident (LOCA; Event 2). This results suggests that the Functional ratings should be evaluated to determine if other rating factors need to be added to enure inclusion of performance in a LOCA.

Table 5. Correlations between functional (P1), generic (P2), and procedural unit (P3) rating scales—crew data (N=34–42)

	Functional Ratings (P1)			Procedural Unit Rating (P3)				
	1	2	3	1	2	3	4	5

P1								
1	…							
2	.86***	…						
3	.85***	.73***	…					
P2								
1	−.06	−.15	−.00	.23	.45***	.02	.03	−.15
2	.05	−.07	.09	.10	.42***	.14	.01	−.07
3	.34**	.22	.38**	.23	.20	.07	.23	24
4	−.14	−.11	.12	.15	.12	.10	.09	20
5	−.14	−.07	−.03	.05	.03	−.01	−.11	09
6	−.40**	−.46***	−.27	−.04	.29*	−.04	−.35**	−.38**
7	−.28	−.29*	−.30*	−.14	.07	−.12	−.54***	−.53***
8	.47**	.55***	.44***	.47***	.32**	.56***	.41**	27*
9	.56***	.58***	.52***	.53***	.09	.27*	.51***	37**
10	.17	.03	.26	−.21	−.03	−.23	.11	27*
11	.09	.12	.21	−.01	.01	.02	.12	08
P3								
1	.23	.47***	.22	…				
2	−.05	.01	.04	.34**	…			
3	.34**	.49***	.24	.33**	.39**	…		
4	.51***	.56***	.60***	.49***	.28*	.39**	…	
5	.51***	.53***	.61***	.26*	−.01	.36**	.68***	…

*p<.10
** p<.05
*** p<.01

Correlations between Generic and Procedural ratings indicate that all five Procedural ratings correlate significantly with monitoring component status related to an automatic action (Generic Item 8). These correlations also indicate that specific performance in each Procedural rating corresponds to a different pattern of Generic actions. For example, specific LOCA performance (Procedural Event 2)

Table 6. Generic rating (P2) scales (N=34–42 crews)

	Generic Ratings (P2)										
	1	2	3	4	5	6	7	8	9	10	11
P2											
1	…										
2	.89***	…									
3	.42***	.28*	…								
4	.27*	.26*	.15	…							
5	.46***	.45***	.22	.12	…						
6	.43**	.31*	.10	.30*	.34**	…					
7	.10	.02	−.02	−.01	−.12	.60***	…				
8	−.06	.00	.26*	.03	−.06	−.04	−.02	…			

9	−.16	−.13	.20	−.13	−.19	−.28**	−.22	.57***	…		
10	.04	.09	.07	.04	−.09	−.23	−.13	.04	.14	…	
11	−.09	−.00	−.08	−.37**	.27*	−.10	−.23	.13	.12	−.03	…

*p<.10
** p<.05
* ** p<.01

is related to acknowledging and reporting alarms (Generic Items 2 and 3). Specific procedural actions for Reactor Coolant System Depressurization (Procedural Event 4), are related to monitoring component status and process parameters for manual and automatic actions (Generic Items 6, 7, 8, & 9).

After computing and interpreting the correlations between performance assessment instruments, we presented these data to subject matter experts to confirm these conclusions about operator performance requirements assessed in each of the instruments. This panel of experts consisted of nuclear engineers and training simulator experts, who reviewed these data to verify that the Functional ratings identified the critical Generic actions and that the critical Generic actions varied appropriately for each of the Procedural Unit rating scales. This panel was also useful in recommending ways to improve these instruments (e.g, modify the Functional rating scales to include critical actions involved in the LOCA event).

CONCLUSIONS

Assessment of human performance in complex systems presents a challenge in fully representing all performance requirements. This paper presented procedures for constructing three alternative performance assessment instruments and an approach to verify the reliability and validity of these instruments. Correlations between ratings obtained from each instrument were used to: (1) interpret the ratings obtained from each performance assessment instrument; (2) verify that the rating accurately operator performance requirements; using a panel of experts and (3) obtain recommendations for improving the ratings scales if one or more appear deficient.

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PRODUCTIVITY IMPROVEMENT AND WORK-RELATED INJURY PREVENTION VIA A JOB ANALYSIS APPROACH

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Forty different tasks in a local linen and uniform service factory were reviewed via observation and interview to identify the necessary task procedures (e.g., loading/unloading, washing, ironing and folding). The current task procedures were compared with job elements defined by the Dictionary of Occupational Titles. The most efficient and safe job procedures and sequences were developed via an on-site video study, an operation process chart analysis, and an operator process chart analysis. A detailed job description and safety instruction was then developed to specify the minimal hiring/operation requirements. A training video with an emphasis on the safety procedure was also developed for each high risk operation. A computerized ergonomics analysis system including these variables was developed to monitor job performance and identify potential ergonomics problems.

INTRODUCTION

The amount of time and the most efficient and safe operation sequence that a job takes is an important component in the establishment of cost allocation, production planning and scheduling, evaluation of alternatives, and incentive plans. The basis of job evaluation is job analysis, a procedure for making a careful appraisal of each job and then recording the details of the work so that it can be evaluated fairly by a trained analyst. In other words, the purpose of job analysis is to collect complete information on all requirements of the job with the consideration of quality, productivity, and safety. A job evaluation is conducted and implemented in a local linen and uniform service company to reduce some unnecessary operations, design safer and better workplace, layout, and performance aids.

For many years manual materials handling has been recognized as a major hazard to industrial workers by authorities in the field of occupational health and safety. It is estimated that approximately one-third of all jobs in industry today involve some forms of manual materials handling. The National Safety Council reports that approximately 25 percent of all compensable industrial injuries and illness in the United States result from manual materials handling. The average low-back injury costs $6,800 per case. If the injury leads to an operation, it can cost from $30,000 to $60,000 for each case (Konz, 1990). As an estimate, back pain problems cost American industry $16 billions per year (Konz, 1990). During our visit to a local linen and uniform company, we found that a major portion of operations are composed of manual materials handling. For example, loading/unloading of garments from/to route trucks; soil separation; loading/unloading of garments from/to washers, dryers. In other words, without proper analysis and design, potential work-related injury may occur.

OSHA has published the ergonomics guidelines for the American Meat Institutes (AMI) to reduce Cumulative Trauma Disorders (CTDs) in the meatpacking industry. In general, the ergonomics program should include: 1) employer commitment; 2) employee involvement; 3) training and education of employees at all levels; 4) ergonomics analysis to identify potential hazards; 5) injury prevention and control; and 6) medical management system. This project is targeted towards satisfying these requirements.

JOB ANALYSIS

A comprehensive job analysis was conducted in establishing a most safe, efficient, and productive method and assessing the amount of time required for different tasks to be performed by the linen industry workers. In order to achieve our objectives, the following steps were conducted—

- Step One—review existing tasks to identify the necessary task procedures (e.g., loading/unloading, washing, ironing and folding). Forty different tasks were reviewed (e.g., extractor operator, garment assembler, maintenance mechanic, route sales, flatwork folder).
- Step Two—identify job elements based on the definition from the Dictionary of Occupational Titles (USES, 1986). For example, the job elements of extractor operator (581.685–038) are defined as follows:
    - Pushes loaded handtrucks or portable extractor baskets into position at machine or under hoist.
    - Lifts material from handtruck, or raises baskets, using chain or electric hoist to load extractor.
    - Distributes material uniformly in extractor baskets to balance load and reduce vibration.
    - Observes tilt of portable baskets to verify balance when using hoist.
    - Closes cover and starts machine.
    - Unloads materials into handtruck for transfer to subsequent work station.

- Step Three—develop the most safe, efficient job procedures and sequence via on-site, video study, operation process chart, process flow chart, and operator process chart analysis. The personal protective equipment needed for the job was defined. For example, the ear plug, hard hat, non-slip waterproof boots, and back support belt are required for the extractor operator. The necessary safety precautions for the job were also identified with consultation to the machine manual, safety manager, operator, and supervisor. For example, the operator must make sure all the routes are clear before lower the lift to raise the sling.
- Step Four—specify the minimal hiring/operation requirements. The Statement of Minimum Qualification (SMQ) includes: 1) Job description, 2) General requirements, 3) Specific knowledge and skills, 4) Physical requirements, 5) Working conditions, 6) Personal protective equipments, and 6) Performance standards. An example of SMQ of the extractor operator is shown in Figure 1.
- Step Five—develop job description according to results obtained from the previous steps. In general, a job description should include: 1) general information, e.g., department, date, job title; 2) summary of duties; 3) detailed statement of work performed; 4) source of supervision; 5) tools and equipments; 6) materials; 7) responsibility; 8) qualifications required, e.g., special knowledge, previous experience, physical; 9) working conditions, e.g., surroundings, hazards; 10) job evaluation scale.

JOB TITLE Extractor Operator **DEPARTMENT** Washing

DOT CODE 581–685–038

STATEMENT OF MINIMUM QUALIFICATIONS

Job Description:

To operate centrifugal extractor that removes water from garments which have been washed

General Requirements:

- No back, leg, shoulder, and hand injury history.

Specific Knowledge and Skills:

- Education—Requires to read the number and letters.
- Experience—Preferred.

Physical Requirements:

- Must be able to push/pull the 30–60 pounds.
- At least 5′ 6″.

Working Conditions:

- Noise level—83–92 dBA.
- Heat level—85–95°F during the summer.
- Hazards—
  - •• Wet and slippery floor.
  - •• Struck by or against washing bag or cart.
  - •• Caught in or between the extractor machine.

Personal Protective Equipment:

- Back support belt
- Ear Plug
- Hardhat
- Non-slip waterproof boots

Performance Standards:

- Current standard—Process 800 pounds per hour.

Figure 1. An example of the statement of minimum qualifications.

ERGONOMICS ANALYSIS

There are several areas in the laundry facility that present potential ergonomics hazards due to the enormous amount of physical labor used in the plant. Therefore, this task is focused on a comprehensive ergonomics analysis to identify and solve those potential ergonomics hazards. The following steps was conducted in this task.

Step One–	review of past injury and illness records (e.g., lost time, accident/injury reports, medical and disability records) to identify high risk operations.
Step Two–	detailed task analysis to identify potential problems via Ergonomics Information Analysis System (Chen, 1991) and interview.
Step Three–	ergonomics risk analysis to identify and quantify the severity of occupational hazardous factors via physical investigation (e.g., anthropometric measurement) and detailed job studies (e.g., Physical Work Stress Index and Ergonomics Analysis System; Job Severity Index Analysis; NIOSH Lifting Guideline Analysis).
Step Four–	closing discussion with company to identify and prioritize possible ergonomics problems, describe and justify possible alternative solutions.
Step Five–	implement recommended alternatives via job redesign, process modification, workplace redesign, and/or providing performance aids if necessary.
Step Six–	follow-up and audit after the implementation. OSHA recommends that top management review the program at least semiannually, and managers, supervisors and employees quarterly.

DEVELOPMENT OF COMPUTERIZED ERGONOMICS ANALYSIS SYSTEM

After the completion of the job analysis, all the important contributory variables in productivity and safety were identified and defined. A computerized ergonomics analysis system including these variables was developed to monitor job performance and identify potential ergonomics problems. The system, adopted from Ergonomics Information Analysis System (Chen, 1991), includes five major sections: case identification, job description, problem description, workload analysis, and remedy. The case identification section records general personal (e.g., age, gender) and anthropometric data (e.g., height, weight, back strength, leg strength, arm strength, pulling strength, pushing strength, and predicted lift strength) along with job location. Currently, 52 workers' anthropometric data have been collected (Table 1). The mean and standard deviation for each anthropometric data were compared to 1985 projected body size from NASA Anthropometric Data (1978) and found that the height, weight, and other measurements are slightly smaller than the reference populations. The isometric strengths measured on the male and female workers were compared to reference population (NIOSH, 1980), The results show that the arm lift, back lift, pulling, and pushing strength are higher than the reference population, but the leg lift strength is lower than the population. The job description section requests data, describing the job, environment, workplace, parts and tools. The structure and information of this section is basically based on the job description and the statement of minimum qualification. The problem description section records the incidence of injury from the task, poor product quality and poor quality of work life, if any. A postural discomfortability assessment chart is developed in the workload analysis section. The major body discomfort areas and the possible occupational causes were identified. Table 2 shows the most discomfort body parts associated with tasks along with their contributing factors. Shoulder, back, and leg discomfort were the most frequently mentioned pains. Repetitive upper arm motion and standing too long were the most commonly listed contributing factors to discomfort. Back support belts and anti-fatigue mats were suggested and implemented to improve the working conditions and reduce the body discomfort. This section also includes biomechanical and physiological information pertaining to load descriptions of the job. Engineering modifications, job organization, training and methods improvement were recorded in the remedy section.

Table 1. Subject's demographic and anthropometric data.

Characteristics	Male (N=29)		Female (N=23)	
	Mean	Std. Dev.	Mean	Std. Dev.
Age (yrs)	31.00	10.26	32.83	7.91
Height	175.04	7.51	158.56	7.99
Weight (kg)	79.92	13.49	73.30	16.63
Shoulder Height (cm)	147.06	7.08	132.00	7.09
Abdominal Depth (cm)	23.67	4.35	23.43	4.64
Hand Length	18.66	2.17	16.87	2.13
Arm Strength	46.16	12.30	25.92	6.51
Leg Strength	68.62	31.51	41.42	15.55
Back Strength	104.73	28.25	56.23	19.14
Pulling Strength	61.49	21.15	35.41	10.60
Pushing Strength	61.83	20.56	29.38	10.94

Overall Strength	34.49	6.13	16.87	2.13

DEVELOPMENT AND VALIDATION OF THE STRENGTH PREDICTION MODELS

A person's lifting strength is depended on the person's muscle strength and skeleton rigidity. The larger amount of muscle, the larger is the strength being produced. Also, the larger size of human body, usually required high skeleton rigidity to support. Therefore, "Taller and heavier workers are stronger than their counterparts" (NIOSH, 1980). A similar approach to Keyserling, et al., (1978) have been adopted to attempt to predict isometric strengths based on individual worker's anthropometric.

Table 2. Summary of body discomfort parts and contributing factors.

Task	Body Discomfort Parts	Contributing Factors
Truck Driver	Shoulder, upper arm	Loading/unloading
Extracting	Shoulder, upper back, lower arm	Frequent pushing/pulling heavy slings, balancing the loads
Flatwork	Shoulder, lower back, leg	Repetitive upper extremity motion, standing too long
Laundry	Back, leg	Frequent back bent forward, trunk twisting, standing too long
Soil Belt Sort ing	Shoulder, upper arm, leg	Frequent arm outstretch, standing too long
Soil Separation	Shoulder, leg, upper arm	Frequent arm outstretch, standing too long
Towel Folding	Shoulder, lower back, leg	Repetitive upper arm motion, standing too long

The strength prediction model includes arm lift, back lift, leg lift, pulling, and pushing strength. Five attributes (e.g., age, height, weight, shoulder height, and abdominal depth) were identified as the major contributing factors to these isometric strengths. The multivariable linear regression analysis was performed by using the five anthropometric data as independent variables to identify the major contributing factors. For female subjects, the height has an effect on arm lift strength and leg lift strength. The weight and abdominal depth are more related to back lift strength, pushing strength and pulling strength. For male subjects, the age plays important role in back lift and leg lift strength. The height has an impact on arm lift strength. However, there is no significant relationship between the anthropometric data and the pulling and pushing strength. The multiple linear regression analysis was then run again with those contributing attributes to develop prediction models (Table 3). Calculated coefficients of determination (R^2) indicate that these anthropometric variables only explain one-third of the population variance. This is because of the contributory factors to the worker's strength may not only depend on the anthpopometric measures. Other environmental, physiological, and psychological factors may influence the worker's strength. And the relationship of the anthropometric and strength data will not necessarily be linear. Regression and correlationship analysis are based on the theoretical assumption of normal distribution and linear relationship only. The relationship between those attributes can become non-linear quite possibly rather than linear. The number of subjects participated in this study was also relative small to represent a normal population. The standard deviation of the data were rather large.

Table 3. Strength prediction models.

Gender	Prediction Models	R^2Value
Male	Back Lift=−239.75+0.75C+1.84D	0.276
	Arm Lift=−90.18+0.56C+ 3.26D−3.08F	0.430
	Leg Lift=−115.68+1.56C−1.71D+3.38F− 2.56G	0.264
	Pushing=−199.73–0.61E+1.85F+1.64G	0.234
	Pulling=−202.17+0.69D+0.29E+0.8F	0.421
Female	Back Lift=44.34+0.87E−2.22G	0.365
	Arm Lift=−8.74–1.39D+1.93F	0.258
	Leg Lift=26.31–4.74D+6.06F−1.4G	0.356
	Pushing=104.65–3.29D+0.38E+3.44F− 1.53G	0.321
	Pulling=38.34–0.37C+0.33E−0.64G	0.131

Where C—Age, D—Height, E—Weight, F—houlder Height, G—Abdominal Depth

The predicted strength data were then calculated by plugging in the anthropometric data to the above equations. The predicted strength were compared to the actual lifting strength measurement in graphical form. An example of the comparison of pulling strength is shown in Figure 2. Basically, the prediction model performs satisfactory for most of the situations. However, the predicted model misses those "outliners" which showing the subject has either extremely low or high lifting strength due to the subjects' attitudes in performing the lifting measurement. The predicted strength data were compared to the actual strength measurements by using regression and correlation analysis (Table 4). Table 4 shows that the predicted arm lifting strength had highest r value for male subjects and the pulling strength was being lowest for female subjects.

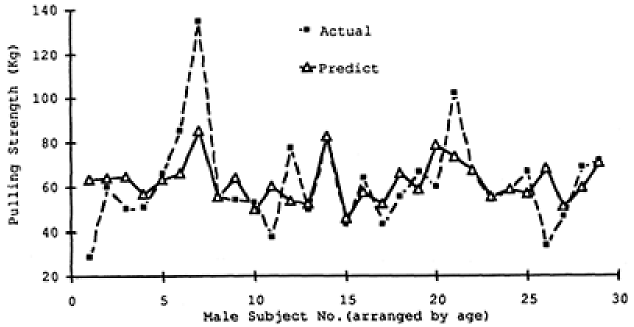

Figure 2. The comparison of the predicted and the actual pulling strength.

Table 4. Correlation matrix between the prediction model and actual strength measurements.

Type of Strength	Correlation Matrix	
	Male	Female
Back Lift Strength	0.514	0.605
Arm Lift Strength	0.656	0.508
Leg Lift Strength	0.514	0.597
Pushing Strength	0.483	0.566
Pulling Strength	0.649	0.362

DISCUSSIONS

In this study, forty different tasks were reviewed and high risk operations were identified. Each of these operations were analyzed and evaluated using different ergonomics methods. The job description and the statement of minimum qualification for each task were also defined based on the definition of the Dictionary of Occupational Titles, safety requirements, and productivity considerations. Following the ergonomics risk analysis, recommendations were provided on the basis of administration controls and engineering controls. A computerized ergonomics analysis system was developed to monitor these jobs on a regular basis. The training vedio with an emphasis on the safety procedure was also developed for these high risk operations. The improvement of productivity and safety demonstrated the effectiveness of the training vedio.

The strength prediction models were developed and evaluated with actual lifting capacities. Although it may be incautious to use these models alone to predict any worker's strength and used it to place the worker to the specific physical demanding job, these models could still be used for providing the reference for a manual lifting guidelines, job screening and placement, assessing the physical demand for different operations, and improving the working environment.

It is clearly that the integration of ergonomics programs into the safety, quality, and productivity programs can substantially reduce the risk of occupational injuries.

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ERGONOMIC ANALYSIS AND EVALUATION OF LEMON PICKING

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Lemon pickers were studied to determine what job stresses could contribute to chronic back and shoulder disorders. The ergonomics problems included high force pinch grips, static shoulder flexion, upper and lower trunk stress and high energy expenditure. The causes in the workplace included glove and tool design, bag design, ladder design and picking pattern. The solution concepts were to be investigated with the suppliers of the tools and equipment. The grower had reservations about the willingness of the suppliers to seriously begin the necessary research and development.

INTRODUCTION

Citrus harvesting has long been considered hard work. The pickers work outside, often in the hot sun. The job includes carrying ladders and heavy bags of fruit. Often, these must be carried over uneven ground. The workload is increased by climbing the ladder with a heavy, partially loaded bag.

Over the years, the job and the tools have evolved: Ladders have been modified to lower the weight and make handling easier; cutters have been redesigned to minimize stress to the hand and wrist; and the bag has been changed so that it will hold a load of specific weight depending on the type of fruit. In an attempt to keep equipment and tool costs down, suppliers have moved toward a “one size fits all” concept. This is especially true in the design of the cutter, bag and gloves. Now, the picker’s individual needs are less of a consideration in the designs.

There is on-going research into ladder design and tool design. However, much of the research is focused on mechanizing or in some way automating the harvesting process (Prussia, 1985). Automation or mechanization is not practical for existing orchards or for small growers with little available capital. Mechanization often requires different tree spacing and shape and expensive equipment.

BACKGROUND

The employer in this study was a moderate sized, privately owned grower of lemons, oranges and avocados. The company had been in business for over a hundred years. The pickers were represented by a union. The labor/management relationship was excellent.

The company was experiencing a rise in Workers' Compensation costs. The company was working with the insurance carrier and universities on various approaches to solve the injury problems.

An analysis of the injury data from 1988, 1989 and 1990 revealed a dramatic increase in the cost of ergonomics related injuries in 1990 (Figure 1). The company decided to do an analysis of the field operations in an attempt to develop practical short- to mid-term solutions. Analysis of the injury data from the field operations showed that most of the ergonomics related injuries (60%) came from the task of picking the fruit (Figure 2).

Figure 1. Cost of ergonomics related injuries.

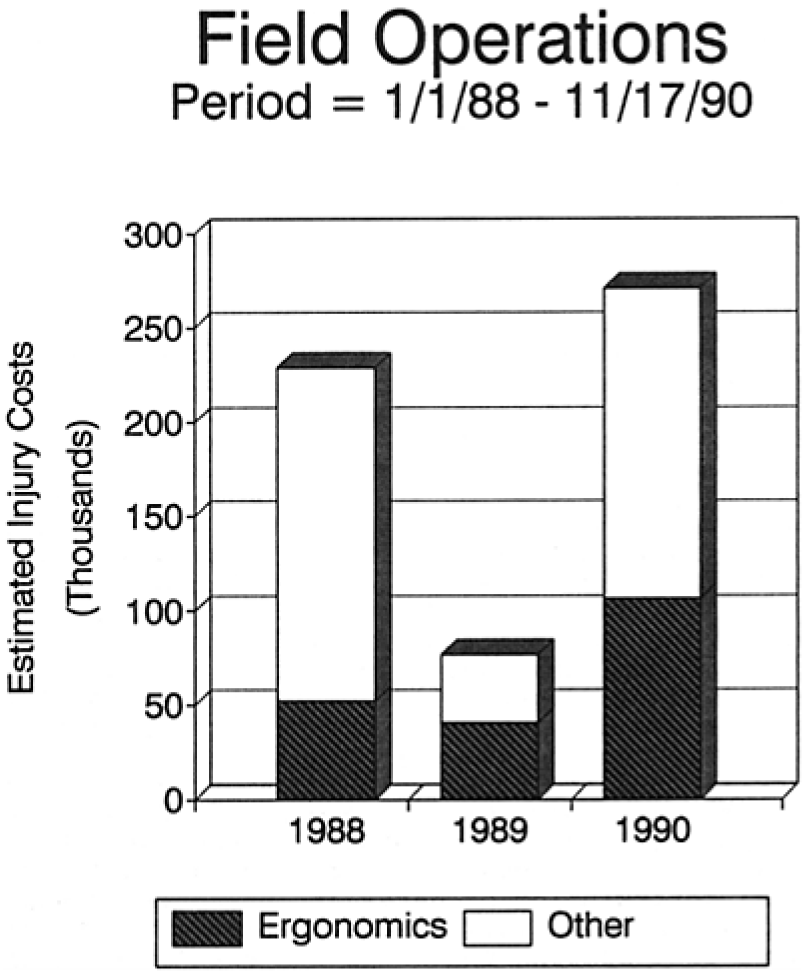
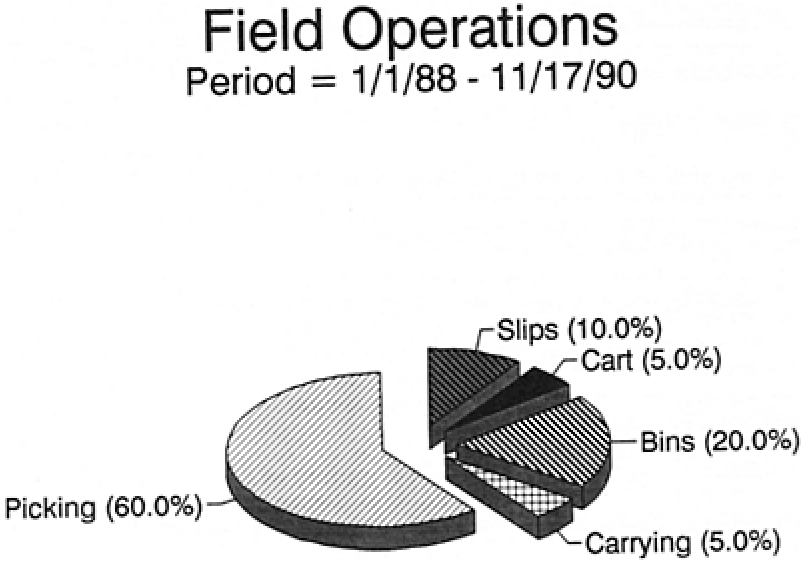


Figure 2. Distribution of ergonomics related injuries.



METHOD

Two pickers, 24 years seniority (subject A) and 8 years seniority (subject B), were video taped while doing the job in the normal manner. The video tape was used to do a detailed task analysis (Drury and Wick, 1984) of the job to determine postural stresses. The employees were interviewed to gain their input and determine how the job effected them physically. Computer programs were used to determine energy expenditure (University of Michigan, 1986), compressive forces on the L5/S1 spinal disc (Fish, 1978) and the forces on the ankles, knees, hips, shoulders and elbows (University of Michigan, 1986). Hand gripping forces were measured with dynamometers (Yonda, 1986).

The evaluation of the data was compared to criteria which has been developed to allow 90% of the population to do the work without injury. The population characteristics considered in developing the criteria included age, sex, stature and physical fitness. As a result of the evaluation of the data, the ergonomics problems could be identified and quantified; the causes of the problems could be determined; and solution concepts could be developed through brainstorming at a solution development meeting. The solution development meeting was attended by representatives of the insurance company and the employer.

Criteria used in the analysis were:

–Spinal disc compressive force—250 kg max. (Chaffin and Park, 1973).
–Energy expenditure—3 Kcal/minute max.
–Static loading—50 seconds max. (Monod, 1967).

–Pinch grip—8 pounds (3.6 kg) max.

FIELD CONDITIONS

The lemon pickers were paid on an incentive rate based on tree size and fruit size. They worked an eight hour shift with a half hour lunch break. Rest breaks were allowed at the discretion of the picker.

The tools used were:

–Eight foot (2.5 meters), 19 pound (8.6 kg) tripod ladder to access the tops of the trees;
–Fifty five pound (25 kg) capacity picker's bag with a single over-the-shoulder strap worn across the trunk;
–Angled nose lemon clippers to clip the fruit stem;
–#9 sizing ring, a go-no-go gauge.

Protective clothing included:

–Hardhat;
–Heavy leather gloves with gauntlets to protect the hand from the spines on the lexmon tree;
–Heavy cloth forearm protectors to protect the arm from the spines on the lemon tree;
–Heavy cloth chap on the leg on which the bag rested.

The orchard consisted of category 3 trees. Category three trees were 12 feet (3.7 meters) high, 20 feet (6.2 meters) in diameter spaced 24 feet (7.4 meters) trunk to trunk. There were eight trees in a group. The ground was dry and slightly uneven. The weather was sunny with a moderate temperature.

Cycle time was calculated by:

90 boxes per shift, 230 lemons per box
32 trees per shift, 3 boxes per tree
1 cycle=1 tree=15 minutes

The tools and protective clothing could be expected to be constant in all lemon picking situations. The weather, terrain, fruit density and tree spacing would vary.

RESULTS OF THE ANALYSIS

The conditions of the job imposed stresses to the back, shoulders and hands and required a high level of energy expenditure (fatigue). Stability was impaired resulting in slips and falls.

Table 1 shows the ergonomics problems and the associated causes.

Table 1. The ergonomics problems and workplace causes.

ERGONOMIC PROBLEMS	WORKPLACE CAUSES
High Force Pinch Grips	
Right—Static	Thick gloves, spines on the trees
Stressful Pinch Grips	
Right—Fingers 4,5	Tool design.
Shoulder Flexion	
Left—Static Right—Static	Picking pattern, tree shape. Picking pattern, tree shape, bag strap.
Knees	
Static	Picking pattern, tree shape
Back	
Twist	Ladder handling, tree shape
Upper Back	
Static	Picking pattern, tree shape, bag strap.
Dynamic	Ladder design, tree shape, terrain.
Lower Back	
Static Dynamic	Picking pattern, tree shape. Ladder design, tree shape.
Energy Expenditure	
	55# load, tree shape, tree separation, terrain, ditches
Stability	Narrow ladder tread.

Subject A reported pain/discomfort in upper back, bottom of feet and hands.

Subject B reported pain/discomfort in upper back, lower back, left shoulder (strap side), right hand (cutter hand) and bottom of feet. He was also fatigued at end of shift (dumped partial bags).

The ladder design and handling method had a negative impact on quality due to damage to tree limbs, broken branches, lost fruit and lost blossoms.

Many of the causes of the problems were considered beyond practical solution such as:

– Tree shape—Pruning must generally follow the natural growth pattern of the tree;
– Tree separation—Tree density in an orchard must make maximum use of available land for maximum production;
– Terrain—Orchards must follow the contour of the land;
– Ditches—Irrigation must be provided unless sprinklers are installed;
– Spines—Sharp spines are present on lemon trees.

The causes which were considered to be practical to attempt to solve were:

– Thick gloves—The thick leather gloves required high finger forces to use the cutter;
– Cutter design—The handle shape and action required high finger forces in the ring and small finger to make a cut;

– Bag strap—The over-the-shoulder strap put a majority of the load on one shoulder inducing asymmetrical loading on the spine;
– Ladder design—The tripod ladder required awkward postures of the arms, shoulders and back to place it in and remove it from the tree;
– Picking pattern—Standing up from a squat while picking the lower part of the tree and picking overhead stressed the shoulders, knees, upper back and lower back;
– Loaded bag—The maximum 55 pound load contributed to a predicted energy cost of greater than 5 Kcal/minute;
– Narrow ladder tread—The three inch (7.6 cm) tread would contribute to instability and slips and falls accidents.

Potential Solutions

One of the difficulties in developing solutions for citrus picking was that the problems identified in the ergonomics analysis have been recognized as problems for many years. Many attempts have been made by growers to make the job easier. The designs of the tools and equipment were the result of evolution over a long period of time. However, the detailed ergonomics analysis provided new information to be combined with what was already known to address the problems. Many ideas were discussed at the solution development meeting. Some were new and unique, while others were variations on old themes. The following are the concepts which were considered practical enough to investigate further:

1. Improved gloves—Develop more flexible gloves with protective leather backs, pliable cloth palms and smaller seams. It may be possible to use some of the newer materials designed to protect the wearer from puncture wounds for the back of the gloves.
2. Picking pattern—Establish a picking pattern where the lower part of the tree is picked from a squat posture loading the bag to a maximum of 50%; ladder work loading the bag to a maximum of 75%; picking while standing upright on the ground loading the bag to 100%; and no reaching higher than eye level.
3. “Vest” bag support—Develop a replacement for the over-the-shoulder bag strap similar to a vest to distribute the weight across both shoulders. The design must include a provision for easily sliding the bag from leg to leg as the picker moves about tree.
4. Improved ladder design—Develop a ladder that does not have to be “thrown” into the tree. Such a design might be a cantilever base with dish shaped skids to facilitate moving it around the tree. The ladder would have to be collapsible to allow transport to and from the orchard.
5. Wider ladder treads—Design 12 inch (30.5 cm) wide treads.

When the solutions were evaluated for effect on the ergonomics problems, it was found that improved picking pattern would have the greatest impact. The challenges with establishing an appropriate picking pattern were three: (1) The pattern can vary considerably with fruit density; (2) Implementation would require training pickers to break old habits; (3) Diligent supervision would be necessary to insure compliance. Establishment of "new" picking patterns would be more effective if combined with the other potential solutions.

The other potential solutions, however, depended on the cooperation of tool and equipment vendors. The company tried to affect changes in tools and equipment in the past. Not all of the attempts were successful.

Many manufacturers of tools and equipment cite the high costs of research and development (R&D). They believe ergonomics "does not sell" and the cost of R&D can not be justified. Equipment, such as ladders, must be thoroughly tested to ensure their safety. That testing is costly. For these and other reasons, the vendors are reluctant to make changes.

Such was the case in this project. Many of the problems remain unsolved because properly designed equipment is not available at reasonable cost.

DISCUSSION

Many of the ergonomics problems with lemon picking could be accurately identified and quantified using an appropriate analysis methodology. The data allowed the analyst to precisely determine the work/workplace causes of the problems. The potential solutions seemed simple enough. Solution became difficult when the company had to rely on recalcitrant vendors.

Suppliers of tools and equipment must begin to accept more of the responsibility for ergonomics related injuries. They need to design safer products and be more responsive to solving problems caused by their products. This includes redesigning existing products.

Too often the answer would seem to be to automate. However, most of the time automating is not at all practical. That is the situation in lemon harvesting. Major changes must occur in orchard layout and tree selection. These changes are not feasible for existing orchards. Thus the need to solve today's problems with modifications of today's tools and equipment.

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ERGONOMIC ASSESSMENTS OF THE IDAHO NATIONAL ENGINEERING LABORATORY LAUNDRY AND RESPIRATOR CLEANING FACILITY: A CASE STUDY

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The Idaho National Engineering Laboratory (INEL) is a multifaceted U.S. Department of Energy site. EG&G Idaho, Inc. is the prime contractor for the site, and as such, performs a number of support services, including the laundry service and respirator cleaning service. This paper presents an ergonomic assessment conducted at the laundry and respirator cleaning facility at the INEL. Descriptive background information, the methodology employed, the types of ergonomic problems encountered, and recommendations for resolving concerns found are presented.

INTRODUCTION

The Idaho National Engineering Laboratory is a multifaceted U.S. Department of Energy site that performs a variety of engineering and research functions. Nuclear technology is the primary area of engineering and research activity. EG&G Idaho, Inc. is the prime contractor for the INEL and, as such, performs support services for the entire site in addition to technical, research, and development functions. These support services include warehousing, food service, bus service, laundry service and respirator cleaning service. The EG&G Idaho Industrial Hygiene Initiative identified potential areas that were not ergonomically sound. As part of the Initiative, ergonomic assessments were conducted at fifteen of the identified areas. This paper focuses on the assessment conducted at the INEL Laundry and Respirator Facility.

The INEL Laundry and Respirator Facility has 15 employees. One of the unique characteristics of the facility is that it proesses both very low-level radioactively and potentially contaminated (“hot”) and non-contaminated (“cold”) laundry and respirators. While that is a unique characteristic, the ergonomic concerns are similar for both hot and cold processes. The facility processes approximately 900 kg of very low-level radioactively contaminated (“hot”) laundry and 560 kg of non-contaminated (“cold”) laundry per day. The hot and cold laundry is processed in the same building, although the two processes are physically separated by a wall. In the same building, employees clean, inspect, and repair 125 respirators daily. The majority of the respirators cleaned are “cold”. Please note that this paper is not intended to present the respirator and laundry cleaning processes in detail.

METHODOLOGY

The ergonomic assessments were conducted by a team made up of trained ergonomists of the EG&G Idaho’s Human Factors Research Unit. The primary aid, an ergonomic checklist, used by the team was developed specifically for use in conducting the assessments. The checklist addresses eight areas, including

- accident/injury information,
- general office requirements,
- general industrial requirements,
- lifting,
- repetitive motion,
- workstation design,
- vibration, and
- glove box/laboratory hood design.

The first section of the checklist is a set of questions formatted as a flow diagram is assist the user in determining which sections of the checklist should be completed to conduct a thorough ergonomic assessment of each work site. Further information on the checklist and its development can be found in Ostrom, Gilbert, and Hill (1992) and Ostrom, Gilbert and Wilhelmsen (1991).

The assessment process consisted of three parts. First, a review of accident statistics available from the company was made. Next, an initial walk around of the work place was done to meet the supervisors and employees, to see the facility in operation, and determine potential problem areas and effort needed for the detailed assessment Then, a detailed assessment of the facility was done. The detailed assessment included several days of observation, discussions with the personnel, and collection of data regarding the physical layout and design as well as the job functions being performed.

Sources consulted in developing the ergonomic checklist and the general assessment approach include Ayoub and Mital (1989), Calisto et al (1986), McCormick and Sanders (1982), NIOSH (1973), NIOSH (1981), Putz-Anderson (1990), and Rodgers (1983).

FINDINGS

Many ergonomic concerns were found during the assessments. The finding are presented separately for the respirator and laundry facilities. In addition, findings are presented for the hot and cold areas for each of the processes.

Respirator Cleaning Facility

In general, the respirator cleaning process consisted of receiving respirators from field locations, washing the respirators, inspecting the respirators and repairing them as necessary, and then bagging the finished respirators for use. Although the processes for hot and cold respirators is similar, there are sufficient differences that a separate discussion of each process and associated findings from the ergonomic assessment is warranted.

Hot Respirator Cleaning Process.

Respirators arrive at the respirator cleaning facility in large polyvinyl alcohol bags (approximate size 661). The bags of respirators are placed by the delivery personnel into a radiation survey station that is installed in the exterior wall of the facility. The bags are pushed through the survey station manually and each bag of respirators sits on a platform at the end of the survey station until retrieved by an employee of the laundry. If the bag of respirators is found to be contaminated above a certain level of radioactivity, special procedures are followed and precautions taken which will not be discussed in this paper. Approximately one bag of hot respirators arrive at the facility per day. The maximum weight of a bag of respirators is approximately 20 kilograms. The standard practice was to lift the bag of respirators from the survey station and lower it to the floor. An employee then dragged the bag of respirators to a scale where it is weighed. Weighing the bags of respirators ensures a mechanic has not inadvertently placed a tool or other object in the bag. The bag of respirators was then dragged to the cleaning room where the bag was lifted and placed into a large industrial dishwasher. Since the bag is made of polyvinyl alcohol it dissolves in the dishwasher. It was found that the employees do not have adequate means of moving large bags of respirators to and from the work stations. In most cases the bags of respirators are dragged or carried. This condition can cause back stress. It was recommended that a cart be used to move the bags of respirators. Using a cart would eliminated the need to lower the bag of respirators to the floor and then lifting it into the dishwasher. An additional advantage is that the bag could be weighed while on the cart and eliminate the lifting to and from the scale.

After being washed the respirators are placed in a dryer. From the dryer the respirators are inspected At this point, the respirators are considered “clean” and radioactivity is at background levels. The inspection process involves placing the respirator on a mimic of a human face called a boot The boot has holes in the top that pull a vacuum on the face side of the respirator. The inspector then used an air gun to spray a leak detector chemical around the sealing surfaces of the respirator. The inspectors had to deviate their wrists in an apparently stressful manner in order to actuate the trigger on the gun and spray detector on all sealing surfaces. For approximately 80% of the respirators, the exhalation valve failed the inspection and had to be repaired. The respirator then had to be re-inspected. The valve inspection task appeared to be a more stressful task because of the wrist motions involved than the valve repair task. To eliminate the extra motions required by the inspection, exhalation valve repair, and then re-inspection of the respirator, it was recommended that the exhalation valve be repaired, if needed, on all respirators before the inspection task was performed. Also, a redesign of the spray gun was suggested. The redesigned gun would allow the inspectors to keep their wrist in a more neutral posture while performing the inspection task.

After inspection and any needed repairs, the respirators were placed in individual plastic bags and heat sealed. Then up to 20 respirators are placed in large plastic bags for delivery to the storage facility. In this step the employees draped the opening of the bag over the lip of a drawer and dropped the respirators in the bag. The bag was then tied off and dragged to the door of the facility where the respirators awaited pick up. It was recommended that a cart be made with a jig will hold the large bag open while it is filled with bagged respirators. The bag could then be tied closed and then moved around without excessive handling.

Cold Respirator Cleaning Process

The cold process involved steps similar to the hot process except the bags of respirators arrive in large plastic bags and are placed on the floor by the delivery door. There was no need to pass the bags through the radiation survey station. From their arrival point, the bags of respirator are dragged to a scale and weighed. The bags were then dragged to the cleaning room. The bag was then untied, lifted, and the respirators poured into a sink. The respirators were then carried one or two at a time to an industrial dishwasher. It was again recommended that a cart be used to move the bags of respirators from work station to work station.

Additional Respirator Operations

The respirator cleaning area also repairs self-contained breathing apparatus (SCBA). Employees performed work on SCBA regulators while seated. The work bench was not designed for seated work. It was basically a lab bench with drawers and cabinets doors. It was recommended that the lab bench be modified to accommodate seated work.

Laundry Operations

In general, laundry operations include delivery, cleaning, drying, folding, and bundling of laundry. The following is a description of the laundry cleaning process, the ergonomic concerns found and recommended solutions.

Hot Laundry Cleaning Process

The hot laundry primarily cleans coveralls and anti-contamination (anti-cs) suits that may have been potentially contaminated with radioactivity. The dirty laundry arrives in polyvinyl alcohol bags. In the laundry facility the bundled laundry was dragged from the arrival point, weighed, and then dragged to the “hot” washing machines. The bags are then lifted and placed, bag and all, into the machine. These washing machines are side loaders with two openings. In this process, the dirty laundry always is placed in one opening and the washed laundry always comes out of another opening. The two openings are on either side of a wall. This division ensures dirty laundry does not contaminate the clean laundry. The wet, clean laundry is pulled out of the washers and placed in spring loaded carts. Because the laundry is wet, it weighs considerably more than when dry. The loaded carts are then pushed to the dryers and the laundry was lifted from the cart into the dryer. The steps just described require a considerable amount of manual handling in awkward postures. It was recommended that a conveyor system be used to move the laundry from its arrival point in the facility to the washer and then from the washer to the dryer. The employees would still need to be involved in loading the laundry onto the conveyor, but the amount of manual lifting and lowering and associated awkward postures would be reduced.

The laundry from the dryer was then placed in spring loaded carts and pushed to the radiation survey room. The door to the survey room swings out into the dryer room. This was found to be a problem because the employees usually opened the door with one hand and pulled the cart through with the other hand. This operation placed required the operator to attain a very awkward posture. It was recommended that the door open both ways.

Each pair of coveralls or anti-cs was then stretched out on a radiation survey table. The garment was then surveyed by the instrument for radiation contamination. After survey the garment was pull from the survey table and placed on a table. Another garment was then placed on the table. While the instrument surveyed the next garment, the first garment was folded. After folding, the garments are stacked and bundled with twine. It was found that the heights of the tables where the garments are folded were not proper for the majority of the employees and it was recommended that tables with adjustable work heights be used. The bundles of coveralls and anti-cs were then placed on carts and pushed to the loading dock door where they awaited pick up.

Cold Laundry Cleaning Process

The cold laundry was primarily for towels used in the shower rooms and some non-contaminated coveralls. The cleaning process is similar to the hot laundry except the washers and dryers are in the same room. Also, the volume of laundry handled was considerably less. However, it was recommended that a conveyor system be used to move the laundry from work station to work station. As in the hot laundry, the tables where the laundry was folded were too low.

Additional Laundry Operations

The loading dock was not the same height as the back of the laundry delivery truck. As a result, the laundry was lifted and carried in and out of the back of the truck onto the loading dock rather than utilizing a hand truck or push carts. The bags of laundry are heavy and bulky, and employees make frequent lifts. These elements create the potential for causing back stress. It was recommended that the loading dock be modified so it would directly meet the back of the truck. A properly matched loading dock and truck allow the use of hand trucks, carts, or other manual materials handling equipment to transfer loads of laundry with reduced potential for injury.

CONCLUSIONS

The ergonomic assessment approach, including the use of the checklist, was successfully used to identify a number of ergonomic problems in the respirator cleaning and laundry facility. For the most part, relatively easy solutions were found to reduce the stress associated with these problems. The solutions included utilizing carts to move bags of respirators rather than carrying them, using a conveyor system to move laundry to and from the various machines, and modifying the loading dock so that the manual handling of the laundry could be avoided as much as possible. Some of the solutions have been implemented and have proven effective. Others are being evaluated by the facility management.

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AN ERGONOMIC EVALUATION OF THE PALLET REFURBISHING PROCESS

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INTRODUCTION

The purpose of this study was to perform an ergonomic evaluation of the job risk factors encountered during the pallet refurbishing operation in the soft drink beverage distribution business. The pallet refurbishing operation, manned by two to four employees, is responsible for processing approximately 1000 pallets during each ten hour workday. The job is characterized by three basic components: pallet sorting, pallet refurbishing, and clean-up. A description of this process follows.

Upon arrival at the plant, all pallets are transported by forklift truck to the pallet work area which is located outdoors. An initial sort requires the manual lifting, inspecting, rotating, carrying and lowering of each sixty pound pallet. The lifting is performed by a single employee without the aid of a mechanical lifting device. This initial sort allocates each pallet into one of three stacks: good, thus requiring no repair, irreparable, or repairable. The stacks of pallets are then transported by forklift truck to their respective destinations, i.e., to await future use, garbage dump, or refurbishing area.

From the stack requiring repair, each pallet is manually lifted, visually scanned to detect the location of damage, then carried to and placed on the repair table if judged repairable; otherwise, it is placed in a discard pile. The damaged wood is removed with a crowbar and the scrap wood is thrown a distance of three feet into a dumpster. Protruding nails remaining in the pallet are hammered into the pallet. A new board is then put in place of the damaged one and attached using a nail gun. Repairs continue on both sides of the pallet until it is refurbished. The repaired pallet is manually lifted off the table and carried two to four feet and placed on the repaired stack. The stack of repaired pallets is piled from the ground to a height of twelve pallets (60 in.), then a forklift removes the stack.

In addition to sorting pallets, refurbishing pallets and driving the forklift truck, the employee is also responsible for clearing the work area of debris generated during the sorting and refurbishing processes. This includes both nonwork generated garbage which arrived with the pallets and junk wood, nails, and nail clips accumulated during the refurbishing process.

The company employes individuals supplied by a temporary service; employee turnover is high with employment durations of a few days to two years.

METHOD

Work in progress was surveyed for determination of job risk factors. The ergonomic analysis consisted of (1) observing and photographing employees performing job tasks, (2) recording workstation dimensions, (3) conducting brief informal interviews with the employees, (4) collecting work content data, and (5) examining the previous year's weather patterns.

The survey revealed that potential hazards fall into the following categories: lower back injuries, environmental stress, cumulative trauma disorders of the upper limbs, and general safety hazards.

Back Injuries

Low back problems are often associated with the size and duration of the compressive force on the spine and the lifting frequency of the job. Specific work-related risk factors of back injuries in manual material handling include lifting, twisting, bending, reaching, carrying, excessive weights, and job satisfaction. Lifting tasks were evaluated using three approaches: the biomechanical approach, the physiological approach, and the psychophysical approach (Ayoub, et al., 1986).

The biomechanical approach recommends weight limits for lifting based on the amount of force placed on disks in the lower back region. In general, the force on the back can be mapped, as shown in Figure 1, as a function of two variables: The weight of the lifted load and the distance from the load's center of gravity to the spine. Lifting tasks producing compressive forces on the lower back in excess of 1340 pounds are considered hazardous (NIOSH, 1981).

The physiological approach recommends limits based on the metabolic energy expenditure of lifting loads (i.e., oxygen consumption, heart rate). In general, the energy expenditure required by the task is a function of 3 variables: the weight of the load, the frequency of lifting (lifts per minute), and the position the body assumes to lift the load. Figure 2 shows equal 5 kcal/min curves based on the model reported by Garg (1976). Lifting tasks which require an energy expenditure exceeding 5 kcal/min should be redesigned.

The psychophysical approach is used to determine the weight of lift which is acceptable for an individual. The method described by Ayoub, et al. (1986) considers the variables: range of lift, frequency of lift, population percentile, load size and gender of subject.

When any one of these three approaches suggests that job redesign is necessary, corrective actions or redesign of jobs to reduce risk is indicated. Corrective actions typically include: anthropometrically determining optimum work height, redesigning the work layout plans, and redesign of the load.

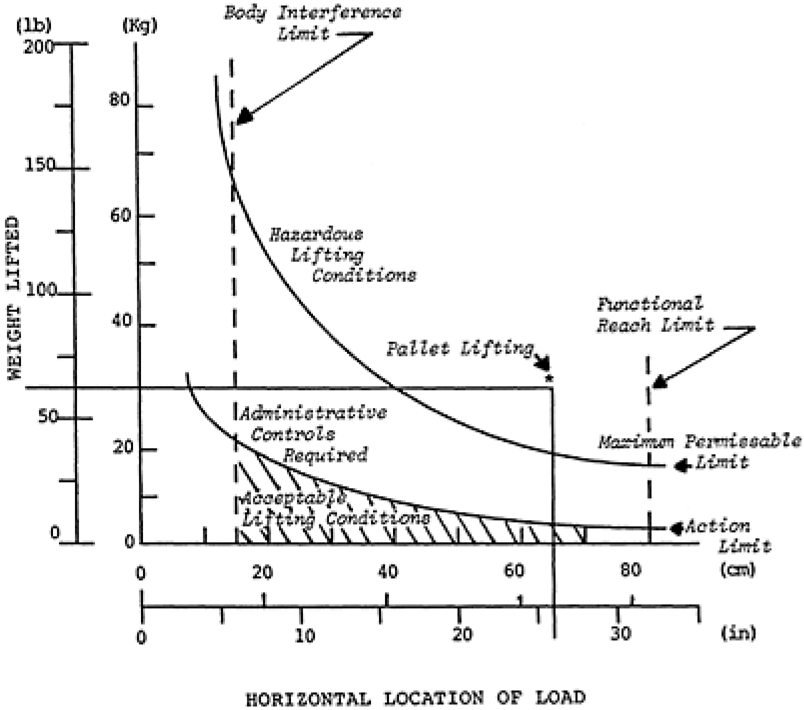

Figure 1: Lifting Regions Established by NIOSH Guidelines

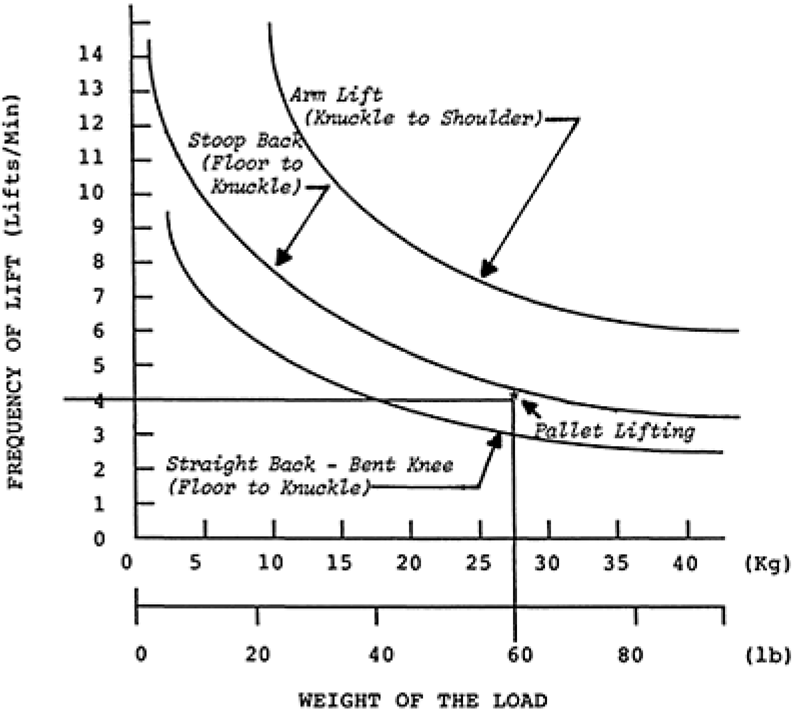

Figure 2: Weight of Load Based on Physiological Criterion (Adapted from Ayoub, et al., 1986)

The effects of risk factors can also be reduced through strength and fitness testing and training, work enlargement, worker rotation and training.

Environmental Stress

For exposure to hot environments, the National Institute for Occupational Safety and Health (NIOSH) recommends that a Heat Alert Program be implemented when the National Weather Service forecasts that a heat wave is likely to occur (NIOSH, 1986). A heat wave occurs when the temperature exceeds 95 degrees Fahrenheit or when temperatures over 90 degrees are 5 degrees higher than the preceding days. The 95 degree temperature is a reasonable alert limit in areas of low relative humidity such as West Texas. Data specific to the site evaluation, obtained from the National Weather Service, was used to examine the environmental stress experienced during the year prior to the study.

Cumulative Trauma Disorder of the Upper Limbs

Work-related cumulative trauma disorders have been associated with jobs that include the following factors: (1) repetitive movements of the upper limbs, (2) forceful grasping of tools, parts, and loads, causing direct pressure on skin and muscle tissue, (3) awkward positions of the hand, arm elbow, shoulder, neck and head, (4) fatigue due to insufficient rest, and (5) vibration caused by hand tools. Cumulative trauma disorders which might be expected with pallet work are tendinitis, lateral epicondylitis, rotator cuff tendinitis and carpal tunnel syndrome.

RESULTS

Company records were used to calculate work content per employee. Data from twenty days of work during the months of May to October were randomly sampled to determine frequency of lift and total weight handled per employee. The records included the number of workers per day, good pallets sorted, junk pallets (sorted), pallets to repair (sorted), and pallets repaired.

Assumptions of the average number of times each pallet was lifted were two, three, two, and three for good, junk, sort to repair and repaired pallets respectively. Rehandling occurred because a pallet must be inspected over its entire surface area and carried from stack to stack or table. It was estimated that when two to four workers were employed, each individual lifted a total daily average weight of 71,500 pounds, varying from 47,000 pounds to 100, 500 pounds per day, depending on the work content.

During the period of evaluation, two workers were employed. By decreasing from 4 to 3 to 2 workers, the average number of pallets processed per day decreased from 1600 to 1300 to 1200 pallets; however, the total average weight lifted per employee increased from 53,000 to 56,000 to 80,000 pounds respectively. Thus, as the number of workers decreased, each worker remaining on the job “picked up part of the slack” by increasing his individual productivity. Based on a ten-hour workday with two employees, in which an average 280 pallets were repaired, each repair requiring three minutes, the average lifting frequency was four pallets per minute. The work content data was used to analyze lifting tasks for risk of potential back injury.

The biomechanical approach evaluates the amount of force placed on the lower back as a function of the weight of the load and the distance the center of gravity of the load weight is from the spine. Load weight is 60 pounds and pallet dimensions are 36 in.×36 in.×5 in. This places the load’s center of gravity a distance of 26 inches from the spine (8 in. body interference+1/2*36 in. pallet size). As shown by the asterisk in Figure 1, the compressive force on the back from the pallet lifting task exceeds the Maximum Permissible Limit (MPL) of 1430 pounds established by NIOSH (1981).

The physiological evaluation approach is used to determine whether the energy expended on a task is at an acceptable level. Physiological limits can be mapped as a function of load weight, frequency of lift, and body position. For a lifting frequency of four lifts per minute, using a stooped back posture for lifting 60 pound pallets, the asterisk in Figure 2 indicates that energy expended during the sorting task is within the 5 kcal/min physiological limits; thus, the task is acceptable according to the physiological criterion.

The psychophysical limits are based on the amount of weight an individual feels he is capable of lifting given the set task conditions. In this pallet lifting task, three conditions were analyzed: lifting from the ground to pallets stacked at shoulder height, lifting form the ground to knuckle carrying height, and lifting from knuckle carrying height to shoulder height. Using the method described by Ayoub, et al. (1986), acceptable loads for four lifts per minute were 30.8 pounds, 36.8 pounds, and 32.4 pounds, respectively, at these three height conditions for the average (fiftieth percentile) male. From a psychophysical standpoint, the 60 pound pallets are too heavy (when lifting at a frequency of four lifts per minute) for the three lifting conditions.

Examination of the pallet refurbishing workstations in current use showed they were fabricated by stacking several wooden pallets, nailing them together for stability and then covering the top with a wood mat to create a work surface area. The heights of the two workstations are 31 inches and 36 inches. According to good anthropometric design, the height at which heavy work is performed should be in the range 35.5 inches to 39.5 inches from the floor (Ayoub, 1971). Specifically, the work should be performed at 8 inches below elbow height. In the case of the pallet task, in which the pallet is 5 in., the work is currently performed in the 36 inch to 41 inch range. The use of stacked pallets caused one station to have insufficient foot space for the worker, causing the worker to assume a stooped posture while working. The use of stacked pallets as a workstation presents further hazards. The wooden pallets and the top mat were in poor condition, e.g., with broken, uneven edges and protruding nails.

All work in the pallet refurbishing operation is performed outdoors, thus employees are subjected to existing environmental weather conditions including sun, heat, cold, rain, snow, and winds. The National Weather Service reports were consulted for a one-year period to determine the occurrence of undesired weather conditions. By totaling the days in which work would have been interrupted, including days in which NIOSH would have recommended a heat alert program, and days of extreme cold, rain, and snow, it seems that for a year, as many as 1/6–1/7 of the total number of work days (27–33 work days) may need some form of work restriction due to inclement weather.

Employees of the pallet refurbishing operation are exposed to risk factors associated with the development of cumulative trauma disorders. The workers complete repetitive movements of the upper limbs in awkward postures during the lifting process. When only two workers are employed on the job, the work rate is increased to keep up with job demands, thus not allowing for sufficient rest breaks to recover from fatigue. Also, when only two workers are employed, the total weight moved throughout the day is excessive. The refurbishing operation requires forceful grasping of the pallet, hammer, and crowbar. This risk factor is magnified by poorly fitting gloves. The gloves used by at least one of the workers were observed to be loose fitting and in deteriorating condition. The use of such gloves causes the worker to grasp an object more forcefully than normal, thus exacerbating the problem. Gloves in such a deteriorated condition expose the worker to the hazard they were originally designed to eliminate.

CONCLUSIONS

Potential hazards of the pallet refurbishing operation include lower back injuries, environmental stress, cumulative trauma disorders and general safety hazards. Evaluation of the lifting task indicated that the task is unacceptable and requires the implementation of engineering controls. It was recommended that the company conduct a cost/benefit analysis and consider gradually replacing wooden pallets with lighter and more durable plastic pallets. Additional advantages of plastic pallets include: recyclability, freedom from splinters, low maintenance and longer life expectancy.

To reduce the frequency of lifts, an initial sort may be performed prior to shipping the pallets to the refurbishing operation. Currently all pallets are gathered and shipped to the pallet refurbishing area regardless of damage. A pre-sort would reduce the overall handling and shipping performed by the company, as well as the amount performed by the refurbishing operation.

The workstations were unsatisfactory. In general, anthropometrically, the heights of the stations were acceptable; however, a height adjustable station, such as a scissor lift table, would permit workers to select a comfortable work height which may change throughout the day. A table would also permit adequate foot room and allow work to be performed in an upright posture. A permanent workstation would remove hazards posed by protruding nails and deteriorating wood. An adjustable table also has the potential of decreasing the amount of lifting and heights of lifts.

Workers were exposed to environmental conditions ranging from excessive heat (102 degrees Fahrenheit), rain, wind and snow. Data from the National Weather Service showed that according to NIOSH recommendations, a Heat Alert Program should be instituted by the company.

The highly repetitive work and awkward postures assumed indicate that employees may be at risk of developing cumulative trauma disorders of the upper limbs. Due to the high worker turnover rate and the use of an outside temporary service, there were no company medical records for the employees of the refurbishing operation. It was recommended that the company institute a medical surveillance program for the early detection and prevention of low back and cumulative trauma disorders.

Recommendations to help alleviate the risks of developing cumulative trauma disorders included: suspending the nail gun above the work table to decrease the amount of searching, stooping, lifting and hand grip force used; considering the use of bent-handled hammers (Konz, 1986); and using properly fitting gloves which are maintained in good condition to decrease the required grip force and potential of slippage.

General safety considerations may be evaluated through the use of safety checklists. Sight specific recommendations included eliminating tripping hazards by moving electrical cords and repairing uneven walking surfaces, and requiring the use of safety glasses to protect eyes from missiles and dust.

These recommendations were produced through the use of a systematic procedure to conduct worksite ergonomic evaluations.

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THE EFFECT OF MAILBAG DESIGN ON LATERAL TRUNK MUSCLE FATIGUE

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The effect of three different mailbag designs on lateral trunk muscle fatigue as investigated. A double bag which divided the load between the two sides of the body significantly reduced lateral trunk muscle fatigue. A conventional mailbag with a waist strap did not reduce fatigue significantly.

INTRODUCTION

Musculoskeletal disorders are one of the most frequent and disabling conditions effecting people during their productive years. This is supported by the fact that musculoskeletal disorders are second only to cardiovascular disease as a cause of occupational disability (Kelsey, White, & Pastides, 1979; Wells, Zipp, Schuette, & McEleney, 1983). Attempting to alleviate this problem, industrial programs have focused on improving safety measures, training personnel in proper lifting techniques, and identifying individuals thought to be at greater risk for musculoskeletal injury. The U.S. annual direct cost in terms of lost wages due to musculoskeletal problems approaches $5 billion dollars, and indirect cost estimates are twice this amount (Wells et al., 1983). The continuing expense of the problem attests to the need for more effective preventive strategies.

Letter carriers are an occupational group that is at risk for musculoskeletal disorders (Miller & Murray, 1984). Wells et al. (1983) estimated that from 1975–1980, 64% of disability retirements among letter carriers were due to musculoskeletal problems. Furthermore, an additional 21% of workers not receiving disability retirements experienced musculoskeletal problems while working. Studies have demonstrated that between 30% to 70% of letter carriers experience low back pain (Miller & Murray, 1984; Wells et al., 1983) Wells et al. (1983) and Miller and Murray (1984) hypothesized that the carrying load was a source for the increased spinal disorders. Page (1984) found that the direct compressive load on the spine was minimal but that muscular fatigue of the trunk muscles opposite or contralateral to the load may occur after 3 minutes of carrying 35 pounds. Page concluded that a source of low back disorders in letter carriers was fatigue of the lateral trunk muscles, in combination with shear forces from an asymmetrical load on the spine. Page also demonstrated that wearing a pelvic waistbelt to support the load reduced the required contractile force of the contralateral trunk muscles.

The United Postal Workers Union and the Salt Lake City Post Office contracted with personnel at the Mechanical Engineering Department at the University of Utah to design a more mechanically efficient mailbag. The most common type of mailbag is the standard mailbag or U.S. Post Office Mail Satchel The maximum amount of weight carried in a standard mailbag by regulatory enforcement only is 35 pounds (United States Post Office, 1985). When loaded on the shoulder, the standard mailbag rests against the ipsilateral side of the pelvis producing an asymmetrical load on the spine. The models developed by the University of Utah were designed to distribute the mail load more symmetrically than a standard bag. One model, a side pack, includes a pelvic assist (waistbelt) and the other model, a double bag design, consists of two side packs supported by a pelvic waistbelt. These three mailbag configurations are shown on Figure 1. The purpose of this study was to determine which mailbag causes less fatigue of the lateral trunk flexors.

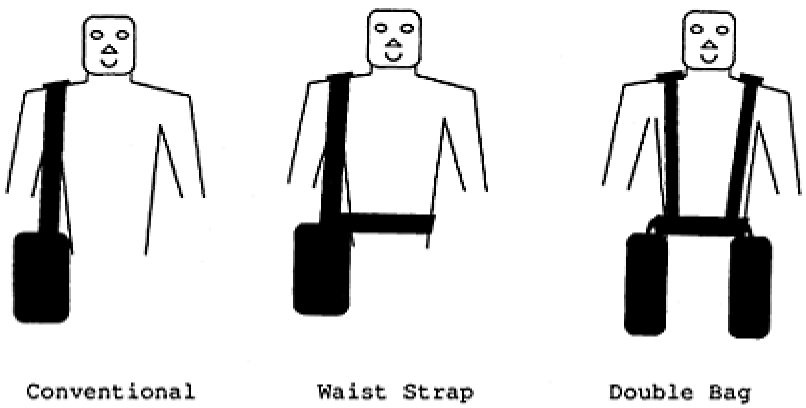

Figure 1 Mailbag Types

METHODS

Pilot Studies

Pilot studies were performed to obtain test-retest reliability data for the lateral trunk flexion fatigue test (LTFF test) developed for this study. At the same time of day, over a 3 day period, one investigator performed the test on 6 subjects. The LTFF test consisted of positioning subjects on their right sides with their superior iliac crest resting on the edge of a padded bench. The musculoskeletal challenge which was used to invoke fatigue was an isometric endurance task. This task consisted of measuring how many seconds the subject was able to keep the unsupported upper part of the body horizontal Fatigue was operationally defined as the time required for the subject to drop 2 inches below a horizontal marker after the investigator gave the subject one opportunity to correct horizontal alignment., The reliability coefficient for all 3 days was .76. Removing the first day's results from the analysis as well as the results from a subject who experienced delayed onset muscle soreness, improved the reliability to .96. These data demonstrated a learning effect with a plateau of times occurring for the final two trials.

A second pilot study was performed to determine if the LTFF would be sensitive enough to measure fatigue experienced while carrying a side pack. The LTFF test was administered before and after walking a simulated mail route. Subjects 1 and 2 walked for 30 minutes; subject 3 walked for 45 minutes; and subject 4 walked for 70 minutes. Each subject carried 30 pounds in a side pack without a waistbelt. The subjects underwent three trials with 30 minutes rest in between trials to minimize the effect of latent fatigue. The results showed that 30 minutes provided sufficient time for recovery from muscle fatigue. The difference between pre and post fatigue scores increased as walking time increased, thereby demonstrating a dose-response relationship. Also, there was no overlap of pre and post-test scores, demonstrating sensitivity of the test to fatigue. The test possessed a discriminatory function to identify individuals unable to maintain a required work output.

A third pilot study analyzed the prime muscle movers for lateral trunk flexion. Electromyography (EMG) analysis confirmed that the contralateral external obliques and the iliocostalis were active both while walking with a standard mailbag and during the LTFF test. Congruent validity was demonstrated when the EMG data revealed that the prime muscle movers responsible for carrying a standard mailbag were active during the LTFF test (Bogduk & Twomey, 1987).

The test method for measuring fatigue of the lateral trunk flexors has a subjective element. This is due to the fact that the test relies on the maximal effort of the subject and the consistency of the investigator conducting the LTFF test. The subject's movement was video recorded using a Motion Analysis System to assess the accuracy of the investigator and the protocol was standardized to reduce measurement errors of the investigator. Fatigue was operationally defined as the time required for the subject to drop 2 inches below a horizontal marker. Subjects were given similar verbal encouragements to perform maximal effort for every test. Other limitations are (a) nonrandom, small sample size; (b) the fact that low pain tolerance may prevent consistent measures during the fatigue test. Delimitations of this study include the selection of only: (a) healthy, male subjects between the ages of 18–39; (b) above 5′4″ in height, and (c) with right-side dominance.

The following hypotheses are specific to this study:

1. Subjects carrying a side pack with waistbelt experience less fatigue (measured by the LTFF test following a simulated mail circuit.) than subjects carrying a side pack without a waistbelt.
2. Subjects carrying a double bag with a waistbelt experience less fatigue than subjects carrying a side pack without a waistbelt.

3. Subjects carrying a double bag with a waistbelt experienced less fatigue than subjects carrying a side pack with a waistbelt.

Subjects

Healthy, right-handed volunteer male subjects were recruited from undergraduate engineering and science classes at the University of Utah. They were between the ages of 18–39 years, 173–198 cm in height, 61.2–95.7 kg in weight. Subjects completed a medical history questionnaire to screen for any history of low back pain. All subjects read and signed an informed consent form. In a previous study (Sebesta, 1991) males below 5′ 4″ inches in height complained of subjective discomfort and fatigue carrying the double bag therefore, only males above 5′4″ in height were tested.

Procedures

Subjects carried three different mailbags during a 1 hour simulated mail delivery route. The order of mailbags carried by the subjects was randomized. The 3 mailbags carried by the subjects were the United States Post Office Mail Satchel, a side pack with waistbelt assist, and a double bag design with waistbelt assist. Subjects carried 35 pounds in each trial, and received a 30 minute rest between trials to minimize the effect of latent fatigue. Time-to-fatigue of the left lateral trunk muscles was measured before and after each circuit.

The lateral trunk fatigue test followed guidelines established for the Sorensen's fatigue test. The subjects were positioned on their right side, on a Saba Angle Bench. They placed their right arm across their chest and their left arm along the left side of their body. Braces anchored by C-clamps prevented hip rotation and the subject's superior iliac crest rested on the edge of the bench. The time-to-fatigue was measured while the subject held the unsupported, upper body in horizontal alignment with the table. Horizontal alignment was measured by correlating a marker on the C7 spinous process to an adjustable external marker on a stationary post. The test was terminated when the subject fell 2 inches below the horizontal marker after the investigator gave one opportunity to correct horizontal alignment.

The mail delivery route was inside with obstacles to simulate a letter carrier's job as closely as possible. The course, .23 miles in length, was circular with one set of 4, 4″ steps, one set of 6, 6″ steps and 3 push open doors. Subjects began the course by climbing the 4″ steps and then ambulating .13 miles. Next, subjects walked through two push open doors and immediately climbed the 6″ steps. The subjects finished the course by ambulating another .1 mile and opening an outside push door for a breath of fresh air. For each trial the subjects ambulated a total of 2.53 miles at 100 paces per minute. Subjects were paced using a metronome, ensuring the same absolute workload between subjects.

The total testing was accomplished over three days. The fatigue test was performed on the first day to familiarize the subject with the test's protocol. On the second day the subjects performed the fatigue test a second time. On the third day the subjects returned a final day to perform a fatigue test before and after carrying 3 types of mailbags for 1 hour. The time-to-fatigue of the lateral trunk muscles was measured on three consecutive days at the same time of day. These scores pcalculated a second reliability coefficient (n=12).

Three trials were performed on the third day. for each trial the time-to-fatigue of the lateral trunk flexors was recorded before and after the one-hour performance of the simulated mail delivery route. A 30 minute rest period was allowed between trials and a 1 minute rest between the fatigue tests and the simulated mail carrying.

A one-way ANOVA of gain scores tested the data for significance. A difference score was computed by subtracting the post-test score from the pre-test fatigue score. The pretest data are used to adjust the post-test means to account for initial differences between treatment groups and increase the power of the analysis by reducing the within-group variability (Huck & McLean, 1975). Tukey's post-hoc comparison determined which groups significantly differed. Reliability coefficients for the isometric fatigue test were calculated using Cronbach's Alpha.

RESULTS AND DISCUSSION

This study investigated three different carrying devices and the resultant effect on trunk muscle fatigue. To assure that the treatment effects did not originate from measuring errors of the isometric fatigue test, a reliability coefficient was calculated. The reliability of the visual fatigue test was calculated prior to this study in a pilot study where Coefficient Alpha=.97 (n=5). Because the sample size of the pilot study was small, data were collected to calculate a second reliability coefficient. Test-retest reliability was calculated after 12 subjects performed the fatigue test over a 3 day period at the same time of day. The data from subjects were analyzed using the SPSS reliability package. The testretest reliability coefficient was .87.

The appropriateness of the isometric visual fatigue test was validated through the use of an objective (Motion Analysis) system. The time for the subject to drop 2 in. according to the visually measured isometric fatigue test should correlate positively with the time as measured by the Motion Analysis System. The means for the visual fatigue test for day 1 and day 2 were 98.96 sec. and 114.38 sec., respectively. The means for the Motion Analysis data for Day 1 and Day 2 were 98.24 sec. and 113.61 sec., respectively. Data from Day 1 and Day 2 calculated a Pearson Product Moment Correlation of .89 and .99, respectively. Combined data from Day 1 and day 2 yielded a Pearson Correlation Coefficient of .97 (n=8).

Treatment Effect

Factors which could negatively impact results including an order effect from the mailbags and latent fatigue were minimized by randomizing the order of the mailbags carried. However, the pre-test scores demonstrated carryover of fatigue from trial to trial.. The mean of the pre-test scores significantly decreased from 108 seconds to 91 seconds and then to 84 seconds. In spite of the accumulation of fatigue, a one-way ANOVA of gain scores calculated a significant difference between treatments. A "difference" score was computed for three trials by subtracting each subject's posttest score from the pre-test score. The difference scores were examined for normality and homogeneity of variance.

The data contained no outliers and demonstrated a normal curve. Mauchly Sphericity test, a multivariate analysis, was not significant ($p<.80275$) demonstrating equal variances and co-variances between groups. Therefore, a univariate analysis was used to assess the differences between groups (Huck & McLean, 1975).

The results of the ANOVA are shown in Table 1. Examination of the table reveals a significant difference between group ($p <.001$). According to Tukey's post-hoc comparison, the groups with a mean difference in time-to-fatigue greater than or equal to 12.98 seconds showed significantly different responses to treatment.

Table 1 ANOVA of Different Mailbag Types

Time to Fatigue	SS	DF	MS	F	Sig
Within Cells	3507.65	22	159.44		
Time	3239,14	2	1619.57	10.16	.001

The difference score means for the trials were:

(a) 7.07 sec. for the double bag trial,
(b) 9.23 sec. for the standard bag with waistbelt trial,
(c) 28.18 sec. for the standard bag trial.

There was a significant difference in fatigue scores between the standard mailbag trial compared with the double bag and single bag with waistbelt trials. There was no significant difference in fatigue scores between the double bag trial compared with the single bag with waistbelt trial. Further calculations indicated that 30.4% of the variation in fatigue could be explained by the difference in mailbag type.

Discussion

The results of this research indicate that there is significantly less fatigue of the trunk muscles resulting from carrying the double bag or side pack with a waistbelt compared with the standard mailbag in medium or tall healthy males.

It was hypothesized that less fatigue of the trunk flexors would occur during the double bag trial compared with the side pack with waistbelt trial. Although the subjects carrying the double bag appeared to have less muscle fatigue than the subjects carrying the side pack with the waistbelt, there was not a large enough deviation in scores for the two bags to significantly differ. The treatment effect was not large enough to create a significant difference between the double bag trial and the side pack with waistbelt trial. The results suggest that the waistbelt is as effective in symmetrically distributing the load as positioning double bags on either side of the pelvis.

CONCLUSIONS, RECOMMENDATIONS

Conclusions

This investigation supports previous research which demonstrated decreased trunk muscle fatigue when a waistbelt was used to symmetrically distribute the load from the mailbag. The double bag and side pack with a waistbelt produced less trunk muscle fatigue compared with the standard mailbag. The study did not establish a significant difference in fatigue scores between the double bag and the side pack with waistbelt possibly due to the lack of power calculated for those two trials.

The visual isometric fatigue test was confirmed a reliable and valid tool when measuring fatigue in young healthy males. Coefficient Alpha was .87 illustrating the reproducibility of measures over time. Congruent validity was established when the time-to-fatigue as measured visually compared to the time as measured by the Motion Analysis System produced a Pearson Product Moment Correlation of .97. The strong validity coefficient suggests the accuracy of the visual isometric fatigue test.

Recommendations

There is a need to identify and correct workplace hazards because the financial cost musculoskeletal disorders place on industry and the health care system is enormous (Kelsey et al., 1979). This is the motivation for research that evaluates the source and extent of increased musculoskeletal injuries in letter carriers.

Due to the many controls in this study the conclusions cannot be generalized to the letter carrier population. This study needs to be repeated and include male and female letter carriers in the small, medium, and tall categories for height and weight. The letter carriers should walk an actual mail route with uneven terrain for approximately 4 or 5 hours to increase the effect size and establish whether a significant difference exists between the double bag and sidepack with waistbelt. A control group of walkers only (no mailbag load) is needed to discern the amount of fatigue resulting from the walking. Although it is important to repeat the study on postal workers, they should not have previously carried the double or the standard mailbags with the waistbelt on their routes to prevent bias.

Due to the observation that small stature males experienced increased counter trunk rotation and subjective discomfort when carrying the double bag, the mailbag most mechanically efficient for the letter carrier may be dependent upon anthropometric characteristics. As previously stated, this study should be repeated with small, medium, and tall subjects. If an interaction exists between anthropometry and mailbag type, the United States Postal Service should have 2 “standard” bags including the double bag and the sidepack with a waistbelt.

There is a need to redesign the mailbags. There were some subjective complaints of shoulder pain and discomfort from the sidepack with waistbelt and the double bags swinging freely. A new suspension system is needed for the double bags to prevent subjective discomfort from counter trunk rotation and to prevent the bags from rubbing against the subjects’ thighs. The shoulder strap on the standard bag and the side pack with a waistbelt should be redesigned using soft rubber that conforms to the shoulder to prevent the strap from slipping off the shoulder. In addition, a shoulder strap which anchors to the outer lower corner of the side pack with a waistbelt would force the load inward toward the pelvis possibly further decreasing the trunk muscle fatigue.

Recent studies indicate that nonspecific, nonstructural low back pain can be associated with excessive back muscle fatigue. Excessive back muscle fatigue may result from decreased endurance of the trunk musculature. This study demonstrated increased muscle fatigue when carrying the standard mailbag; however, a cause and effect relationship was not established between low trunk muscle endurance and low back injuries. Future research must determine if there is a significant decrease in low back injuries and worker's compensation costs when the double bag or single bag with waistbelt is used. If compensation costs or number of injuries are reduced then one may infer a primary cause of the low back injuries is trunk musculature fatigue which may be reduced through appropriate mailbag design.

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The Ergonomic Evaluation of Several Chairs: A Case Study

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Purchasers of industrial and office seating are challenged with the responsibility of specifying and evaluating chairs based on various factors (e.g., use adjustability, stability, code compliance, appearance, durability and performance). Therefore a software program was developed to aid individuals (who are novices in ergonomics) in the specification and evaluation of chairs to objectively rate them according to the above factors. Results indicate that the total points scored by task chairs as specified for use from major office furniture manufacturers varied from 60% to 71%, thus confirming that the software and its objective protocol are effective tools for specifying and rating task chairs.

INTRODUCTION

Seating is defined as a body position in which the weight of the body is transferred to a supporting area, mainly the ischial tuberosities of the pelvis and their surrounding tissues (Schoberth, 1962). Seating draws its roots back to the earliest stools used in ceremonial purposes, however, today, seating is an important tool in the work environment. Its' development, similar to most work tools, came about as a device which could save human energy and increase the worker's well being. As a result of using a seating tool worker's experience less fatigue and are able to perform their jobs more efficiently. In the modern office and industrial workstations, the advantages that seated work possesses over standing work is that it (1) provides greater control, (2) consumes less energy, (3) places less stress on the lower extremity joints, (4) lowers the hydrostatic pressure on the lower extremity circulation and (5) ensures stability for foot control of machines (Chaffin and Andersson, 1991). However, as a result, nearly 75% of all workers in industrial countries have sedentary jobs (Grandjean, 1988).

Though increases in productivity are difficult to measure, some studies have documented increases in productivity due to proper seating providing comfort for equipment and non-equipment users (Brill et al., 1985). However, with the increased quantity of sedentary jobs with limited movement, injuries associated with seated tasks have decreased productivity and their costs have reduced company profitability. Approximately 60% of adults have back pain at least once in their lives, and the most common cause is disc trouble (Grandjean, 1988). The economic impact of back injuries in the U.S. may be as high as $20 billion per year (BNA Report, 1988). Although sedentary task injuries such as disc degeneration only account for approximately $2.5 Billion annually, this type of back pain is reported as persistent and with each reoccurrence, lost work days are reported as expensive overhead costs, reducing productivity and profitability in the workplace.

Risk factors for back injury.

The causes of intervertebral disc degeneration are not totally understood, unnatural posture, bad seating, and long duration, are three of the major factors which are believed to speed up deterioration of the discs. This degenerative process impairs the mechanics of the vertebral column and allows tissues and nerves to be strained and pinched, leading to muscle cramps, sciatic troubles and in severe cases paralysis of the legs (Grandjean, 1988). Anderson et al. (1974) revealed that a slumped forward, unsupported posture generated disc pressures twice that of standing. Seated workers, experiencing chair discomfort, not only report pain in the lower back, but also pain and stiffness in the shoulders or neck, forearm, upper arm, upper thoracic area, legs (underside of thighs and lower legs) and feet. Absence of arm supports transfers upper torso loads to the vertebral discs, while arm supports set too high force the shoulders to be lifted, which increases the forces and tension on the shoulder joints and muscles of the shoulderneck area (Chaffin and Andersson, 1991). When a chair is set too low, the knee flexion angle becomes smaller than the recommended 90 degrees. The load of the upper torso is transferred to a smaller area over the ischial tuberosities, thus increasing pressure on the soft tissues. When a chair is set too high, the feet are unable to reach the floor, and pressure is applied to the thighs close to the knees. This can result in swelling and pressure to the sciatic nerve (Chaffin and Andersson, 1991). Kroemer and Robinette (1969) and Bendix (1987) report that those whose work is predominantly seated, have an increased risk of lower back pain. Furthermore, the symptoms of back pain become more prevalent as the duration of the sedentary task increases. Combining unnatural postures and poor seating orientation with extended sitting duration and no dynamic movement, provides a high risk environment for low back pain development.

Subjective evaluation techniques

Radiographic, electromyographic, and disc pressure measurements have been used effectively in the laboratory to objectively assess the physiological responses and biomechanical forces due to seating designs. In the office environment and industrial environment, more subjective evaluations have been utilized to measure seated comfort. Measurement techniques include observations of body postures and movements (Grandjean et al., 1960; Wotzka et al., 1969), observations of task performance (Jones, 1969), or direct subjective ratings of general comfort utilizing chair feature checklists (CFCL), body area comfort ratings, and general comfort ratings (Grandjean et al., 1960; Jones, 1969; Wotzka, 1969; Hall, 1972). Drury and Coury (1982) proposed an evaluation procedure for a prototype chair. They utilized the general comfort questionnaire and the CFCL of Shackel et al. (1969) combined with the Body Part Discomfort (BPD) of Corlett and Bishop (1976). In essence, a comparison with anthropometric data, standards, and ergonomic principles was used in their study. Then a five minute adjustment period was provided to the sitter in order to maximize comfort, followed by a 2.5 hour sitting and working period. Every thirty minutes the general comfort and BPD scales were given, and CFCL was administered at the end of the session. Despite the work in this area, no general agreement has been reached on which technique possesses the best precision or reliability.

ERGONOMIC EVALUATION FACTORS

Anthropometric

In the wake of this indecision, Chaffin and Andersson (1991) suggest an evaluation of seating approach which first evaluates a chair against anthropometry and physiological data, followed by the use of comfort trials and direct workplace observations to evaluate final designs. In order for an office chair to meet the anthropometric characteristics, it must be adjustable or fit the limiting population. Since anthropometry varies for populations, different countries have developed their own standards. These standards usually include the following seat dimensions: seat height from the floor, seat width (breadth), seat length (depth), and seat slope. Additional standards include shape of the seat, its frictional properties, softness, adjustability, and climate comfort (Chaffin and Andersson, 1991). Standards have also been developed for the backrest and the armrests of an office chair. Recommended dimensions for backrests include height at the top, middle, and bottom of the backrest measured from the seat pan; backrest width and horizontal radius; and backrest-seat angles. Included with these objective factors are other factors such as pivot and recline characteristics, softness, adjustability, and climate comfort. Finally, standard dimensions for armrests include length, width, height from the seat pan, width between armrests, and distance from armrest front to seat front. A composition of these standards is presented in Table 1.

Physiological and Biomechanical

Physiologically, research has provided some general seating design standards. Grandjean (1988) points out that dynamic seating is needed to accommodate forward leaning and slightly reclined work. This change in posture and pressure also provides the intervertebral discs a chance to replenish their blood supply (Kramer, 1973). Andersson et al. (1974) suggest that office chairs should incorporate an adjustable backrest-seat angle equal to 110–120 degrees. This design feature was shown to generate the largest decrease in disc pressure and muscle activity. Smaller decreases in disc pressure, yet still essential, were reported with the use of a lumbar support equal to 5 cm in width from the back of the seat back and 1–2 cm in height from the seat pan. Decreased muscle activity in the upper extremity and decreased disc pressure were also noticed with the addition of arm rests. Lumbar support is essential in maintaining the lower spine in lordosis, which in turn distributes pressure across the surface of the large ischial tuberosities structures. In essence the weight has been distributed over four areas (elbow/forearm, lumbar, seat pan, legs) instead of the seat pan alone. To enhance this proper posture and reduce slipping, the seat pan should be tilted backwards at 5–10 degrees and should incorporate a front waterfall edge.

Table 1. Recommended Dimensions for Office Chairs. (Dimensions in Centimeters, Angles in Degrees)

	A	B	C	D
Seat				
Height	43–51	39–54	42–54	39–51
Width (breadth)	41	40–	40–45	42
Length (depth)	36–47	38–47	38–42	38–43
Slope angle	0–5	0–5	0–4	0–4
Backrest				
Top height	33–	–	32–	–
Bottom height	20–	–	–	–
Center height	–	17–26	17–23	17–22
Height	–	10–	22–	22–
With (breadth)	30–36	36–40	36–40	36–40
Horiz. radius	31–46	min. 40	40–70	40–60
Vert. radius	convex	–	70–140	convex
Backrest-seat				
Angle	95–105	–	–	–
Armrest				
Length	22	20–	20–28	20–
Width (breadth)	4	4–	–	4
Height	16–23	21–25	21–25	21–25
Inter-armrest				
Width	47–56	46–50	48–50	46–

Adapted from Chaffin and Andersson (1991).

A: U.K. standards 3079 & 3893	C: German standards (DIN)
B: European standards (CEN)	D: Swedish standards (SS)

Ergonomic standards

Current American standards specify safety constraints such as tipping forces, seating impact, flammability, etc. These are found in ANSI/BIFMA X5.1–1985 standards. In 1988, American National Standards Institute (ANSI) and the Human Factors Society (HFS) drafted anthropometric and physiological standards in their document ANSI/HFS 100–1988 standard, Section 8.7 for seating. These standards, which are presented in Table 2, are well needed guidelines for VDT, industrial, and office workstation designers. However, an all inclusive seating evaluation tool which incorporates ergonomic factors, code compliance, and durability could help novices in ergonomics to choose appropriate seating and possibly reduce workstation fatigue and injury through appropriate seating.

Table 2. ANSI/HFS 100–1988 Standard.

Section	Standard
8.7.1	Seat Height—should allow feet to be placed firmly on a surface to provide stability and adequate lower leg support. Adjustment range shall be 16 to 20.5 inches.
8.7.2	Seat Depth—should be between 15–17 inches. Any depth exceeding 16 inches shall provide relief to the back of the knee (i.e., waterfall design).
8.7.3	Seat Width—should be a minimum of 18.2 inches.
8.7.4	Seat Pan Angle—should be adjustable or fixed between 0 and 10 degrees sloped back. If forward and back tilt is provided, the seat fabric should provide sufficient friction to avoid sliding.
8.7.5	Seat Pan to Seat Back Angle—should be adjustable or fixed between 90 and 105 degrees. Tilt options should not allow the torso to move forward past vertical.
8.7.6.	Back Rest—should provide lumbar region support. Back width should be a minimum of 12 inches.
8.7.7.	Armrests—should possess a minimum inside distance of 18.2 inches.
Misc.	Footrest—should be provided if the user's feet do not sit appropriately on the floor.

Adapted from ANSI/HFS 100–1988, Section 8.7 Seating.

ERGONOMIC SEATING ASSESSMENT TOOL

In response to a need for a complete seating evaluation system, Progressive Solutions Group, Inc. (PSG) developed a software tool called "The Evaluator", a seating specifier/evaluator. The purpose of this software was to aid individuals (who are novices in ergonomics) interested in specifying or purchasing chairs to be able to rate chairs in terms of anthropometric features, adjustability, durability, safety, and other factors. Currently, purchasers of industrial and office seating are burdened with the responsibility of manually evaluating chairs based on a long list of standards, criteria, and specifications without a scoring technique. To their disappointment, very few researchers have attempted to develop seating evaluation techniques, protocols, and scoring systems. Ayoub et al. (1984) did develop one of the more successful evaluation programs. With the Ayoub et al. (1984) program as a guide, a comprehensive, objective, assessment tool was developed by PSG.

The main objective in development of “The Evaluator” was to design a quick and efficient seating assessment tool, which was based on a set of specified standards and criteria, could generate a score with which to rate chairs. The major factors examined were anthropometric features, adjustability, durability, safety, and other factors. Subcategories for these factors included seat and backrest width and height, seat depth, height of lumbar support, seat pan inclination, range of seat height adjustment, tilt tension range, tilt lock adjustment, manufacturer’s life of the structure and material, type of seat upholstery, tipping force, adherence to codes and others. Each factor was weighted similar to the weighting scheme proposed by Ayoub et al. (1984), where ergonomic and safety factors account for more than 50% of the total points. If for whatever reason a measure was not entered, the program has the capability to neglect that particular measure, and adjust the weighted scale in the total evaluation of the chair. The software is coded in TURBOPASCAL, is PC based, and is menu driven. Sample screens have been reproduced in Figures 1 to 3. Measurements may be entered in either English or Metric units.

<MAIN MENU>
1—Introduction
2—Ergonomic criteria for office seating
3—Seating Evaluation
4—Glossary of terms
5—List and retrieve data file
6—Exit
Enter your choice (1–6)

Figure 1. Main menu screen

Seat Height Adjustability
Is the seat height adjustable (y/n)?
If yes, please enter the range (in inches)
From to _____ to _____ (i.e. 16.5 to 20.5)
Degree of Difficulty to adjust (0–5)>
0=very difficult 5=very easy

Figure 2. Seat height adjustability screen.

Seating Depth Measurement
ENTER SEAT DEPTH (in cm.) >
Round total measurement down to the nearest 0.5 cm.
Measure at the deepest point.

Figure 3. Seat depth measurement screen.

With the development of the software for the Evaluator complete, the objective of this case study was to confirm that the software and its objective protocol are effective tools for rating task chairs.

METHODS AND PROCEDURES

The PSG Ergonomic Seating Evaluator software was executed on a 386 personal computer which was positioned in a typical office workstation environment, per the specifications for chair usage. The main portion of the validation was performed by the lead researcher who used a tape measure to collect dimensions on eleven (11) chairs from major office furniture manufacturers. These physical measurements were then entered into the program. Manufacturing safety test and code compliance information, was to be provided by the chair supplier (on their response portion of the specification requirements). This information was also entered into the program when prompted. The chairs were next presented one at a time in a random order to eleven (11) volunteer chair evaluators with differing anthropometric measurements, ages, and genders. Each volunteer was allowed 5–10 minutes to adjust the chair. At the end of the five minutes, the volunteer completed a few subjective assessments of comfort of the chair as prompted by the software. Mean scores were calculated from the subjectives scores and entered in the software program.

RESULTS AND CONCLUDING REMARKS

Mean scores for each of the chairs which were evaluated are provided in Table 3.

Table 3. Chair evaluation scores.

Chair ID	Mean Raw Score	Mean Total Weighted %
A	41/63	65.08
B	44/63	69.84
C	44/62	70.97
D	37/62	60.65
E	40/63	63.49
F	42/62	67.74
G	43/63	68.25
H	42/63	66.67
I	42/63	66.67
J	44/62	70.97
K	40/62	65.57

Some questions/queries went unanswered in the software. This is why the raw score was not out of 100. One reason for this situation was complete data/information were not available from the chair manufacturers. The software, however, was sensitive enough to rate the chairs on other key evaluation factors.

Results indicate that the raw score points varied from 37% to 44% and total weighted % scores varied from 60% to 71%. This indicates that the software is an effective and sensitive tool to ergonomically evaluate task chairs.

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TIME PATTERN ANALYSIS AS A TOOL FOR COMPARING WORK TASKS IN AN ASSEMBLY LINE INDUSTRY WITH SPECIAL REGARDS TO MUSCLELOAD AND PAUSES

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INTRODUCTION

Musceloskeletal disorders has been predominant in reported occupational disorders in industrialized countries during the last years. In engineering industries the extent of disorders in the neck and upper limbs are particularly high. In Sweden more than 50 percent of long term sickleave and early retirement pensions were due to neckshoulder disorders during 1991. This causes high costs for the individual, the society and the companies (Snook, 1987).

The exact emergance mechanism for work-related muscular disorders has yet to be fully established. It is knovn that monotonous repetetive work tasks with static working postures are of great significance (Kilbom, 1986 Silverstein et al, 1986). In order to improve jobs like assembly line work, which are known to have a high incidence of workrelated musculosceletal disorders, there still is a great demand for methods to study different work tasks.

The aim of this study was to evaluate two similar types of assembly work tasks with different work cycle. Physical strain an occurrence of pauses was of special interest.

METHOD

Two assembly work stations were chosen. From a production engineering point of view those work tasks were similar except for the fact that one of the tasks (Task I) had a calculated working cycle of 132 seconds and the another (Task II) had a calculated working cycle of 400 seconds.

Four experienced female assembly workers volunteered to participate in the study. All four of them had been on the work stations in question the last three years.

None of them had any complaints from the muscleloskeletal system. The workers were instructed to work in their habitual work pace. Electromyography (EMG) were recorded by bipolar surface electrodes from the trapezius muscle pars descendens on both sides. The signals were preamplified in preamplifiers fastened to the skin close to the electrodes. This system was connected to the major amplifier by a 10 m long cable allowing the subjects to move freely on their work place. The raw EMG-signals were monitored on an oscilloscope screen in order to check the quality of the signals during the exprimental ses-sion. For calibration and normalization purposes, test contractions including maximal voluntary contractions (MVC), which gave values of maximal voluntary electrical activity (MVE) in the muscle, were performed before and after each recording session. The 10—percentile of the amplitude was used as value for the static load.

The EMG signals were analyzed by a new method (Linderhed, 1990). The method is based on a computerized program creating sequensies for different amplitude-levels. In this study the electrical signals in amplitude mean frequency (AMF) were registered at 200 load levels during 0, 3 second time period. The number of such sequences that are registered below each load level could be regarded upon as pauses at that specific load level.

A “time pattern” of the EMG-signal consisting of the duration and frequency of the registred AMF levels could thus be presented. Registrations were made on several occasions covering the whole working day. Each recording session lasted 20 minutes. All registred working cycles were recorded to be able to control the representability of each cycle.

RESULTS

Task I: For the two subjects studied at this assembly workplace the static load varied between 2, 7 and 4, 0 percent of MVE and the median load level varied between 6, 0 and 9, 5 percent of MVE (Figure 1).

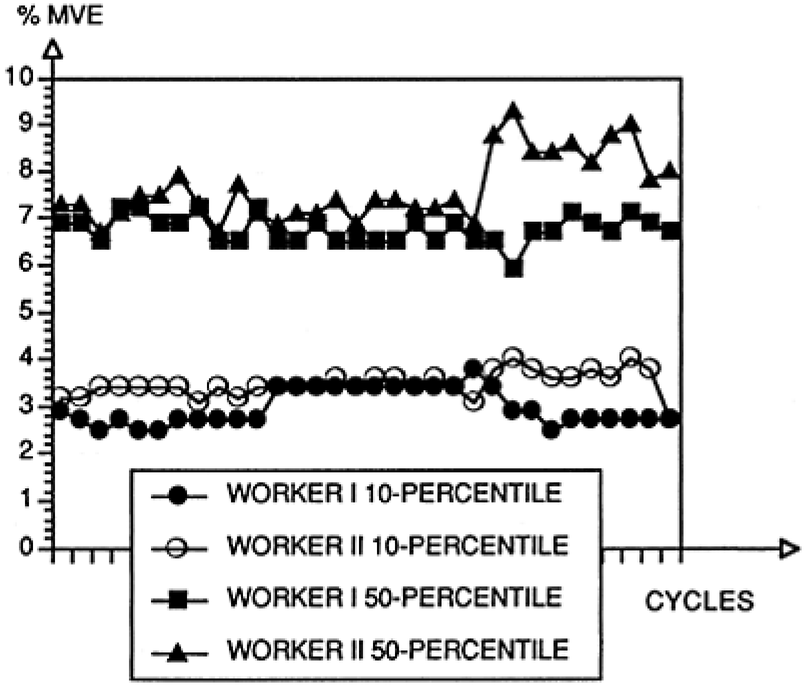

Figure 1. Static and median load on trapezius muscle in short work cycles.

Task II: For the two subjects studied at this assembly workplace the static load on the right side of the trapezius muscle varied between 3, 3 and 5, 9 percent of MVE (Figure 2 A & B). On the left side static load levels at 10 percent of MVE and median amplitude up to 15 percent of MVE were registred.

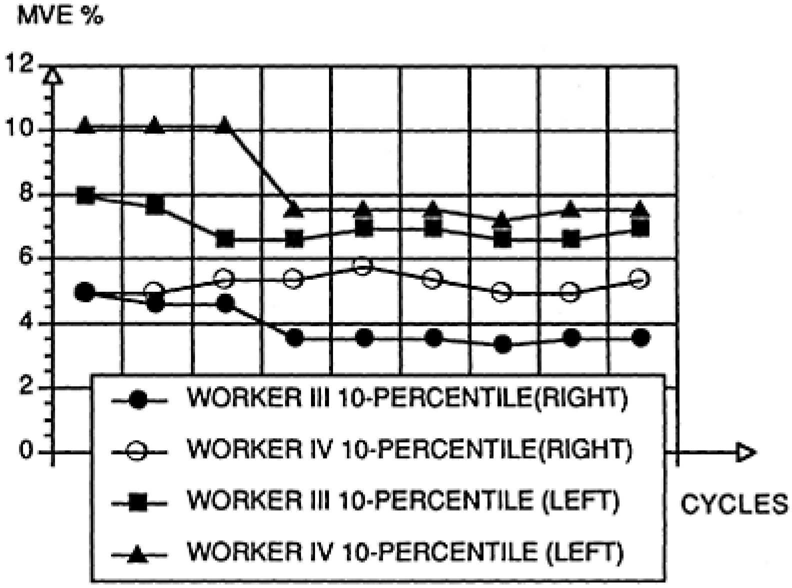

Figure 2 A. Static load on trapezius muscle in a long cycled work task.

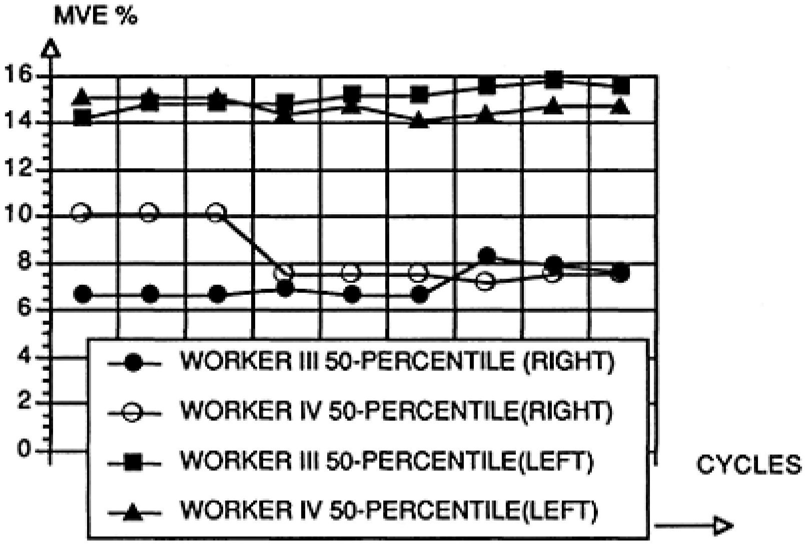

Figure 2 B. The difference in median load on the left and the right side of the

trapezius muscle in the long work cycle.

There was no registration below the level of 2, 5 percent of MVE in either work cycle. Pauses with a duration of 1 second were found on a level of 10–12 percent of MVE in Task I (fig 3).

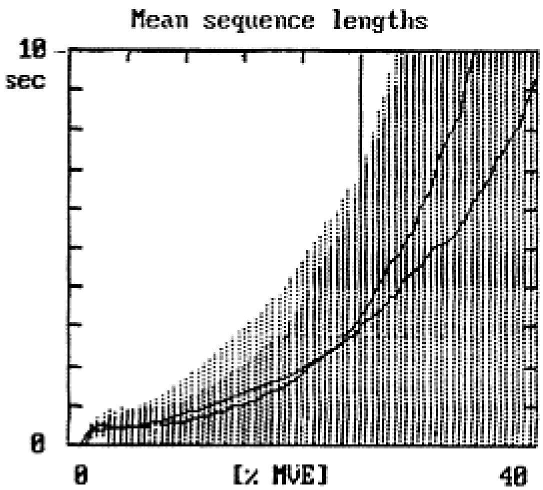

Figure 3. Mean sequens length in Task I in relation to MVE.

In Task II no time sequences were found 3 MVE. For one of the workers in Task the first time sequence duration of 1 second was fond on the level of 35 percent of MVE (fig 4).

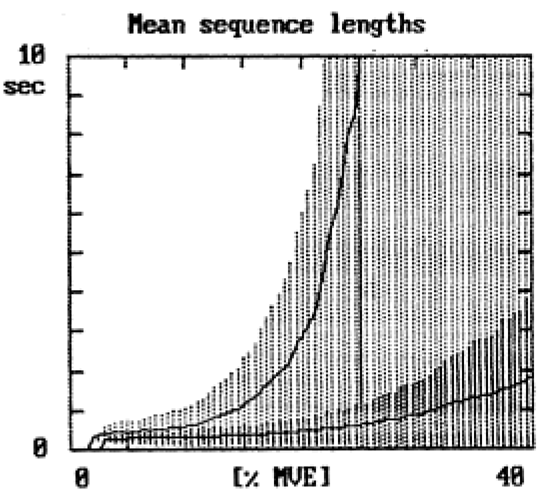

Figure 4. Mean sequence time in Task in in relation to MVE.

DISCUSSION

This study indicates that the length of a work cycle is of importance for the muscular load in assembly work. Although the work tasks studied are almost identical, but for the work length, the muscle strain differ in these tasks. It also shows that Pauses of physiological significance are nonexistent in the working taks that were studied.

Electromyography (EMG) has been used both in laboratory studies and in worksites studies for many years (Örtengren 1975). Still there is no method that could be easily used in applied ergonomics. Therefor there is a demand for relevant, valid and reliable methods in analyzing work tasks. The analyse used in this study gives information on both the amplitud and the temporal aspects of the EMG-signal.

For assembly line work there are still no genereal recommendations for temporal pattern of pauses, although its importance have been stressed in several investigations during many years.

Static muscular load, even on very low levels have been considered to play an important role in the development of shoulder-neck disor-ders. Static musle load levels at one percent of MVC have been found to be harmful if exposure for monotounous repetetive work is prolonged (Waersted and Westgaard, 1987). This might be explained by the postulate made by Henneman (1965) that motorunits in the muscle always are recruted in one succession while extinction of neuromuscular signals would take place in the opposite way. In accordance to this recruitment theory it is not enough to strive towards low levels of muscle work, it is also of outmost importance to have pauses in the muscular work.

In the work tasks in this study we found statical load levels around four percent of MVE. Static and median values were considerably higher on the nondominant side in the longer work cycles. This could be explained by the fact that operators in assembly work often have to use their nondominant hand as fixing plate. Individually differing muscular load could be due to poor working technique which is known to affect the work load (Parenmark 1988, Kilbom 1987). Work pace as well influences the muscular load (Parenmark et al, 1989).

Exact how organizational factors affects the human work load are important to consider in ergonomical interventions. The effect from such changes need to be studied further.

CONCLUSION

To make improvements in ergonomics it is essential to know how pauses and work load are distributed in different work tasks. Therefore there is a great need for sensitive and practical methods in order to make correct and valide appraisals. The ergonomic efforts might otherwise result in “improvement for the worse”, and not as intended contribute to prevention of workrelated disorders.

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PREFERRED SETTINGS IN STANDING VDT WORK

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INTRODUCTION

During the last few decades, office chairs have been the target of several ergonomic improvements, resulting in better cushioning, contouring, and adjustability. However, during the same period, musculoskeletal problems have increased among office workers, in particular, back and shoulder problems (Waddell, 1987, Hünting et al., 1981).

Low back pain has usually been related to lifting and other heavy physical work. However, researchers have noted that those who maintain sedentary postures over long periods also report significant low back pain (Hult, 1954, Eklund, 1967, Magora, 1972, Wood and McLeish, 1974, Kelsey, 1975, Lawrence, 1977). These workers include vehicle operators, VDT and computer users, and typists.

Unexpected intervertebral disc morbidity has been found in work groups who spent extended periods sitting at work (Wood and McLeish, 1974). Disc deterioration in the sedentary posture is believed to be caused by high intradiscal pressures (Andersson et al., 1974, Nachemson, 1975) due to an unsupported, kyphotic posture or poor disc nutrition due to the lack of pumping mechanism that supplies nutrients to the disc (Adams and Hutton, 1983, Holm and Nachemson, 1983).

One of the aims of improving VDT workstation design is to reduce muscular activity to maintain the sitting posture, thereby minimizing physical work load. However by reducing discomfort caused by postural muscular activity the worker is exposed to another detrimental effect, lack of physical activity (Winkel and Oxenburgh, 1989).

Magora's work on alternating postures showed that there exists a "U" shaped relationship between the level of activity and back pain. Pain increases with extended durations in a confined posture, either sitting or standing. Extreme situations-either constant sitting or constant standing-are associated with a higher incidence of low back pain. Workers who alternate periodically between the two have less back pain (Magora, 1972).

Reducing constrained positions for VDT operators may be accomplished by varying the tasks over the duration of the day (Hunting et al., 1981, Winkel and Oxenburgh, 1989). Variation can be brought about by the introduction of a sit-stand workstation. The worker could alternate between sitting and standing during the workday without interrupting or inhibiting work productivity. This idea of a sit-stand workstation was introduced early in the century (Galloway, 1919) and has been more recently suggested by Schobert (1962), Ishai (1987) and Bridger (1988).

Unfortunately few evaluations of sit-stand workplaces exist. Some studies have found there to be promise in sit-stand workplaces. Aarås' (1987) showed that introducing a sit-stand workplace, along with other ergonomic improvements, reduced locomotor-system complaints and decreased worker turnover in an industrial environment. Winkel and Oxenburgh (1989) examined the introduction of a sit-stand workplace into an office environment. The results demonstrated increased variability in back muscle tone and slightly decreased neck and shoulder complaints, without causing more orthostatic problems than in traditional sitting (increased foot swelling over a working day).

VDT work traditionally results in relatively static constrained postures. If a worker must assume a constrained posture, an unsuitable setting of the workstation increases the risk of injury. Adjustable workstations should be adaptable to the different anthropometric data of employees to reduce this risk of injury (Grandjean, 1984). As Grandjean et al. (1983) pointed out, if the settings of a workstation are not optimized for a constrained posture, in this case standing, fatigue, stiffness and discomfort will result. This will obviously lead to a decrease in worker productivity.

To define and develop a sit-stand workstation more information is needed on a standing work station. The range of adjustability for a standing workstation is needed. For seated VDT work, preferred settings are properly evaluated following guidelines set forth in the literature (Hunting et al., 1980, Miller and Suther, 1981, Grandjean et al., 1982, Grandjean et al., 1983, Grandjean et al., 1984, Starr et al., 1985, Cornell and Kokot, 1988, Povlotsky and Dubrovsky, 1988).

Little work has been done on the preferred settings of standing VDT workstations such as monitor height and tilt and keyboard height and tilt. Recommendations have been made by Woodson et al. (1972) and Rupp (1973) that offer some guidelines for the recommended heights for a standing workstation but it is unclear whether either of these sources used studies with subjects to determine preferred settings or the recommendations were made from existing anthropometric data.

Preferred settings are found to determine the proper ranges of adjustability under the assumption that the user will prefer the optimal adjustment. Povlotsky and Dubrovsky (1988) looked at the relation of "recommended" versus "preferred" settings. They noted that several studies found that preferred settings were often different than anthropometrically determined recommended settings. Often the preferred settings were recognized as harmful yet none of these studies used a systematic approach to determine the extent of deviation from acceptable limits. Povlotsky and Dubrovsky found that preferred settings did not deviate greatly from recommended settings and fell within acceptable ranges. Although their work was only preliminary we feel that a preferred settings approach warrants merit and the settings of a standing workstation should be investigated in such a manner.

Certain factors must be accounted for to avoid influencing the subject's adjustment of the workstation. It has been found that in similar studies subjects do not significantly alter their workstations after 5–10 minutes of testing (Bendix and Bloch, 1986). Subjects have been shown to decide on their preferred workstation setup by the second day of testing in one study (Bendix and Bloch, 1986) and keep their preferred settings the same during a week of testing (Grandjean et al., 1984). Other studies have found that mean values of preferred settings remain practically unchanged for a week (Grandjean et al., 1984) and over a nine month period (Cornell and Kokot, 1988). It has previously been demonstrated that initial conditions of the workstation significantly influence the preferred settings (Bendix and Bloch, 1986, Brown and Schaum, 1980). The subject may adjust the workstation differently if the initial conditions are high than if they are low.

OBJECTIVE

The aim of this paper is to investigate the subjectively preferred settings for a standing workstation. It is hoped that from this information that a sit-stand workstation can be designed to accommodate the needs of seated workers. The effect of the number of days of testing and the effect of starting position will be examined.

MATERIALS & METHODS

Workstation

An adjustable workstation that allows workers to sit or stand was adapted from a commercially-available sitting workstation made specifically for computer use. The workstation can be easily adjusted to modify desk height, desk tilt, monitor height and monitor tilt. It has two separate work surfaces, one to hold a keyboard (measuring 25 by 70 cm) and the other to support a monitor and CPU (measuring 45 by 69 cm). The heights of these surfaces can be adjusted over a range of approximately 23 cm.

The keyboard table can be adjusted from 0 to 14 degrees of tilt and the monitor table can be adjusted from −8 to 5 degrees of tilt. The keyboard is on a sliding surface which allows for modifying the distance between the keyboard and the monitor by up to 21.5 cm.

The computer used was a DELL System 200, the screen measuring 24.7 cm×19.2 cm. It was equipped with a swiveling base that could tilt 11 to −5 deg. above and below the vertical. The keyboard measured 20.4 cm×48.1 cm, the surface inclining 8 degrees when placed on a horizontal plate.

Subjects were free to move the monitor over the plate to any position desired. Precautions were taken to ensure that direct glare or reflected glare would not be a factor in the results of the testing.

Subjects

Ten subjects, five men and five women, with no history of low back pain, participated in the study. All were typists who spend at least two hours of each workday typing. Subjects' ages ranged from 18 to 32 years, with an average of 24.5; heights ranged from 162.5 cm to 190.5 cm, with an average of 172.5 cm; weights ranged from 47.6 to 81.6 kg, with an average of 60.23 kg.

Procedure

Subjects were introduced to the workstation. Each subject was asked to perform a typing task and were instructed to adjust the workstation to a comfortable position. Readjustment of the workstation was allowed at any time during the 15 minutes of testing.

Measurements were made after each of two 15 minute test intervals each day. This procedure was repeated for four days. The workstation was set up with all adjustments in their most extreme positions, both low and high at the start of each interval. The initial conditions were set up at the extreme conditions in order to make the task impossible to accomplish unless the workstation was adjusted.

The following measurements were recorded:

Monitor Height: Distance from the center of the monitor to the floor

Keyboard Height: Distance from the home row of the keyboard to the floor

Monitor Tilt: Tilt in degrees of the monitor from the vertical,

Keyboard Tilt: Tilt in degrees of the keyboard from the horizontal

Monitor Distance: Distance from the bridge of the subject's nose to the center of the monitor

Eye Height: Distance from the subject's eyes to the floor

Elbow Height: Distance from the subject's elbows to the floor.

Statistical Methods

Statistical analyses were conducted to determine whether there was an effect of order (days) on adjustments and whether there was an effect of starting position (high vs low). A 4× 2 repeated measures analysis of variance was conducted for each of the five independent variables: keyboard height to floor, keyboard angle, monitor height to floor, monitor angle and monitor distance.

RESULTS

There was a significant effect of starting position on monitor distance, keyboard angle and monitor height and an effect of days on monitor height only. There was no effect on the keyboard height or monitor angle. The observed settings for 10 subjects averaged over both starting setups for all 4 days (80 observations) are shown in Table 1.

Table 1. Mean Settings.

Measurement	Mean	Std Dev	Minimum	Maximum
Keyboard height[1]	102.01	7.82	86.6	123.4
Keyboard tilt[2]	9.48	3.57	−6.0	18.0
Monitor height	137.12	3.37	118.1	158.8
Monitor tilt[2]	10.90	4.46	0.0	23.0
Elbow height	106.32	7.48	96.5	124.7
Eye height	154.73	9.76	137.2	175.3
Viewing distance	55.00	3.74	44.7	70.6

[1] Measured from the top of the interspace key.
[2] Angle related to a vertical plane.

The 95% confidence range for the workstation adjustments is listed in Table 2 [$\times \pm t_{9,0.975}$ (S)].

Table 2. 95% confidence range for the workstation adjustments.

Measurement	minimum	maximum
Keyboard height[1]	84.32	119.70
Keyboard tilt[2]	1.40	17.56
Monitor height	129.50	144.74
Monitor tilt[2]	0.81	20.99

[1] Measured from the top of the interspace key.
[2] Angle related to a vertical plane.

Keyboard height and monitor angle did not vary within subjects across days and starting positions ($p>0.10$). Viewing distance and keyboard angle varied depending on starting position. Viewing distance was greater when subjects started in the high position ($F=2.01$, $p=0.027$, df=1, 9). Keyboard angle was also greater when the subject started in the high position ($F=27.44$, $p=0.002$, df=1, 9). Monitor height varied depending on both day and starting position. A high starting position led to a higher monitor height ($F=21.04$, $p=0.001$, df=1, 9), and the monitor height increased for days 1, 2 and 3 ($F=18.59$, $p<0.001$, df=3, 27).

DISCUSSION

Subjects adjusted the monitor higher as the testing progressed. The average height findings are consistent with recommendations made by other researchers. For example, recommended monitor height for a standing workstation has been indicated as 140 cm (Woodson et al., 1972) and 140–165 cm (Rupp, 1973).

The viewing angle is defined here as the angle from a horizontal line from the middle of the VDT monitor to the line from the VDT monitor to the user’s eye (approximated in this study by the bridge of the nose).

Viewing angle=arcsine (eye-monitor/viewing distance)

In the present study, subjects showed a mean angle of 18.8 degrees. Commonly recommended viewing angles for sitting work are between 10 and 15 degrees (Van Cott and Kinkade, 1972), between 2 and 15 degrees (Grandjean et al., 1984) and between 0 and 7 with a mean of 3 (Miller and Suther, 1981).

It is difficult to contrast the standing keyboard height to sitting keyboard values unless the keyboard heights from the floor are compared to the elbow height of the subject. Unfortunately most of the literature never reports the height of the elbow during work at the workstation. An average difference of 4.29 cm was found for elbow to keyboard height difference.

Due to the large difference between keyboard and monitor surfaces heights we would have to recommend that the workstation be built so the supporting surfaces can be independently adjusted. It is not advisable to put both the keyboard and monitor on the same surface. The difference in heights between the monitor and keyboard is much larger in our study than in sitting studies. It would be advisable to raise the monitor off the working surface. In a sitting study (Miller and Suther, 1981) it was stressed that the separate keyboard support is vital because when keyboard and monitor are on the same surface optimization of keyboard and monitor height becomes complicated.

Our subjects chose an average distance of 55 cm between eye and monitor, similar to the distances recommended distance reported in the literature of approximately 50 cm (Van Cott and Kinkade, 1972, Woodson et al., 1972) and 38–76 cm (Sanders and McCormick, 1987).

The keyboard angle was the least adjusted and the least readjusted variable. The subjects often did not raise it up from the low starting position but did adjust it when it was at a very high position. There has been much written on the physiological effects of extreme positions of the wrist but little has been reported in the literature on the preferred keyboard angles. Miller and Suther (1981) found the angle to be between 14 and 25 degrees with a mean of 18 degrees. Scales and Chapanis (1954) found half the subjects preferred the slope between 15 and 25 degrees. Galitz (1965) also found no significant differences in efficiency between the angles of 9, 21 and 33 with 21 being preferred by the subjects. This is one of the least studied parameters of preferred workstation settings and needs to be addressed further in the future.

There is an effect associated with days. Subjects did not adjust the workstation significantly to justify testing on a fifth day. Testing for 4 days would give a significant representation of the subjects preferred settings as predicted.

In addition most adjustments on the workstation were completed in the first two minutes of the test. Only three subjects consistently made alterations throughout the 15 minutes of testing. This is consistent with the findings of Bendix and Bloch (1986).

Many subjects appeared restless and there was considerable movement of the legs. Subjects would often cross their legs or shift weight from one leg to another. Providing a footrest would allow subjects to rest one leg (one subject specifically asked for a footrest).

CONCLUSIONS

The positions and adjustability of the workstation have been monitored to determine the ideal standing workstation. The average adjustments for each parameter were keyboard height: 102.01 cm, keyboard angle: 9.48 degrees, monitor height: 137.12 cm, monitor angle 10.9 degrees. Subjects stood an average of 55.00 cm from the monitor when typing. From the 95% confidence levels, recommendations to furniture manufacturers can be made concerning the ranges of adjustability for standing and sit-stand workstations. For a standing position, assuming an average keyboard thickness to the interspace bar of 3 cm and an average height of 18.5 cm between the bottom of the monitor and the middle of the monitor, the keyboard table height should be adjustable between 81.32 and 116.70 cm, the keyboard tilt should be adjustable between 1.40 and 17.56 degrees, the monitor table height should be adjustable between 111.00 and 126.24 cm and the monitor tilt should be adjustable between 0.81 and 20.99 degrees. These criteria have been designed and are currently being implemented. The next step in our research is to determine if there are effects on preferred settings associated with different populations. The next study will investigate the effects of sex, age, and typing experience. Presently, modifications to our experimental workstation are being made to allow continuous monitoring of the system's position.

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ANALYSIS OF CRITERIA RETAINED BY HANDLINGMEN IN THE CHOICE OF A HANDLING METHOD

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Individual interviews averaging six and half hours were conducted with 28 experienced handlers. The interviews were carried out using a questionnaire consisting of partially close-ended questions and a video illustrating different types of handling performed in different spatial contexts. The aims of this study were to verify whether there was a consensus between experienced handlers as to what was a good handling method and to identify the criteria taken into consideration by them. The results show that there was no strong consensus among the handlers on what constitutes a good handling method: they favor different criteria and evaluate a given criterion in different ways. However, the four criteria most often favored are the reduction of fatigue, reduction of effort by the back, control of the merchandise and safety.

INTRODUCTION

It is generally accepted that musculoskeletal problems of an occupational origin, and particularly those affecting the back, are one of the most important causes of absenteeism. Also, handling has often been identified as a hazardous activity for the back. Training in safe handling has commonly been used up to now to reduce the incidence of back pain. However, its effectiveness has not been evaluated extensively. The few studies published on the subject tend to show that in its actual form, training has had only limited success: the incidence of injuries or accidents has decreased only slightly (Chaffin et al., 1986; Brown, 1976; Snook et al., 1978) and workers use the recommended handling methods hardly at all, even after having received training (St-Vincent et al., 1989, Hale and Mason, 1986). Two types of explanations are often given to explain this underutilization: 1) The content of the programs is probably poorly adapted to the working contexts (Ayoub, 1982; Chaffin et al., 1986; St-Vincent et al., 1989) and to individual characteristics; and 2) The methods taught, based essentially on minimizing stresses on the back, might not adequately take into account the criteria considered by the handlers at the time they are performing a handling, such as controlling the load, stresses on the shoulders, and balance. At the present time, we are finding that the more the experimental studies integrate a large number of measurements and criteria, the more difficult it appears to be to determine what a good handling method is. For example, the study by Hart et al. (1987) shows that a decrease in the muscular moments at L5/S1 may be accompanied by an increase in the activity of the erectores spinae, which is a source of fatigue. Studies also show that the articulation of the shoulder might constitute the limiting factor in certain handling activities (Yates et al., 1980, Svensson, 1987) and that minimizing the stresses on the shoulder could have the opposite effect on those on the back (Gagnon et al., 1987; Gagnon and Smyth, 1991).

These results suggest that optimization (namely the simultaneous minimization of all stresses) would be difficult to achieve. As a result, handlers probably make choices when they adopt a handling method, which would explain why the handling methods observed are so different from those recommended (Baril-Gingras and Lortie, 1990). At the present time, **we** do not know how handlers make these choices and what criteria are favored at the time a method is adopted. This identification seems essential in developing suitable and efficient training programs. The purpose of this study is to identify, for different contexts, the criteria favored by the handlers at the time they perform a handling operation, and to verify whether there is a consensus among them.

MATERIAL AND METHODS

Individual interviews of an average length of six and a half hours were carried out with 28 handlers from two transport companies whose work consists of loading and unloading semitrailers. The interviews were carried out using a questionnaire consisting of partially close-ended questions and a video illustrating different types of handling carried out in different spatial contexts. All these handling operations were filmed in one of the two companies. Three themes were dealt with, namely: handling methods, preferences in relation to work contexts, and the position of four-wheel carts in the unit. For this article, we will present only the results dealing with the handling methods.

Choice of subjects studied:

The handlers were selected on the basis of the four following criteria: they had to have had at least ten years of experience, had to be recognized by coworkers and by management for their professional skills, had to have had few work accidents since their hiring, and had to have no musculoskeletal problems with their back and shoulders. All handlers participated in the interviews on a voluntary basis and were compensated.

The interview:

Twenty video sequences were presented to the handlers. Each one showed two different handling methods carried out in the same context. The handlers were familiar with the merchandise presented. For each of these sequences, we first asked the handler to identify which of the two methods was the most advantageous on the basis of 10 criteria (Step 1). The list of criteria is presented in Table 1. The handler subsequently identified the method preferred overall, namely the one that he would prefer to use if he had to handle the same load 25 times in the context presented (Step 2). In each of these steps, the handler could also determine that neither of the two methods was advantageous, that they were equal, or that he did not know. When a preference was indicated, the handler was asked, for each of the criteria in which the preferred method has been considered more advantageous in Step 1, to determine whether it was a major reason for choosing the method (Step 3). Finally, he had to identify the 3 most important criteria (Step 4). The handler could specify criteria other than those presented.

RESULTS:

Agreement between the handlers

Four agreement levels, based on the highest percentage of handlers making the same choice, have been retained to qualify the agreement between the handlers as either strong (70%–100%), average <55%–70%), low (45%–55%) and very low (30%–45%). Table 1 presents the agreement level of the 28 handlers for each of the 10 criteria studied and for the method preferred overall in the 20 sequences presented (Steps 1 and 2).

The results show that there is no strong consensus between handlers when evaluating a method on the basis of a given criterion. On average, they agree strongly for only 20% of the sequences. Furthermore, there is no criterion for which there is strong agreement in the majority of the sequences: in the best cases, namely "controlling the load" and "making the load work for you", this strong agreement is present in only 30% of the sequences. In addition, it is observed that for 15% of the sequences, there is very low agreement, and that disagreement is the most marked for the "fatigue" criterion. One notes that the handlers disagree to an even greater extent when they are determining the most advantageous method to use, with a strong agreement being observed in only 20% of the sequences.

Table 1. Distribution of the 20 sequences on the basis of the level of agreement of the 28 handlers during evaluation of the 10 criteria and the method preferred overall.

	Agreement level				
Criterion	Very low (30%–45%)	Low (45%–55%)	Average (55%–70%)	Strong (70%–100%)	Total
Back	1	7	8	4	20
Shoulders	2	9	6	3	20
Legs	3	6	6	5	20
Fatigue	6	3	7	4	20
Balance	1	9	8	2	20
Controlling the load	–	9	5	6	20

Rapidity	2	6	7	5	20
Safety	4	6	8	2	20
Direct placement	2	11	4	3	20
Making the load work for you	3	3	8	6	20
TOTAL	24	69	67	40	200
Method preferred overall	4	6	7	3	20

However, there is more agreement between the handlers when they are identifying the criteria considered important at the time a handling method is chosen (Step 3), with a strong agreement being observed in 38% of the sequences (results not shown). Hence, if the agreement of the handlers is relatively low when they are identifying the method that they prefer, agreement is even greater when they are identifying the advantages that would be offered by a method in a specific context.

Identification of favored criteria:

Table 2 shows the frequency and percentage of times when a criterion was identified as one of the three most important reasons for choosing a method overall by the 28 handlers for all the sequences.

The results show that the handlers favor certain criteria more often when they are choosing a method. Reducing fatigue is the reason most often mentioned for choosing a method (namely for 41% of all sequences).

Table 2: Frequency and percentage of the times in which a criterion was identified as one of the three most important reasons for choosing a method overall by the 28 handlers and for all sequences.

		Frequency×100
Criterion	Frequency	448 handling-sequences[1]
Fatigue	184	41, 1
Back	163	36, 4
Controlling the load	155	34, 6
Safety	151	33, 7
Balance	148	33, 0
Direct placement	99	22, 1
Rapidity	81	18, 1
Other3	61	13, 6
Shoulders	34	7, 6
Legs	22	4, 9
Making the load work for you	89	39, 6[4]
Total	1187[2]	

[1] If all had chosen one method, there would have been 560 handling sequences (28 handlers×20 sequences).

[2] if the 28 handlers had always preferred one method and identified 3 reasons, the total would be 1680 (28 handlers×20 sequences×3 criteria), which is not the case.

[3] Regroups the criteria mentioned by the handlers that are not in the list presented.
[4] Since this criterion does not apply to all sequences, the percentage is calculated on n=225.

Then comes effort by the back, balance, controlling the load, and safety, whose percentages vary from 36% to 33%. Decreasing the effort by the legs and shoulders is rarely one of the three reasons for favoring a method, with the percentages varying between 4% and 6%. Finally, one notes that having the load work for you is a very important criterion since more than 40% of the times when the situation justifies it, it is one of the three reasons for having chosen the method. Furthermore, an analysis of the results by handler shows significant inter-individual variability. For example, the fact that one method is considered easier for the back is for some handlers one of the three main reasons for choosing this method in more than 85% of the sequences, whereas others never mention this criterion. These major variations are observed for most of the criteria. However, the results show that handlers who gave importance to the same criteria have a greater tendency to choose the same method. In fact, if all the handlers are divided into two groups on the basis of the choices expressed for the method preferred overall, one notes that there are significant differences between the groups ($p< 0, 10$; Fisher exact method) for 17 of the 20 sequences presented. For example, we presented the two following methods: in the first, the handler moved a box without pivoting on his feet, by using back torsion; the second method was the opposite. The results show that handlers for whom back effort and good balance were major reasons for choosing the preferred method were significantly more numerous in choosing the method without back torsion, while those for whom rapidity of execution was a major reason, opted to a greater extent for the method with back torsion. The strength of the relationship (Cramer's V coefficient) between the chosen method and the importance given to certain criteria is furthermore very strong (>0, 700) one time out of three.

However, this tendency is not systematic because the means of evaluating a criterion varies with the handler. During the evaluation with the 10 criteria, the handlers were asked to explain their choices. A qualitative analysis of the reasons given has shown that the handlers sometimes evaluate the same criterion by using different parameters. Consequently, even if they give priority to the same criteria, two handlers will not necessarily choose the same method. For example, we asked the handlers to identify which of the two methods was the easiest on the back. In the first method, the worker tossed the load, while in the second, he carried it and then put it down. Some answered that tossing it was easier on the back because the load did not have to be supported for a long time, while others stated that supporting a load was easier on the back because it avoided the sudden movements that occur during throwing. Therefore, depending on whether the parameter used in evaluating the method was the duration or the intensity of the effort, the judgment on the methods was different.

DISCUSSION:

Analysis of the results shows that handlers choose differently when they are identifying which of the two methods is the most advantageous. Two factors may explain this lack of agreement: first, they do not all give priority to the same criteria, and second, the same criteria may be evaluated differently. It is probable that individual characteristics generally considered, such as the worker's age, size, weight or seniority affect, at least partially, the strategy developed by the worker. The inter-individual variation observed by Smith et al. (1982) shows that individuals performing the same task do not carry it out in the same way. However, it is probable that some of this variation reflects the different ability levels of the workers, such as sense of balance, precision of movement, and the ability to use the momentum of the load. For example, a worker capable of developing a precise movement may feel that throwing a weight, provided it is not too heavy, is an effective method because it avoids him having to support the load and also reduces displacements. Conversely, the handler with a "less precise" throw will see no advantage in it if he, among other things, has to handle the load again to adjust where it is placed. From this standpoint, the favored method appears to be a means adapted to the capacities and abilities of the worker. When the handlers' choices are compared, this hypothesis is supported by the fact that a relationship exists between the method chosen and the criteria favored.

Despite these major inter-individual variations, the workers are overall seen to choose a method on the basis of several criteria rather than just one, and certain criteria are seen to be more determinant than others: this is the case with fatigue, back effort, balance, safety and load control criteria. Up to now, handling methods have been mainly recommended on the basis of one criterion, namely the compression force, most often a maximum, generated in the lumbar spine. In fact, back effort is generally a major criterion in choosing a method, even if we cannot say here whether the handlers' evaluations are based on the same parameters. One may think that this is not the case, because as we saw earlier, handlers evaluate back effort differently, on the basis of such things as whether they favor duration or intensity. Biomechanical studies show that a method resulting in a smaller maximum compression force may, in return, generate a larger integrated compression force (Leskinen et al., 1983; Gagnon et al., 1987) and that a decrease in the lumbar stresses can be achieved against an increased expenditure of energy (Garg and Saxena, 1979; Kumar, 1984) or muscle fatigue (Hart et al., 1987). At the present time, we still do not know the importance that must be given to each of these parameters. However, the importance given by the handlers to the fatigue criterion leads one to believe that the integrated value of the compression force as well as the muscular activity obtained by EMG are important parameters. The results also show the importance of balance during handling activities. An analysis of 611 accidents in one of the two transport companies from which the subjects were selected, which showed that 22% of the injuries were the result of a loss of balance (Lamonde et al., 1988), confirms the need for evaluating a method on this basis. Up to now, balance was mainly analyzed from the standpoint of the position of the feet. It is probable that load control and back position also have an impact on stability. Finally, one notes that safety and load control, given as much prominence as back effort by the handlers, are normally not considered in evaluating a method.

The choices made by the handlers encountered are probably not all safe. However, studies have shown that experienced workers could have developed work methods that result in fewer and/or more balanced stresses between the various articulations (Gagnon et al., 1987; Patterson et al., 1987). We should remember, however, that we have chosen experienced handlers who have rarely had accidents and are free of musculoskeletal problems.

CONCLUSION

This study shows that it is difficult to make an absolute judgment about a method without taking into account a series of criteria as well as inter-individual differences. To do this, a training strategy based on an analysis of handling situations and on finding adapted solutions could be a promising avenue.

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DEVICES AND TECHNIQUES

STANDIA: an intelligent voice-acti vated switchboard

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INTRODUCTION

Design engineering sets up the various features of a system which are used in a different world. Communication between these worlds takes place through the system itself. In this case, human factor science aims at establishing the link between designers and users at all steps; preparing the manufacturing of the system. The various types of know-how must be fitted to optimize the use of new technologies. In order to design an intelligent voice-activated switchboard: STANDIA, one has to change man-man dialogue into man-machine dialogue.

In the field of man-machine communication, many results have been obtained, in research and development, on computers which provide automatic treatment of voice processing. The machine, now having a cognitive ability, must be given a model of the user with which it interacts, in order to execute a task.

To be as close as possible to natural speech, it is necessary to study actual cases so that the users can easily learn to use the system. The set-up of a voiceactivated electronic switchboard must take this principle into account.

In view of designing a prototype of such an electronic switchboard, we have studied the dialogues between two speakers in the framework of a traditional telephone switchboard. The analysis of the data, containing 530 conversations, reveals for other than standard calls, a number of situations where the caller and the operator have to revise their pre-established strategies to reach their goal.

SPEECH RECOGNITION.

Automatic speech recognition consists, in general, of the transformation of a vocal signal into a set of words making up a given vocabulary. Speech is a continuous phenomenon;

there are no dividing spaces such as one finds in written language. The periods of silence do not always correspond to punctuation marks.

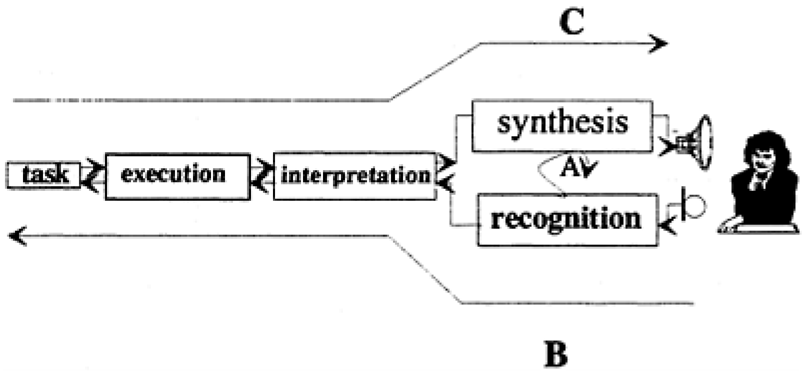
MAN-MACHINE ORAL COMMUNICATION

Speech is one of man's natural communication faculties. It requires, of course, understanding of speech but has the following advantages:

speech production is natural, therefore non-stressful for the organism

in the field of data processing, its inclusion does not require any significant equipment (microphone)

the telephone branching allows speech to be routed just about anywhere, and in this manner computer dialogue becomes more easily acceptable to a large segment of the public unaccustomed to keyboard use.



The above diagram represents a man-machine communication scheme based on vocal support.

The recognition and synthesis modules represent the vocal input and output; they communicate with a module designed to interpret the sentence pronounced by the speaker.

The double arrow linking the recognition module to the interpreter is the symbol for the recognition/understanding paradigm.

Three possible data transmission networks are represented:

A: how the task is affected during use
B: the task's effet on the user
C: vocal dialogue between user and system.

We note here, however, some difficulties inherent in oral dialogue:

possibility of interrupting the speaker or the system at any time;

spontaneity of expression which tends to be simple and often brief;

ignorance of grammatical rules, and the use of a much greater vocabulary than actually required by the task (FALZON, 1986).

Speech recognition automation generates restrictions of oral dialogue characteristics:

vocabulary size restrictions

difficulty in handling short and garbled messages

reduced spontaneity due in part to the system's delay in answering

undeterministic recognition characteristics which introduce a disturbance parameter in the understanding of the message and therefore in the unfolding of the dialogue.

A sound ergonomic concept of the various dialogue systems allows minimization of the inconveniences due to such limitations (A.K.MATROUF, 1990).

METHODS OF OBSERVATION.

The telephone switchboard that we observed, is an old system operated by teams of 3 expert operators and one novice with overlapping working hours. The task of each operator is to deal with the request of a caller until the latter is satisfied. There were about 1500 calls per day. Each operator received about 400 calls for 4 hours of work. The dialogues with the callers and the strategies used to solve the problems put to the operators allowed us to know the key-words which trigger the end of the conversation and the connect between the persons calling and those called. Different charts show the search of the operators based on signs which help satisfy a request, occasionally giving a poor answer with respect to the goal.

The data was processed from a set of 530 meaningful conversations recorded during one day of work. The various kinds of calls were classified according to specific characteristics. Their analysis permits the study of cases where callers and operators must revise their strategies in order to solve their problems.

Human factor analysis (FALZON, 1986) based on task analysis, revealed periods of saturation of the switchboard which induced somewhat harsh dialogues; the stress due to the flashing indicators of incoming calls induced a lack of greetings and a dialogue poor in natural utterances.

We could evidence the behaviour of an expert operator who, based on a detailed knowledge of the structure of the called party, introduced problems, by giving excess information, to the callers.

The analysis of the dialogues allowed us to determine models of usual situations typical of general public telephony (M.F.CASTAING, F.NEEL, 1991).

CONCLUSIONS.

The aim of this work is to aid in ameliorate the design at LIMSI, of a prototype of a voice-activated switchboard, which, thanks to our results, should give the users the possibility of having, dialogues as close to natural ones as possible with a machine.

The analysis of the dialogues with operators and the study of human factors in working conditions suggests we should take into account parameters which were not a priori obvious:

quality of dialogues at different times

quality of dialogues according to the quality of the answers given by the operators to the requests
quality of dialogues following the initial formulations of the operator: greetings, efficiency in questioning..

This shows the necessity of studying the human factors to explore the working environment. The results reveal some characteristics which are not obvious for software designers dedicated to automatic voice processing. Indeed, man-man dialogue is based on semantic aspects which can hardly be reproduced by computers. However, designers can take advantage of our work to build systems based on manmachine oral communication which are close enough to those using man-man dialogues, taking into account the limitations of voice recognition technology (S.K.BENNACEF, 1991). At present, one can already find software offering 2 or 3 levels of menus which are supposed to cover all the situations of calls. But, for general public use, such systems cannot be controlled by occasional users; a new technology requires a learning phase. It is therefore likely that the caller will hangs up if he has to follow the various branches of a menu to get an answer to his request.

Remark.

It is a rule that a test of the menu must be performed with potential users before launching a system (E.VERNETTE, 1989). It is much better to simplify the tasks, rather than to extend the system to all possible cases, which requires too large a memory effort for average users.

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ERGO-INDEX. A MODEL TO DETERMINE PAUSE NEEDS AFTER FATIGUE AND PAIN REACTIONS DURING WORK.

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A new, ergonomically better, working method must also have economical advantages to be accepted on the market. Ergo-Index is a model that enables comparison between different methods to complete a working task. The total time for a working task consists of the operation time plus the pause time that is required after the work to recover from fatigue. The model gives information about physical stress and pause needed for recovery. It is based on a previous model, experiments and biomechanical calculations. It has been developed for use in the construction business.

INTRODUCTION

Fatigue reactions in muscles can be studied by means of power spectrum analysis of myoelectric signals. In the ErgoIndex model, developed by Glimskar et al. (1987) the exponential form of the muscle fatigue and recovery curves (Lindström, 1979) was used to predict the pause need after static contractions. The 2-D Static Strength Prediction Program (Univ. of Michigan, 1985–1991) was used to find the performance limiting muscles, i.e. the highest load in relation to maximum voluntary capacity on the body parts when performing a given working task. A limit for fatigue development was set at 15 percent of maximum force found by Rohmert (1960) to give “infinite” endurance. External loads below that level resulted in no pause need according to that model. The model was found to have good prediction power at higher load levels but failed at lower levels. To improve the model investigations were undertaken dealing with three different issues. A detailed report of that work has been published in Swedish (Rose et al., 1991). A description of the methods and studies that led to the refined Ergo-Index model is given by Rose et al. (1992).

METHODS AND STUDIES

To improve the model the following studies of light work in awkward postures were carried through: (1) A study of joints loaded passively, (2) Loading in awkward static working postures with low external load and (3) Loading by only the weight of the own body parts.

In the studies experiments were carried through where the test person stated intensity and the origin of the main pain or discomfort using Borg’s symptom scale (Borg, 1982) every 15th second during loading until the endurance limit and every 30th second during recovery until the person stated he could start working again, if the experimental task was his job. In some of the experiments power spectrum analysis of myoelectric signals, as described by Lindström (1979) and Glimskär et al. (1987), were carried out to study fatigue reactions and recovery in the muscles. Most experiments were also carried through with repeated loading. The test persons were healthy subjects, not used to the quite strange working postures; in one series of experiments also construction workers were included, however.

The purpose of the first study was to investigate whether it is pain and discomfort from joints and ligaments or from muscles and tendons that causes work to be interrupted when joints are at their maximum angle in working postures. Experiments with the upper arm supported by a cushion and the wrist loaded with different load were carried through to study reactions at the elbows. The purpose was also to study how the endurance time and the pause time needed afterwards varied with external load. Differences between endurance time and pain development when the joint was at its maximum angle and when it was almost at its maximum angle were also investigated.

The aim of the second study was to investigate fatigue development when the external load is low but the posture is awkward. For that purpose, two different types of experiments were carried through: a) with the back in a steeply forward bent position, and b) with low external loads in one arm at eye-level. Earlier studies have shown that at high degrees of forward flexion of the back, there is almost no activity in the erector spinae muscles. This suggests that other structures than the muscles, probably ligaments, carry the stress. Therefore two experimental situations were studied where the back was in a steeply forward bent position. In one situation the test person moved nails on a plate placed at foot level and in the other he held a 10 kg weight in his hands and stood bent forward with the back as relaxed as possible. Many working situations in the construction industry require work above the shoulder-level with one or both arms elevated. Quite often the external load is low but the working posture awkward. Therefore a study with a working posture with one arm elevated in front of the body to eye-level and handling of different loads was chosen to represent a drilling simulation. The external load varied between 0 and 100 N.

In the third study stress caused by the weight of the own body segments were calculated and considered as a part of the total stress. When the external load is small and the working posture awkward, the stress due to the weight of the own body segments can be a large part of the maximum stress that can be handled in that posture. In such cases, this stress must be considered when calculating the need for pause in the model.

RESULTS AND DISCUSSION

The strategy for the modelling of the fatigue development during load and recovery has been to include the stress caused by the body weights in the model and use experimental results from the studies to create a model that gives better prediction of pause need when the external load is low than the first Ergo-Index model did.

The joint study

The results of the joint study showed that pain from muscles and not from joints were limiting the endurance in most cases. An exponential relation between external load and endurance (1) was found.

$$T_{max} = 10.23 \exp(-4.69x) \qquad x \in [0,1] \tag{1}$$

where T_{max} denotes the endurance time and×denotes the external load normalized to the maximum voluntary contraction.

It was noted that persons with elbows that could be extended to a large angle stated that pain developed in the joints. Most of the test persons could not straighten the elbow to the same extent and they reported pain from the muscles surrounding the elbow. Also when the elbow was somewhat bent, the maximum load was higher but the endurance time shorter than when the elbow was fully extended. However, pain after unloading disappeared faster when the elbow had been somewhat bent.

Loading in awkward working postures

The results from the different experiments showed that the endurance was shorter than values calculated according to Rohmert (1960). It was found that there was a need for rest also after experiments where the external load had been below 15 percent. It was also found that the origin of pain in the deeply forward bent positions was in most cases in the thighs and hamstring muscles and not, as presumed, in the back.

The construction workers in the study who were used to the working posture, moved nails on a plate as a simulation of tying reinforcement bars together. They had almost 50 percent longer endurance compared to persons who lacked such experience, but still shorter than they should have according to Rohmert. The pause time needed afterwards was almost 50 percent shorter for subjects who were used to the task than for the others.

These findings can be explained by the natural selection, i.e. that persons who get problems from the extreme working situations just have to change work. Those who stay in the profession form an elite group in that point of view. An other explanation is that performing the same task often gives a training effect, muscles get stretched out and the endurance time increases. In using a model of the ErgoIndex kind it is important to be aware of these effects.

In some experiments the working situation during loading led to that the stress partly was unloaded. This was the case in for example one drilling simulation, where a handle was pushed with a force of 5 N. The stress caused by the arm’s weight was unloaded and the situation could be compared to leaning towards a support. This led to longer endurance. On the other hand it was found that extreme working situations led to shorter endurance than in most of the experiments.

In the EMG-analysis the centre frequency of the power spectrum was calculated and the time constants for fatigue and recovery were estimated and fitted to the data. For fatigue equation (2) was selected

$$f_c(t)=f_c(0)\ \exp(-t/t_f) \qquad (2)$$

where $f_c(t)$=the centre frequency, $f_c(0)$=the centre frequency when the muscle i rested in the beginning of the experiment and τ_f=the time constant for fatigue.

For recovery equation (3) was selected and fitted to data

$$f_c(t)=f_{c2}+(f_{c1}-f_{c2})\ \exp(-t/\tau_r) \qquad (3)$$

where f_{c2}=the centre frequency when the muscle has recovered, f_{c1}=the centre frequency at the end of the experiment loading and τ_r=the time constant for recovery.

The values of the time constants for fatigue were very large and the variation was considerable. This means that it takes long time before fatigue has developed to such a level that the endurance is limited. No definite conclusions could be drawn from the EMG-analysis because of the large variations. The external loads were probably too low (5 to 100 N) and the time periods too short (two to four minutes). The constants differed also for different muscles. This can be explained by that different muscles have different time constants but also by that the muscles were at different activity levels in given postures.

Influence of the body weights

The stresses at different joints for different postures were calculated as moments and expressed in percent of the maximum moments that could be exerted. Different joints were “limiting joints” in different postures.

Table 1 shows the moments caused by the body weights compared to the maximum moments in nine different working postures (preferred postures).

Table 1. Contribution from body weights in nine different working postures.

Work distance [cm]	Height level [cm]	Moment in % of maximum due to body weights	Limiting structure
H=20	V=34	27.7	hip
H=50	V=34	30.7	hip
H=70	V=34	32.7	hip
H=20	V=102	27.9	knee
H=50	V=102	11.1	shoulder
H=70	V=102	22.1	L5/S1
H=20	V=170	12.4	shoulder
H=50	V=170	13.9	shoulder
H=70	V=170	23.6	knee

Several ways to summarize the data into one model were tested. To begin with a model based on the transformation

$$f(x)=(x-a)/(1-a) \quad (4)$$

was tested. Here x denotes the normalized load according to Rohmert, $x \in [0,1]$ a denotes the normalized load due to the body weight, $a \in [0.11, 0.33]$ and f(x) denotes the external load in the new curve.

The basis for this model is that Rohmert's endurance curve is valid for situations where load due to body segments weight is neglectable.

Table 1 identifies nine different classes requiring different equations. Depending on working posture one of these should be chosen. But when such a model was compared with the endurance times gained from the experiments it showed that the calculated endurance times were much to short.

A different kind of model was designed on the assumption that not the whole contribution of joint moment from Table 1 should be used, but a fraction of it.

The endurance time calculated by such models was lower than the experiments indicated. Thus it was decided to base the model more on the experiments than on the calculations.

Model for fatigue during load and endurance time

When the results from the experiments were put together an exponential relation (5) with r^2=0.96 was suggested to describe the relation between external load and endurance

$$T_{max1} = 7.96 \exp(-4.16x) \quad x \in [0,1] \quad (5)$$

where T_{max1} denotes the endurance time and×denotes the normalized external load.

But when unloading is possible in the working situation or the person is used to the situation equation (6) with r^2= 0.97 should be used instead.

$$T_{max2} = 14.74 \exp(-5.04x) \quad x \in [0,1] \quad (6)$$

The developed model for external load—endurance is shown in figure 1. The curves in the figure are based on experimental results up to x=0.2. The remaining part is based on the force endurance curve according to Rohmert (1960).

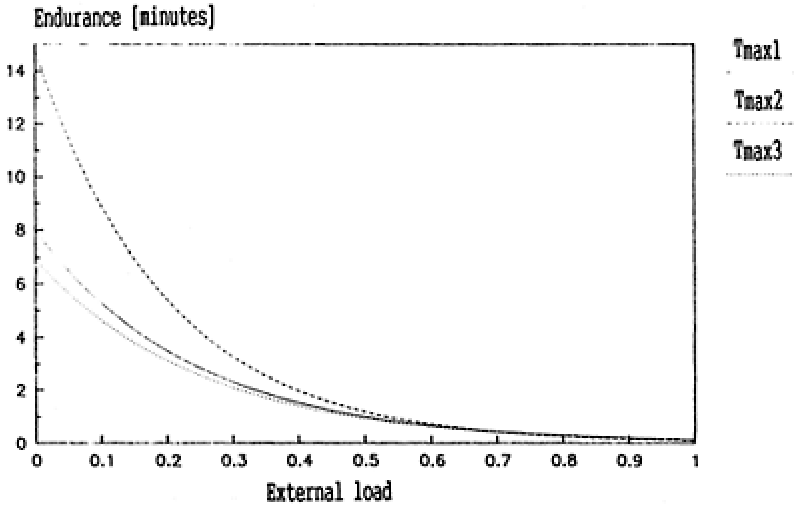

Figure 1. Developed model for load and endurance time.

If on the other hand the working situation is extreme, equation (7) with r^2=0.97 is suggested

$$Tmax3 = 6.89 \exp(-3.99x) \quad x \in [0,1] \tag{7}$$

The relation between external load and endurance time from the joint study (1) is similar to the relation for muscle stress (5) based on the other experimental studies in the project. Most subjects reported pain from muscles and tendons as limiting the endurance. This led to the conclusion that in the Ergo-Index model (5) could be used also for working postures were joints were extended.

Model for recovery time

The chosen model for recovery is similar to the one in Ergo-Index 1. The form of the equation used to determine pause need also originates from the first Ergo-Index model. The equation used has the form

$$t_{pause}=3t_{op}(T_{max})^{-1.52} \tag{8}$$

where tpause denotes the pause need, top the operation time and T_{max} is maximum endurance time according to Rohmert's force-endurance curve.

In the new ergo-Index model recovery time is also calculated when the external load is below 15 percent.

A computer program based on the model is under development. The model enables comparison between different methods to fulfil a working task, both ergonomically and economically, since the total time consists of the operation time plus the recovery time. If the stress on the lumbar spine exceeds 3 400 N this is indicated.

The present form of the model should not be used for individuals but on groups because of the large variations involved.

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DEVELOPMENT OF A PRACTICAL METHOD FOR MEASURING BODY PART DISCOMFORT

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Musculoskeletal problems should be prevented when (re)developing production means or consumer products. Due to the lack of specific valid ergonomic guidelines, studies have to be done to select design alternatives on the basis of measurement of musculoskeletal effects. For this purpose practical and valid methods to be used by practitioners are needed. Rating discomfort in body parts is an interesting approach for direct estimation of musculoskeletal loads. A method for rating and analyzing Localized Musculoskeletal Discomfort (LMD) was developed and tested. The method turned out to be practical, reasonably sensible and reliable for comparisons of relative low static loads. Software, supporting the method will be available soon.

INTRODUCTION

Relevance

It is well known that prevention of musculoskeletal health problems is of major importance. Repetitive movements of body parts or (quasi) static postures or force exertions cause musculoskeletal loads and discomfort that may result in disorders (Hagberg, 1986, Fine et al., 1986).

Also in product development, increased competition results in a greater emphasis upon evaluation of user discomfort.

Ergonomists and occupational health specialists are however faced with the problem of lack of valid quantitative ergonomic guidelines fitting specifically to the situation or population under consideration (Dul & Hildebrandt, 1987), especially on (quasi) static loads.

However, specific guidelines can be derived from testing design alternatives on musculoskeletal loads in work practice or in simulated situations in the laboratory (Wiker et al., 1989).

For this type of research, especially in work practice, practical and valid methods are needed. Additional to the objective measuring methods the subjective measuring techniques attract more and more attention for reasons of simplicity of use. The question arises how reliable and valid these methods are.

Aim of this research

The aim of this research is to develop a practical and valid method for determining internal musculoskeletal loads *'directly'*.

Separately from this, research was done on practical methods for measuring loads *'indirectly'*, by means of posture and movement registration (Douwes & Dul, 1991). Those methods may be used together with biomechanical models.

Stages of development

The development started with a review of the literature to select interesting methods. This was followed by stages of modifying and testing. A practical method for implementation in the field is the final objective. Further development and implementation of this kind of methods for practitioners is stimulated by grants from the Dutch government.

The aim of this paper is to report about the development results.

THE LMD-METHOD

Selection of a practical method

The literature was reviewed (Van der Grinten, 1990) on the basis of practical and scientific criteria. For ergonomic purposes, methods that give discriminated results between loads per body part are preferred for their better association with specific work design parameters.

Rating of body part discomfort, by means of a group of about 10 to 20 subjects, experiencing the load themselves, was selected as a relatively simple approach for evaluating differently loaded body parts at once. Discomfort sensations occur after a certain exposure time and disappear after rest and may originate from *actively and/or passively* involved musculoskeletal structures (Wiker, 1989, Manenica, 1986, Harms-Ringdahl, 1986, Boussenna et al., 1982, Chaffin, 1973). The sensations are considered as an evaluation criterion on itself, but may have a relation with longer term health effects, although this has not yet been proven.

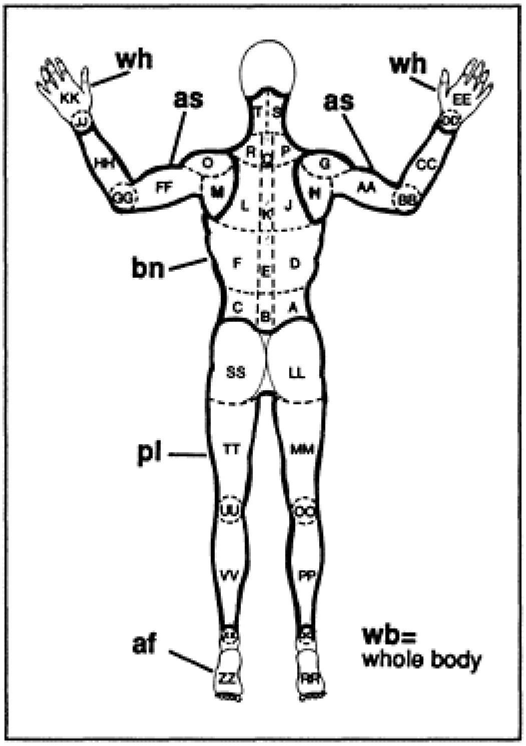

Figure 1. Body map with regions (A-ZZ) for rating discomfort. Clusters are depicted in bold.

Table 1. Six global clusters

nr	abbr.	name
1	wb*)	‘whole body’
2	sa	‘shoulders-arms’
3	wh	‘wrists-hands’
4	bn	‘back-neck’
5	pl	‘pelvis-legs’
6	af	‘ankles-feet’

*) all regions aggregated

In static situations with dominant active muscle exertions, a good to reasonable relation on group level can be found between local discomfort with endurance time percentages (Meijst & Dul, 1992, Manenica, 1986, Taksic, 1986), locally applied forces or biomechanical moments (Rohmert et al., 1986, Boussenna et al., 1982). These are aspects of the validity of this type of methods.

In situations with low to medium energy consumption, subjects are mostly able to localize discomfort in different body segments. In situations with high energetic consumption, general cardio-pulmonary sensations may become dominant and body part discomfort may be obscured.

The method of measuring Body Part Discomfort of Corlett and Bishop, (Boussenna et al., 1982), best known in the field of ergonomics, formed the basis for further development of the LMD-method. On fixed moments (time samples) subjects are requested to localize the body parts where discomfort is perceived with the help of a body map and rate the intensity of discomfort on a rating scale.

Development of the LMD-method

Discomfort is broadly defined here and includes localized musculoskeletal sensations like tension, fatigue, soreness, heat, tremor, pain, etc. Major requirement was to assemble primarily a reliable method for determining (quasi) static loads; lower intensities should be discriminated as well. The major modifications brought into the method of Corlett & Bishop are:

1. More regions were depicted in the body map to discriminate possible asymmetrical loads in shoulders, back and neck and separate effects around the joints (A-ZZ in figure 1).
2. A category scale with ratio properties (Borg, 1982) was applied for rating the intensities. In the CR-10 scale verbal categories are coupled to ratio rating numbers in a non-linear way (ranging from no discomfort=0,…, to extreme discomfort, almost maximum=10). In the lower range of the scale much verbal categories are distinguished, this is expected to be relevant for rating low loads.
3. Discomfort variables (figure 1, table 1) are defined to aggregate the results for reasons of sensitivity and simplicity. Per respondent the ratings over time samples are first added, resulting in region intensity ratings (variables TA-TZZ). Next, region ratings are added to get functional cluster ratings (6 global variables Twb-Taf are presented). Although more fuzzy in its meaning, these global sum-variables are constructed for reasons of sensitivity. Two possible effects are namely included: (1) changes in the amount of regions affected (spreading of discomfort), and (2) changes in the intensity of discomfort. The variable ‘Twb’ is an indicator of ‘overall discomfort’.

Basic procedure

Each subject is exposed to each physical load condition during a fixed exposure time, followed by rest. Discomfort of regions with discomfort (>0) is sampled with fixed time intervals. As far as possible, the physical load condition is left unchanged during verbal rating. The subject has to concentrate on the body for a while. The body diagram and scale are positioned near or within the visual field of the task to be executed. If regions have equal discomfort, they may mention the letters of the regions involved, followed by one rating number. The subjects are thoroughly instructed and do a try-out with the method while holding a leg or arm posture. The sequence of experimental conditions is systematically varied over the subjects. Differences between mean values of discomfort due to the different conditions are statistically analyzed within subjects.

SENSITIVITY

Introduction

Small differences in relatively low static loading (e.g. postural loads) may have important consequences for differences in endurance times. It was decided to test the LMD-method first for its ability to detect effects of relatively small postural differences (about 15% of the range of movement).

Testing method

A group of 10 female office workers participated in a pilot study (mean age: 32 years (SD=6); body length 1.68m (SD=.06); body weight 630N (SD=50). Nine pairs of 'neighbouring postures' distributed over the 'neutral', 'middle' and 'extreme' range of movement of each body segment served as stimuli. Trunk postures were evaluated in standing, the other in sitting position. The positions, each held for 2 min. and followed by 2 min. rest, were (vertical=0°; for shaded areas, see results):

1	symmetrical trunk flexion	:(-3° and 13°)	(42° and 58°)	(87° and 101°)
2	r.upper arm elevation in a vertical plane, 45°abducted from the sagittal plan, elbow angle 90°	:(20° and 41°)	(79° and 94°)	(120° and 135°)
3	symmetrical head flexion	:(-1° and 7°)	(19° and 27°)	(45° and 54°)

The trunk, upper arm and head angles were controlled by individually calibrated adjusting means.

Results and conclusion

In 7 (shaded) of the 9 pairs a significant difference between mean values of both postures was found on at least one discomfort variable (T-test/pairs; $p<0.1$). It is concluded that the method is reasonably sensitive.

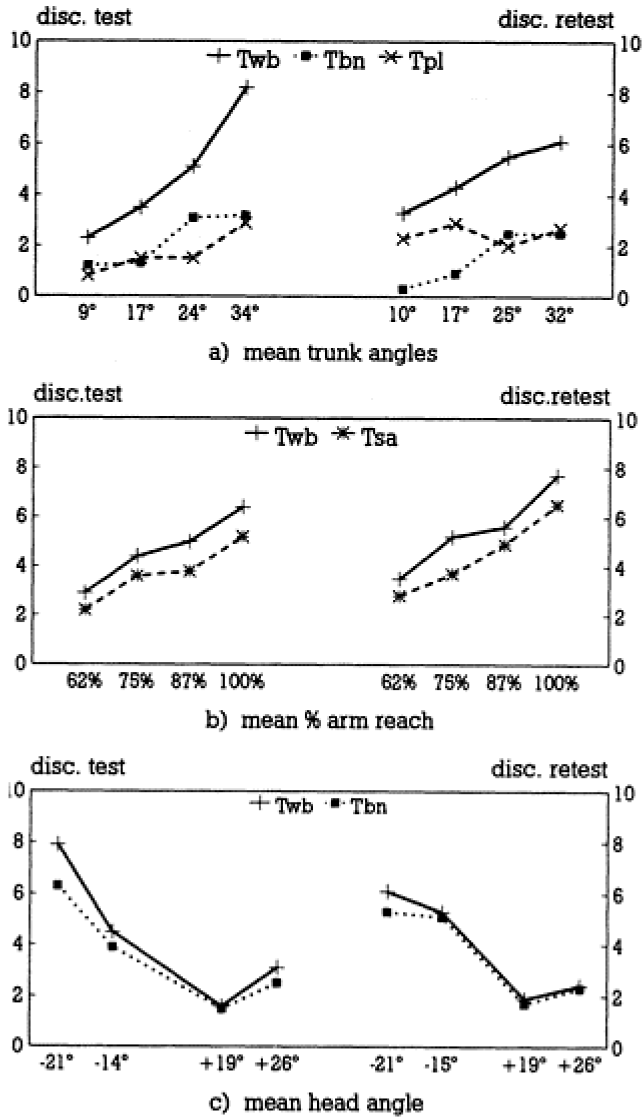

Figure 2. Mean discomfort in test and retest from trunk arm and head postures.

TEST-RETEST RELIABILITY

Introduction

Indications of the association between levels of physical load or endurance time percentages on the one hand and levels of exertion or discomfort ratings on the other hand can be derived from the literature. Indications on the test-retest reliability are however scarce. The LMD-method was tested for this property.

Testing method

A series of 12 relatively low loading postures was repeated 14 days later. A new group of 16 office workers (8 females and 8 males) participated (mean age 33 years (SD=7); body length 1.75 (SD=.08); body weight 680N (SD=80). Each posture was held for a few minutes (followed by rest).

The 3 sets of postures were (mean from test and retest, vertical=0°):

1 symmetrical trunk flexion			
10°	17°	24°	33°
2 forward reach of right hand at acromion level (% of max.)			
62%	75%	87%	100%
3 symmetrical head flexion and extension (−)			
26°	19°	−14°	−21°

The trunk was flexed while standing, the other postures were while seated. Trunk and arm postures were held for 2 min., head postures for 3 min. The positions were controlled.

Results and conclusions

In this study discomfort in the extremities was in general low (variables Taf, Twh). Figure 2 (a, b, c) shows the mean results per set of postures for the global variables with discomfort significantly greater than zero. Mean discomfort differs more or less from test to retest as can be seen in figure 2. More results on reliability are revealed in Van der Grinten (1991). The overall variable Twb (fig 2; a, b, c) and the global variables Tsa (b) and Tbn (a, c) show rather congruent trends in both series (relative reliability). The variable Tp1 (a) was less reliable, but this may partly be explained from a small, but significant shift in leg postures in the retest (observed from photographs). The leg postures were only instructed, not controlled.

When comparing the means relatively towards each other within test or retest, an ergono-mist would draw twice the same conclusions on conditions with lowest and highest discomfort. The region variables showed less reliable results, except for the arm postures.

Major conclusions are: global variables are reasonably reliable when relatively low static loads are compared; the region variables are less reliable. In comparative studies the LMDmethod gives results from which consistent conclusions can be drawn. The amount of regions depicted in the body map was too large for common use in situations with the 'whole body' loaded (in this study the trunk postures) and thus may reduce the reliability.

REVISED LMD-METHOD AND PC-SOFTWARE

Revisions

Using recent experiences in the laboratory and in practice, the LMD-method was further revised. For common applications, the *amount of regions is reduced.* Nineteen regions and 12 global clusters are defined now, including 6 new clusters for studying asymmetrical load effects. In case of studying only a part of the body (e.g. arm loads or head postures) one could decide to apply a part of the original body map with 40 regions depicted (figure 1).

Moreover, different options for data reduction are added to the software. The summing operation can be used for evaluation of relatively low loads (see above). A 'maximum' operation is added. The maximum rating within a time series and/or a cluster can be chosen to detect highest discomfort *('max'),* When used in the clustering operation, the rationale behind it is the hypothesis that the 'weakest link' within a cluster is normative for the whole cluster and thus will determine eventually subsequent postural behaviour (Rohmert et al., 1986). Contrary to sum-variables, these cluster variables can be interpreted as measures of *'intensity'*.

General description of the software

Software is developed to support data handling on an AT-PC with a MS/DOS and VGA-configuration and will be available soon. The program includes modules for data-entry, analysis, presentation and export (in ASCII) to other programs, like SPSS/PC. Print-screen and 'grab-function' (Word Perfect) can be used to print graphs for concept respectively report purposes. The user friendly LMD-program can be used interactively in (field) research with a lap-top PC. The ratings per time sample can be entered per respondent during the experiments. For controlling or feed-back purposes, the individual and group results can immediately be inspected on the screen with a few key strokes.

Data-entry

Before entering the LMD-ratings, one has to define the design of the experiment. It is possible to define two sets of independent conditions C1 and C2 and for each condition a series of time samples TS. It is possible to edit previously entered data.

Calculations and presentation

After all data have been entered one can start with the calculations of the region variables. First it is possible to subtract the ratings at the first time sample from the rest of the time samples to compensate for possible occurring *baseline discomfort*. The second step is a *data reduction* of the time samples within each combination C1 and C2. There are three options:

1. Selection of *one* time sample of interest.
2. Calculation of the *maximum* rating over all time samples.
3. Calculation of the *sum* of the ratings.

After this data reduction, the cluster variables will be calculated (‘*sum*’ and ‘*max*’ clustering can be chosen) and displayed per variable.

For efficiency and methodological reasons one is advised to analyse and present first the clusters and region variables with highest rating percentages (over all conditions together). Selection can be based on series of bar graphs displayed, which show the *relative frequencies* of ratings >0 for all variables. After selection of a particular region or cluster, a graph will show the ratings as function of the conditions (e.g. fig. 3). Here the user has options to display the group and the individual values.

The following ‘one way’ tests per type of condition are performed: the Friedman test for overall significance of differences between conditions, the Wilcoxon signed-rank test for differences between pairs of adjacent conditions.

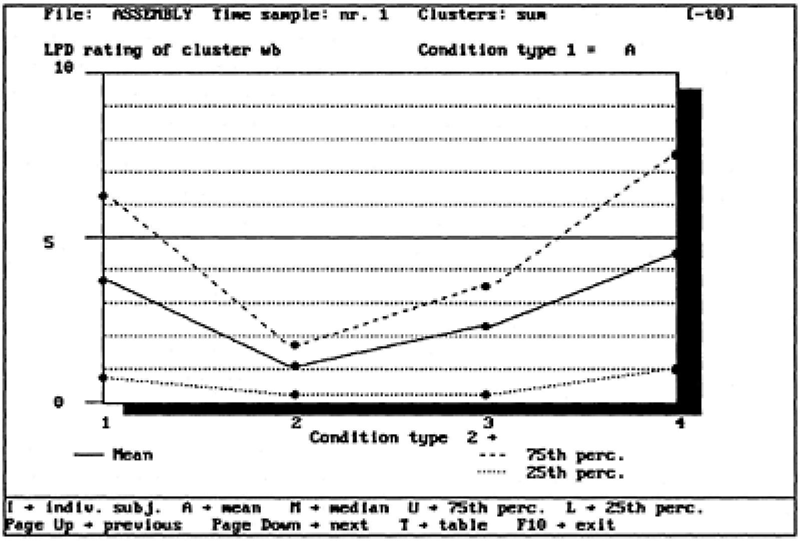

Figure 3. Graph of the Twb discomfort variable; mean, 25th and 75th percentile from 4 working heights in an assembly task in practice (n=8).

Additional applications

Additionally, the LMD-program can be applied in studies on discomfort, fatigue, or pain (input range limited 0–99) with other body maps or rating scales differing from the CR-10 scale. When using the clustering options one has to be aware of these input differences. Examples are the 5 or 7-point discomfort scale (Boussenna et al., 1982), the RPE-scale for (local) exertion (Borg, 1982), VAS for (local) pain (Harms Ringdahl, 1986).

DISCUSSION

Electromyography (EMG) is another method frequently used to measure local muscle loads. EMG measures *electrical muscle activity* of local muscle structures in a direct way. The method requires instruments on the body and qualified personnel to prevent misuse or misinterpretation of the results. For parallel evaluation of more than a couple of muscle groups, quite an instrumentation has to be applied. Furthermore, thorough calibration procedures with special equipment is required in postures similar to those in the task to calculate relative muscle activity levels. However when used correctly, EMG may be a very sensitive measuring method for muscle activity. Yet, for common use by practitioners in work situations, the EMG-method is too complicated.

Rating methods for local musculoskeletal discomfort are a good alternative for sampling load sensations in different body parts. The method measures short or medium term load induced effects. The sensations may originate from *active and passive* loaded local structures or local metabolism. The ratings are direct indications of relative loads per body part. The constructed cluster sum-variables in the LMD-method seem to be reasonable reliable and sensitive.

Both methods can be combined in evaluation studies. If one is interested in EMG-results limited to one or two body regions to keep the procedure simple, one may verify possible adverse effects in other body regions by applying the LMD-method.

CONCLUSIONS

The LMD-method is reasonably sensitive and reliable and can be used for comparing situations with (quasi) static loads. In general, the cluster sum-variables have a greater reliability than the region variables.

A userfriendly computer program supports the method and can be used in field or laboratory measurements. The results are presented at once.

RECOMMENDATIONS

The LMD-method can be advised as a practical ergonomic method for parallel evaluations of body part loads in comparative studies supposed that the loads are more or less (quasi) static. When long intervals are planned between sequential experimental conditions, one has to be aware of some shift in mean values.

The LMD-method should be further evaluated in more dynamic or highly repetitive types of work.

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DESIGN OF 3-DIMENSIONAL ANTHROPOMETRIC DATA ACQUISITION SYSTEM USING MOIRE INTERFEROMETRY AND IMAGE PROCESSING TECHNIQUES

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In this study, moiré interferometry, image processing and computer vision technique are used to acquire 3D anthropometric data in more systematic and economical Banners. Sixty one anthropometric variables were measured. They are basic anthropometric data such as stature,weight and neckbase circumference, etc., and also contain areas of various contours. Cluster analysis was performed with these contour information, and somatotyping was carried out to obtain four distinct types of body shape. The results of the cluster analysis based on the data from the 36 subjects substaniate the efficiency and objectivity of our method compared with the Martine type. And they show 71.88 consistency.

1. INTRUDUCTION

The anthropometry is classified into two methods of measurement, i.e. the direct measurement and the indirect according to whether the measurement equipment contact the human body or not.

The moiré interferometry, the stereo photogrammetry, the multiplex projection and the silhouette are taken as exampls of the indirect method.[1]

It takes much time and costs a great deal to use these 3-dimensional anthropometric methods. Thus in this study we intend to develope the somatotype equipment and the measureing scheme guananteeing reliability and economical efficiency and design the algorithm to reconstruct the anthropomorphic data. Also the somatotyping method and the discriminant method are suggested as the basic data for industrial design. First the theory related to light sourse, grating for making moiré interferometry equipment is considered and image processing technique and computer vision are applied to our experiments. The algorithm for the actual measurement is developed in the process of experiment. The region of the brest of the plaster figure, venus is measured to obtain the moiré information for the 3-dimensional reproduction.

And in the preliminary expriment one subject is selected for anthropometric measurement. After that 36 subject are measured. The cluster analysis is used to seize the relation between the different somatotypes from the acquired data. A comparative study between the above data and the classified somatotype using the discriminant funtion is made.

2. EXPERIMENTS

2.1. Subjects

Tab. 1 Characteristics of subjects

Subject No.	Age	Stature	Weight	Subject No.	Age	Stature	Weight
1	43	171.0 cm	75.0 kg	19	18	171.0 cm	37.0 kg
2	29	173.0 cm	81.0 kg	20	20	163.0 cm	70.5 kg
3	25	172.0 cm	63.0 kg	21	20	167.8 cm	61.0 kg
4	22	158.8 cm	50.0 kg	22	21	175.8 cm	67.0 kg
5	22	175.0 cm	64.0 kg	23	20	177.5 cm	62.0 kg
5	22	175.0 cm	61.0 kg	23	20	177.5 cm	62.0 kg
6	22	167.0 on	56.5 kg	24	19	163.8 cm	57.0 kg
7	22	170.0	61.5 kg	25	20	170.0 cm	69.0 kg
8	22	171.5 cm	74.0 kg	26	26	174.8 cm	65.0 kg
9	25	162.0	63.0 kg	27	26	164.8 on	62.5 kg
10	24	169.0 cm	61.0 kg	28	15	170.8 on	65.0 kg
11	26	173.0 cm	61.0 kg	29	18	174.5 on	71.5 kg
12	25	167.8 cm	62.0 kg	30	17	175.2 cm	71. 5 kg
13	28	170.0 cm	56.0 kg	31	16	171.2 on	59.0 kg
14	25	160.4 cm	70.0 kg	32	14	174.0 on	71.5 kg
15	20	168.0 cm	58.0 kg	33	16	712.2	60.0 kg
16	28	173.5 cm	62.0 kg	31	14	159.0 cm	50.0 kg
17	23	170.0 cm	67.0 kg	35	15	166.8 cm	64.0 kg
18	18	171.0 cm	67.0 kg	36	15	163.8	54.0 kg

The principle object of this research is not the construction of a criterion but the developement of a method which can be used for the 3-dimensional somatotype measurement. So restricted population are selected and measured. The subject of this experiment are 36 males who are from 14 to 43 years old. They are sound bodied males (6 middle school boys, 3 high school boys, and 27 colleage or graduate cource)

Table [1] shows age, hight and weight of subjects.

2.2. Experimental Equipments

Experimental equipments consist of the visual processing system to perform moiré interferometry and Ar-ion laser, light source and grating etc.and to produce moiré frenge.

[fig. 1] shows the organization of these equipements and [fig. 2] shows a black diagram of the measurement data processing system.

The specifications of the visual processing system,light sourse system and grating are as follows.

A. Vidicon Camera

TV camera is used for the visual data input device. In this research,our data is obtained by using SONY video camera HYC-80 and adapter, VHA-210A.

B. Image Processor

The interface board changing analogue signal of image from videcon camera into digital one, buffer memory storing the signal and image processor constitues image processing system.

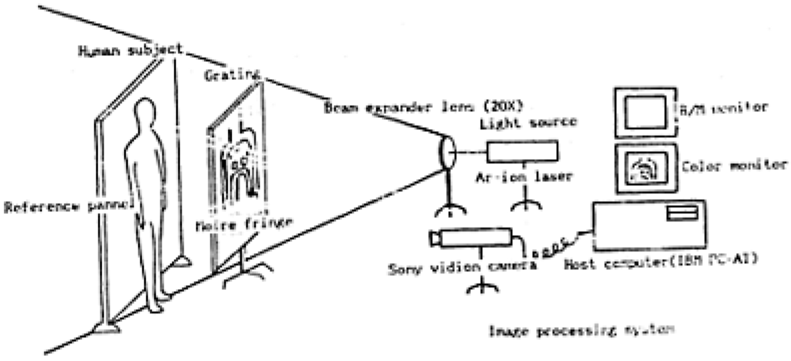

Fig.1 Data acquisition system

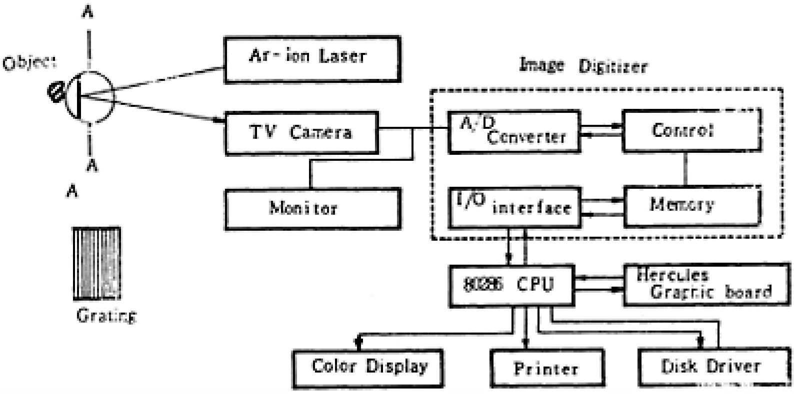

Fig. 1 Data acquisition system

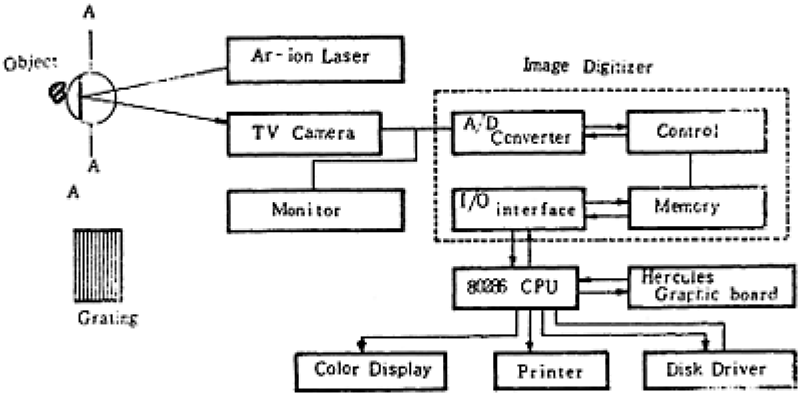

Fig.2 Block diagram of 3D anthropometric data acquisition system

In this experiment, UT 2853–60Hz was used for hardware board of image processing. UT 2853 board has 512*512*256 resolution level and hardware to attain the input data which is compatible to RS-170, MTSC, RS-330.

Futhermore, DT2853 board whose total memory size is 5M byte has two image processing buffer in itself.

IMAGE-PRO and PC SEMPER can be utilized as preprocessing and application software. BASIC, FORTRAN, C-Programme language—can be used by library.

The Hercules graphic board (720*340 pixel) and 640K byte Ram was used to generate 3-dimensional data and process them.

Above image processing system used IBM-AT as a host computer and processes the image signal.

C. Light Source System

The light source used in this experiment is highly generated Ar-ion laser of 5W and beam expandet. Among them, laser is a product of spectra physics. We used laser light by examing green light of 5145A among a wave length(4765–5145A) with rear prism and then magnifying it with micro scope lenz of 20*(f=1.25m).

D.Moiré Contour Graph Equipment

The gratings used to generate moiré contour graph are listed as follwings.

(1) Local grating

We make grating of which interval is 0.5mm and available area is 270mm* 370mm and nylon thread of diameter 0.5mm was used in this experiment.

(2) Grid for whole body

Relatively thick nylon fiber is used for analizing body type which is similar or dissimilar to other people. Moreover, grating-diameter, gap: 2mm , efficient area: 1100mm*2000mm—is used. Grating is coated black, in order to obsorb light and to prevent scattering.

2.3. Methodology

Main procedure of experiments are as follows;

(1) Calibrating magnification of vidicon camera.

(2) Visualizing moire pattern by using vidicon camera which is produced by above-mentioned experimental equipment.

(3) Storing image processed cordinates in computer memory.

(4) Collecting fundamental data for cluster analysis obtained from evaluation of absolte area between contours which is previously drawn up.

A. The Calibration of Camera Frame Skewness.

The Varaition of input image due to the skewness of lens and light density by its source must be considered when camera is used as a input sensor. To calibrate the skewness of lens, zoom lens is used for wide range of mesurement area instead of long focus camera.

Because image alters much by change of light grey level, ratio of area screen with distance method was used to calculate the moving distance of camera.

B. Image Processing

In this experiment, subject is positioned at the backward center of grating and moiré frenge is generated by using prescribed experimental equipments. Then, generated frenge was visualiged by vidicon camera and then, processed by digitiger. Attained two dimensional coordinates after above procedure was stored in memory. There are difficulties to analyze set arithmetic and geometric characteristics in Run-length representation method and Chain Code method for analysis of binary image [2, 3].

In this experiment, we get image information *from* the head and the brest of the subjects difficult of mesurement and represantation. Since in the generated moiré frenge, the contour of height H has characterstic coordinate with respect to Z—coorinate axe, it is possible to get the 3—dimensional coordinate of the actual mesurement—sample image. [4] The frenges, image information stored in computer memory are represented as relative thick line in digital image. So we change it to binary image and then extract the skeleton in it.

3. SOMATOTYPE ANALYSYS USING CONTOUR

There are many applications of moiré potograph to the anthropometry. But in the published researches the preparation of contour and the 3-dimensional coordinate transformation are time-consuming. Hence we intend to classify the somatotype of the sampling population through cluster analysis to investigate the validity of our research.

3.1. Somatometry

The above mentioned experimental

Tab. 2 Anthropometric variables list by moiré interferometry

Variables	Contents	Variables	Contents
B0	No. of object	B14-B28	Area of left face (contour 1–5
B1	Age		
B2	Stature		
B3	Chest circumference	B29-B43	Area of right face (contour 1–15)
B4	Chest breadth		
B5	Waist circumference		
B6	Weight	B44-B51	Area of left body (contour 1–8)
B7	Foot length		
B8	Procers breadth		
B9	Nose breadth	B52-B59	Area of right body (contour 1–8)
B10	Nose length		

B11	Neck base circumference		
B12	Hip circumference	B60	Length of trunk 1
B13	Thigh circumference	B61	Length of trunk 2

equipments are used to measure 36 male subjects. In case of the head, after 7 contours of Menton-Sellion length (from nose to mental spine) are produced, each are is calculated.

Also the trunk with acronion, stermum and omphalion as the central figure is processed by the same method. [Table 2] shows the measuring region. The cluster analysis using Ward [5] of SPSS which is the algorithm by the minimum variance shows 4 cluster. [Tab. 3] The cluster 4 was eliminate because

of its isolation from the others.

Tab. 3 Results from cluster analysis

Cluster Category	Subject No. in the cluster	No. of cases
1	2, 9, 16, 26, 3, 10, 15 18, 29, 19, 17, 21, 1, 22, 30, 20	16
2	25, 36, 32, 33, 13, 14, 35	7
3	11, 27, 5, 12, 6, 7, 31, 4, 34	9
4	8, 28, 23, 24	outlier value

4. DETERMINATION OF THE DISCRIMINANT FUNCTION

In this study stepwise regression being performed to know the relation between the somatotypes abtained from cluster analysis and the Martin-type anthropometric variables, the possiblity of the somatotype classification is discussed by calculating the discriminant function. The analysis results in the following equations, 1, 2 containing 3 variables.chest circumference (B3), Weight (B6), neckbase circumferenee (B11).

$$F1=1.53342-0.00164*B3+0.25414*B6-0.04459*B11 \quad (1)$$

$$F2=13.19530+0.00570*B3+0.00228*B6-0.002219*B11 \quad (2)$$

The classification decision map is abtained from the values of F1 and F2. Fig. 3 shows the result of the 36 subects to be grouped by the above equations. Also the results that the Martine-type anthropomorphic data about the 36 subjects is compared with that of the classified group show 71.88% consistency as [Tab. 4].

This means the proportion of group belonging to the population when the discriminant function contains 3 calssification variables (B3, B6, B11).

Tab. 4 Classification results

Actual Group		No. of cases	Predicted group membership		
			1	2	3
Group	1	16	10	1	5

		62.5%	6.3%	32.3%
Group 2	7	1	5	1
		14.3%	72.4%	24.3%
Group 3	9	1	0	8
		11.1%	.0%	88.9%
Percent of “grouped” cases correctly classified: 71.88%				

For statistical test the above 3 variables are considered about the original 36 subjects and others 43 subjects. The values of the variables are applied to the equation 1, 2 as shown in Fig. 4. Thus we know that all except sample 29 and 30 are suited for the population.

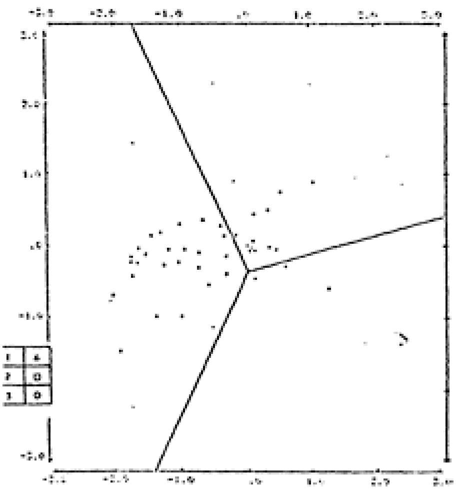

Fig.3 Groups scatter plot map

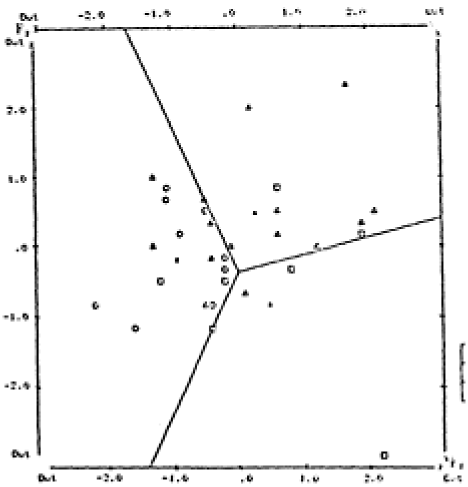

Fig.4 Groups plot another subjects

5. CONCLUSION

In this study, by using the moiré interferometry, image processing and computer vision technique.the methods and the equipment by which the anthropomorphic data can be detailed obtained was developed. Also the quantification and the interpretation scheme of the antropomorphic data which enable us to utilize them for the industrial design was suggested.

The results of the cluster analysis based on the data from the 36 subjects substantiate the efficiency and objectivity of our method compareed with the Martin type. And they show 71.88% consistency. The stepwise regression was performed and tested to know the relation between the somatotypes obtained from cluster analysis and the Martin-type anthropomorphic variables. For this the discriminant function value about the 43 subjects not involved in our experiment was calculated.

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TITLE: Development of an Image Analysis System for Evaluation of a Manual Lift

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Taylor & Francis, 1992

Video Ergonomic Evaluator (VEE) is a computer system designed at Texas A&M University to analyze a manual lift according to the new NIOSH Work Practices Guide. The goal in this endevor was to create a low cost NIOSH Work Practices Guide analysis system which would require minimal user effort and standardize NIOSH analysis and output. With this system, a video tape of a manual lift is played through a computer system and analyzed with the assistance of the computer user. The user selects measurement landmarks and points of analysis on the target individual, such as ankles and load center, by using a mouse. A NIOSH Work Practices Guide analysis is subsequently produced utilizing the entered data and other summary information.

INTRODUCTION

Video Ergonomic Evaluator (VEE) is a lifting analysis tool developed for the new NIOSH lifting guide. The goal in developing this tool was to create a low cost NIOSH Work Practices Guide analysis system which would require minimal user effort and standardize NIOSH analysis and output. VEE utilizes a video tape of a lifting situation which has been created at a work area. This lift is then played back through an image capture system which will perform subsequent NIOSH analysis. Once the analysis is complete, the user has access to a complete NIOSH analysis as well as pictures of the lift environment and background information on the lift. In order to perform workstation redesign these lifting analysis details are essential.

SYSTEM CONFIGURATION

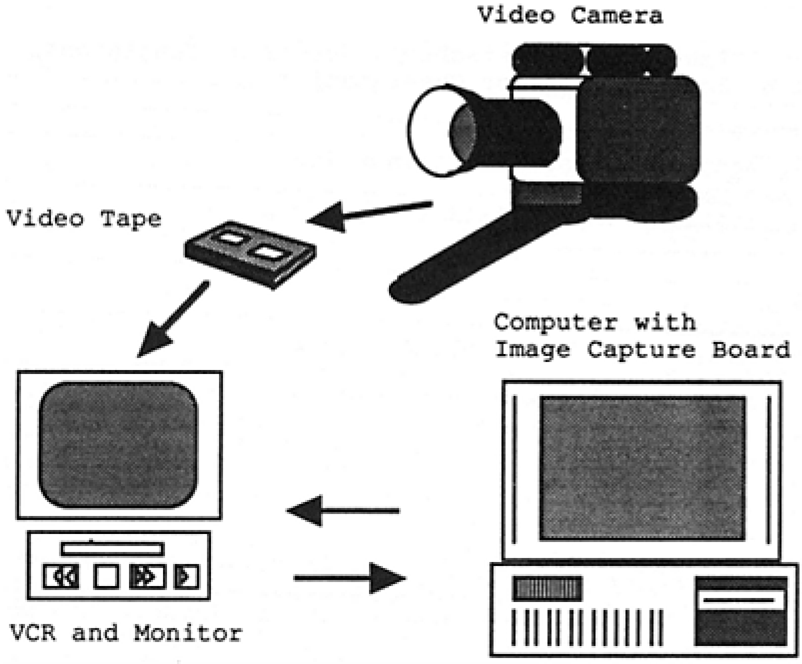

Figure 1. Components of the Analysis System

As shown in Figure 1, the VEE system is comprised of a PCVision Plus image capture board (Imaging Technology) installed in a PC 386 computer containing Windows 3.0, a VCR and monitor both connected to the image capture board, and a camcorder for collecting the data.

DATA COLLECTION

VEE is designed to make data collection as easy as possible. All that is needed to collect NIOSH H, and V parameters is a video camera, video tape, and a reference marker. A reference marker can be anything that has a known length such as a yard or meter stick.

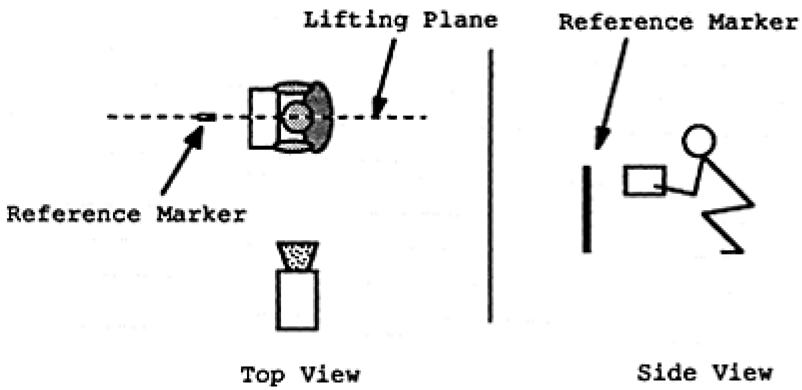

Figure 2. Camera position at origin of lift

An illustration of how the lifting person must be positioned at the beginning of lift with respect to the video camera can be found in Figure 2. All video taping must be performed 90° to the lift in order to analyze line length correctly. If the lifting person twists the upper body while placing the load at the destination of the lift, the video camera may need to be repositioned in order to capture video tape 90° to the final lifting position. Relocation of the reference marker may also be necessary if the camera position changes.

DATA ENTRY AND ANALYSIS

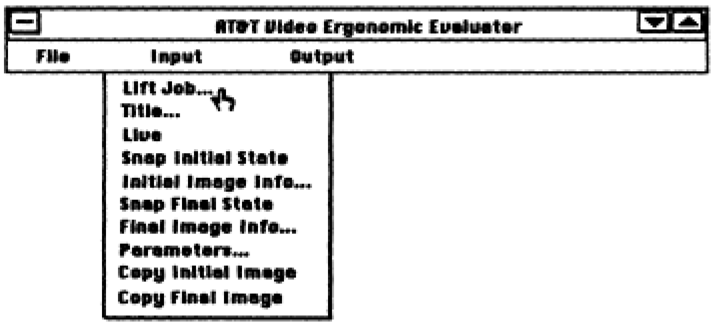

Figure 3. Opening VEE menus

Once the video images have been collected, the data is entered within the VEE computer program.

• "Lift Job" allows the user to select whether a lift with single or multiple tasks is to be used for analysis. This program will allow calculation of either type of lift

• "Title" provides a spot for the gathering of general and historical information.

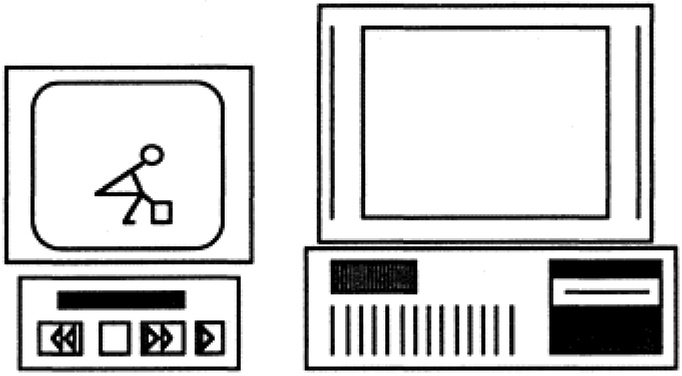

Figure 4. Beginning of the lift as seen on the side monitor

• “Live” electronically activates the image capture board. The video tape can be viewed on the monitor next to your computer. Once the beginning lifting segment has been found move to step 4.

• “Snap Initial State” will freeze the video picture on the monitor to the side of your computer for analysis.

• “Initial Image Info”, using a mouse, gives the user an opportunity to calibrate the lifting frame by moving a cursor across the side monitor and clicking at either end of the reference marker. Calibration is complete once the length of the reference marker has been entered. The mouse is then used to select the load center, floor surface, near ankle and far ankle.

• The latter three steps are repeated for “Snap Final State”, “Final Image Info”. This will gather the data for the final position of the lift.

• “Parameters” allows the user to view NIOSH lifting parameters for analysis. It here that object weight, frequency, duration, coupling, and angle of twist are entered into the program.

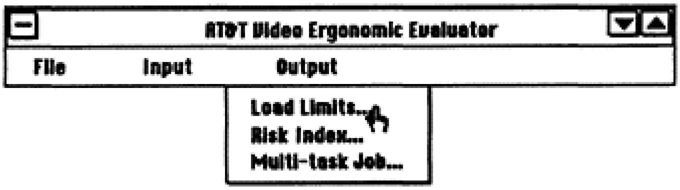

Figure 5. Output menu

NIOSH Load Limits can now be viewed by selecting “Load Limits” under the Output menu.

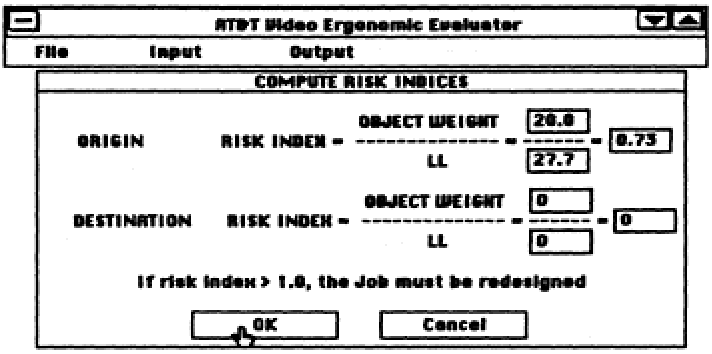

Figure 6. Load limits screen

• "Load Limits" shows multiplier values as well as Load Limit (for single task work areas), and Frequency Independent Load Limit (for multiple task work areas).

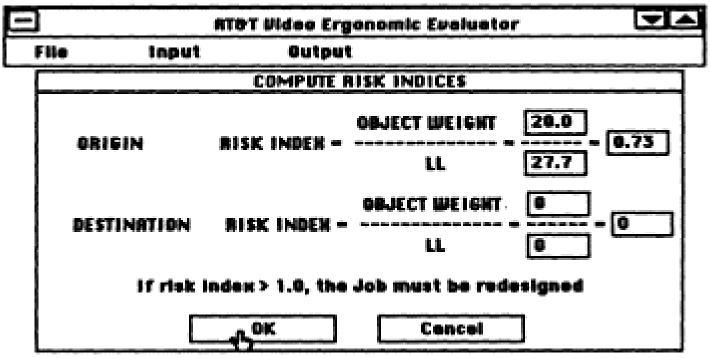

Figure 7. Risk Index for single task jobs

• "Risk Index" gives the calculations for origin and destination of lift for the single task analysis.

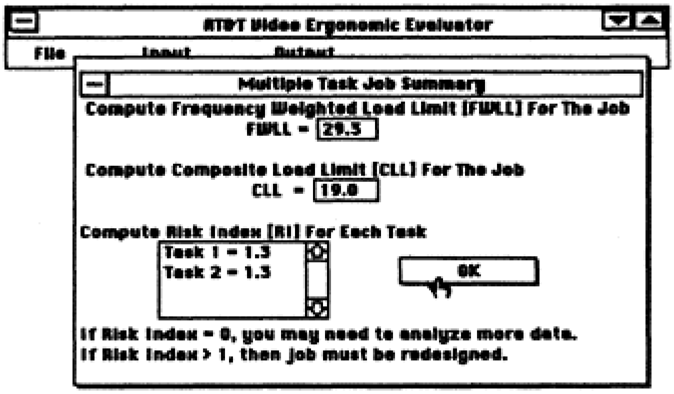

Figure 8. Risk Index for multiple task jobs

• “Multi-task Job” lists the risk index for each separate task performed for analysis.

SUMMARY

While a full scale study on human accuracy with tape measure versus the VEE system is forthcoming, preliminary studies on VEE measurement accuracy with human users have shown it to be within 1/2″ of actual distances.

In conjunction with accuracy, VEE’s strengths lie in the ability to standardize the NIOSH lifting analysis format, easy analysis of both single and multiple task lifts, and with its low cost. The system’s design to keep accurate records of each lift as it is analyzed enables anyone familiar with NIOSH Lifting Guide terminology to be able to read VEE output as a report.

The current version of VEE is unable to automatically record the angle of twist. Future releases of VEE will incorporate the ability for this kind of analysis or a remote device to aid in measurement.

ANALYSIS OF VIDEO TAPED TASKS INVOLVING UPPER EXTREMITY CUMULATIVE TRAUMA RISK FACTORS: VALIDITY AND VIEWER BIAS

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The effect of viewer background on the ability to identify upper extremity cumulative trauma disorder risk factors was measured. Subjects had backgrounds in business, health, engineering, medicine and nursing, behavioral and social sciences, physical sciences, and life sciences Subjects with backgrounds in medicine/nursing and life sciences did better than the other groups.

INTRODUCTION

Professionals practicing as ergonomists have a wide variety of undergraduate training. Degrees can be found in the humanities, engineering, behavioral and social sciences and the life sciences to name a few. This project investigates the effect of background and training on the identification of ergonomic risk factors.

276 subjects attending five courses in the principles of ergonomics viewed a videotape of actual work situations. The tasks involved a variety of upper extremity cumulative trauma disorders (UECTD) risk factors. The viewing of the tape followed approximately five hours of lecture and discussion on the types, causes, and risk factors of UECTD. Collected subject background information included formal training and college degrees (undergraduate and graduate), areas of current practice and amount of experience in ergonomics.

METHODS

The subjects viewed eight videotaped tasks and were asked quantify eight risks factors involving varying degrees of poor postures, high forces, and high frequencies. These were: ulnar deviation, wrist flexion, wrist extension, reaching behind the body, upper arm adduction/articulation, head/neck posture, grip (power grip versus pinch grip), and frequency. Subjects were also asked to to rate the overall risk of each task. The subjects were instructed to assume the tasks were performed for an eight hour shift with fifteen minute breaks in the morning and afternoon and a half hour lunch. The risk factors were rated on a scale from one to five, with one representing little or no risk and five representing significant risk.

The tasks were also rated by Donald Bloswick, P.E., Ph.D. Dr. Bloswick has over ten years of experience in the on-site and video tape analysis of ergonomic risk factors. Dr. Bloswick rated the tasks at two different times to first assign the rankings and then again to confirm the initial rankings. These ratings reflect one expert's opinion of the ergonomic risk factors for the video taped jobs, and for the purposes of this paper, are assumed to be the "correct" score. The ratings of the subjects were grouped into two categories. Those scoring the same as or within one of the correct score and those scoring two or more away from the correct score.

The subjects were placed in eight categories based on their formal training and undergraduate degrees at the bachelors level. The categories are based on colleges or departments found within a university setting. These are: business (B) n=4, health (H) n=146, engineering (E) n=18, medicine and nursing (M/N) n=8, behavioral and social sciences (B/S) n=20, physical sciences (PS) n=12, and life sciences (LS) n=29. The eighth category is no undergraduate degree (NO) n=22.

Two types of analyses were conducted. The proportion of each category scoring within the accepted range was compared to the probability of selecting an answer within the accepted range by chance. Also, the number of each category responding within and outside the accepted range was compared to the proportion of all other respondents within a two by two table and tested for independence by χ^2 analysis. As an example, figure 1 represents the two by two table for testing the category of life sciences against all others in the study.

1	within accepted range	outside accepted range
life sciences	1299	467
all other	10481	4314

Figure 1. Example of two by two table for χ^2 analysis.

The total number of responses is approximately the number (n) in each category multiplied by the the eight tasks multiplied by the eight risk factors. This is an approximation, because not all participants responded completely. Actual number of responses was used in the calculations.

Fifteen subjects answered "yes" or "B.S." in when asked for the bachelor's degree. These responses are included in the χ^2 analysis when each category is tested against the other categories.

RESULTS/DISCUSSION

The data was analyzed in two methods. A χ^2 analysis of (1) categories and overall response of all tasks and risk factors tested and (2) sample proportion of each category and risk factor. The χ^2 analysis tests if the the participant's bachelor's degree, and the associated training, is independent of the the participants ability to recognize and quantify UECTD risk factors. Table 1 presents the results of this analysis and indicates that the ability to quantify UECTD risk factors was significantly dependent ($p<0.05$) on training in engineering, life sciences, and medicine and nursing.

Table 3. Comparison of categories and risk factors showing the percent difference from the probability of responding by chance.

	Percent difference from scoring correct answer by chance*							
RISK FACTOR	B n=4	B/S n=20	E n=18	H n=146	LS n=29	M/N n=8	NO n=22	PS n=12
ulnar dev	4.2	−9.0	−10.2	−16.1	−2.0	0.0	−10.4	−1.3
wrist ext	28.3	−5.8	7.5	4.9	14.2	6.4	1.8	14.2
wrist flex	17.5	24.6	20.1	27.0	24.1	32.0	25.4	21.0
upper arm	32.1	15.7	19.1	21.5	23.8	26.4	18.2	10.8
head posture	18.8	20.4	9.0	20.0	14.5	27.7	16.6	20.6
grip	14.9	12.2	13.6	7.7	17.6	13.1	15.1	16.8
frequency	12.8	28.0	20.2	26.3	24.5	36.6	31.9	20.6
reach behind	35.0	24.4	27.1	31.1	27.8	30.5	22.3	36.5
overall	30.0	25.5	25.5	30.3	31.5	30.3	29.6	30.0
AVE. DIFF	21.5	15.1	14.7	17.0	19.6	22.6	16.7	18.7

Upper, lower confidence intervals for all proportions (expressed as percents) are less than 0.2 percent.

Medicine/nursing and life sciences scored the first and third best averages. The business category scored the second best. The sample size for the business category, however, is small, and the results may not be representative.

CONCLUSIONS

The χ^2 analysis suggests that there are variables associated with fields that are a part of the medicine/nursing and life sciences that lend themselves to recognizing and quantifying UECTDs. These two categories also do well in their performance in the analysis conducted in table 3.

An understanding of biomechanics and physiology/anatomy are important in the analysis of UECTDs. The medicine/nursing category would certainly understand the physiology and anatomy, and, depending on the field, there should be a good understanding of these concepts in the life sciences.

It was expected that the health category (occupational therapists, physical therapists, exercise physiologists, for example) would score as well as the life sciences since these groups also have training in biomechanics, anatomy, and physiology. No explanation for the relatively low score is available. Other specific disciplines (ie, industrial engineers) may have performed well with this analysis but were grouped within the overall engineering category. Further analysis is also required to determine viewer bias independent of outside expert opinion. For example, do ergonomists with different backgrounds "see" different UECTD risk factors in a given job.

Table 1. Results of the χ^2 analysis for each category as compared to responses of all other participants in the study and the corresponding p value.

CATEGORY	% CORRECT RESPONSES*	% DIFFERENCE	p value, (χ^2)
BUSINESS (B)	75.4	4.3	.125
ENGINEERING (E)	68.5	−2.8	.048
HEALTH (H)	70.9	−0.5	.409
LIFE SCIENCES (LS)	73.6	2.8	.017
MEDICINE/NURSING (M/N)	76.8	5.8	.004
PHYSICAL SCIENCES (PS)	72.5	1.4	.417
BEHAV/SOCIAL SCIENCES (B/S)	69.0	−2.3	.089
NO DEGREE (NO)	70.9	−0.3	.853

Upper, lower confidence intervals for all proportions (expressed as percents) are less than 0.2 percent.

The life sciences (2.8%) and the medicine/nursing (5.8%) categories scored proportionately more accepted answers compared to the remaining group. The engineering category scored fewer acceptable answers (−2.8%) when compared proportionately to the remaining group. Table 1 suggests that the variables surrounding the fields included in the life sciences, medicine, and nursing may be advantageous when evaluating upper extremity cumulative trauma disorders.

The proportion of each category scoring within the accepted range for each risk factor was compared against the probability of scoring within the accepted range by chance. Table 2 indicates the probability of scoring within the accepted range by chance for each risk factor. A risk factor with a correct response of one or five only allows for a two-in-five chance (40%) of randomly selecting the correct answer. A risk factor with a correct answer of three allows for a three-in-five chance (60%) of randomly selecting the correct answer.

Table 2. Probability of selecting an accepted answer by chance for each of the risk factors.

RISK FACTOR	PROBABILITY	RISK FACTOR	PROBABILITY
ulnar deviation	.525	grip	.575
wrist extension	.500	frequency	.550

wrist flexion	.525	reaching behind	.450
upper arm	.550	overall	.575
head posture	.600	average	.540

Table 3 illustrates the performance of subjects from the different fields when compared to the probability of specifying the correct rating totally by chance.

VALIDATION OF THE GRIPMASTER™ AS AN ERGONOMIC TOOL FOR EVALUATING GRIP FORCES AND WRIST ANGLES IN REAL TIME

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INTRODUCTION

The need for accurate and reliable devices to aid in ergonomic analysis and tool design has been well established. One such need is for a tool used to identify potential risk factors for carpal tunnel syndrome and other cumulative trauma disorders found in the workplace. A new tool has been developed to aid in ergonomic job evaluations (Figure 1). The GripMaster™, developed at EXOS, Inc. of Burlington, MA, is a two-dimensional goniometer with the capability of measuring force from five separate pressure transducers (resistive ink sensors made by Interlink Electronics). This study was designed to validate the GripMaster™ versus standard equipment now used in the ergonomics field. Results from the force sensor validation studies will be presented in this paper.

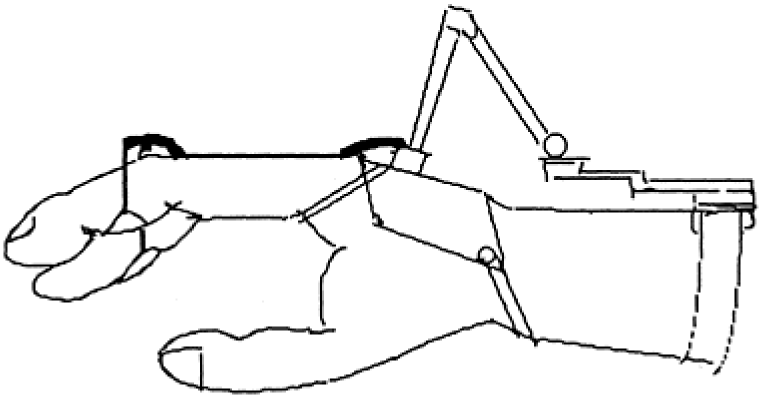

Figure 1. The GripMaster™

METHODS

Subjects

Ten right hand preferred female subjects were tested in this study. The subjects were chosen from the student population at the University of Massachusetts at Amherst and were required to sign an informed consent document and have no medical history of hand problems. Subject characteristics were as follows: mean height, 168.0 cm (sd, 5.2), mass 60.2 kg (sd, 6.3), age 24.8 years (sd, 3.6).

Experiment I

Each resistive ink sensor was mounted onto a stirrup shaped platform. Known masses were hung from each sensor individually (Figure 2). Once good contact was established between the mass distributor (a Plexiglass cube covered with latex) and the sensor surface, sampling began. Data were sampled in an uncalibrated format, at 50 Hz by a 12-bit A/D board in a microcomputer for three seconds. After sampling, the next mass was placed in the basket so as not to disturb the load distributor placement. This procedure was followed until all conditions were tested (2, 4, 6, 8, 10, 12, and 14 kg) on one sensor. Then the sensor was replaced with an adjacent one. Sampling was repeated until all sensors were tested for five trials. The same procedure was followed a second day for a repeated measures design.

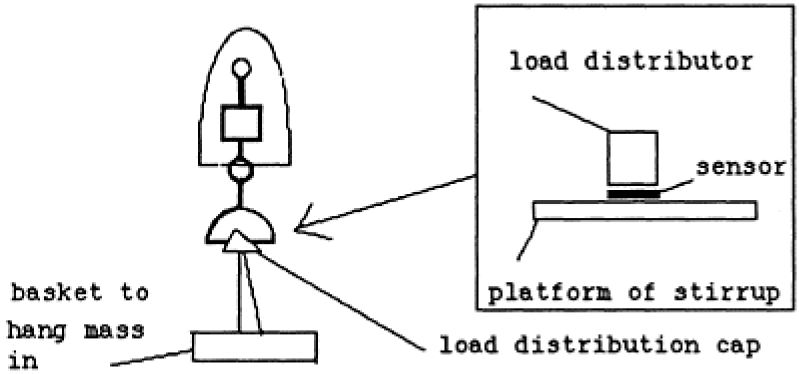

Figure 2. Sagittal view of testing apparatus.

Experiment II (force sensors versus dynamometer)

GripMaster™ calibration data was collected for every sensor prior to each experimental session. The same procedure used in Experiment I was followed, except one trial for each known mass was used (4, 6, 8, 10 kg). Sensors were mounted on the middle phalange of the fingers and thenar eminence of the subject's preferred hand with athletic tape. The subject was then seated with their shoulder abducted 30 degrees and neutrally rotated, elbow flexed at 90 degrees with forearm and wrist in neutral position as done previously by Pryce (1979); Thorngren and Werner (1979); and Mathiowetz et al. (1984). The subject was asked to grip a hand dynamometer in their preferred hand using a power grasp. The dynamometer was supported on a table. Initially, two trials of maximum voluntary grip force (MVGF) were measured. Using visual and verbal feedback, the subjects were told how much force to exert (25%, 50% or 75% of MVGF) for the remaining conditions. Three trials were given per condition and testing repeated on a second day for a repeated measures design. The visual feedback consisted of an average strength reading in pounds from the Jackson Strength Evaluation System (Lafayette Instrument Co., model 32528). Verbal feedback was given by the investigator as either higher or lower. The subject was allowed only enough time to establish the desired force output without risking muscle fatigue before data collection began. Trials lasted for 4 seconds and at least 1 minute of rest was allowed between trials. The same procedure was followed for the pinch grip trials except that the subject sat with forearm supinated and gripped the dynamometer with a pinch grip. The thumb sensor was moved from the thenar eminence to the distal phalanx. Criterion measures included the dynamometer 3 second average and a three second average of the summed finger and thumb forces collected by the GripMaster™.

Data Analysis Experiments I and II

For Experiment I all trials of uncalibrated data were plotted versus known mass for each sensor. The line of best fit was then determined using the method of least squares for each day of testing per sensor. This calibration curve was used to convert the sensors' uncalibrated values into Newtons.

For Experiment II the calibration trials were plotted versus known mass and a best fit line was determined for each sensor per subject. The first three seconds (150 points) for each trial were averaged together as one datum per sensor. That value was then converted to Newtons using its respective calibration curve. A sum (in Newtons), of all five sensors was taken as the total grip strength.

RESULTS

Experiment I

The results of a three way repeated measures ANOVA (REANOVA) on uncalibrated data showed significant differences between sensors, days, and conditions ($p \leq 0.01$). Scheffe's pairwise comparison of conditions demonstrated significant differences in all conditions except 6 and 7 ($p > 0.05$). These conditions correspond to 12 and 14 kg respectively. Intraclass correlations, computed on the uncalibrated GripMaster™ data, ranged from 0.72 to 0.88. Intraclass analysis also revealed a strong sensor by day interaction. Eighty-seven percent of the sensors showed a decrement in performance on average of about 6% from day 1 to day 2. Documented use of one sensor over twelve sessions, showed a drastic decrement in performance. This was termed "sensor death". Figure 3 represents this graphically.

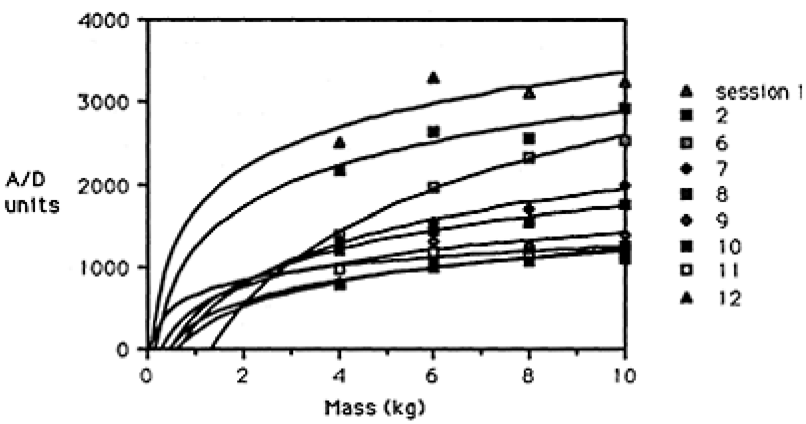

Figure 3. Typical sensor response decline over twelve testing sessions.

Experiment II

A three way REANOVA performed on all conditions showed significant differences between subjects, conditions, and devices ($p \leq 0.01$). Further analysis of the power and pinch grasp conditions revealed devices were only significantly different for the pinch grasp conditions ($p<0.05$). Intraclass correlation analysis performed on the GripMaster™ and the dynamometer denoted ranges of 0.00–0.97 and 0.82 0.95 respectively (see Table 1). A regression of the GripMaster™ with the dynamometer produced a correlation coefficient of 0.52. A similar regression with the outliers removed yielded a correlation coefficient of 0.74. The outliers were defined as having a standardized residual greater than plus or minus 3 standard deviations from the regression line.

Table 1. Intraclass correlation coefficients for the GripMaster™ and dynamometer.

Cond	mean GM	mean DN	sd GM	sd DN	R GM	R DN
power						
25%	78.3	82.3	23.8	16.7	0.22	0.82
50%	188.3	164.6	61.2	33.4	0.75	0.88
75%	346.3	246.8	207.7	46.6	0.56	0.88
pinch						
25%	35.6	20.2	13.6	7.0	0.00	0.95
50%	66.0	39.6	30.8	12.8	0.71	0.88
75%	141.2	59.8	122.3	18.9	0.97	0.93

where:
GM=GripMaster™ and DN=Dynamometer sd=standard deviation

DISCUSSION

Calibration accuracy

External calibration of the GripMaster™ force sensors proved to be very difficult because of the differences between sensors, differences over days and their characteristically logarithmic response. The results suggest that in order to get meaningful readings from the GripMaster™, each sensor must be calibrated individually with at least 7 known masses each day prior to use. Since the typical sensor's response ranged from 1000–3000 A/D units for 2–14 kg loads (see Figure 3), it is highly recommended that more loads be applied at the lower end of the response curve (<2 kg) and that loads should not exceed 12 kg to determine a more accurate logarithmic relationship.

Sensor reliability

Intraclass correlation coefficients on the uncalibrated data ranged from 0.72 to 0.88. This suggests that the sensor response is moderately reliable over trials and days when applying a load as done in Experiment I. This validates the procedure of loading the sensors using a Plexiglass cube coated with latex but may not extend to use with human fingers. For almost all conditions, there was a significant sensor by day interaction. Specifically, eighty-seven percent of the sensors used showed a decrease in response on average of 6% per day. These decrements were the first indications of "sensor death", characterized by the flattening out of the logarithmic sensor response curve. It is doubtful that the intraclass coefficients would remain as high if the data included 4 or more days of testing.

Reliability of GripMaster™ and Dynamometer Readings

The reliability of the dynamometer and the GripMaster™ were tested using an intraclass coefficient. The results indicated that the dynamometer was highly reliable over trials and days with intraclass coefficients ranging from 0.82 to 0.95. In contrast, the GripMaster™ had coefficients ranging from 0.00 to 0.97. Extremely low intraclass coefficients were caused by greater variance due to days and trials as compared to variance due to subjects. This is most dramatically seen in the 25% pinch and power conditions (Table 1). The low reliability appears to be influenced by the sensor/finger interface. In Experiment I the load from the known mass was distributed directly onto the force sensing region of the sensor through a Plexiglass cube covered with latex. In Experiment II the force was dispersed through the fleshy pads of the finger. Buchholz (1989) established that human skin is initially compliant until it reaches a large deformation at low loads and then stiffens to a constant deformation at higher loads. This would explain very low reliability at low force loads.

Tissue deformation, in combination with the positioning of the force sensor between the finger and dynamometer handle, posed a serious problem. The force sensor was highly influenced by the properties of the material in contact with it and the area that the force was applied over. It was only reliable when the load was applied with a non-yielding material over the same surface area as seen in Experiment I. Jensen et al. (1991) circumvented this problem by applying an epoxy dome over the sensor's sensing area. This allowed for even distribution of the load and also helped to keep the sensor rigid under loading. The investigators found an insensitivity to the position of the force sensors when the epoxy dome was used and a high sensitivity to the surface area without the epoxy dome.

Comparison of the GripMaster™ versus a Dynamometer

The results of a 3 way REANOVA with days, conditions and devices as main effects revealed a significant difference between the two devices tested. Since there were two different grips used in the experiment (power and pinch), two additional 3 way REANOVA's were computed. Results showed a significant difference between the GripMaster™ and the dynamometer in the pinch grip only.

Using the dynamometer readings as the "gold standard", the GripMaster™ over-predicts for all three pinch grip conditions. One possible explanation for this is the calibration method. Tested pinch grip strength ranged from 8.8 to 114.4 Newtons. Since the finger contribution has been measured at 24–34%, 24–33%, 21–28%, 15–21% for fingers 2 through 5 respectively, the GripMaster™ force sensors were measuring strength of 1.3 to 37.8 Newtons (Radwin et al. 1990; Hazelton, 1975 and Ohtsuki, 1981). It is likely that the low end calibration of the sensors did not adequately characterize the sensor's response at low force levels because the lightest mass applied during calibration was 4 kg (38.7 Newtons). Therefore the GripMaster™[1] s readings were extrapolated from the calibration curve, contributing to over-prediction for each sensor. The error was then summed over all 5 sensors. This may explain why the GripMaster™ over-predicted for each pinch grasp condition by nearly 2 times that of the dynamometer results; specifically, 17.6 to 61.6 Newtons over the mean dynamometer readings.

In the power grasp conditions, the devices were not found to be significantly different. The power grasp conditions measured grip strength ranging from 44 to 365.2 Newtons. With finger contributions as previously mentioned, the GripMaster™ was measuring forces from 6.6 to 124.1 Newtons in each sensor. For most subjects the 50% and 75% conditions were well within the calibration range of 4–10 kg. This evidence supports the calibration process as the source of the inaccuracy. Even though the differences observed between the dynamometer and the GripMaster™ were not statistically significant, the GripMaster™ still over-predicted on average of 1.2 times that of the dynamometer reading (about 0–96.8 Newtons). This could be due in part to the summing of error components in each sensor's prediction.

Explanation of Outliers

The regression of the GripMaster™ data with the dynamometer data depicts the GripMaster™'s over-prediction across all force levels. When the outliers were removed the coefficient of determination increased approximately 20%. These outliers were due to the logarithmic response of the sensors. The higher the A/D measure, the more likely that an exaggerated prediction would result. Outliers were even more probable as the sensors got older and underwent sensor death. A degenerating sensor has a smaller A/D range of response, hence a decreased sensitivity. Therefore a small increase in A/D output could result in an exaggerated prediction. In fact, the seven outliers that were removed involved summed forces from sensors that had up to twelve uses (see Figure 3). By the twelfth day the sensor was depleated.

Recommendations for Further Development of the GripMaster™

A full characterization of the force sensor's static and dynamic response under different loading conditions must be studied. This should be performed over an extended period of time to determine the useful life of a sensor and to delineate when sensor death starts to occur. At this time it is recommended that the sensors be treated as disposable. For a more accurate calibration method, the sensors should be attached to the subject in order to incorporate any tissue deformation into the calibration curve. It is highly recommended that an epoxy be applied to the sensing area to distribute all force evenly into the sensor as done by Jensen et al. (1991). Finally, for the sensors to be useful in a field situation they should be of a sturdier construction so as to withstand a reasonable amount of field use.

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A Technique for the Determination of Physiological Demand: Its Utilization in Task Simulator Development and Ergonomic Intervention Assessment

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INTRODUCTION

In order to minimize the injury potential of new workers in a smelter operation and maximize the quality and effectiveness of training, the development of job simulators reflective of the physiological and biomechanical job demands was proposed. To quantify the physiological requirements of entry level jobs, an inexpensive technique was desired that would reflect the physiological capacity of workers currently performing those jobs.

Quantification of the physiological demands for heavy labour industrial jobs may be very problematic due to the nature of jobs and the hostile (toxic fumes, open flames, heat and noise) environments in which they are performed. Although it is possible to determine the oxygen uptake using portable devices, these relatively expensive devices are not always compatible with the safety equipment required to perform a job. Estimation of the oxygen uptake (VO_2) for a given job may be done by comparing the heart rate for a given work situation to the work load-heart rate relationship obtained from a cycle ergometer test (Astrand and Rodahl, 1977). However, this is very time consuming, especially when studying a large number of individuals.

The primary purpose of this project was to develop realistic job simulators to assist in the training and assessment of individuals newly assigned to heavy labour, entry level jobs. To do this, the concept of Heart Rate Reserve Utilization (HRRU) was developed. Its use will be illustrated for the "tapping stand" simulator, one of five task simulators developed.

As a result of the development of a shovelling simulator, the technique was utilized to assess the physiological consequences resulting from a proposed ergonomic intervention.

A previous ergonomic analysis of individuals shovelling in the plant revealed that the size of the shovel being used for the material to be handled placed the workers above the NIOSH Action Limit. The secondary purpose of the project was to apply the HRRU concept to determine that the physiological demands of the task were not unduly increased due to modification of the shovel.

METHOD

Heart Rate Reserve Utilization

To quantify the physiological cost of performing the jobs and simulations the concept of heart rate was elaborated upon. Heart rate reserve has been discussed by Astrand and Rodahl (1977) and involves subtracting the resting heart rate from the maximal heart rate. To determine a training heart rate, this concept is utilized in the standard Karvonen equation (American College of Sports Medicine) shown in Equation 1.

$$THR=(HR_{MAX}-HR_{REST})\times TI+HR_{REST} \quad (1)$$

where:

THR=*Training Heart Rate (bpm)*

HR_{MAX}=*Maximum Heart Rate (bpm)*

HR_{REST}=*Resting Heart Rate (bpm)*

TI=*Training Intensity* (*usually* 0.6–0.8)

In this project the training heart rate was replaced by the workers heart rate at any time (t) *(HR(t))*. Maximum heart rate was predicted using 220—age. *TI* was replaced by Heart Rate Reserve Utilization *(HRRU(t)),* the percentage of the heart rate reserve that the worker uses at any time (t). Equation 2 shows the modified equation produced by these substitutions, solving for *HRRU(t)*.

$$HRRU(t) = 100\times \frac{HR(t) - HR_{REST}}{APHR_{MAX} - HR_{REST}} \quad (2)$$

where:

$HRRU(t)$=*Heart Rate Resrve Utilized at time "t" (%)*

$HR(t)$=*Heart Rate at time "t" (bpm)*

$APHR_{MAX}$=*Age Predicted Maximum Heart Rate (bpm)*

HR_{REST}=*Resting Heart Rate (bpm)*

The first section of the project involved quantifying the physiological profile of experienced workers performing entry level jobs. Heart rates (HR) were obtained every 15 seconds, while performing the task(s) in question, using a chest electrode/transmitter and wrist watch/receiver system (Polar Vantage XL, Polar USA Inc.). The chest belt and watch were fitted to workers during a scheduled break and they sat quietly for a minimum of three minutes to obtain a resting baseline. They performed their assigned task until their next scheduled break. Workers were then instructed to relax quietly for a minimum of three minutes while the recovery heart rate was recorded. The heart rates from the watch were then downloaded to a microcomputer either manually or utilizing a computer interface provided with the watch/receiver.

These heart rates were then entered into a customized computer software package that allowed the compilation of the average profiles. To accommodate for the varying time each workers took to complete a task, the heart rate record for each worker was normalized to 100% of time required to complete the task. Heart rate profiles were then interpolated or extrapolated to 101 points, to encompass the 0–100% normalized time scale. The individual *HRRU(t)* profiles were then averaged together by task, producing an experienced worker average *HRRU(t)* profile for each individual task.

Ergonomic Intervention Evaluation

The development of a shovelling simulator required that the modified shovel design (i.e decreased blade size) be evaluated to determine the shovel that workers should use in the simulation. Ergonomic analysis had already determined that a decrease in tissue loading would result with a modified shovel (Frazer, 1991). However, the issues of productivity and physiological cost had not been addressed. To determine if an increased physiological cost was required in order to maintain productivity using the modified shovel, the shovelling simulator previously developed was utilized in conjunction with HRRU.

The simulator consisted of two opened top boxes, 0.64 m wide by 1.22 m long by 1.04 m high. Each box had a ground level opening of 0.61 m by 0.61 m. These dimensions were chosen to represent average heights, lengths and distances that workers had to shovel under, from and into. The boxes were position 1.2 m apart, corner to corner, at right angles to each other. From task analysis, a typical load of 800 kg was moved in 10 minutes. In the simulator 200 kg of material was required to be shovelled from the ground level opening into the top of the other bin in 5 minutes. Experienced workers were tested shovelling from the left box to the right box and vice versa using both shovels. The variables measured included HRRU profile, the number of shovelsful required and the time to complete the task.

RESULTS

HRRU(t)

Figure 1 shows the *HRRU(t)* profile for a novice worker performing a normal, lead operations “tapping” task at the end of his first day. His *HRRU(t)* profile is plotted against the workers’ mean *HRRU(t)* profile. The experienced workers’ mean *HRRU(t)* rarely exceeds the 50% level. The new worker, however, shows a dramatically different HRRU profile. This individual utilizes over 80% of their heart rate reserve in order to simply perform the requirements of a typical “tap”, leaving minimal reserve to utilize in case of an atypical “tap” or in the event of an emergency situation. Due to the varying pace of workers performing a “tap”, examination of the *HRRU(t)* profile cannot identify which task components are problematic for this individual.

The simulator of the tapping station helps eliminate this problem. The *HRRU(t)* profile of an inexperienced person attempting this task in the tapping simulator is shown in Figure 2. The precise pacing of the simulator task allows the identification of when specific task components are being performed, as marked by the vertical lines. By comparing an individual's *HRRU(t)* profile to the experienced mean *HRRU(t)* profile, components of the task which require a larger portion of the heart rate reserve can be identified. Increases in heart rate reserve utilization may be due to heat exposure, increase in strength requirement or inefficiency in technique due to inexperience.

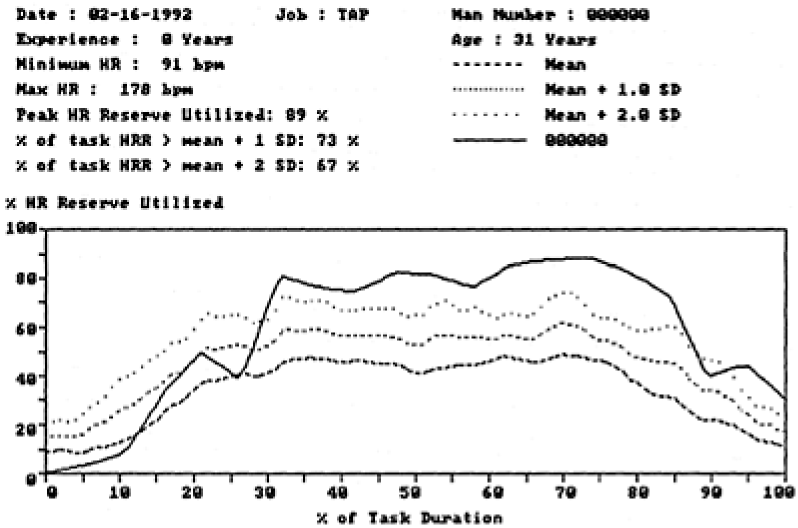

Figure 1. Heart Rate Reserve Utilization (HRRU) profiles for an inexperienced worker (solid line) and experienced workers (dashed line) performing a tapping task in the production environment.

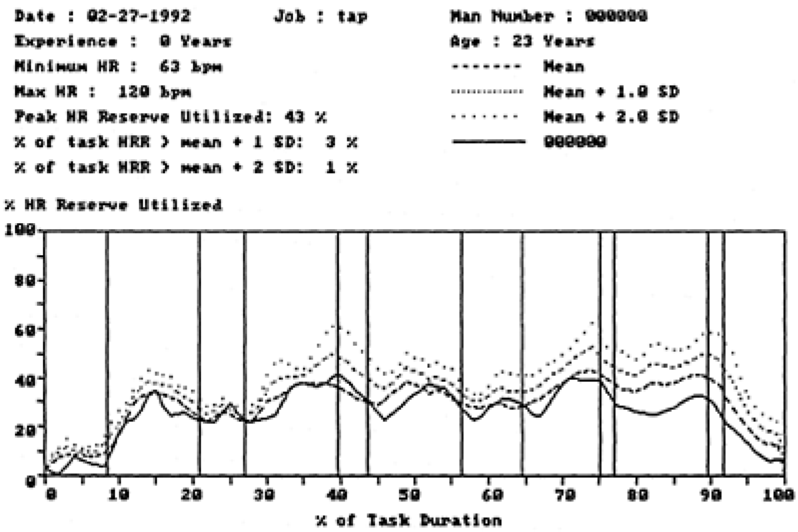

Figure 2. Heart Rate Reserve Utilization (HRRU) profiles for an inexperienced worker (solid line) and experienced workers (dashed line) in the tapping task simulator. The HRRU profile for this individual matches well with that of experienced workers.

Ergonomic Intervention

The original shovel blade was 0.41m by 0.31m and held an average load of 11.4 kg. To produce the modified shovel, the original shovel blade was trimmed to 0.33m by 0.28m, reducing the capacity to 9.5 kg.

The *HRRU(t)* results of the shovelling simulator for a worker using the original and modified shovels showed only moderate differences. Using the original shovel, workers required an average of 18 shovelsful in 2 minutes to shovel the load. A moderate increase to 22 shovelfuls was required with modified shovel. Regardless the shovel used, or the direction shovelled, experienced workers completed the task in an average of 2 minutes. Visual inspection of the *HRRU(t)* profiles showed no shovel or direction difference between the tests. As reported earlier, the ergonomic intervention (i.e. decreased blade size) reduced the task below the Niosh Action Limit. Based on these results, the modified shovel was selected for use in the shovel simulation and more importantly, became the standard shovel to be used in production.

DISCUSSION

The technique of *HRRU(t)* has provided an inexpensive and efficient means of documenting the physiological demands of industrial activities that could not be examined using other conventional techniques. Heart rate has been used by other researchers to document the physiologic cost of work being performed, but only after heart rate has been related to VO_2 (Astrand and Rodahl, 1977). This technique is time consuming and manual materials handling tasks have been shown to deviate from this relationship (Petrofsky and Lind, 1978). The work environment may also affect the VO_2-heart rate relationship. Due to the thermal environment, VO_2 has been shown to remain constant while heart rate increases (Brouha, 1967). Brouha (1967) concluded that heart rate was a better measure for the assessment of cardiovascular requirements because it is more reflective of the total demands being placed on the body. Brouha (1967), however, utilized the absolute heart rate in recovery to document a workers ability to perform a given task. This method fails to take into consideration the age, sex, experience, and fitness level of the individual. By utilizing *HRRU(t)* profiles, job demands, environmental influences and physiological factors are all taken into consideration. The physiological cost for a wide variety of workers performing the same task mat then be compared. This method is also advantageous because it allows the entire job/task to be monitored, quantifying the entire task. Therefore, not only are suspect task elements quantified, but activities previously thought to be non-problematic may also be discovered.

The second section of the project involved the development of the work simulators. These were constructed utilizing actual production components were possible and configured to replicate production layout. To duplicate the thermal environment, electrical radiant heaters were used. To use the simulators as a training technique, it was desired that they be reflective of typical workloads and workrates. In an effort to make the simulation as safe as possible, work rates were paced below normal production levels. For machine paced work, this level was set at 50% of production rate.

To compare the physiological intensity of the simulators to the production environment, workers who had been tested in the plant were reevaluated in the simulator. Comparison of these two sets of *HRRU(t)* profiles indicated that the simulator was indeed of similar timing in task duration, but with a decreased pace. It was felt that the simulators represented tasks that were of a reduced physiological magnitude, but still required workers to handle loads of similar size, shape and weight as those used in production. The development of the job simulators and documenting the physiological intensity would not have been possible without the ability to compare the physiologic cost between work and simulation.

Combined with the extensive in-house training program currently offered, the simulators are invaluable in providing a more realistic orientation for new workers. The major reason for this is the elimination of the hostile environment (toxic fumes, open flames, heat and noise) these workers must contend with. By providing a safe and controlled sample of the job requirements, new workers have been able to focus on learning the skills and techniques that they will be required to apply in the production environment.

The assessment of the ergonomic intervention by simulation was essential in documenting the effects of the intervention in a controlled fashion. The issue of worker acceptance of the intervention was raised and it was felt that workers may resist using the shovel because they “would not feel as productive” and “would therefore have to work harder” to maintain productivity. Although a moderate increase in the number of shovels was recorded, the physiologic cost of the task did not change. The cost of the extra shovelsful may have been offset by a decrease in the muscular work required to lift the lighter load. Worker also reported they had more control with the modified shovel. Maintenance of the same physiologic cost combined with a decrease in tissue loading was compelling evidence for workers and management that this intervention was worth implementing.

In conclusion, the HRRU technique has been invaluable in the assessment of jobs, the development of realistic simulations and in quantifying the effects of ergonomic intervention. The technique has been very well received by both workers and management, primarily due to its objectivity and its ability to compare profiles. The establishment of task simulators has helped create a very positive training environment, which has subsequently carried over into the production environment.

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TESTING AND EVALUATION

FUNDAMENTAL PROBLEMS IN BEHAVIORAL TEST AND EVALUATION

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INTRODUCTION

Behavioral test and evaluation (BT&E) has distinctive characteristics that mark it off from behavioral measurement in general and impose special requirements on the evaluation. This is because ergonomics, which it supports, has distinctive characteristics that differentiate it from other disciplines. The most important of these characteristics is that there must be a translation or transformation of behavioral functions or factors into physical ones; and vice versa.

When we measure human performance in a system (the term is used in future to represent systems, equipments, tasks, designs, work stations, and operators) we attempt to relate that performance to some characteristic(s) of the system. Sometimes the relationship is obvious, as when we measure how correctly an operator can read a display with differing font sizes. With large, complex systems the relationship may not be at all apparent, because of the variety of factors that could be responsible for that performance. In an experiment which we develop specifically to test hypotheses, we create the relationship between the performance and the system factor under test and can therefore point to it directly. But many BT&E situations do not involve experiments, so the relationship must be extracted deductively. The relationship may in fact be only inferred, and so may have merely the status of an hypothesis.

The evaluator in BT&E should consider a number of factors in planning a test because they may lead to different test procedures. This paper can present only an abbreviated summary; for more detail see Meister (1985, 1986, 1989).

THE PURPOSE OF BEHAVIORAL T&E

The purpose of the measurement is all important. If the purpose of the test is to determine the effect of specific variables on performance, it is necessary to conduct an experiment and certain consequences ensue. An experimental design must be created. All variables except those in which the experimenter is interested must be controlled. I will not go into the various types of experimental designs that may be used; they are described in a variety of well-known texts. This design will be determined by the specific variables for whose test the study is being performed. There are other consequences. The experiment demands a special environment, because the control required cannot easily be achieved in a nonexperimental environment. Thus, the experiment ordinarily requires either a laboratory, a special test facility or a simulator. Because of the control exercised, which constrains the free action of variables, the experiment is somewhat artificial and should therefore always be validated by measurement in the operational environment. How that validation can be conducted in the operational ("real" world) environment is a subject for an entire separate paper, if not a book, and cannot be dealt with adequately here. In addition, because of the need for control, the experiment may not permit replication of the real world situation in which the system will be used, because a primary characteristic of that situation is that it. lacks control.

The first question the evaluator must therefore ask himself is whether an experiment is needed to answer his question, because there are BT&E situations that do not require an experiment. These are:

(1) Where one wishes to determine only which one of two or more systems is superior in performance to the others. This is a sort of quasi-experiment, because it is controlled to the extent that all systems under test must be treated in exactly the same way. Because the evaluator is not interested in which variables affect performance, these are not partitioned and they are not controlled. Hence the operational setting in which the system will actually perform can be replicated in the test situation, or the test can even be performed in the operational environment. Since a number of systems are being compared, it would be desirable to have the same subjects perform on all systems (subjects acting as their own control). This may require dividing subjects in two or more groups and counter-balancing to eliminate practice effects. If, for some reason, subjects cannot serve as their own controls, so that each system has a different subject sample, great care must be exercised to procure subjects of the same background in the various samples. They should of course resemble in background and experience those who will eventually operate the system; this is a requirement that. applies generally to BT&E. Examples of this type of test situation are: a comparison of different types of display, or a comparison of performance effects of training in an aircraft simulator versus training in the operational aircraft.

(2) Another purpose of BT&E may be to determine that the system satisfies specified performance standards. Obviously the standard (preferably a quantitative one) must exist before such a test can be performed. Here the evaluator need concern himself with only a single system because the human performance with that system is compared with the standard of desired or required performance. How one develops standards will be discussed later, but once they are available the conduct of this type of test is quite straightforward. It requires only one group of subjects and one type of test situation, although that situation may involve several tasks or missions. The test situation may have any degree of operational fidelity, but obviously the less fidelity, the less confidence one can have in the usefulness of the resultant data. If the system is being tested in the operational environment with operational personnel, operational fidelity is of course complete and automatic.

(3) Absent any standards of human performance, one may simply wish to determine how subjects perform with a particular system. This is the easiest of all test situations to create. Given subjects of requisite background, one simply exposes them to the system and sees how they perform. Of course, without any explicit or implicit standard, the results may not be very meaningful, because they are not easily interpretable. If each subject, for example makes five errors in performing a task, is such an error rate reasonable to expect? Without a standard which indicates that five errors are too many or minimally acceptable or rather low, how is one to know? One can however use this kind of study to build up a human performance database to answer the question, how well do operators perform? Such a database is important for establishing standards for later updates of the system.

(4) One may wish to determine the kinds of problems personnel will have with a new system. Such a question would naturally be considered along with all the preceding types of non-experimental tests and would require no separate test; all that would be needed is to attend to these problems.

(5) The preceding are formal tests and performed under more or less controlled conditions with a functioning system. They can also be performed in early design, provided that a mockup (or its computer equivalent, initial software) is available. In an early stage of system design one might also wish to simulate performance of a procedure before the system is available. The intent is to determine that the tasks to be performed can indeed be performed and without conspicuous difficulty. The “walkthrough” lacks all controls and can be quite informal, using, for example, design drawings of the work station to simulate the system. (6) When a system is to be sold to many different users (e.g., office furniture), it is valuable to put samples into the hands of typical users and allow them to use the system as they would ordinarily. Such a test may ask the question: when you put the system into operational use, what problems will the user have with it, and particularly for commercial systems, what does s/he think of it? Although the system is not under the evaluator’s control when it is operated, it is necessary for the evaluator to establish certain test controls, such as: the user must report performance in certain categories at specified intervals; s/he must be available to report on system performance in a personal interview.

(7) If, early in design, the designer performs hardware mockup tests, or rapid prototyping of software, s/he is asking: how should the design be refined? The degree of control and operational fidelity in such a test can vary from none to high; this depends on the designer and because of this I suspect there is less rather than more control, because control and operational fidelity are expensive in time, money, and subjects. Control implies a standard test and task situation, selected subjects, formal measures, and formal data gathering, but not necessarily any experimental variations. Lack of control means no formal data collection, randomly selected subj ects, etc.

(8) There are other situations in which little control can be exercised. The industrial ergonomics hygienist who collects accident statistics and other demographics asks the question: what is the state of health and safety in a particular industry or area? What control there is, is exercised by applying a single set of classification categories to all data. However, the hygienist may bias his data collection by the data categories he develops; he may have hidden assumptions which may affect the way in which he collects data.

(9) There are other activities which are not specifically BT&E but which are related to it. For example, to establish a realistic test situation it may be necessary if one is not familiar with the system to collect information from experts on how the system functions. Where a procedure for operation has not been formally described, it may be necessary to interview experienced operators on an individual or group basis to arrive at a consensus. The technique is of course not a test situation but one presents stimuli (questions, suppositions, situations) to subjects and asks them to perform symbolically by answering the question: if X occurs, what do you do or what do people in general ordinarily do?

THE HUMAN-SYSTEM RELATIONSHIP

One of the most difficult problems from a measurement standpoint is to understand the relationship between the performance of any operator in the system and the performance of the team and that of the system as a whole. What does operator X contribute to system performance and how is that contribution made? Is that contribution of significant importance? These are questions of diagnostics; knowing these relationships permits one to decide what produces inadequate performance.

It seems logical that no one works in a system without making a contribution to the end product or performance; if s/he does not, there is no point in having her or him as part of the system. But there are presumably gradations of importance. How important? One has to know this because if an operator is critically important, then an error on his part could destroy the system.

One can determine the pattern of relationships between the individual, the team, and the system, by performing a dependency analysis. If a failure to act or an error by one individual will affect the system critically, shutting it down or causing it to perform in unwanted ways, then there is a high dependency and the individual's contribution to system performance is great. If what the individual does or does not do has no significant effect on system performance, then there is little dependency and his contribution is slight. Meister (1991) describes dependency in greater detail.

PERFORMANCE OBSERVABILITY

As systems become larger and more complex, they are also becoming more cognitive. This means that more of what goes on in the guise of performance does so in the head, as a consequence of which that performance is less accessible to observation. How do we make this performance more observable? It is necessary to ask the performer to reveal himself by explaining why he did what did. To ask him to verbalize while performing is inadmissable because the need to report distorts his performance. It is preferable to replicate the performance by visually and aurally recording what the performer does and replaying the record while asking the performer to explain his actions. However we get the information, the subject must be interviewed following the performance. This applies as much to the experiment as to the non-experimental test.

MEASURE SELECTION

The determination of the proper measures to use in a test has always been a significant problem and remains one. One has to examine all potential measures in terms of what each one says about system functioning. If a measure does not describe some aspect of important system performance, that measure can be ignored. The evaluator will develop a list of all possible measures and then proceed to reduce the list by asking: if I eliminate this measure and that one, would I fail to learn something significant about system performance? If the answer is no, that measure can be eliminated.

STANDARDS

The initial paragraph of this paper remarked that BT&E is different from measurement in general. The latter requires only the recording of test performance; the former requires that we compare the test performance with a standard that tells us whether the performance is good, bad or mediocre. To do this however, it is necessary to develop the standard before we can measure. It is dubious science to record test performance and then make that performance a standard of what we want the system to do. Because it requires the development of standards, evaluation is more sophisticated, more complex, than simple measurement. Ultimately the standard is a judgment of value, of utility. The judgment can be derived from two types of experts: knowledgeable operators of related systems and those who commissioned the system in the first place and presumably have some notion of what it should do and how. Because it is subjective, the standard must be applied to external performance referents. If we say that good performance is X, X must be visible to us and must be achieved as a consequence of doing all the things that lead to X. Nonobjective, non-quantifiable standards, based on the internal judgements of "experts," are merely intuitions.

There are various ways of developing standards. One can ask experts directly, individually or in a group, or one can ask operators to perform a task and have the experts judge the performance for us. Standards must be secured for three levels, good, poor, and minimally acceptable. The development of standards is not cheap, particularly in terms of time, but the cheapest method is the direct one (asking experts specifically about what constitutes good, etc. performance). Although some experts are reluctant to specify standards, with discussion and probing they will provide useful material.

MEASUREMENT IN PROLONGED MISSIONS

In complex systems involving prolonged missions, particularly those that are contingent on prior occurrences, measures may be taken at a number of points in the mission. One must of course measure the terminal output, to determine whether the system has in fact performed satisfactorily. But a terminal measure does not present a complete picture of system functioning. So one must work backwards, but how far backwards, and, more important, at what points in the mission?

These are points at which the status of the system changes significantly. If one were to measure pilot performance, it would be at takeoff, climb, cruising, and during the landing, because at each of these points the system changes in relation to its working environment.

If there are many personnel engaged in performing the mission, the selection of those individuals to measure is determined by the degree of dependency the terminal system output has on a particular individual. A dependency matrix is a tree-like chart which starts with the terminal output and works backward in time, the critical variable illustrated being the degree of dependency of the terminal output on individuals and tasks.

GENERALIZATION AND VALIDATION

These are problems in all measurement and they arise because most often we measure in a non-operational setting and what we have learned from the measurement can make sense only in relation to the operational world. There are of course situations in which validation and generalization are less important; if one wishes only to know whether one system is better than another or meets a standard or is functioning adequately, then generalization is irrelevant, although validation is always important, because the selection of the superior system must be superior in the real as well as in the test world. The test may determine that the system performs according to the standard, but will it do so when it is placed out in the real world? Validation in the sense that non-operational performance is replicated operationally is important in every test situation, including the experiment which purports to add knowledge to our knowledge structure; it is particularly important in research because the data resulting will be used extensively in many applications. These two topics deserve (and have received) a book all to themselves and therefore they cannot be fully discussed here.

SUBJECT SELECTION

The selection of subjects for testing, particular the type of subject and the number of them, is another facet of trying to ensure operational realism in the test. If the evaluator knows who the eventual operator/user of a system will be, and if the test is to be conducted in the operational environment, then this aspect does not present a significant problem. If there are multiple users or if the nature of the user is undetermined, and if the test is to be conducted in a non-operational setting, then it becomes more difficult.

The general rule is to select subjects as much like the eventual operators/users as possible. This means that one must know who these people are and what their outstanding characteristics are. If the system to be developed and tested is an updated version of one already in existence, then the operators of the earlier version can be interviewed and their characteristics examined. If a system is completely new (which rarely occurs) and experienced operators do not exist, they must be hypothesized and a group corresponding to their hypothesized characteristics must be sought.

As to numbers, the statistical design of the test will determine the minimum number of subjects required. If the minimum number demanded by the statistics cannot be found, then one gets as many subjects as one can and prays for good results.

As to whether only the most qualified subjects should be used, or a mixture of best and less well qualified, that is a matter of whether one wishes to show the system in its best light or a more truthful light. Using the most qualified subjects as test personnel will make the system look better than it actually is, because these subjects will be able to overcome problems in operation that less well qualified people will not be able to overcome. How one is to establish who is better qualified than others is a problem; indices of qualification must be developed or found out.

THE TEST ENVIRONMENT

Whether one tests in a laboratory, a test site or a simulator is, as has been discussed, a matter of control. It is always preferable to test in the operational environment, but this may not be possible for various reasons, of which the matter of lack of control is only one. If one does not test in the real world, it becomes necessary to reproduce the operational environment in the test situation; and this then becomes a compromise between degree of control and degree of realism.

PREFERRED METHODS OF TESTING

Various criteria of method selection must be applied in deciding the test methods to be used: simplicity (because complex methods are more likely to fail in practice); cost, because the financial resources available are often limited; ease of method use, because some methods are inherently more difficult to apply, hence more likely to fail (e.g., physiological methods and measures); the extent to which a particular method is more or less likely to provide desired data (this last criterion should be the determining one, but usually has to be balanced against the preceding ones). No hard and fast rules can be applied; the particular method(s) selected is a judgement call and, as has been indicated, involves a balancing out of positive and negative factors.

CONCLUSIONS

It is apparent that the development of a BT&E situation is a complex problem, for which it is difficult to establish simple, invariant rules. What has been described in this paper is a set of considerations for the measurement specialist, a sort of checklist which s/he should consider before developing his test plan. Whatever that plan is, it must be developed to fit the individual BT&E situation s/he faces.

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DEVELOPMENT OF HUMAN FACTORS ENGINEERING CRITERIA FOR COMPARISON OF COMPETITIVE SYSTEMS

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A recurring problem in the source selection from competing commercial-off-the-shelf (COTS) systems is the definition of appropriate and meaningful criteria for human factors engineering evaluations. Typically, requests for proposals have not included concrete human factors criteria. Two criteria that can be used to assess usability are percentage conformance to principles of human factors design and measures of complexity of use. Their use in the system selection from a field of COTS equipment to provide a common hardware and software operating environment is discussed.

INTRODUCTION

A current trend in the military is the use of an acquisition philosophy that emphasizes nondevelopment items (NDI) as a source for system development (U.S. Army Acquisition Command, 1986). NDI systems are commercial-off-the-shelf (COTS) hardware and software that can be utilized in military applications with minimal modifications. An NDI acquisition follows the same basic process as the traditional approach by releasing a request for proposal (RFP), reviewing and evaluating the proposals, and selecting a vendor. It differs from the traditional approach by providing a shorter and less costly development cycle.

A critical part of an NDI acquisition is the market survey, or as Meister (1986) refers to it the "fly-off," used to select the best vendor from all the respondents to the RFP. This is performed by comparing each candidate system's performance against the evaluation criteria specified in the RFP. These evaluation criteria should be designed to specify what the system should do not how it does it, leaving the implementation up to the vendor. The key element behind these types of evaluations is the existence of well defined evaluation criteria to which each of the competing systems can be compared, including usability.

In these comparisons, evaluation criteria for usability typically include compliance with design specifications, such as MIL-STD-1472 (Department of Defense, 1981), and specified minimum and maximum system performance requirements such as error rates and performance times. With an NDI acquisition, the systems have not necessarily been designed to conform to military standards, and human-system performance criteria may be very elusive. Therefore, since there may not be well defined evaluation criteria for usability, how can system comparisons be made?

This was a problem faced by human factors engineering (HFE) personnel during a recent NDI acquisition. The acquisition's objective was to select a suite of common hardware and software for use as a platform for future U.S. Army command and control systems. The RFP specified the "what" but not the "how." Therefore, the design philosophies taken by prospective vendors to meet the system requirements were anticipated to be very different. Included in the proposal response was the requirement for participation in an operational effectiveness demonstration involving typical users. System and user performance was to be compared during this demonstration.

The only usability criteria included in the RFP was a general statement that the "successful candidate system would subscribe to good principles of HFE." The challenge to the HFE personnel was to develop criteria for usability that would allow a meaningful comparison of several computer systems with differing design philosophies during the operational effectiveness demonstration.

METHOD

Two assumptions were made by the HFE personnel in developing the criteria that were employed to assess the relative usability of each vendor's system. First, even though each candidate system could have a very different design philosophy for user interaction, measures could be developed based on system goals, not the implementation philosophy. Second, comparisons could be made using measures based on attributes of computer systems known to contribute to usability. Two measures consistent with these assumptions were created for the comparison: percentage compliance with accepted HFE design guidelines, and complexity of use. Each of these are measures, along with how they were applied, are described in the following paragraphs.

Percentage Compliance with HFE Design Guidelines

One tool typically used for the evaluation of systems in the acquisition cycle is the application of design checklists (Meister, 1986). Checklists are comprised of statements that describe design attributes with which the system should comply. These statements can be drawn from a number of sources of human factors design guidelines and standards. In the military arena, MIL-STD-1472 (Department of Defense, 1981) is one of the usual sources.

While the candidate systems were NDI and not necessarily designed in accordance with military standards, these standards describe principles of good human factors design.

Therefore, one candidate criterion for selection was how well each design adhered to the principles contained in these standards.

Checklists to measure compliance with these design principles were derived from the U.S. Army Test and Evaluation Command (TECOM) Test Operations Procedure (TOP) for the soldier-computer interface (Avery, 1985). This TOP contained a number of design checklists that addressed the humancomputer interface (HCI). The items on these checklists had been drawn from MIL-STD-1472, MIL-HDBK-759 (Department of Defense, 1975), and assorted other documents that provided private industry guidelines for the design of an HCI. As such, the checklists contained in this TOP provided guidelines that were broader in spectrum than just military standards.

Appropriate checklists were selected for use, and then tailored to make them more appropriate to the needs of the evaluators. This provided the evaluators with a set of design checklists from which a measure of the percentage compliance could be calculated. Figure 1 illustrates one of these checklists.

Complexity of Use

For this evaluation, complexity of use was operationally defined as the difficulty of performing typical tasks with the candidate systems. Attributes for this criterion were selected by developing a list of measures that are indicators of complexity of use and then selecting those that were thought to be the most measurable during the operational effectiveness demonstration. These attributes are presented in Table 1.

Data Collection

Three vendors were selected to participate in the operational effectiveness demonstration. Each vendor provided suites of hardware and software ranging from hand-held to desk-top units, along with printers and other peripheral devices to allow for communication over tactical radios and data switches. Each vendor also provided training, designed primarily to support the operational effectiveness training, for the users assigned to them.

Users consisted of groups of nine military personnel, matched by age, sex, computer experience, and aptitudes as measured by the Armed Services Vocational Aptitude Battery (ASVAB).

To provide the structure for measuring usability, a set of critical tasks was defined that the candidate systems would have to support. These tasks are listed in Table 2. A realistic script was then developed that lead each operator through the performance of each task.

HFE personnel observed the users perform the critical tasks in both a static walk through and a dynamic format. The design checklists were applied during the static format and compliance with the design attributes was noted. The complexity of use measures were collected during both the static and dynamic formats.

Design Checklist

Interactive Control

Test Title

Test Project No. Date

Detailed Design Considerations	Yes	No	N/A	Comments
a. General				
1. Control actions selected from a discrete set of alternatives displayed prior to the time of selection (5.15.4.1.5)				
2. The current value of any parameter with which the operator is interacting is displayed. (5.15.4.1.5)				
3. When an operator steps through multiple display levels. (5.15.4.1.6):				
a. The number of required levels is minimized.				

Figure 1. Sample of a design checklist used for evaluating candidate systems human-computer interface.

RESULTS

The application of the criteria for usability developed for this effort provided a number of measures to judge the relative usability of each candidate system. Given the competition sensitive nature of the data, they were not released to the public and can not be described in any detail in this paper.

Percentage compliance was calculated by dividing the number of guidelines met by the total number of guidelines applied. All the vendors compliance was 50% or less.

For complexity of use, each measure was summarized by critical task, with one-way anovas performed on the means for the time and error data. Data analysis indicated that each vendor’s usability varied by critical task, and that some of the systems were not able to perform all the tasks. Operational experts then made subjective determinations of which tasks were the most critical to facilitate comparisons.

Table 1. Attributes used to measure complexity of use in evaluating candidate systems human-computer interface.

Keystrokes—Average number of keystrokes required to input a command for each type of software application program.
Commands—Average number of commands (or menus) required to implement a function for each type of software application program.
Message Understandability—Number of times the operator had to use the manuals to understand prompts and/or error messages for each software applications program.
Feedback—Number of instances when the software did not indicate to the operator that an operation was being performed and the length of time required before the operator received on-screen feedback of command or data entry.
Adequacy of Help—Number of times that the operator, after using the on-screen help, had to then go to the manuals for clarification or assistance.
Critical Task Time and Error Rate—Time and error rates recorded during the performance of critical tasks by the user personnel under all expected use conditions.

Table 2. Critical tasks to be performed by representative personnel.

System Setup	Data Access and Update
Initialization	Analyze Data
Message Preparation	File Comparison
Message Transmission	Fault Isolation/BIT
Communication Reception	System Shutdown
Graphics Transmission	System Teardown
Graphics Reception and Update	

The data was then placed in a table, by individual vendor, to provide the information on usability necessary for the individuals responsible for source selection.

CONCLUSIONS

While a number of problems existed with the criteria used in this effort, they did provide a valuable set of measures to assess relative usability of competing systems. These problems included a lack of a means to summarize across the measures of complexity of use, and the difficulties in comparing systems that could not perform all the required tasks.

Another difficulty experienced during the comparison involved the vendor training. Each vendor’s training program was significantly different, and created potential sources of bias. One was focused heavily on motivating the operators. Another was directed towards an audience who were much more sophisticated than the subjects, causing attitude and performance problems with their operators. Therefore, each user group was not necessarily trained to the same level of performance prior to the start of the evaluation.

These criteria were, by definition, based on face validity as opposed to construct validity as there were no absolute performance measures to compare each candidate system against. This does not rule out the usefulness of these measures for discriminating between systems. With more control over the total evaluation environment, a better understanding of which measures truly contribute to usability irrespective of user interface implementation, and a better method to summarize the data, these measures can become important tools for evaluating usability of competing systems in both the military and private sectors.

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DETERMINATION OF INFORMATION REQUIREMENTS FOR TRAINING ASSESSMENT*

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INTRODUCTION

The Navy's operating areas at sea can be thousands of square miles. This is due to extended capabilities of sensors, weapons, and communication systems available for modern warfare. This capability also complicates operations, since one usually fights an enemy outside visual range. The command at sea must rely on sensor data that are often relayed via communications networks. To further complicate matters much of modern naval warfare requires numerous ships working in concert with one another, i.e., a battle force or battle group.

The complexity of the command, control, and communications of these operations is potentially enormous. This is especially true when the operations cover such vast expanses of ocean. In preparations for these operations each unit must be trained as a unit and as a member of a battle group.

The battle group is a mix of ships of different classes, e.g. a battle group can consist of one or more carriers and/or battle ships, with frigates, destroyers, supply ships, etc., depending upon the mission(s) they are expected to carry out. The battle group has an organization for the command, control, and communications over the units of the group. The units, however, are responsible for their own internal operations.

Battle group operations involve a number of warfare areas, such as Anti-Submarine Warfare (ASW), Anti-Air Warfare (AAW), and Anti-Surface Warfare (ASUW). The command, control, and communications within each warfare area are the responsibility of a warfare area commander, such as the Electronic Warfare Commander (EWC). These warfare commanders report to the battle group commander.

The warfare area commanders must be trained in the command, control, and communications needed to utilize the capabilities of the various units that make up the group.

SCOPE

Warfare area training is continuously assessed to improve battle group training and performance. The project and methodology described in this paper represents one such assessment and improvement effort. More specifically it is focused on one aspect of the commander's decision making tasks, i.e., information requirements and usage. The project has three phases; one for each of the following objectives.

* This project is sponsored by the Operational Readiness Assessment Program of the Naval Sea Systems Command

OBJECTIVES

The three objectives are: (1) Verify the validity of the information used by warfare area commanders. (2) Determine where and when in training the information is transmitted so that its availability can be recorded. and (3) Develop diagnostic techniques for use by naval personnel. The procedures used to achieve these objectives are described and discussed.

APPROACH

The first and second phase of this project are complete, and the third is in progress. Efforts in the first phase lead to verifying the currency of the warfare area commanders' tasks and related information elements. An established data base was used for this purpose. In the second phase a determination was made as to when in selected training scenarios the information elements were needed, the sources of these information elements, and where in the actual systems could one record the availability of those elements. The third phase involves the development of analytical techniques to determine the root causes of unacceptable levels of performance. The techniques are adopted for use by naval officers from those used in Total Quality Leadership (TQL) and behavioral research.

PHASE 1: VERIFICATION OF INFORMATION

Decisions made by warfare area commanders are supported by a variety of infomation elements from various sources. Since the requirements for these elements can change over time they must be reviewed and verified for use in inport training.

There were a number of ways to approach such a review. A review could have been made of all the official documents related to such decisions and their respective information requirements, or one could have conducted extensive operational research and analysis, or one could have made use of an existing data base and experienced seasoned officers who have worked in the respective warfare areas. This latter approach of user involvement has been used for years in one form or another and was used in this project. The approach is currently called “Participatory Ergonomics” (Noro and Imada 1991). The concept is in keeping with the emerging emphasis on TQL which has been derived from Deming Philosophy (Deming 1986). It is a user oriented management philosophy with emphasis on quality of goods and services.

An established information data base provided the basis for the work in this phase. The data base has task/information requirements for commanders in six different warfare areas; Composite Warfare Area Commander (CWC), Strike Warfare Commander (STWC), Anti-Air Warfare Commander (AAWC), Anti-Submarine Warfare Commander (ASWC), Anti-Surface Warfare Commander (ASUWC), and Electronic Warfare Commander (EWC). The data base is organized into three phases; Planning, Direct and Control, and Evaluation. For this project the Direct and Control Phase is being used. This Phase has the following five major functions in the data base: (E) Command; (F) Surveillance, Search, Detection, Localization, TMA and Tracking/Trailing; (G) Classification, Identification, and Threat Analysis; (H) Engagement and Attack, Reengagement and Reattack, Evasion and Avoidance; and (I) Battle Damage Assessment and Reporting.

Tasks required for each of the above functions are present in the data base as a set of Matrices. Figure 1, is a partial matrix for the “Command” function. The tasks are listed on the left of the matrix while the column headings on the right identify the various warfare area commanders. Within each column Xs identify those specific tasks required of each warfare commander. The associated information elements are not provided in this output.

MULTIPLE WARFARE TASK INFORMATION MATRIX PHASE: 2.
DIRECT AND MONITOR OPERATIONS FUNCTION: E. COMMAND

TASKS		STWC	AAWC	EWC	ASWC	ASUWC	CWC
1	ACCEPT & REPT TO CWC	X	X	X	X	X	
2	ASSIGN ALT. COMMANDER	X					X
3	ASSIGN ALT. & SUBORDS	X	X		X	X	X
.	. . .	.	.	.	.	.	.

Figure 1: Tasks of Warfare Area Commanders

Information elements available in the data base are in a different format as shown in Figure 2. By using the columns to the left, the information elements can be identified for each phase, function, task and information element for the STWC. Similar listings are available for the other warfare area commanders.

INQUIRY BY POSITION FOR IMPORTANCE=CRITICAL BATTLE GROUP
POSITION: STWC

PH	SCM	TSK	ELEMENT	DESCRIPTION
2	E	1	3.02.03	RULES OF ENGAGEMENT
2	E	1	3.02.04	FORCE/GROUP MISSION
2	E	1	5.01.02	VOICE CIRCUITS
.	.	.	.	.

Figure 2: Data Base Information Elements

The above formats are not well suited for data collection, A new format was developed as shown in Figure 3. It is a modification of those shown Figures 1 and 2.

DIRECT AND MONITOR OPERATIONS STWC FUNCTION: COMMAND

1 ACCEPT AND RESPOND TO ORDERS/QUERIES FROM CWC
(INFORMATION ELEMENTS: CRITICAL)
RULES OF ENGAGEMENT (ROE)
FORCE/GROUP MISSION
VOICE CIRCUITS
. .

Figure 3: Data Collection Form

The warfare area commander’s tasks were identified for each function and each information element was listed under the respective tasks. These forms were used to verify whether or not each information element was still critical and/or important.

The verification was made during interviews with senior naval officers experienced in the warfare areas. As expected the verification produced some shifts in information values as well as additions and deletions.

PHASE 2: DETERMINATION OF INFORMATION CONNECTIVITY

Training scenarios are based upon specific situations and are continually being changed as new situations develop. Training scenarios used in this project were but. a small sample of the possible scenarios that could be generated. However, scenarios established for the above warfare areas required some combination of the commanders’ functions, tasks, and their respective information elements. It is important that the emphasis be on the combination rather than the scenarios since scenarios are seldom faithfully replicated in real operations.

The first step determined when the specific information elements would be needed in the various training scenarios, i.e., which information elements would be needed for a particular time or event in a scenario. This was accomplished by project personnel with the aid of Naval officers who were experienced in the respective warfare areas. This saved the project hours of making observations and doing analyses.

The second step involved the identification of information sources, i.e., from what unit (ship, submarine, and/or aircraft) and from what system (sensor system, communication system, etc.) the information would be provided for the respective events of the scenarios. A systematic review was made of each scenario and the source(s) of each required information element. Although, many sources were self-evident some were not. Some information elements were derived from a single source and some individual information elements were derived from a number of different sources.

The remaining step was to identify the actual physical points in the systems where recording equipment could be used to determine whether or not the information was sent and/or received by the decision maker when it was needed. This step required different naval personnel than those mentioned previously. These were people who operated and maintained the individual systems aboard the naval units. Visits were made to the various units where the systems personnel were briefed on the project. With their aid, the points of system connectivity were identified.

PHASE 3: DEVELOP DIAGNOSTIC TECHNIQUES FOR USE BY NAVAL PERSONNEL

This phase of the project is in progress. The remainder of the paper is a discussion on the methodology that is being employed. This phase is of two fold importance. First, the concept of cause and effect is being expanded beyond “laying blame” to that of finding root causes of operational outcomes. And second, some of the methods and techniques adopted for inport training are being identified for use by naval officers in reviewing at-sea exercises. The analytical methods and techniques are being adopted to determine the root causes of unacceptable levels of training/operational performance, i.e., performance attributed to the warfare area commander or other sources.

Basic Situation:

Consider the situation where outcome measures for a completed scenario are unacceptable. If appropriate information elements were available when required, then one can say the decision maker did not make adequate use of the information. If the appropriate information elements were not available when they were required, then one can say the decision maker did not have adequate information to make the decision. In either case there is much more to be learned.

Numerous factors may bear on the decision making of warfare area commanders. Some are specific to the situation such as doctrine, tactics, and rules of engagement. Others can be attributes of the equipments, such as the organization and format of information. Such factors as stress, and workload may affect decision making (Meister, 1991).

To evaluate the commander’s performance so that he will realize a training benefit one has to probe into what decisions he did make and why. The answers to these “whys,” and those of the decision context, can not be assumed as indicated above. TQL methods and techniques that can be adopted for these probes (Scholtes, 1990). The TQL methods and techniques can be easily assimilated by naval officers and training personnel. Further, they do not involve lengthy procedures which would be impractical, considering the constraints on available training time. It is anticipated that once these methods and techniques have been adopted to the training setting some of them will be readily transferable to at-sea operations. That is, operational performance analyses will be enhanced by using these methods and techniques. A few candidate techniques will be discussed in a hypothetical training situation to demonstrate their simplicity.

Training Scenario:

The training scenario can call for the ASUWC to launch a six missile attack against an enemy carrier. The scenario, at this point, has the enemy carrier turning into the wind and the time of the last launch of enemy aircraft was such that launch and recovery operations should start soon. Information relevant to the enemy's intentions should have been received by the ASUWC. The four possible outcomes for this point in the scenario are shown in Figure 4.

		INFORMATION	
		Received	Not Received
LAUNCH ORDERS	Given	I	II
	Not Given	III	IV

Figure 4: Scenario Outcomes

There are three events to record; what was sent, what was received, and the resulting action, if any. Determining whether or not the requisite information was present or not should be relatively easy for the inport training situation. This would be accomplished with the aid of the data base and the experts of the various shipboard systems. The sending and receiving points would be identified and recording equipment connected. It is important that both ends of the communication link be checked if those potential problem sources are to be identified. The commander's performance would be evident by his actions or inactions.

Consider the situation where the information was received and the launch orders given (I, Figure 4). In this situation we assume that. he did as he was trained to do. Similarly, if the information was not received and no launch orders were given (IV, Figure 4) then the commander's inactions were appropriate. This leaves two other possibilities. First, if he received the requisite information and failed to act (III, Figure 4) it could be viewed as a missed opportunity (poor decision making). Second, if he did not receive the requisite information but still ordered a launch (II, Figure 4) one must ask, was it a mistake or did he base his decision on other criteria such as those he developed through experience?

Further exploration of the outcomes I and IV may not appear necessary but there is a possibility that the decisions were made on information other than that provided, or not provided as the case may be. This has been the case with Army field commanders making decisions. Klein (1989) found that experienced field commanders used their experience to decide on an action that would work and hence did not analyze all the options available to them.

Outcomes II and III need further exploration by the trainers because it is not sufficient, in training or during operations, simply to say that the commander failed to act appropriately. The root cause(s) for his decision needs to be identified. There could be other explanations for the inappropriate performance that were not so obvious, e.g., ancillary information could have misled the commander, the information format could have been ambiguous or the information source could have proven unreliable on previous occasions. This is where TQL is applicable. The methods used here are well known, e.g., open-ended interview and nominal group techniques.

The TQL approach assumes that the commander would have made the correct decision if it were possible. It assumes that the commander is a competent decision maker, i.e., he uses sound logic. That is not an invalid hypothesis since the commander is a senior naval officer with considerable at-sea experience. It has been observed in industrial settings that most system output errors are due to the “system”, not those carrying out their tasks. Quality assurance experts have observed that approximately 85% of system output errors are due to the “system” and not to the personnel within the system (Deming, 1986). The commander’s decision is not just based upon the information received. The decisions are made within a “system” or context of regulations, doctrine, ROEs, and tactics.

At the beginning of an interview or meeting with the naval officers above assumption is expressly enunciated. It and the assurance of confidentiality provides the basis for cooperation.

When the outcome is as expected, i.e., the information was there, and the decision was made to launch, then only a simple review of the steps followed is needed. This can yield suggestions as how to improve the delivery of information in either form or substance, or elimination or simplification of steps in the decision making process.

When outcome IV occurs then the causes for having missing information must be sought within the specific shipboard systems. This requires the cooperation of the commander and system personnel. If the possibilities are straightforward, then Flow Diagraming can be used. A flow diagram already produced during the process of determining where to connect the recording devices in Phase 2 could be used. Tracing the communication connectivity for the missing information should lead to one or more system personnel. Again it is assumed that if it were possible they would have transmitted the information in a timely manner. The shipboard system personnel can use the nominal group process (Scholtes, 1990) to find out the root causes. The root cause is what needs correction to change the outcome. It may not be the individuals involved.

At-sea operations can be considerably more complex and require differernt techniques such as using “the “Cause and Effect Diagraming” technique (Ishikawa, K., 1986). This technique is often used for diagnosing complex problems of industrial processes. An simplified example of one is shown in Figure 5.

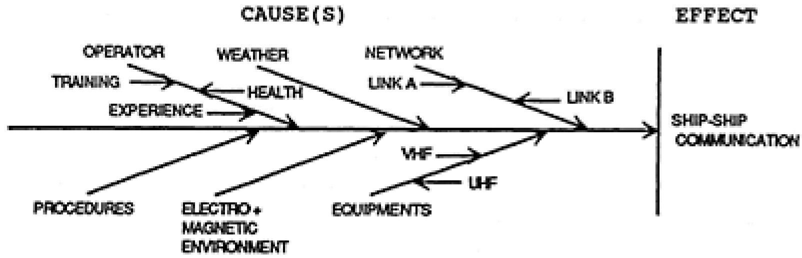

Figure 5: Example of a Cause and Effect Diagram

Whatever causes are identified above they must be verified when the scenario is repeated. This is another requirement of TQL, i.e., data must be collected and analyzed to verify the initial finding similar to what is done when using the scientific method. For example, if a piece of equipment failed to transmit during an inport exercise, it must be observed during subsequent exercises. If repeated, it is the fault of the "system". Simple frequency counts and time measures may be used.

The remaining two possible outcomes should be of the highest interest to the trainers. First, consider the situation where the information is available but the decision was not made to launch: outcome III. Did the commander not perceive the information? Was it in among non-relevant elements? Was it in an unexpected form? Did he consider the source to be unreliable? Was there some previous experience that would undermine the value of the information? Was there something in the doctrine, ROE, or tactics being used that could account for his not making use of the information? The open-ended interview with the commander can again be appropriate.

The last, outcome II, to be considered is where the information did not arrive and yet the commander decided to order a missile launch against the enemy carrier. How to determine why the information was not available has already been discussed. The remaining issue concerns the basis upon which the commander made his decision to launch. This situation would not be explored if we looked only at system performance as the determinant of successful decision making. As someone once said "You do not need to explain success." But in this case there is no apparent reason for the launch decision to be made. Certainly, however, there is a reason for that decision and it may prove that there are alternatives to the prescribed tactics although they may not be officially recognized. The unofficial criterion may be a better alternative, but it may also have a higher possibility of failure, if repeated.

The TQL Cycle which consists of the steps "PLAN, DO, CHECK, and ACT" is similar to the scientific approach in that a test is planned and implemented, data collected, and results analyzed. In this case however, the results are analyzed with a the objective of improving the process and repeating the cycle until the process is operationally perfected.

If in-depth TQL procedures are used in inport training and then used at sea, where and when a need is indicated, there will be continuous improvement not only in training but also in at-sea operations. This will be TQL working in the operational Navy.

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HUMAN PERCEPTUAL DEFICITS AS FACTORS IN COMPUTER INTERFACE TEST AND EVALUATION

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Issues related to testing and evaluating human computer interfaces are usually based on the machine rather than on the human portion of the computer interface. Perceptual characteristics of the expected user are rarely investigated, and interface designers ignore known population perceptual limitations. The test and evaluation community can address the issue from two primary aspects. First, assessing user characteristics should be extended to include tests of perceptual capability. Secondly, interface designs should use multimode information coding.

INTRODUCTION

The focus of Human-Computer Interface (HCI) design literature and research has been on the software, displays, physical environment, and computer equipment aspects of the interface. The approaches to testing and evaluating human-computer interfaces are usually based on the machine rather than the human portion of the computer interface. The perceptual characteristics of the expected user are rarely investigated, and interface design ignores known population perceptual limitations. Using color to transfer information does not take into account the potential incidence of color-deficient vision problems in the user populations. Using auditory codes does not take into account expected hearing deficits by frequency and adjust outputs according to known population characteristics. The distribution of visual acuity within the user population is usually not considered. It is more likely that environmental impacts on the system will be defined than will user perceptual characteristics.

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The interface issues presented in the following material were initially identified by the author through workplace observations. The placement of computer displays was different in each office. The color schemes of the commercial software packages varied and were different from office to office. The level and nature of the auditory environment in each section varied greatly. Some individuals were forced to tilt their heads to read displays that were fixed in place. The effect of glare on fixed screens in both commercial and military environments (i.e., Automated Teller Machines (ATM) and/or other fix mounted displays) was often a serious interface problem for users. The need for larger displays and the small size of the text on the display were frequent operator complaints. These observations raised the questions about interface design and user perceptual problems.

BACKGROUND

The military test and evaluation community is exposed to numerous systems involving HCI. There are standard resources for anthropometry and volumes dealing with computer interface designs. Although information is extensive, the military standards system does not provide data about the distribution of perceptual deficits within military populations. Personnel entering the military are routinely screened for vision and hearing, and results are recorded in individual records. The lack of a deficit is used by the assignment system to screen personnel for some job categories. Data on perceptual capabilities of the overall personnel pool data have not been aggregated into an information resource. It is known that military personnel will have correctable vision to a given standard, hearing within a standard range, and physical characteristics within a standard range. But the distribution of color vision capabilities is not known and is not identified for specific personnel unless it is used as a job-screening item. We do not know who wears glasses (contacts) and what types (i.e, bifocals, trifocals, reading glasses, etc.). We do not identify hearing limitations in the subject population or those that may occur due to a career-induced exposure. The distribution of hearing deficits for the overall population by frequency range is not aggregated. The military system does not provide a resource for cataloging perceptual deficits within the military population.

The military problems are a subset of the more general civilian issues. The civilian population represents a larger range of perceptual capability than does the military population. The details of perceptual problems among this larger, more diverse population are more difficult to obtain and less predictable. The various license agencies and professional medical associations could serve as a basis for estimating the extent of deficit within the general civilian population, but the information is not systematically aggregated. Specific surveys are not generally available for problems, such as partial color vision deficit, and have not been accomplished in sufficient detail for population estimates to be reliable. Information has not always been obtained under standard conditions, making aggregation difficult. There is no central resource or standard information base for the distribution of population perceptual capability. Self-reporting (i.e., questionnaires and surveys) of the general population is not a reliable source of information because large numbers of people are unaware of the nature or extent of their perceptual deficits. It is obvious that perceptual deficits are common in the general population, based on the observation of persons using perceptual aids and the amount of commercial activity associated with these items.

TEST AND EVALUATION RESULTS

The military regularly undertakes test and evaluation projects that involve HCI. In a number of recent experiments undertaken by the author and his associates, self-report data were collected on some aspects of visual perception. Data on the need for vision correction and types of corrective vision appliances were collected from participants by questionnaire. The incidence of color vision deficit was also solicited. The sample size was less than one hundred military personnel and did not qualify as either random or representative of the overall military population. Data were collected from officers and enlisted personnel who volunteered to participate in experiments testing prototype computer software. Responses of participants indicate that over fifty percent used some type of visual appliance. The most common was glasses with a single lens, rather than bifocal, trifocal, or blended lens. The user self-report distribution of nearsighted, farsighted, and astigmatism was approximately equal. The reports on color vision problems were less certain. Approximately sixty percent could not state if they did or did not have any color vision deficit. The remaining forty percent reported some color vision deficit in about half the group, that is, in approximately twenty percent of the total group.

Because the identified problems extend to the general civilian population, observational data were collected by the author in the commercial area. It was noted that most fixed, mounted screen interfaces are placed at median eye height. Observation shows that users of such interfaces frequently tilted their heads, and it was assumed they did this because they were required to use a multifocus lens to read the screen. It was also noted that environment glare was a common interface problem. The use of monochrome displays (i.e, plasma panels, liquid crystal displays (LCDs), etc.) were observed to be difficult for many people to read when viewing conditions were less than ideal. The smaller the display font size, the more likely that the average user would have difficulty reading the screen. The use of lower contrast color displays (i.e, color LCD) caused readability problems for persons with color vision deficits. The use of color to code information is a common commercial software technique. The color coding is often not redundant with some other modality and therefore a potential problem for users with color deficit. There appears to be no standard for auditory cues in terms of frequency or loudness. The loudness issue is complicated by environmental noise factors and, in most cases, no adjustment is provided to the user. A self-selection of frequency (hertz) has generally not been made available to users to accommodate persons with a hearing range deficit.

The commercial interfaces are unacceptable to persons who lack a perceptual modality or are handicapped. The screens do not in general provide an auditory modality for the blind or a visual mode for the deaf. The height of most screens does not allow for persons below the fifth percentile in height or the wheelchair-bound user. Total color blindness is not allowed for in most interfaces. Observation of interfaces, such as ATM, telephones, information displays, and public computer terminals, shows no design effort in the area of handicapped access. Given the less obvious nature of partial perceptual deficits, the interfaces are not designed to account for these problems.

CONCLUSIONS AND RECOMMENDATIONS

Investigation of user population characteristics is most often directed toward intellectual abilities and anthropometry. The difficulty of measuring perceptual capability combined with the lack of organized databases on these aspects of the specific populations has resulted in the issue being ignored. Problems are compounded by the fact that some of these perceptual deficits tend to be found in higher-than-overall population distribution in some user groups. The military, for example, selects for some job types on perceptual capabilities, which means that the groups in the military not selected for these jobs have a higher-than-population average of perceptual deficits. For example, those in the military deficit group are also more likely to be selected as computer operators because, in general, there are no perceptual screening programs for these jobs.

The scope of the problems in various populations should be explored to provide a better understanding of the extent of the problems. The test and evaluation community could and should include data collection on perceptual deficits as a standard part of user-interface evaluations. Where possible, aggregate data from the general population should be consolidated. Interface designs should be evaluated with these limitations in mind. The test and evaluation community can address the issue by extending the assessment of user characteristics to include tests of perceptual capability.

The design community, as well as test and evaluation professionals, should identify possible compromises in the user interface to accommodate the larger population of users. For example, a public computer interface such as an ATM could be placed at a lower level and slanted. The level should allow the accommodation of those who are wheelchair-bound. The tradeoff would cause tall persons to bend down to use the interface but would increase the overall user access. The glare problem could be reduced

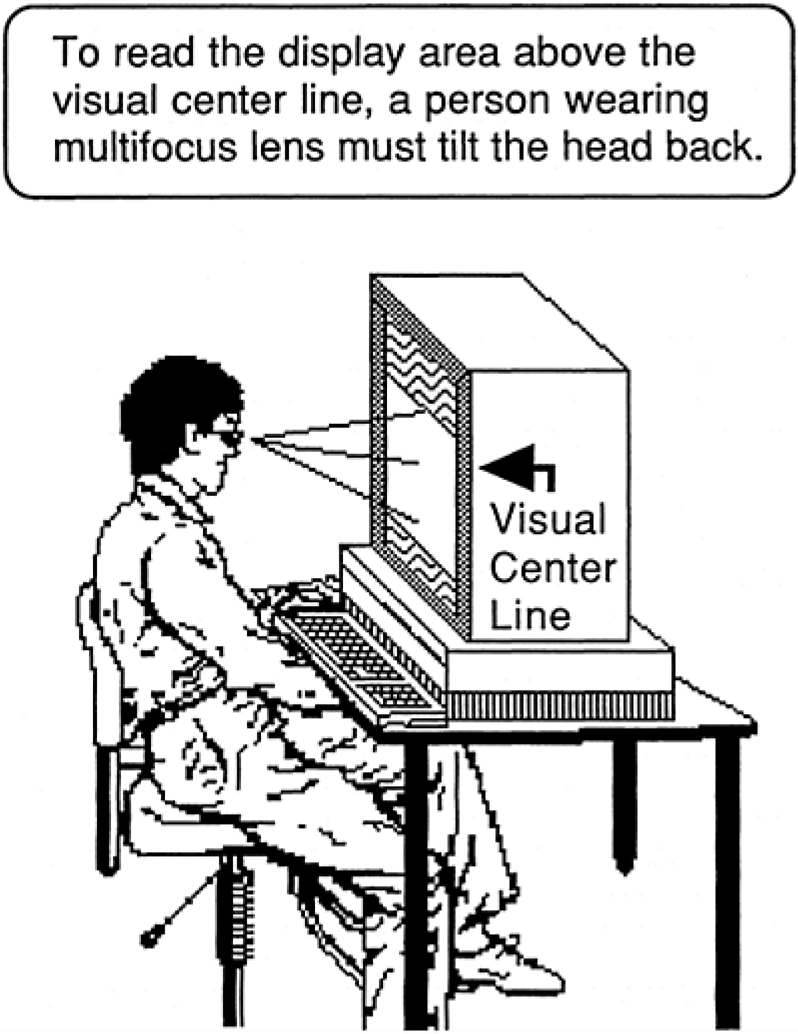

Figure 1. User Visual Range

by slanting the display and using glare-resistant screen covers. The lower position would aid the users who employ multifocus vision aids by improving the visual angle. The use of monochrome displays should include larger text fonts, since the contrast effects are limited by this display mode. When color is used for coding user information, at least one secondary coding method should be employed to ensure the interface usability. It would also improve the interface if auditory signals could be directly adjusted by the user. Consideration should be given to voice interactive systems to aid the severely visually handicapped. The example of an ATM interface applies to all screen interfaces that require public access.

The design community, including the military, may also need to change design and evaluation approaches. The use of monochrome displays is common, and the requirement for larger text sizes due to reduced contrast should be recognized. The need to allow vertical height and tilt adjustment of screen displays should be accommodated as much as possible. See Figure 1. The impact of glare on low contrast displays should be a standard part of test and evaluation. Work environments are often noise-filled, and the capability to adjust frequency and loudness of the auditory interface is important. The use of color coding in computer systems is extensive. Interface designs should use multimode information coding. It follows from these main issues that the use of single mode information coding needs to be reduced and that the collection of perceptual capabilities data should be expanded.

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TAGUCHI'S LOSS FUNCTION IN ERGONOMIC JOB EVALUATION

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Taguchi's Quality Loss Function methodology is an appropriate tool for analyzing and justifying the need for an ergonomic improvement in the process. The impact of leaving out the indirect cost can adversely affect the outcome of economic justification. The Loss Function can be effectively used to justify an improvement in a work station that may already be below the required limit. The Loss Function can show how improving the work situation beyond the minimum required can benefit both the worker and the company.

INTRODUCTION

The main goal of any organization is to achieve a profit. An ergonomist, like any other person in the organization, will therefore be expected to help the organization achieve its goal.

Taguchi's Quality Loss Function methodology is an appropriate tool for analyzing and justifying the need for an ergonomic improvement in the process. The impact of ignoring indirect costs can adversely affect the outcome of any economic justification procedure during investment analysis. The Loss Function can be effectively used to justify further improvements in a workstation or work cell which may be already within acceptable standards. It can then be used to demonstrate the benefits to both the worker and the management of the potential consequences of continuous improvement in, or modifications to, the worksystem using reasonable economic or quasi-econonomic criteria.

ERGONOMIC COSTS AND BENEFITS

Before any attempt can be made to justify the cost of making ergonomic improvements, it is essential that the analyst understand all of the costs that are involved. The costs can be grouped into two main categories, direct and indirect.

Direct Costs

Direct costs are the costs incurred through such aspects as:

1. Damages to equipment;
2. Compensation for loss of earnings, pain and suffering;
3. Insurance premiums.

In Canada, both the 2nd and 3rd item would be covered by payments that are made to the Workers' Compensation Board (WCB). WCB determines a rate for an industry rate group and employers are grouped according to the product they produce. The rate group is then assessed a premium rate per 100 dollars of payroll. The size of the premium will be dependent on the assessable total payroll for the firm. As long as the firm's performance is consistent with the performance of their rate group, no surcharge will be assessed.

The Injury Frequency Rate is used as a base to compare the performance of individual firms and industry groups. The frequency rate is calculated as follows:

$$\frac{\text{Number of allowed compensable claims} \times 200{,}000}{\text{total hours of exposure}}$$

To receive a surcharge, the company must meet each of the two following criteria in both the most recent year under review and in one of the two previous years:

– the accident frequency for compensable claims is at least 125% of the industry average, and
– actual accident costs are at least 125% of the employer's expected accident costs.

As an example, ABC company has 500 employees and a payroll of $14,000,000. The rate group they are in is assessed at $4.00 per $100 of payroll. The premium to WCB would be $560,000 for the year. In addition, if ABC company had claims and accidents in excess of 125% of the industry average over the last two years, they would be assessed a surcharge of between 50% and 100% of their premium ($280,000 to $560,000).

Indirect Costs

The following are some of the indirect costs (Wilson & Corlett, 1990) that can be associated with ergonomic problems;

1. Safety administration costs: the time of the safety officer and committee dealing with the investigation of the accident and proportion of time for any secretarial support.

2. Medical centre costs: the time of the doctors and nurses involved and the medical supplies used in the treatment of injuries.

3. Welfare/pension payments: the proportion of the payment made by the company to the employee whilst off work. 4. Cost of the time of the other employees: including;

(a) the time taken by other employees in helping the injured man.
(b) the time taken by the supervisor in aiding the injured man.
(c) time taken by the witness in answering questions during the accident investigation.

5. Replacement labour costs if the worker is replaced.

6. Loss of production costs: due to the unavailability of manpower and machines.

7. Damage to the plant and machinery costs: incurred when repairs are needed and replacements are ordered and fitted.

8. Other costs: arising from the investigation of the accident (these include stationery, secretarial and clerical work performed in actually processing and recording the accident and correspondence with Regulatory Agencies and Insurance companies).

If properly implemented, an ergonomic program will yield the following benefits:

Direct—Reduction in lost time; reduction in direct costs due to injury.

Indirect—Reduction in labour turnover; reduction in employee absenteeism; reduction in indirect cost due to injury.

Now that the direct and indirect costs/benefits have been defined, how do we relate these to an ergonomic improvement in a work station?

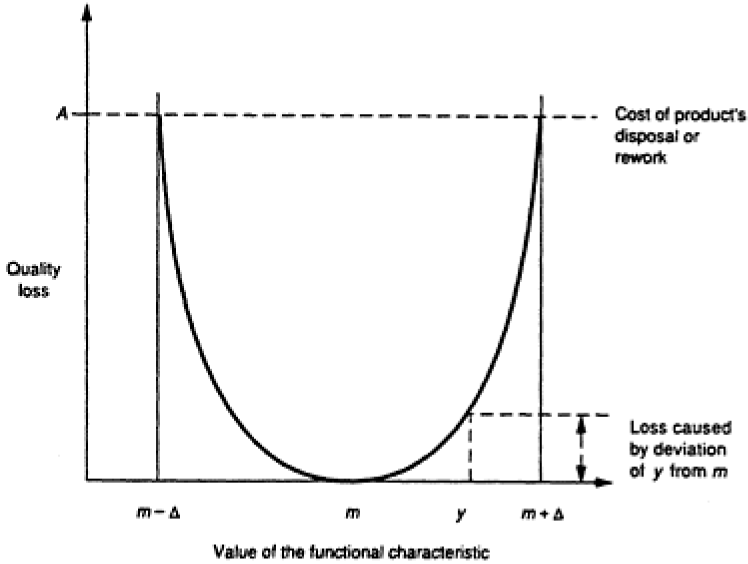
JUSTIFYING ERGONOMICS

The reduction in labour turnover and employee absenteeism are usually the result of the implementation of an entire ergonomic program. For this reason, it is difficult to determine what effect, if any, the improvement in one particular work station would have on them. To determine what effect an ergonomic program has had on the turnover and absenteeism rates, a comparison of rates before and after the implementation of the ergonomic program could be made. It would not be too difficult to estimate the reduction in recruitment costs, retraining costs, and reduction in sick payments, from the results. Once the potential injury assessment has been conducted, however, how do you justify an ergonomic improvement to work station that has not had any previous injury claims?

Taguchi Method

Dr. Genichi Taguchi developed an approach known as the Quality Loss Function (QLF) to determine the economic impact of tightening the tolerance to improve product quality. Before we can answer the question as to whether or not Taguchi's method for justifying quality control can be applied to ergonomics, we must first understand how Taguchi justified improvements in quality control.

According to Dr. Taguchi (Ryan, 1988), the quality of a product is the (minimum) loss imparted to the society from the time the product is shipped. He associates loss with every product that the consumer interacts with. This loss includes, among other things, consumer dissatisfaction, added warranty costs to the producer, and loss due to a company having a bad reputation, which leads to eventual loss of market share. Loss is always incurred when a product's functional quality characteristic (denoted by y) deviates from its target value (denoted by m). Figure 1 shows the relationship between quality loss and the amount of deviation from the target value (Taguchi et al, 1989).



(from Taguchi, Elsayed & Hsiang, 1989, Ref. #5).

Figure 1 Relationship between quality loss and deviation from the target value (m).

LITERATURE REVIEW

In this section a brief review of the literature on the justification of ergonomic changes, and Taguchi's quality loss function, is presented. There is an abundance of information available for human factors related issues; however, information regarding the justification of ergonomic changes is quite scarce.

Imperative to the justification of ergonomic changes is the inclusion of indirect as well as direct costs and benefits. Oborne (1982) provides a section on the cost and rewards associated with an ergonomic program, and the cost effectiveness of accident prevention. Included with the cost effectiveness of accident prevention is an excerpt from Bearham (1976) on the different types of accidents and a list of both the direct and indirect costs. Wilson and Corlett (1990) have produced a text on the methods and techniques of ergonomics. Included with this text is a chapter by Simpson and Mason identifying the kind of data which can be used by ergonomists to build an economic case and some of the procedures and calculations which can be used to present the case.

Nicholson and Ridd (1988) have assembled a book which for the most part constitutes the proceedings from the international symposium entitled, "Workwise Ergonomics, Health and Safety," October 1987. A chapter by Simpson describes the cost of ergonomic limitations and economic return from ergonomic action. Simpson also includes a study reported by Spilling et al (1986) covering ergonomic improvements to reduce musculoskeletal problems at STK's telephone plant at Kongsvinger.

Dr. Taguchi has developed a very effective method of justifying improvements to a process that is already within the specified tolerance limits. Ealey (1988) examines Dr. Taguchi's methodology and philosophy from both a historical and a technical perspective, as well as its increasing influence in the United States. The papers and essays collected by Ryan (1988) discuss the need for and implementation of Taguchi methods. The papers are primarily from the Fifth Annual Taguchi Symposium, conducted by the American Supplier Institute, October 1987, in Detroit.

Taguchi, Elsayed, and Hsiang (1989), describe quality control from an engineering standpoint. The book includes an excellent chapter on the 'Loss Function' approach as a measure of quality, and its use in determining product specification, target values of product characteristics, and desired tolerances.

Taguchi (1986) presents an outline of quality engineering as it affects product planning, research and development, design research, and production quality engineering. Taguchi also includes a question and answer section at the end of each chapter which gives the reader a better understanding of subject material.

TAGUCHI APPLIED TO ERGONOMICS

If we are to apply Taguchi's Loss function to ergonomics, then the product and consumer will have to be changed. For ergonomic purposes, we shall define the product as the work station in which a particular item is produced, and the consumer as the worker performing the tasks. Therefore, by improving the quality of the work station, we will reduce the loss to both the company and the worker.

The idea behind improving the ergonomics of a work station is to reduce the stress on the human body. Therefore, the target value for ergonomic improvements would be to reduce the stress to zero and it could not take on any negative values. This particular characteristic is known as a smaller-the-better characteristic and it has only an upper tolerance.

The Loss function of a smaller-is-better characteristic is:

$L=(A/\Delta^2)*\text{variance}$

where, A=loss to society when upper tolerance limit is exceeded; A=consumer upper tolerance.

The following case study will demonstrate the use of Taguchi in justifying ergonomic changes.

CASE STUDY

ABC company has approximately 500 employees and produces 4 million widgets per year. The projected WCB premium is $560,000 and it is estimated that 35 compensation claims will be filed. The hourly wage plus benefits for the employees is $14.00.

At the final assembly, model ‘X’ widgets are packed into containers 36″×36″ with 150 widgets per container (5 layers of 30 widgets). Each widget weighs approximately 5 kgs and they are packed 2 at a time. The daily production is 2400 widgets over 2 shifts.

The current operation has the containers flat on the floor. The compression on the LS/S1 joint was calculated to be 1571 Newtons. The NIOSH action limit for this task is 3400 Newtons (maximum permissible limit is 3 times the action limit, i.e., 10200 Newtons).

The company ergonomist wants to purchase a pneumatic tilter to tilt the container 35 degrees. The ergonomist has calculated that the compression on the L5/S1 will be reduced to 1202 Newtons. The cost of the pneumatic tilter is $2800.

The Director of Operations claims that they are already below the NIOSH action limit and then the purchase is not justified. How would you justify the purchase of the pneumatic tilter?

Solution

The company is responsible for the employees’ wages on the day that the employee is injured. Therefore, we will assume the average lost time to be 4 hours per injury. The indirect costs associated with the lost time injuries are estimated to be 3 times the direct cost or 12 hours. The total time associated with each injury is therefore estimated to be 16 hours.

Lost time injury cost=16 hrs*$14/hr*35 claims
= $7840/yr
Total direct & indirect costs for lost time injuries=$560,000+$7840
= $567,840

Since the company produces 4M widgets per year, the cost is $0.14/widget. By tilting the container 35 degrees the average reach distance will be decreased by 7″. MTM analysis shows that this will result in a savings of 0.4 seconds/motor.

Direct labour savings=(0.4/360)*2400 widgets*5 dy*52 wk
= $693/yr
Loss Function:
Present Loss=$(0.14/10200^2)*1571^2$
=$0.0033
Proposal Loss=$(0.14/10200^2)*1202^2$
=$0.0019
Net Benefit=(0.0014/widget
=0.0014*2400 widgets *5 dy*52 wk
=$874/yr
Total cost savings from proposal=$874+$693
=$1567/yr

The payback period will be approximately 2 years and the proposal should therefore be implemented.

CONCLUSION

Ergonomic changes are difficult to justify based solely on the direct labour savings. The indirect benefits associated with ergonomic changes must be quantified and included in the analysis if justification of the changes is to be properly evaluated. The case study has demonstrated how Taguchi's Loss Function can be applied to ergonomic changes. The loss function can therefore be a very useful tool in the analysis and justification of ergonomic changes.

Although the case study did not show it, the analysis should include the effects on the entire human body. The human body is a very complicated mechanism, a reduction in the stress on the L5/S1 might have an adverse effect on the shoulder muscles. When determining whether or not the ergonomic change is justified, the cost/benefit analysis must be based on the overall reduction in stress on the human body. Efforts are underway to extend this methodology to the entire human system.

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EFFECTIVENESS OF FITNESS-FOR-DUTY RANDOM TESTING RATES AND FEATURES: ANALYTIC COMPARISON OF NINE SELECTED ALTERNATIVES

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Analytical Modeling was used to investigate the effects of user and program characteristics on the detection effectiveness of random testing programs. Nine alternative random testing rates and three plausible drug user distributions were examined. Relative detection effectiveness of the testing alternatives was found to be consistently ordered across the three drug user distributions. 150% Tailored, 150% Standard Approach, and 100% Tailored 2 Year Cycle Approach were the three most effective, in decreasing order. Drug deterence effectiveness is recommended as the next area of programatic investigation.

INTRODUCTION

Fitness-For-Duty (FFD) random drug testing programs are increasingly being implemented in industrial settings. An optimal random drug testing program is one that maximizes both detection and deterrence rates while minimizing monetary and social costs (e.g., employee morale). Unfortunately, the ability to design an optimal FFD program is currently constrained by lack of information about. patterns of drug use. Both the types of drugs and the frequency with which they are used will determine the relative detection effectiveness of different testing programs with disparate random testing rates and feature alternatives. Consequently, some approaches may be more cost and detection effective for a population continuous users, while others may be more appropriate for a population of primarily occasional drug users.

A modeling approach was adopted to investigate the importance of user and program characteristics for detection effectiveness. A model was specified using nine alternative random testing rates and three different plausible drug user distributions. The model was then used to estimate the proportion of drug users in the population that would remain undetected over time for each possible combination of program and drug user characteristics.

It is important to note at this point that “detection rates” and “deterrence rates” are very different things. Detection effectiveness refers to the probability of detecting drug use in a plausible user distribution. It does not include relative suppressions of use, i.e., “deterrence effects.” While the present modeling effort allows us to estimate the detection effectiveness associated with various programs and user distributions, it does not allow prediction the actual percentage of the population using drugs (as this percentage depends on the type and frequency of drug use). It also does not allow us to estimate what kinds of deterrence effects these programs may be having on the various user populations. Suggestions for further study into the area of deterrence are discussed in the final section of this paper.

METHOD

Described below are the methods of statistical modeling used to analytically evaluate the effects of testing alternatives and user distributions. Characterized in turn are: nine testing rate and feature alternatives, three plausible user distributions, and the modeling procedure used to evaluate the effects of the testing alternatives under each user distribution.

Testing alternatives

Analysis was conducted using nine testing rate alternatives which contain sampling approaches that bracket a standard annual 100% sampling rate:

- 100% Standard Approach—this is achieved through 52 weekly testings of a completely random selection of a balancing fraction (1/52) of the eligible personnel.
- 100% Tailored Approach—this is similar to the 100% Standard Approach in that there are weekly random testings of about 1/52 of the current personnel, but the selection rate for recently tested personnel (within a calendar year time frame) is half that for untested personnel.[1]
- 100% Tailored Two-Year Cycle Approach—this is similar to the 100% Tailored Approach in that there are weekly random testings of about 1/52 of the current personnel, and the selection rate for recently tested personnel is half that for untested personnel, but the process continues for two calendar years rather than ending at the end of one calendar year.
- 25% Standard Approach—this is achieved through weekly testings of a completely random selection at one quarter the 100% Standard Approach fraction of the eligible personnel currently working (0.25/52).
- 25% Tailored Approach—this is similar to the 100% Tailored Approach in that the selection rate for recently tested personnel (within a calendar year time frame) is half that for untested personnel, but there are weekly random testings of about 0.25/52 of the current personnel.
- 50% Standard Approach—this is achieved through weekly testings of a completely random selection at half the 100% Standard Approach fraction of the eligible personnel currently working (0.50/52).
- 50% Tailored Approach—this is similar to the 100% Tailored Approach in that the selection rate for recently tested personnel (within a calendar year time frame) is half that for

[1] Barnes et al. (1988) showed tailoired approaches resulted in greater percentages of personnel tested annually than with the standard approach advocated by others (e.g., Burtis et al., 1987).

untested personnel, but there are weekly random testings of about 0.50/52 of the current personnel.

- 150% Standard Approach—this is achieved through weekly testings of a completely random selection 50% greater than the 100% Standard Approach fraction of the eligible personnel currently working (1.5/52).
- 150% Tailored Approach—this is similar to the 100% Tailored Approach in that the selection rate for recently tested personnel (within a calendar year time frame) is half that for untested personnel, but there are weekly random testings of about 1.5/52 of the current personnel.

These nine testing alternatives allow initial exploration of the effects of various sampling strategies and rate variations. Because they bracket. the standard 100% rate, a realistic assessment can be made of possible programs using a range of testing rates around this standard.

The distribution of drug users, by type of drug used and frequency of use, has a substantial impact on the estimates of the total number of drug users that exist in the employee population. Three drug user distributions were selected based upon their consistency with recent detection rate experience from random testing of licensee employees from the Nuclear Power industry (Durbin et al., 1991). This industry may not be representative of all industries, however, it is satisfactory for purposes of the present analysis. The three distributions used here were chosen for use in this study because they yield an overall first year positive rate of 0.3 percent under a 100% Standard Approach (as was found in the Nuclear Power Industry).[2] Thus, these distributions are “plausible” though differing in specific detection details regarding the mix of detected drugs. The discussions of occasional user distributions here are based on very low occasional use (2 times per year). The effects of using more frequent occasional user distributions would, of course, lead to increased rates of detection. The three distribution alternatives chosen provide for an initial comparison of the differing effects of continuous and occasional distributions on user detection. The three user distributions are:

- Continuous Drug Users—this first distribution is composed of (1) 0.47 percent of persons who use drugs so frequently that their use is continuously detectable (e.g., more often than once every two weeks for marijuana or every half week for cocaine) and (2) the remaining 99.53 percent, who are continuously drug free.
- Occasional Drug Users; Long Duration Drugs—this second distribution is composed of (1) 4 percent who use on the average of only twice a year a drug that remains detectable for a relatively long duration (e.g., marijuana with a two week “window” of post-use detectability) and (2) 96 percent nonusers.
- Occasional Drug Users; Short Duration Drugs—this third distribution is composed of (1) 15 percent who use on the

[2] Specific percentages of users in the three user distributions were determined analytically. Continuous Drug Users, for example, would be detected if tested, but only about 63.6% of personnel are tested over a oneyear period using a 100%-Standard-Approach (cf., Burtis et al.). Hence, the 0.3% detected users found by Durbin et al. (1991) corresponds to only 63.6% of the user population—the actual percentage of continuous users is approximately 0.47%.

> average of only twice a year a drug that, remains detectable for a relatively short duration (e.g., cocaine and other drugs which average a 3.5-day “window” of post-use detectability) and (2) 85 percent nonusers.

An iterative modeling procedure was used to evaluate the progressive week-to-week effectiveness of each testing alternative over a five-year period fot each user distribution (Bittner & Macaulay, 1991). The flow of this process begins with “input user distribution characteristics” (e.g., Occasional Drug User: Long Duration). Incrementally, this is then followed by three steps for each week of testing until the last (52nd) week in a year is reached. The three steps are: (1) evaluation of the weekly proportion of detected users, (2) evaluation of the cumulative proportion of detected users, and (3) characterization of the remaining user distribution (relative proportions of users and total remaining). After the last week in the year is reached, the relative proportion of remaining users is computed and the result is documented as the annual remaining proportion of users. This process is then continued until reaching the last (5th) year, allowing the documentation of detection by year for five years. Comparison of testing programs across user distributions is made on the basis of percent detected at. the end of the five-year time span.

RESULTS

This section evaluates the effectiveness of the nine alternative testing approaches as applied to each of the three user distributions in terms of both detection and cost. Detection effectiveness was generally measured by the extent the various user populations are detected at the end of a five year period. A total population of users and nonusers of 1,000 people was chosen to portray the numeric results for each of the three distributions in Tables 1 through 3.

Cost effectiveness was judged by comparing their detection effectiveness with their relative costs to administer. For simplicity, it was assumed that the standard and tailored testing approaches for each percentage testing rate, e.g., 50% Standard and 50% Tailored, would cost the same to administer. It was also assumed that the 50% approaches cost one-half as much as the 100% approaches and twice as much as the 25% approaches. The results for Continuous Drug Users, Occasional Drug Users: Long Duration, and Occasional Drug Users: Short Duration are characterized in turn.

Table 1 presents the percentage and number (in parentheses) of undetected users remaining in the population after the nine alternative testing approaches were each applied to the Continuous Drug Users distribution. At the beginning (Year 0), this distribution originally contained 0.47 percent continuously detectable users, or 4.71 users per 1,000 persons. The results in Table 1 indicate that the 150% Tailored Approach would be the most effective in detecting continuous users insofar as it produces the lowest absolute number of users—0.001 person—left in the population after five years. For practical purposes, however, all approaches except for the 25% Standard and 25% Tailored would be essentially equivalent in detection effectiveness in that they all eliminate essentially all continuous users after five years. The 25% Standard Approach would be the least effective of all the approaches in that it would leave 1.34 continuous users—or 29 percent of the original user population—at the end of Year 5.

The 50% Standard and 50% Tailored Approaches, which would cost approximately the same to administer, would appear to be the most cost effective to detect continuous users. This conclusion is based on the supposition that there is no practical difference between, for example, having 0.27 person left after five years (50% Tailored) versus having 0.002 person left (150% Standard). Therefore, because all approaches except for the 25% Standard and 25% Tailored would be essentially equivalent in detection effectiveness, the approaches that cost the least would be most cost effective. The two 50% approaches would thus be the most cost effective since they would cost less to administer than the higher-testing-rate alternatives.

Table 1. Percentage and number of users (per 1,000) remaining as a function of testing approach for continuous users.

	YEARS OF TESTING					
TESTING APPROACH	0	1	2	3	4	5
100% Standard	100% (4.71)	36.4% (1.71)	13.3% (0.62)	4.8% (0.23)	1.8% (0.08)	.6% (0.03)
100% Tailored	100% (4.71)	27.5% (1.30)	7.6% (0.36)	2.1% (0.10)	.6% (0.03)	.2% (0.009)
100% Tailored, 2 Year Cycle	100% (4.71)	27.5% (1.30)	4.5% (0.21)	1.3% (0.06)	.06% (0.003)	.02% (0.001)
25% Standard	100% (4.71)	77.8% (3.67)	60.64% (2.85)	47.2% (2.22)	36.7% (1.73)	28.6% (1.34)
25% Tailored	100% (4.71)	76.6% (3.61)	58.7% (2.76)	44.9% (2.12)	34.4% (1.62)	26.4% (1.24)
50% Standard	100% (4.71)	60.5% (2.86)	36.6% (1.73)	22.2% (1.04)	13.4% (0.63)	8.1% (0.38)
50% Tailored	100% (4.71)	56.6% (2.67)	32.1% (1–51)	18.1% (0.85)	10.3% (0.48)	5.8% (0.27)
150% Standard	100% (4.71)	21.8% (1.03)	4.8% (0.22)	1.0% (0.05)	.2% (0.009)	.05% (0.002)
150% Tailored	100% (4.71)	11.5% (0.54)	1.3% (0.06)	.2% (0.009)	.02% (0.001)	<.01% (<0.001)

Table 2 presents the percentage and number (in parentheses) of undetected users remaining in the population after the nine alternative testing approaches were applied to the Occasional Drug Users: Long Duration Drugs distribution. Occasional users of long duration drugs, it will be recalled, would constitute 4 percent of the population and be assumed to use long duration drugs, such as marijuana, with two-week windows of post-use detectability twice a year. This table shows that the initial expected 40 users per 1,000 persons in Year 0 would be reduced to between 22 and 37 by the end of Year 5. Again, the 25% Standard Approach performed least well with an expected 37 remaining users. This contrasts with 22 remaining users for both the 150% Standard and the 150% Tailored, the most detection effective approaches.

The 100% Tailored 2 Year Cycle appears to be the most cost effective of the alternative testing approaches as applied to occasional users of long duration drugs.

While the 150% Standard and 150% Tailored Approaches identify a few (3) more users than the 100% Tailored 2 Year Cycle Approach, the higher costs associated with these approaches make these alternatives less desirable.

Table 2. Percentage and number of users (per 1,000) remaining as a function of testing approach for occasional users: long duration drugs.

	YEARS OF TESTING					
TESTING APPROACH	0	1	2	3	4	5
100% Standard	100% (40)	92.6% (37)	85.7% (34)	79.4% (32)	73.5% (29)	68.1% (27)
100% Tailored	100% (40)	92.5% (37)	85.6% (34)	79.2% (32)	73.3% (29)	67.9% (27)
100% Tailored, 2 Year Cycle	100% (40)	92.5% (37)	85.6% (34)	79.2% (32)	67.7% (27)	62.7% (25)
25% Standard	100% (40)	98.1% (40)	96.2% (38)	94.4% (38)	92.6% (38)	90.8% (37)
25% Tailored	100% (40)	98.1% (39)	96.2% (38)	94.4% (38)	92.6% (37)	90.8% (36)
50% Standard	100% (40)	96.2% (38)	92.6% (37)	89.1% (36)	85.7% (34)	.82.5% (33)
50% Tailored	100% (40)	96.2% (38)	92.5% (37)	89.0% (36)	85.6% (34)	82.4% (33)
150% Standard	100% (40)	89.1% (36)	79.4% (32)	70.7% (28)	63.0% (25)	56.1% (22)
150% Tailored	100% (40)	89% (36)	79.1% (32)	70.4% (28)	62.6% (25)	55.7% (22)

Table 3 presents the percentage and number (in parentheses) of undetected users remaining in the population after the nine alternative testing approaches were applied to the Occasional Drug Users: Short Duration Drugs distribution. In this distribution it is assumed that 15 percent of the population uses a short duration drug, such as cocaine, twice a year. Use of cocaine and other short duration drugs allows an average 3.5-day window of post-use detectability. Table 3 shows that all testing approaches perform relatively poorly for this distribution. Of the initial expected 158 users in Year 0, between 137 and 154 would be expected to remain undetected at the end of Year 5. Not unexpectedly, the 25% Standard and 25% Tailored Approaches again performed the poorest, detecting only 4 users over five years. The other alternatives, however, were only slightly more effective with remaining users of from 137 to 151.

As with the long duration drug distribution, the 150% Standard and 150% Tailored Approaches appear to be the most detection effective. Yet, because of the relatively high costs associated with those testing alternatives, the 100% Tailored 2 Year Cycle Approach with 141 remaining users may be considered the most cost effective approach to detect occasional users of short duration drugs.

Table 3. Percentage and number of users (per 1,000) remaining as a function of testing approach for occasional users: short duration drugs.

	YEARS OF TESTING					
TESTING APPROACH	0	1	2	3	4	5
100% Standard	100% (158)	98.1% (155)	96.2% (152)	94.4% (149)	92.6% (146)	90.8% (143)
100% Tailored	100% (158)	98.1% (155)	96.2% (152)	94.4% (149)	92.6% (146)	90.8% (143)
100% Tailored, 2 Year Cycle	100% (158)	98.1% (155)	96.2% (152)	94.4% (149)	90.8% (143)	89.1% (141)
25% Standard	100% (158)	99.5% (157)	99.0% (156)	98.6% (155)	98.1% (154)	97.6% (154)
25% Tailored	100% (158)	99.5% (157)	99.0% (156)	98.6% (155)	98.1% (154)	97.6% (154)
50% Standard	100% (158)	99.0% (156)	98.1% (155)	97.2% (154)	96.2% (152)	95.3% (151)
50% Tailored	100% (158)	99.0% (156)	98.1% (155)	97.2% (154)	96.2% (152)	95.3% (151)
150% Standard	100% (158)	97.2% (154)	94.4% (149)	91.7% (145)	89.1% (141)	86.6% (137)
150% Tailored	100% (158)	97.2% (154)	94.4% (149)	91.7% (145)	89.1% (141)	86.5% (137)

CONCLUSIONS

The relative detection effectiveness of the nine testing alternatives was found to be quite consistently ordered when compared across the three user distributions. The 150% Tailored Approach typically yielded the somewhat larger numbers of detected users, followed in ascending order by the following approaches: 150% Standard, 100% Tailored 2 Year Cycle, 100% Tailored, 100% Standard, 50% Tailored, 50% Standard, 25% Tailored, and the 25% Standard. The only exception to this ordering occurred in the continuous user distribution where the 100% Tailored 2 Year Cycle Approach was slightly more effective than the 150% Standard Approach. However, the relative detection effectiveness of the 150% Tailored Approach and the 150% Standard Approach after five years of sustained testing typically varied little from other less resource-intensive alternatives. The most cost effective alternative for the short and long duration drug distributions was the 100% Tailored Two-Year Cycle. As discussed above, cost effectiveness need not be considered in relation to detection of continuous users because such users are expected to be almost entirely detected within a five year time span.

It is important to note, however, that the most cost effective alternatives could be more definitively identified if the underlying user distribution were determined (e.g., by debriefing of detected users). Information on industry-wide user distributions would support developing a rationale for selection of the most cost effective testing alternatives.

Assessing the current user distribution would also provide guidance for FFD programs. For example, random and other testing elements would be supported by the finding that the distribution is largely composed of continuous users. A finding that the current user distribution is largely occasional users would alternatively argue for stressing assistance, educational, or deterrence elements of a FFD program to reduce the impetus for drug use (e.g., Employee Assistance Programs).

A concurrent effort to assess the deterrence effectiveness of the nine testing alternatives also appears warranted. Because continuous users are effectively identified using any of the random testing rates, very few continuous users will remain in the population after an initial five year time span. Thus, the users the programs will be attempting to identify will mainly be occasional users that none of the random testing alternatives was very effective at detecting. Deterence may consequently be the ultimate value of a testing program, hence, it is especially crucial to determine deterrence effectiveness for these users.

Optimal Fitness-for-Duty programs consequently need to be determined on the basis of a combination of both the detection and deterrent effects of a given testing program. Because deterrence can be measured by a reduction in the drug use beyond the direct effects provided by detection, the results of this study may be used as a baseline for assessing deterrence effectiveness. Thus, concurrent assessments of the deterrence effectiveness of the nine testing alternatives and the current user distribution would contribute to (1) the identification of the most cost-effective testing alternative as well as to (2) meeting the broader goals of FFD programs. The next area of effort should be an investigation of the deterrence effectiveness of various potential random testing programs.

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IDENTIFYING FACTORS OF COMFORT AND DISCOMFORT A MULTIDIMENSIONAL APPROACH

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A classification analysis was conducted to identify factors that are associated with comfort and discomfort. Descriptors of feelings of comfort and discomfort were collected by a questionnaire survey. A similarity matrix was generated based on the ratings of similarity of each pair of descriptors by 42 subjects. The results were subjected to multidimensional analysis including multidimensional scaling, factor analysis and cluster analysis. Two factors emerged, comfort and discomfort, indicating the multidimensional property of comfort/discomfort.

INTRODUCTION

Comfort is one of the major concerns of office workers (Dainoff, 1986; Kleeman, 1980). Comfort has been frequently used as a measure in workplace assessment, especially for chair evaluation (*eg.* Shackel, *et al.* 1969; Helander, *et al.* 1987). In common parlance, sitting comfort may refer to the feeling of either comfort or discomfort resulting from assuming certain postures when sitting. However, comfort or discomfort has not been operationally defined. There is no study thoroughly investigating what factors may be implicated, and how people perceive comfort and discomfort.

Many investigators tend to assume that comfort and discomfort are the two opposites on a scale of comfort perception. This can be seen in the construction of rating scales for sitting comfort assessment (*eg.* Shackel, et al. 1969). The assumption is that the perception varies subjectively along a continuum from a state of extreme comfort through indifference to a state of extreme discomfort. Or it may be interpreted as that increase in discomfort implies a decrease in comfort, or *vise-versa*.

In this study, these intuitive assumptions were questioned. There is a need to verify by experimentation if comfort/discomfort is truly a single dimension, or if there would be reason to assume, as we did, that there may be several dimensions involved. Some researchers have actually implied that a multidimensional approach may be more reasonable. Considering a seat is a device to provide support of a working posture, sitting comfort has been defined as “absence of discomfort” (Hertzberg, 1972), “a state of no awareness at all of a feeling” and it “does not necessarily entail a positive affect” (Branton, 1969). By this definition, comfort was denoted as a balanced neutral feeling, and the perception of comfort was conceptualized as two discrete stages: Comfort Presence and Absence (or Discomfort Presence). The existence of a sensation of comfort depends on the presence or absence of other factors that may cause feeling to deviate from the neutral state. “If a sensation distracts attention from the task in hand, then a state of discomfort can be said to exist” (Corlett, 1973).

The difficulty in defining comfort may be due to the fact that we do not have enough knowledge about what factors comfort and discomfort entail. Studies on sitting comfort have shown that comfort was influenced by several variables (Habsberg and Middendorf, 1977), and, comfort and discomfort were associated with different factors (Helander, et al. 1987). The objective of this study was to identify these factors. For this purpose, a questionnaire survey study was conducted to collect common descriptions of comfort and discomfort from people in seated workplaces. The similarity of each pair of descriptors was then rated by subjects according to the meaning and relationships. the similarity matrix generated from the ratings was then subjected to different statistical analysis to extract the important factors.

METHODOLOGY

Questionnaire survey

In the questionnaire survey, respondents provided descriptions of the feelings they experienced when they felt comfortable or uncomfortable in a seated workplace. From 106 returned questionnaires, a list of descriptions were collected, see Table 1.

Table 1. Descriptors of comfort and discomfort collected from questionnaire survey

rest ful	relief	relaxed
feel at ease	luxurious	being supported
pleasant	cozy	not think of workplace
spacious	content	happy
agreeable	soft	calm
plush	well-being	safe
refreshed	pleased	
pain	strained	smarting
pressing	dull ache	hurting
cramped	ache	heavy-leg

f idgety	numbness	stiff
sore	fatigue	restless
sleepy	tired	ill at ease
swollen ankle tingling	unsupported	circulation to legs cut off

Rating of similarity

To generate a similarity matrix for classification, the similarity of each pair of descriptors was rated by 42 subjects recruited from the university students. Their ages ranged from 18 to 35.

The ratings of similarity was conducted using a computer program written for this purpose. Forty three descriptors were randomly rearranged. During the rating process, a pair of descriptors and a rating scale were displayed on the computer screen. Subjects were instructed to rate each pair of descriptors in terms of similarity and relationship. All possible pairs of descriptors were rated.

The outcome of this rating process of each subject was a similarity matrix of 43 by 43, the final similarity matrix was the average of the matrices of 42 subjects.

Classification

The final matrix was submitted to classification analyses using Multidimensional Scaling (MDS), Factor Analysis and Cluster Analysis.

RESULTS

Multidimensional Scaling

The MDS approach was used for classification using SAS ALSCAL procedure with Euclidian distance option. The results are shown in Figure 1.

The items in the two dimensional plane were clearly divided into two major groups, comfort descriptors on the right side discomfort descriptors on the left. The two groups can be further divided into smaller clusters.

On the comfort side, from top to bottom, item can be grouped into three clusters: “Sleepy” did not cluster with the other items. It is about equally distant from comfort and discomfort groups. The second cluster on comfort side contains most of the items, The items above the horizontal axis in this cluster are mainly related to biomechanical supporting feature such as relaxed, relieve, rest ful, and refreshed, while the items below the horizontal axis in this cluster are mainly descriptors of well-being and impression related items. The three items on the bottom of the right side formed a third cluster. The objects in this cluster are related to the definition that comfort is a Neutral Feeling.

Similarly, the items on the left side can be divided into three clusters: The six item on the top left section are descriptors related to fatigue/energy, such as tired, fatigue, and restless. The group of items in the middle section describe feelings of pain and circulation cut off to the lower extremities. The bottom part has three items. This cluster may be thought of as describing lack of postural support.

Factor analysis

Since the similarity rating of the descriptors can be considered as correlations, the matrix was also subjected to factor analysis using SAS FACTOR procedure with VARIMAX rotation.

Table 2 shows that first two factors explain about 50% of the total variance, or 73% of the total communality. The first factor contains all the descriptors related to comfort except the impression descriptors, which are grouped in factor 4. The second factor consists mostly of items related to discomfort due to postural constrains.

Although the last 3 factors explained less than 20% of total variance, or 26% of total communality, they are meaningful in the explanation of the conceptual structure of human comfort perception. The 3rd consists of three items describing the feelings of discomfort due to stress including both low and high arousal. The 4th factor, as mentioned early, contains 4 impression descriptors. These items also have relatively high (0.4 to 0.5) loading s on factor 1. The last factor contains two energy related items, sleepy and tired. The former has a moderate loading in first factor, the latter share the large portion of its loading (0.44) with factor 2.

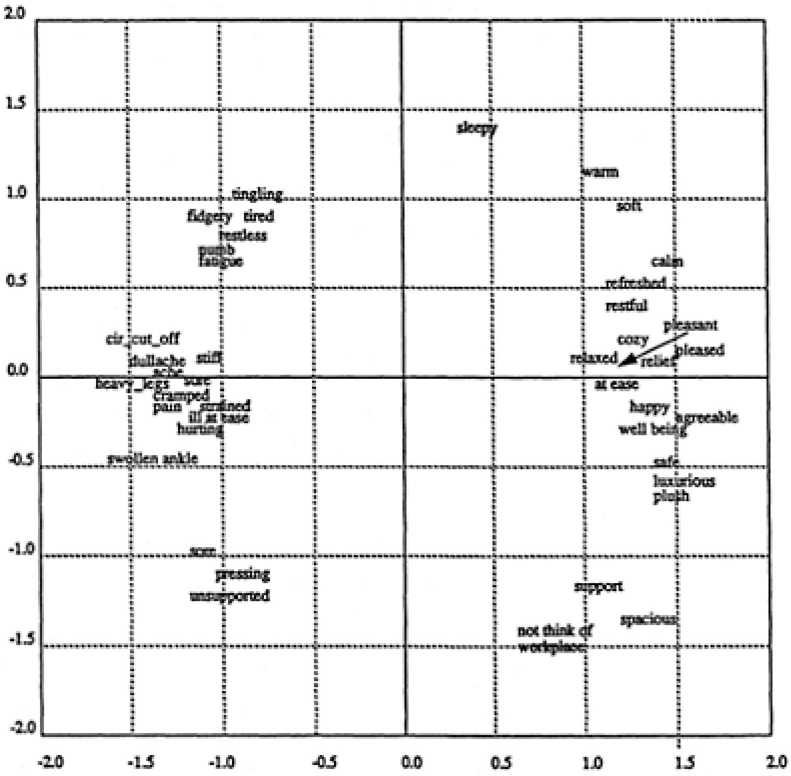

Figure 1. Distribution of objects in two dimensional plane, (MDS)

Table 2. Factor loadings after varimax rotation

	Factorl (comfort)	E Factor2 (discomfort)	Factor 3 (low arousal)	Factor 4 (impre -ssion)	Factor5 (lack of energy)
relaxed	0.824				
at ease	0.818				
happy	0.813				
content	0.807				
pleased	0.806				
pleasant	0.785				
well begin	0.762				
rest ful	0.760				0.323
safe	0.732				
calm	0.729				0.323
relief	0.706				
agreeable	0.702				
ref reshed	0.700				
cozy	0.691				
supported	0.585				
warm	0.535				
not think of workplace	0.492				
sore		0.811			
pain		0.811			
ache		0.806			
circulation to leg cut off		0.791			
hurting		0.790			
dull ache		0.784			
swollen ankle		0.755			
numb		0.708			
stiff		0.708			
feeling of heavy legs		0.684			
smarting		0.629			
tingling		0.627			
cramped		0.625	0.431		
strained		0.583	0.506		
ill at east		0.561	0.531		
fatigue		0.557	0.326		
unsupported		0.435	0.375		
restless		0.370	0.745		
f idgety		0.387	0.691		
pressing		0.424	0.488		
plush	0.431			0.752	
luxurious	0.507			0.715	
softness	0.416			0.617	
spacious	0.430			0.585	

sleepy	0.375				0.783
tired		0.448	0.334		0.658
Total Variance	10.606	9.469	2.876	2.367	2.157

Cluster analysis

The cluster analysis was performed using BMDP 1M procedure with average linkage method. The output is plotted in Figure 2.

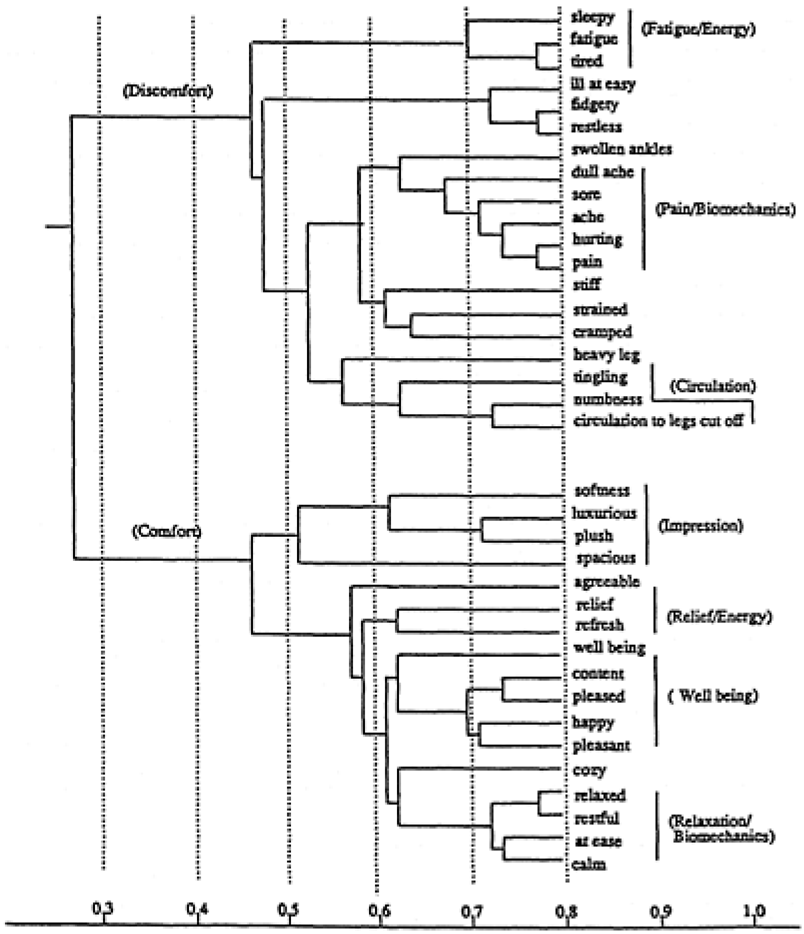

Figure 2. Structure of relationships of descriptors (Cluster Analysis)

The plot of the tree structure indicates that the objects were grouped into two major clusters, Comfort and Discomfort. Two items, “not think of workplace” and “unsupported” jointed into cluster at very late stages, indicating that they are not particularly similar to any of the sub-level clusters. Therefore, they were dropped in this plot. This plot is consistent with the outcome from MDS approach and factor analysis. We interpreted the results to imply that there are two major clusters: comfort and discomfort. Each cluster could be further decomposed into several sub-level clusters based on the principle that the tree structure can be decomposed to a level at which the number of branches remains the same for a longer range (Romesberg, 1984). In the discomfort cluster, the branch was further divided into three sub-branches.

The top group consists of three items, corresponding to factor 5 in the factor analysis. The second sub-branch contains three items, ill at ease, fidgety and restless. They are related to stress and low arousal, as indicated in factor 3. The last branch consists of terms similar to factor 2 in the factor analysis and the middle cluster of the discomfort group in MDS. The cluster analysis provides further information in decomposition of factor 2. This branch was further decomposed into three low level roots clusters. The first root cluster has 6 items describing feelings of pain. The second root cluster consists of three objects relating to constrained spaces. The last root cluster contains the descriptors related to circulation cut off. In the same way, the comfort branch can be decomposed into two sub-branches. The first sub-branch consists of 4 items which are identical to factor 4 in the factor analysis, and describe “aesthetic” impressions. The second sub-branch contains the remaining items, corresponding to factor 1 in the factor analysis. This branch was further decomposed into three low level root clusters: recovery from discomfort (relief and refresh), well-being, and being supported (relaxed, rest ful,…).

The result of the cluster analysis is also consistent with the MDS. The two main branches of the tree correspond to the objects on the two sides of Figure 1. The objects in each root level cluster, or sub-branch in Figure 2 also closely located in the same vicinity in Figure 1. The plot of MDS approach indicates the spatial relationship of the objects, while the plot of clusters presented a structure of subordination. The decomposition provide further statistical evidence that explains the constructive nature of human comfort perception.

CONCLUSION

Three classification approaches consistently demonstrated the multi-faceted aspects of comfort and discomfort as constructs. Each method provided complementary details about the structure or relationship among descriptors. From this statistical evidence we may conclude that comfort and discomfort contain two groups of factors, indicating that comfort and discomfort are multidimensional constructs. Therefore, evaluation of comfort and discomfort needs to assess each dimension in order to provide a meaningful measurement.

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USING FORCE SENSITIVE RESISTORS TO EVALUATE THE DRIVER SEATING COMFORT

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Body pressure distribution and driving posture are important elements in evaluating driver seating comfort. For body pressure distributions, a portable pressure mat was developed from a mesh of Force Sensitive Resistors. Seat pan and backrest pressure distributions for 8 male and 8 female subjects were measured in a Ford Taurus and a Chevy Lumina and then compared with previously published values. The pressure distribution pattern varied significantly between type of auto, location, and individuals. Subjective ratings of comfort correlated best with a relatively uniform pressure distribution.

INTRODUCTION

While the drivers look at appearance, feel, and comfort of seating, auto manufacturers demand durability, reliability, and performance at an affordable cost. This dual challenge requires the design of seating to be expanded beyond traditional manufacturing processes.

In terms of driver comfort, it is not usual for discomfort in the lower back and buttocks to occur within one to two hours of sitting in an automobile seat. In order for the seat to be functional, it must: 1) be adjustable to give the driver access to vehicle controls and optimum visibility, and 2) provide the driver proper posture for exerting the forces necessary to operate the controls while also minimizing the muscular effort needed to maintain this posture for extended periods, i.e. provide the proper contour, padding, and shape to achieve optimum pressure distribution (Wachsler, 1960).

In addition to the comfort problem, there is a potential risk of low back injury due to the nature of driving task. According to Kelsey et al. (1979), men who spend more than half of the time or; their job driving a motor vehicle are three times as likely to develop an acute prolapsed lumbar inter-vertebral disc as are men who do not hold such jobs.

Although, pressure distributions are considered an important factor of seating comfort, most techniques of measuring pressure have involved complex and expensive instrumentation with limited portability. (Betts et al., 1980, Soames et al., 1982, Henning et al., 1982, Treaster and Marras, 1989). Therefore, the objectives of the study were; 1) to develop a simple, convenient but effective method for analyzing the pressure distribution of an automobile seat and 2) to correlate this pressure distribution with driver comfort as expressed by subjective ratings.

METHOD

A sensor mat which can be placed directly on seat surfaces was developed by fixing a matrix of 32 Force Sensitive Resistors (Interlink Electronics, 1989) between two thin sheets of plastic. FSRs are thin film devices which exhibit decreasing resistance with increasing force applied normal to the device surface. They can be easily interfaced with an analog-to-digital converter by using a voltage divider, and have been used to measure pressure distributions on tool handles (Fellows and Freivalds, 1991). Although not linear in the response to force changes, the FSRs can be optimized for force measurement (Stone and Vaughan, 1990).

Voltage output from the 32 sensors were recorded using the DASH 16/F analog-to-digital converter attached to a portable PC (Toshiba 3200). The mat was calibrated to pressure levels (g/cm2) using a third order polynomial regression:

$$\text{Pressure (g/cm}^2\text{)}=1272*\text{voltage}^3\text{(mV)}. \qquad (1)$$

The coefficient of determination for the pressure calibration regression was 0.98.

Following subject familiarization, the seat and backrest pressure measurements were taken by placing the sensor pad between the subject and the seat or backrest surface. Contact size, shape and placement on the FSR can vary considerably between subjects. To keep the same reference point of placement, the distance between subjects hip point and Seat Reference Point (SRP) was kept constant for all subjects.

Eight male and eight female subjects were studied while sitting on a car seat. Prior to the measurement, seven item of anthropometric measurement were taken for each subject: sex, age, weight, stature, acromyon height, trochantric height, and buttock-to-poplitial length (given in Table 1). Subjective rating questionnaires were given and filled out simultaneously with the pressure measurement.

The questionnaire consisted of the qualitative ratings of chair feature checklist, body part discomfort, and general comfort ratings on the all features of the seat.

Independent variables included two types of different car seats (1991 Chevy Lumina—Car A, 1991 Ford Taurus—Car B) measured for seat pan and backrest. Experimental conditions were presented randomly to each subject.

The analysis process included the analysis of variance for the test conditions, comparison of seat pressure levels with available literature, and analysis of the relationship between subjective ratings and pressure levels.

RESULTS

Figure 1 shows 3-dimensional representation of the average pressure distribution for seat pan and backrest for each car. Average pressure of seat pan was 2–3 times greater than that of backrest for each car. Average pressure levels for both cars were about 30g/cm2 for the seat pan and 15g/cm2 for the backrest.

Table 1. Subject Characteristics.

Subj	Sex	Age	Weight (Kg)	Stature (Cm)	Acromyon Height (Cm)	Trochantric Height (Cm)	Popliteal Length (Cm)
1	M	23	77.3	182.3	155.1	107.5	63
2	M	18	75.0	185	161.1	111.7	63.5
3	F	38	56.8	153	127.6	90.5	53
4	F	22	45.5	156.5	134.3	90.5	53
5	F	23	73.2	175.1	151.5	102.6	63
6	M	17	72.7	180	153.6	107.7	57.5
7	M	25	63.6	162.8	140	98	57
8	M	18	70.5	177.5	142.3	102.1	53.5
9	F	22	*	162.3	153.6	94.3	56.5
10	F	33	72.7	163	136.6	101.1	61
11	M	28	65.0	165.5	142.3	91.4	57.5
12	M	23	72.7	167.2	139.8	94.5	57.5
13	M	22	72.7	165.4	141.7	95.9	62
14	F	49	57.3	159.6	134.5	94.1	60.5
15	F	21	51.4	163	137.7	93.4	58.5
16	F	26	54.5	156.5	132.5	88.3	61

Table 2 shows the analysis of covariance (ANCOVA) of pressure with subjects as the covariant. All main effects were significant ($p<0.05$). The location variables (X and Y) and backrest/seat pan difference showed especially high Fvalues.

Komolgorov-Smirov (K-S) tests for goodness of fit (Law and Kelton, 1982) were used to compare the pressure distributions with an ideal uniform distribution. The larger the test statistic (D), the greater the deviation from a uniform distribution. Data from Car B ($D=4.073$ $p\leq0.01$ for backrest, $D=6.291$, $p\leq0.01$ for seat pan) were relatively closer to the uniform distribution than Car A ($D=7.687$, $p\leq0.01$ for backrest, $D=6.782$, $p\leq0.01$ for seat pan).

The results of this study were compared with the seat pan data from the literature (Figure 2). The correlation coefficient was 0.756 ($p\leq0.01$) between Rebiffe (1969) and our data and 0.642 ($p\leq0.01$) between Jurgens (1969) and our data. The results of a

Friedman Test on the ranked average data blocked by location showed no significant differences between the two references and our data (Friedman's s=0.25, d.f.=2 p>0.05).

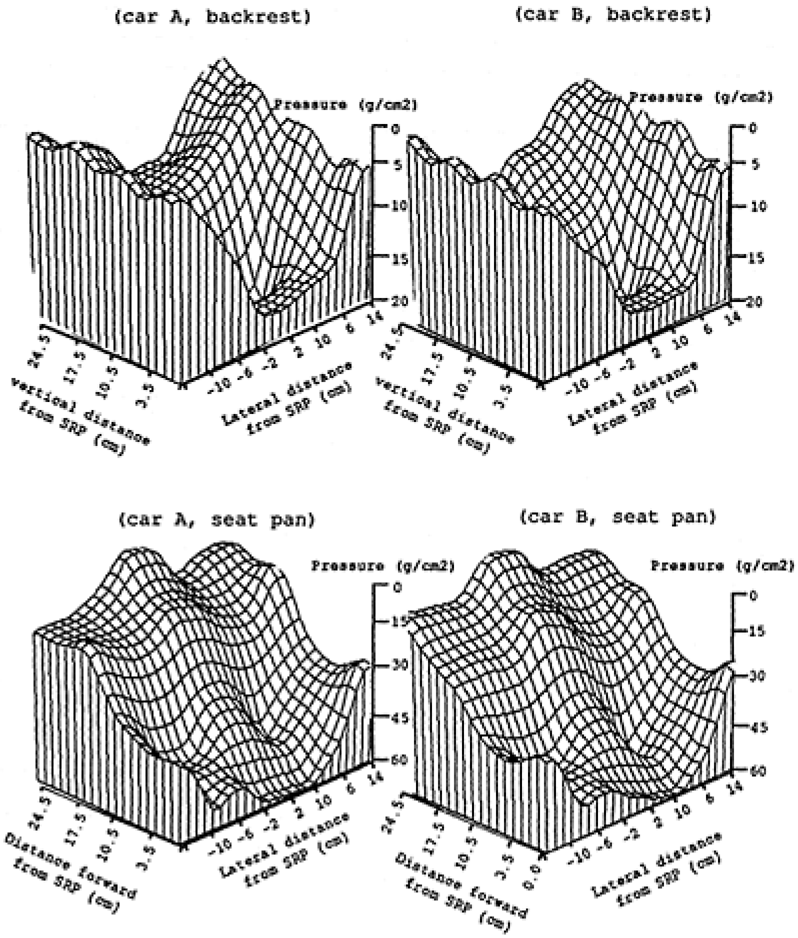

Figure 1. Mean Pressure Distribution

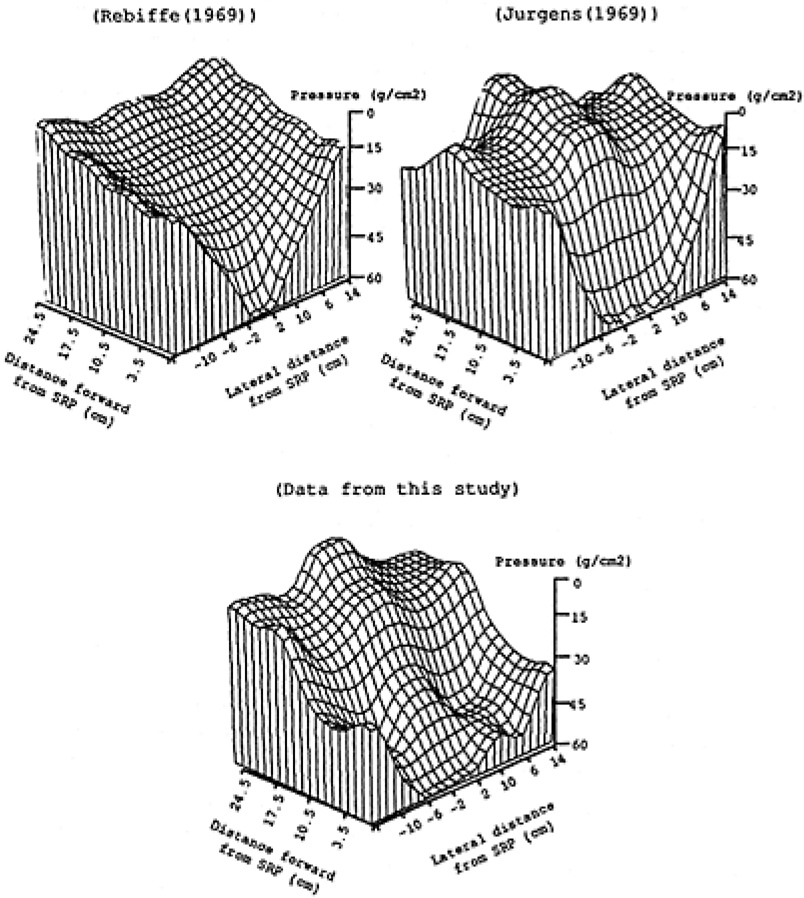

Figure 2. Comparison of pressure distributions

Table 2. Analysis of Covariance of Pressure.

Source	DF	ADJ SS	MS	F	P
Covariates	1	13.5	13.5	0.34	0.558
CAR	1	349.4	349.4	8.84	0.003
B/P	1	56893.3	56893.3	1440.14	0.000
X	7	26951.2	3850.2	97.46	0.000
Y	3	47386.2	15795.4	399.83	0.000
CAR*B/P	1	102.0	102.0	2.58	0.108
CAR*X	7	299.4	42.8	1.08	0.372
CAR*Y	3	888.9	296.3	7.50	0.000
B/P*X	7	10784.0	1540.6	39.00	0.000
B/P*Y	3	15717.9	5239.3	132.62	0.000

X*Y	21	16366.3	779.3	19.73	0.000
CAR*B/P*X	7	274.4	39.2	0.99	0.435
CAR*B/P*Y	3	161.7	53.9	1.36	0.252
CAR*X*Y	21	502.2	23.9	0.61	0.917
B/P*X*Y	21	6479.1	308.5	7.81	0.000
CAR*B/P*X*Y	21	718.1	34.2	0.87	0.637
Error	1919	75811.1	39.5		
Total	2047	259699.0			

For the analysis of the subjective ratings and the pressure levels, questionnaire data and the subject characteristics were combined with the pressure data. Figure 3 shows the summary of subjective ratings for each car.

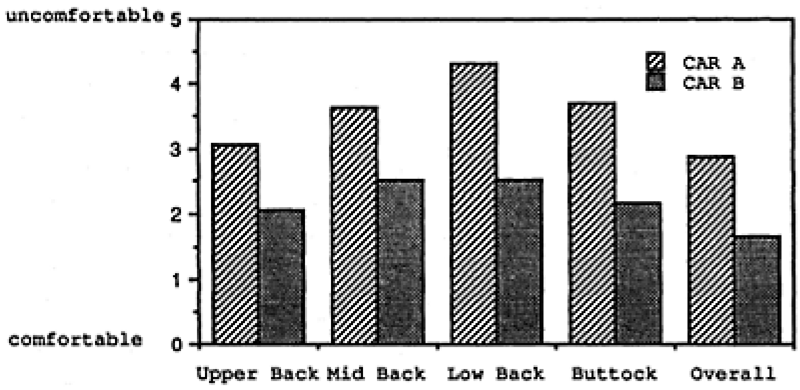

Figure 3. Summary of subjective ratings

Correlation and principal component analysis between subjective ratings and the pressure level by seat part were also conducted. Table 3 shows the correlations between subjective ratings and pressure levels by seat part.

Our results indicate that subjective ratings are affected primarily by the pressure levels of specific body areas. High correlations associated with low back and buttock area for all type of subjective ratings imply that the pressure levels of these areas have the greatest effect on driver comfort.

Table 3. Correlation between subjective ratings and pressure levels ($p<0.05$)

	Subjective ratings			
Pressure Level	Upper Back	Mid Back	Low Back	Buttock
Upper Back	*	*		
Mid back		*	*	
Low Back		*	*	*

Lumbar		*	*	*
Buttock		*		*
Thigh	*		*	*

CONCLUSIONS

The observed pressure distribution patterns were found to vary between the backrest and the seat pan, and the type of car seat used. Comparison of the pressure data with the literature showed that our data was slightly lower than the reported data with a closer pattern to Jurgens (1969) than Rebiffe's (1969) data.

The body part discomfort evaluations and chair feature evaluations were all associated with the pressure distribution of the seat. The seat with the most evenly distributed pressure levels received the most favorable ratings. Comparison of the pressure distribution with the subjective rating of the seat showed that the ratings are affected mainly by the pressure levels of low back and buttock areas.

Using FSR to measure pressure distribution was found to be very simple and practical with regard to operation, hardware interface and portability. Using FSRs could also eliminate most of the difficulties and potential inaccuracies involved in signal processing, amplification and data filtering since raw signals can be used directly for calibrating pressure levels. Application of this technique to dynamic and real time measurements will be studied in the next phase.

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PRELIMINARY TEST AND EVALUATION OF **DATAHAND™** A KEYBOARD ALTERNATIVE DESIGNED TO PREVENT MUSCULOSKELETAL DISORDERS AND TO IMPROVE PERFORMANCE

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The keyboard is implicated in the development of cumulative musculoskeletal disorders among office workers. In response, a variety of keyboard alternatives have been developed. DATAHAND is one that represents an entirely new approach. Test and evaluation of such input devices is complex. We characterize the problem in terms of an evaluation space of three dimensions: the aspect to be evaluated, the level of context, and the population considered. Initial studies of DATAHAND for several points in this space are described. DATAHAND has considerable promise for reducing stress and improving productivity.

INTRODUCTION

Intensive use of keyboards for data input or VDT operation results in high levels of discomfort to a large number of users (Sauter, Schleifer, & Knutson, 1991) and is clearly a major factor in the incidence of cumulative musculoskeletal disorders among office workers. Recent years have seen a substantial increase not only in the number of computers, but in the proportion of users who use them heavily. (Kominsky, 1991; Louis Harris & Associates, 1989) Reported repetitive stress injury in the United States has been characterized as an epidemic. From 1989 to 1990 the rate increased 27%, but among office workers it more than doubled (OSHA, Bureau of Labor Statistics).

Although the degree to which ergonomic factors contribute to the rate of musculoskeletal problems in VDT work has not been clearly determined, a number of studies implicate factors characteristic of keyboard use: repetitive motions, wrist abduction and dorsiflexion, constrained posture and constant application of static forces such as are required to support and pronate the hands. Consequently, there has been a strong incentive to provide alternatives to the standard keyboard to reduce or eliminate these sources of stress.

A variety of alternatives for key-input are either now on the market or soon will be (Sullivan, 1991). They attempt to address keying stress factors by various combinations of 1) splitting, angling, and/or tilting the keyset to reduce wrist angles and hand pronation, 2) providing support for the hands, 3) reducing the key force and/or motion, and 4) repositioning individual keys for easier reach or to distribute the workload better among the fingers. Each of these alternatives, ranging from slight modification to entirely new approaches, has its testimonials and claims for improved performance and productivity and greater comfort and safety from musculoskeletal injury.

But evaluation is extremely complex. If there is no clear understanding of the importance of ergonomic factors as a whole, much less those specific to a keyboard, it is certainly not clear how much reduction of stress, or of what sort of stress, will be beneficial, or to what degree, in any particular work environment. Nor is it clear what the tradeoffs and interactions will be among performance, comfort, safety and cost. The results of controlled, large scale, long term field trials are wanted without their cost or risk. Since that is not possible, practical evaluation will have to be a sequential process composed of smaller studies.

EVALUATION SPACE

An evaluation study of an input device can be thought of as having three separate dimensions, the evaluative aspect that is of concern, the functional *level* and the relevant user *population*. Moreover, for any point (or cell) in this space, the evaluation is undertaken from a particular *perspective*. This is diagrammed in Figure 1. below.

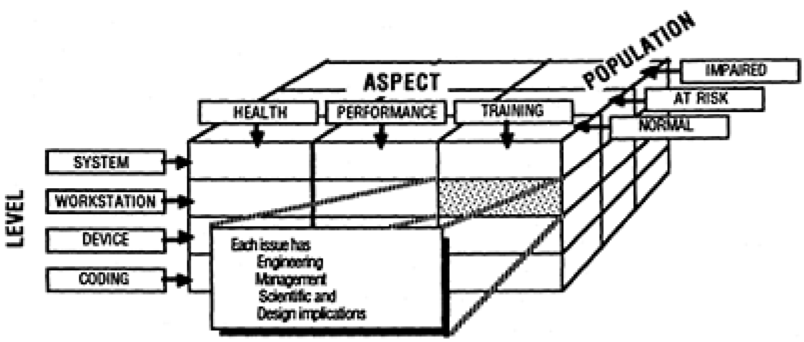

Figure 1. Evaluation space

Figure 1. shows the aspects to be evaluated as health, performance and training, but other aspects are also possible. The functional *level* of the evaluation has to do with how much of the work context must be taken into account. At the device level the focus is on the use of the device itself. At the system level, however, the focus is on the the mutual interaction of characteristics of the device with organizational variables, for example, the impact of the physical stress imposed by the device on the likelihood of absenteeism. The evaluation is conducted with respect to a *population* of users. Populations are shown classified according to musculoskeletal condition, but the relevant distinction might equally be among groups differing anthropometrically. The *perspective* of a study describes the kind of information to be obtained and its intended use, e.g., a study with a design perspective will focus on characterisitics of the device that can potentially be changed for improvement, rather than just on their effects.

In summary, then, evaluation can be characterized as taking a *perspective* and choosing an *aspect* for evaluation with respect to a relevant *population* at an appropriate functional *level*. Additionally, in order to carry out the evaluation, it is necessary to adopt a *methodology* and a degree of thoroughness or *intensity* in its application.

Not all parts of the evaluation space are equally important nor require equal effort, and some parts may be considered equivalent or may be combined in a single study.

PRELIMINARY EVALUATION OF DATAHAND™

A beta-test version of DATAHAND, a new key-input device is shown in Figure 2. The operator's hands rest on two units that can be independently positioned for comfort, and that can act as "mice". In the units there are shallow "wells" that surround each finger tip closely with a set of key surfaces so that small motions of the fingertips (left, right, forward, back or down) activate the key switches.

There are forty key surfaces available to the eight fingertips. Thumb switches are used for such functions as *enter* and positioning as well as for mode shifts that provide capital letters, numbers and all the key equivalents of the extended IBM or Macintosh keyboard. DATAHAND is designed to be plug-compatible with those machines, requiring neither hardware nor software modification. To minimize learning for operators who know how to touch-type, the letter key assignments are such that there is an almost exact duplication of the QWERTY layout. Of the letter keys, only the four that require diagonal reaches, T, Y, B and N, are placed differently.

DATAHAND, in contrast to the standard keyboard, supports the arms, requires no force to keep the hands pronated, allows the wrists to be kept straight, permits a variety of postures and hand positions and hand orientations, reduces motion repetitiveness and requires much less force to operate the keys.

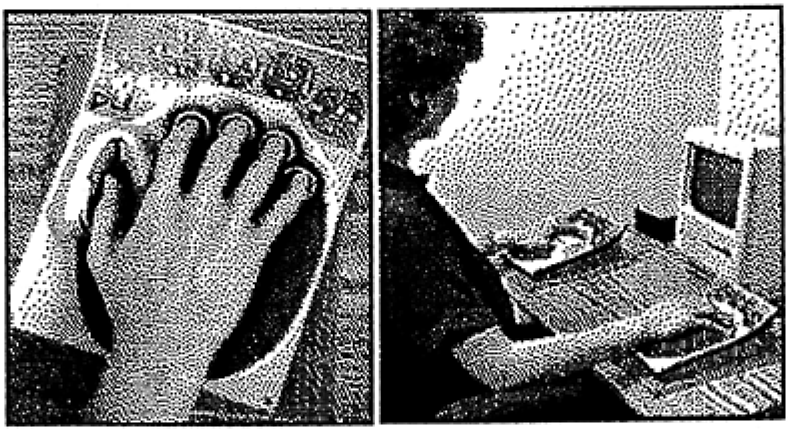

Figure 2. DATAHAND™, an alternative to the keyboard

The preliminary evaluation of DATAHAND has been guided by the evaluation space concept, which encourages a systematic view of the process, especially in the early stages when a design perspective must always be represented to some extent. Studies, thus far, represent the cells in the space that are shown in Table 1.

Table 1. Represented cells in the evaluation space

STUDY	ASPECT	LEVEL	POPULATION	PERSPECTIVE
Basic	Training	device	normal	management
Basic	Performance	device	normal	management
Basic	Health	device	normal	management
Biomechanical	Health	device	normal	science
Biomechanical	Health	device	impaired	science
Organizational	Performance	system	all	management
Organizational	Health	system	all	management

Basic Study

The first set of studies of DATAHAND were undertaken by personnel of Industrial Innovations, Inc., the manufacturer, with the advice and oversight of the second author. They were at the device level, concerned with the normal population and done from the perspective of management. All three aspects, training, performance, and health, were addressed. The methodology was experiment with a small sample of 4 users. All were typists with various levels of skill. Their typing speed on the standard keyboard was assessed using a typing instruction program (Simon & Schuster's *Typing Tutor IV*). They were introduced to DATAHAND in a preliminary session and then were trained in its use with the program. Figure 3 shows their speed using DATAHAND, as a percentage of their speed on the standard keyboard, as a function of the number of hours of practice following the initial introductory session.

With respect to the training aspect, all the subjects approximately reached their keyboard speed after only 10 hours of practice, and consistently exceeded it after 20 hours. The

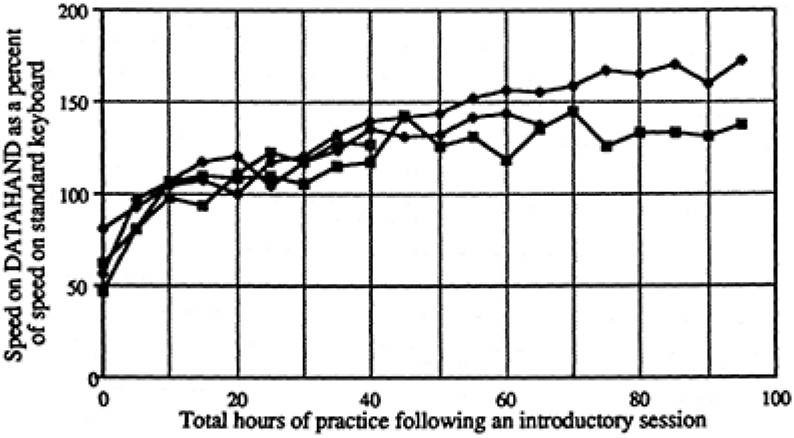

Figure 3. Performance with DATAHAND as a function of practice

results suggest a rapid and straight forward learning process, aided by the high degree of consistency with the QWERTY key arrangement. All subjects continued to improve with additional practice. The two shown going to 95 hours in the figure have subsequently accumulated total experience of almost 200 hours and both have tested consistently at approximately 180% of their keyboard speed.

The subjects' perception of comfort was assessed. An 11 point scale from −5 to +5 was used, expressing judgments of comfort from *extremely uncomfortable,* through *neutral* to *extremely comfortable*. Initially subjects rated the standard keyboard, and then they rated DATAHAND at intervals during training and practice. The ratings of the standard keyboard ranged from −5 to 0, with an average of −2. After the initial session using DATAHAND, its ratings ranged from −1 to +5 with an average of +2.2. But after 25 hours of practice, its average comfort rating had risen to 4.5. Although greater comfort may not necessarily mean greater safety from cumulative musculoskeletal disorders it does signal lower physical stress. In this case the very high comfort ratings for DATAHAND in comparison with the standard keyboard suggest substantially lower stress.

Biomechanical Study

A biomechanical analysis was undertaken by the the third author, considering DATAHAND use by both the normal population and those impaired by rheumatoid arthritis. (Koeneman, 1991)

The user's hand is fully supported in the normal "position of function" on DATAHAND, with the fingers naturally curled as shown in Figure 2. and on the left of Figure 4. This has the advantages that muscle tension is not required 1) to keep the hand above the keyboard, 2) to bring the fingers into working position, or 3) to maintain hand pronation. Further advantages of this are that 4) the moment arm of the force applied to the fingertip is less and 5) the angle of the wrist is such that high pressures are not produced in the carpal tunnel

A further advantage of the support provided by DATAHAND for users who are impaired by rheumatoid arthitis is that the surface can act as a brace to help keep the proper alignment of fingers and metacarpals. This should reduce the tendency of bending moments applied by the extensor tendons to stretch weakened constraint ligaments and cause the ulnar deviation of the fingers commonly observed in rheumatoid hands.

Compression forces generated across the joints of the fingers during function are important. High joint forces may

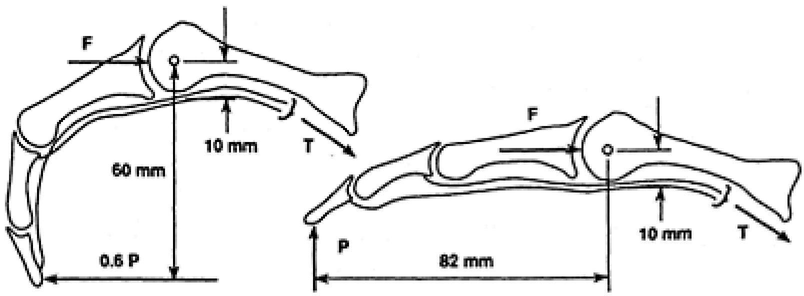

Figure 4. Finger working position for DATAHAND and the keyboard

lead to earlier initiation of osteoarthritis. If the user has arthritis, high joint forces can accelerate the disease. Figure 4 shows the position of the finger when using DATAHAND and when typing on the standard keyboard. For the purpose of calculating the reaction force F at the metacarpal phalangeal (knuckle) joint the forces generated by the flexor tendons are combined into one, T. The applied load force 'with the keyboard is taken as P. With DATAHAND's special key mechanism the load is approximately .6 P. The joint force F is then calculated as 8.2 P for the keyboard, and only 3 P with DATAHAND. Differences between the two devices are likely to be even greater when measured in practice; typists have been observed to use approximately 3 times the force necessary with the keyboard. (Rempel, Gerson, Armstrong, Foulke, & Martin, 1991).

Repetitiveness is positively associated with cumulative musculoskeletal disorders. With the keyboard, each finger activates several keys using essentially the same finger motion for each. With DATAHAND, the 5 different keys for each finger are activated by different finger motions, increasing the variety of movement and reducing repetitiveness. In addition, some of the load on the fingers is taken up by the intrinsic muscles within the hand, reducing the activity of the tendons that pass through the carpal tunnel to the extrinsic muscles of the forearm.

Experimental studies are needed to verify this analysis and to examine the stress levels in the intrinsic muscles; but it is clear that DATAHAND has a number of important biomechanical advantages over the standard keyboard for normal and for, at least some, impaired users.

Organizational Study

The organizational study, which is only in its beginning stages, represents a management perspective at the system level concerned with both health and performance aspects. The objective of the study is to develop a computational model to explore the relationships between ergonomic variables that can be controlled and consequent organizational variables, such as costs and productivity, for purposes of policy making and planning.

> "Management can not be expected to support interventions that lead to reduced productivity, nor can they be expected to be satisfied with improvement of health status only….there is an urgent need to further develop methodology for evaluation of cost effectiveness." (Kilbom, 1988) p. 42.

The literature on cumulative musculoskeletal disorders strongly suggests a multi-factorial causal process relating working conditions to organizational and economic outcomes (Kilbom, 1988) Indeed, there are strong indications that the problem of work-related musculoskeletal problems has a substantial psychosocial component that must be addressed if it is to be understood (Kiesler & Finholt, 1988). For such a complex process, there are important feedback loops in the organizational setting that need to be understood, to be defeated if they are undesirable or exploited if they are favorable. Simple accounting methods will almost surely misstate the actual costs and savings of any intervention, since effects will propagate throughout the organization. Rouse (Rouse, 1989; Rouse & Cacioppo, 1989) has argued for modeling to demonstrate and maximize the contribution of investment in human resources in system design (e.g., investment in training, in safety, and in Human Factors Engineering generally).

Because of the complexity of the problem, one dimensional preventive measures are not likely to be successful. Effective policies will have to address multiple facets of the problem (Ayoub, 1990). However, developing complex policies is difficult. Unaided intuition cannot adequately assess the multiple, interacting consequences of mixtures of initiatives that develop over time. A computational model that exhibits the correct types of behavior, even if it is only approximate in detail, would allow the policy maker to explore and compare alternative options far more effectively than by attempting to imagine or to extrapolate their consequences.

We have adopted System Dynamics modeling, as embodied in the software **ithink™** (High Performance Systems, Inc.), for this study. System Dynamics simulation modeling techniques have long been used to help formulate and explore business policy alternatives (Lyneis, 1980) (Richardson & Pugh, 1981).

It appears to us that the multi-loop, causal nature of the problem of cumulative musculoskeletal disorders needs to be recognized and dealt with explicitly. It may be premature, for lack of data and understanding, to attempt a detailed system model of its aetiology and epidemiology in the workplace, but it does not seem too early to try to take hypothesized causal structures into account in a model to assist in the urgent task of strategic policy planning for prevention. A causal diagram that outlines our current, tentative representation of the problem in the organization is shown in Figure 5. Its representation as a computational simulation model is too detailed to show here, but the model is able to reproduce approximately the dynamic "epidemic" behavior of the reported levels of repetitive strain injury in Australian Telcom between 1981–1987. Basically, the model reveals that there are high indirect costs due to musculoskeletal stress that propagate through the organization that are not caught by the usual accounting methods.

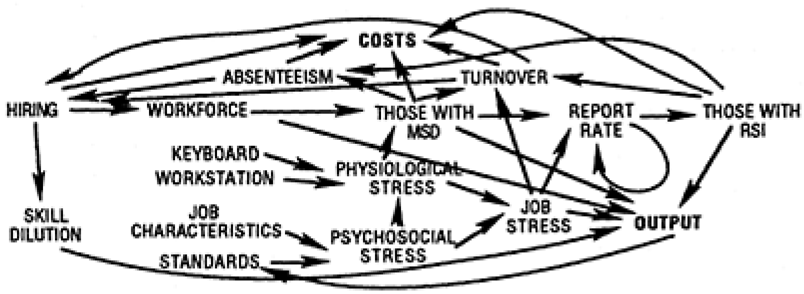

Figure 5. System level causal interactions

CONCLUSION

On preliminary evaluation, DATAHAND appears to be much less likely to produce cumulative musculoskeletal disorders, or to aggravate existing ones, than the standard keyboard, and it holds promise for substantial improvements in productivity with relatively low training requirements.

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ERGONOMIC PRACTICES AND INTERVENTIONS

THE STROOP TEST: THE EFFECT OF AGE, SEX, AND COLOR CONFUSION ON SELECTIVE ATTENTION AMONG UNEXPOSED WORKERS

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Performance deficits in selective attention attributable to exposure to industrial solvents, metals, pesticides, or other central nervous system toxicants have been evaluated using the classic Stroop Test. This study evaluates performance of never-exposed workers. The within-day [PM-AM] difference (7%) in response time was found to be a useful acute measure of treatment. Reaction times also increase with age; however, the response time with interference was found more reliable (.89) than the common use of the Stroop Effect difference score (.54). In summary, the Stroop Test is recommended for neuro-behavioral evaluations of acute or chronic environmental exposures, but interpretation of results is enhanced by controlling for color discrimination.

INTRODUCTION

Significant decrements in selective attention have been examined when workers need to ignore common stimuli in order to detect infrequent flaws in a product on the assembly line or when selectively attending to a foreman's oral orders while tuning out background assembly line conversation. In the presence of industrial solvents, metals, pesticides, or other central nervous system toxicants, deficits in selective attention are intensified, as measured by the classic selective attention task known as the Stroop Test (Anger, 1991).

The term selective attention means the ability to respond selectively to certain stimuli while ignoring others. Stroop (1935) initially designed this test to examine the degree of response time interference between two aspects of a stimulus. A subject's response time without interference was simply the time it took the person to say an underlined color-block among three displayed colors. In the presence of interference, the longer response times were due to the extra time it took subjects to respond to the ink color rather than the printed color-word which spells a different color. Interference in the task comes from both identifying the ink color, which is more difficult because people are more directed toward reading words, and from response competition between saying the ink color and the color word. Later studies (Flowers and Stoup, 1977; Hock and Egeth, 1970) found response competition to be the stronger of the two interference effects.

Given the importance of response selection and color discrimination in the Stroop Test, this study investigates the potential confounding effect of age, sex, and color confusion among never-exposed production workers in a repeated measures study design. For psychometric considerations, the magnitude of potential acute and chronic increase in response time, the reliability of outcome measures, and the statistical power of the Stroop Test are also discussed. The study presents a method to evaluate and interpret the Stroop test in epidemiologic work-place assessments of acute and chronic exposures potentially disrupting the central nervous system.

METHODS

The effect of age, sex, and time of work day on Stroop Test performance is measured. Ninety-four subjects were recruited from support service workers at two local institutions. The workers had never been occupationally exposed to solvents or metals and none had experienced central nervous system disorders. Each subject was tested pre- and post-shift on the same day at the work site. To improve more uniform motivation, subjects were paid $30 dollars for their efforts.

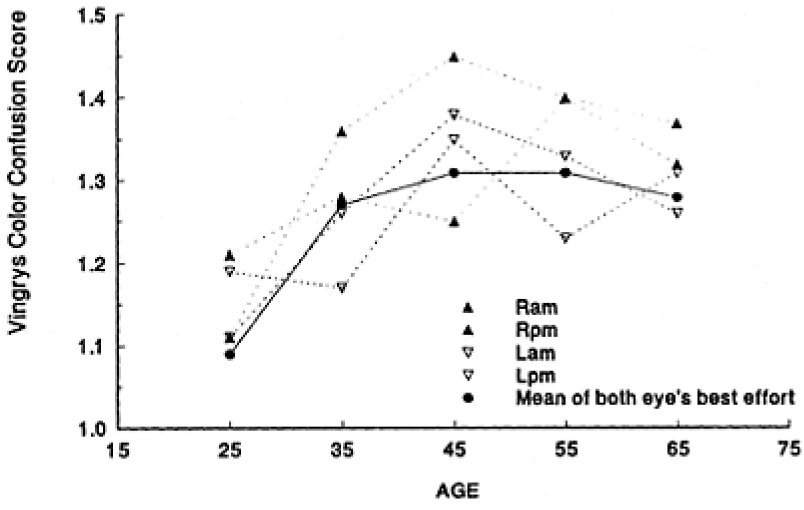
The Stroop Test

The Stroop Test is a modification of an earlier version which used slides and a tape recorder to record responses (Maizlish et al., 1986). This version follows the same test schema implemented on an IBM PC. A worker's verbal responses were coded using a voice recognition board (Votan, 1989) avoiding all motor movement component. For each session, a worker's voice was pre-tested 3 to 5 minutes to train the voice board to recognize 'red,' 'blue,' 'green,' and 'yellow' with 98% accuracy. A worker wore an adjustable head-set such that the microphone was 3 inches away from the mouth. Each stimulus was presented on the screen until the worker responded, but if a worker failed to respond within 5 seconds then the next stimuli was presented. Accuracy and response times for 80 trials were recorded for red (n=20), blue (n=20), yellow (n=20), and green (n=20) colors providing 10 trials with and 10 trials without interference. The order of colors and interference was counter-balanced and the mean response times across all four colors were selected for final analysis.

The Vingrys Color Confusion Test

The Desaturated D-15 Hue Test consists of 16 color caps from the Munsell book of color chosen to create equal chromatic intervals between colors. The Munsell ‘chroma’ of each cap is 2 and the ‘value’ is 8 (Lanthony, 1978). Standardized illumination was provided by a ‘daylight’ GE fluorescent bulb (1150 Lux) at a distance of 30 centimeters over a black matte surface (Mergler, 1987). The Vingrys color confusion index (Vingrys, 1988) quantified color discrimination deficits in the left and right eye separately. Figure 1 presents the distribution of scores for the right and left eye, and average score for each worker’s best effort. Since AM performance did not differ from PM performance there was no statistical need to use distinct covariates for each AM and PM Stroop session. Further, it was thought that some of the AM and PM variance we saw was attributable to unequal motivation. To control for unequal motivation, the best score for each worker’s eye was selected. The average for both eyes was used since the Stroop Test required use of both eyes. Vingrys score was used as a constant covariate in the Stroop Test’s analysis of variance.

Fig. 1 The Effect of Age on the Vingry Score for Color Confusion



Data Analysis

The main hypothesis was to determine if age, sex, AM or PM sessions (learning), and color confusion significantly affected response times with and without interference and on their diffenence score known as the ‘Stroop Effect’ A repeated measures analysis of variance was conducted for the AM and PM sessions for the 3 Stroop measures (2V, BMDP, 1988). Each factor was evaluated for its effect on the mean and potential interaction simultaneously as well as providing the degree of individual variation within each measure. The average age, percent male, and correlations (SPSS V4, 1988) defined the across worker factors. The reliability (Winer, 1973) and statistical power (Vonesh and

Schork, 1986) of each score was computed to evaluate psychometric properties and their usefulness in cross-sectional and longitudinal epidemiologic studies.

RESULTS

Worker Population

Ninety-four production workers volunteered for the study. Four workers did not complete the Stroop Test and 10 workers were excluded from the analysis due to possible confounding factors (i.e. machine error, cataracts, glass eye, tinted glasses, or no glasses used for the test session). The 80 workers accepted for analysis ranged from 18 to 69 years of age (see Table 1).

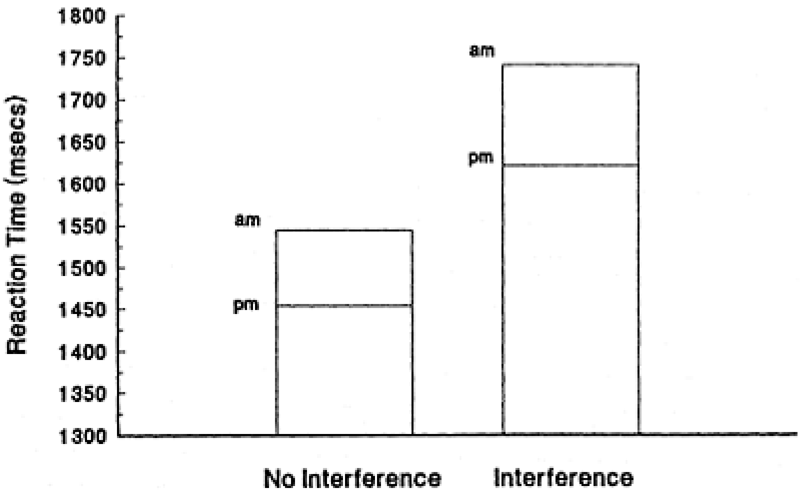
Table 1. Study Population

Age Group	Mean Age	N	% Male
<25	22.56	18	50
25–34	30.05	20	50
35–44	40.06	16	50
45–54	50.38	13	46
55+	61.62	13	08
Totals	38.80	80	41

Acute Measure of the Stroop Test

Workers performed the Stroop Test in the morning before work and in the afternoon after work as seen in Figure 2. There was a 7 percent significant improvement in response times on their second session after work.

Fig. 2 AM and PM Performance of the Stroop Test Reaction Time Improves 7%



Chronic Assessment of the Stroop Test

Response times with and without interference significantly increased with age ($p<.001$) for both AM and PM sessions in a similar manner. Therefore only the AM session is presented in Figure 3. The ability to distinguish colors was used as a covariate. Controlling for poor color discrimination increased reaction times in a statistically significant manner ($p<.001$), though the effect was more to reduce the variance about the means rather than adjust the mean scores themselves. The adjusted responses are the slightly higher lines for the interference and no-interference response times. There was no effect of gender.

Fig. 3 The Effect of Age and Color Confusion on the Stroop Test

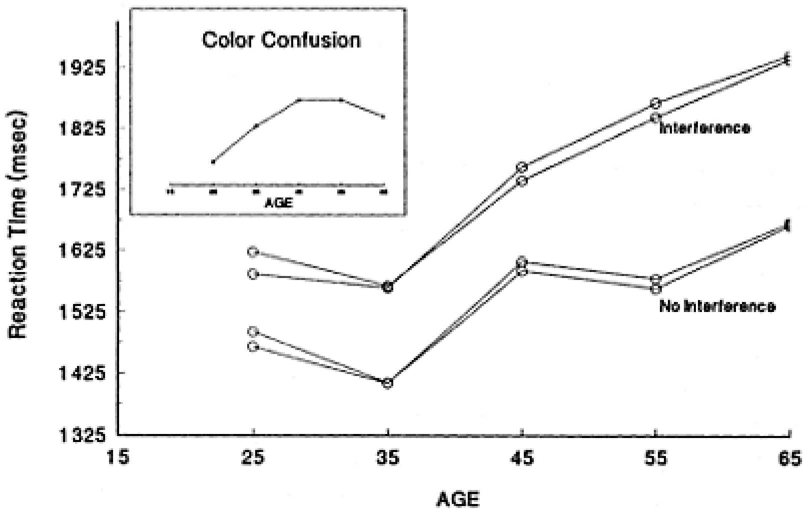


Figure 4 presents the effect of age on the difference score between the interference and no-interference reaction times which was statistically significant (p<.04). The Stroop Effect increased with age and, similar to the reaction times themselves, adjusting for color discrimination increased the effect of age in a statistically significant but not very important manner. There was no effect of gender.

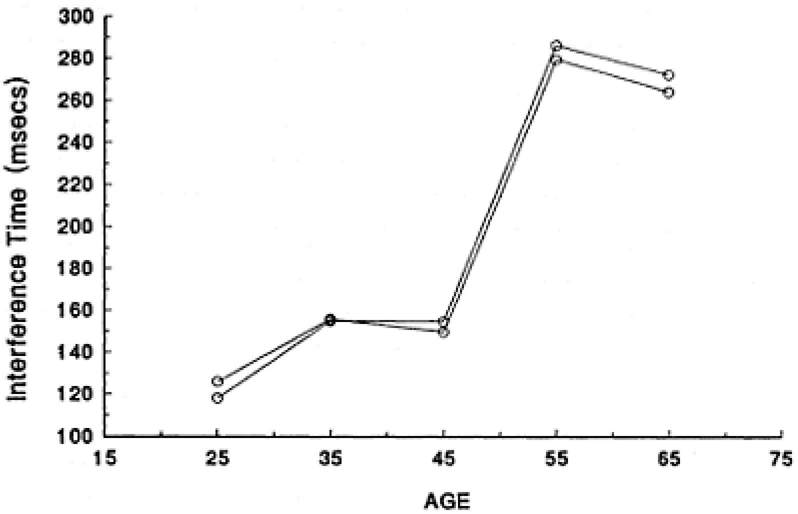
Reliability

Among the three Stroop scores, the interference condition had the best test-retest reliability index of .89. The no-interference score had a reliability of .85 and the Stroop diffenence score was least reliable with an index of .54.

Statistical Power

Based on performance of the most reliable interference response time, 12 workers are required to detect a minimum reaction time over a lifetime at work of 173 msecs [Diff/SD=173 msec/223 msec=.78; r2=.81; a=.05; b=.80]. The minimum detectable difference between decades was 81 msecs requiring as many as 65 workers.

Fig. 4 The Stroop Effect Increases with Age



DISCUSSION

In epidemiologic studies, it is common to test workers before and after exposure over an 8 to 12 hour shift. The within day [PM–AM] difference in response time is a potentially useful acute measure of exposure or treatment. The magnitude of improvement is comparable to an acute pre-clinical deficit from exposure to neurotoxicants since preclinical performance deficits range from 3 to 18% (Echeverria et al., 1991). Potentially significant acute effects in future studies would either expect to see a reduction in improvement or an increased effect exceeding 7%. From a public health perspective, one would caution interpretation of a significant effect if the within-day variation is comparable to the magnitude of the treatment effect.

It is not surprising that the Stroop Test is sensitive to increases in age; however, it is important to note that the response time with interference is the preferred measure over the classic Stroop effect. The decision is based on a higher re-test reliability. Our reliability of .89 is similar to .97, as computed in a prior effort to characterize Stroop performance scores for repeated measures designs (Bittner, Carter, and Kennedy, 1986; Harbeson et al., 1986). The difference in scores is attributable to the use of a voice-recognition board, evaluating only two repetitions, and a more heterogenous population of workers who were used in this study, versus a more reliable laboratory-based investigation.

The results of this study also suggest the importance of controlling each worker's ability to distinguish colors. As seen in Figure 1, the effort to reduce the impact of poor motivation on the crude Vingrys scores also reduced the impact of the Vingrys score as a covariate. Despite the elimination of very high values, controlling for color discrimination remained statistically significant. One could also hypothesize that in an environmentally exposed population there could be a greater number of workers with poor color discrimination (Mergler, D. & Blain, L., 1987). It is reasonable to invoke a hypoxic model to explain how, for example, exposure to solvents would reduce color vision among individuals at high altitudes or under the pull of high gravity. Therefore, to more effectively assess deficits in Stroop performance, the results suggest using both the Vingrys score and a test of baseline visual acuity.

In summary, the Stroop Test is recommended for neuro-behavioral evaluations of acute or chronic environmental exposures. However, interpretation of future results will be assisted by conducting a reliability analysis for each measure and by controlling for color discrimination.

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ERGONOMIC MOVES IN AN ENGINEERING INDUSTRY EFFECTS ON SICKLEAVE. LABOUR TURN OVER AND PRODUCTIVITY THROUGH ERGONOMIC INTERVENTION

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INTRODUCTION

Repetitive tasks such as assembly-line work have a high incidence of musculoskeletal disorders, especially from the upper extremities. This leads to frequent sick-leave (Westerling and Jonsson, 1980). The problem is well known in all industrialized countries and has been described by several authors (Prins and de Graaf, 1986; Andersson, 1984; Maeda, 1982). Obviously, it burdens both industrial planning and medical care and generates high costs (Snook, 1987).

As before, prevention of work load injuries requires correct work place design, which is the object of classical ergonomics or human engineering (Westgaard and Aarås, 1985). Research has shown, however, that more factors must be dealt with in order to reduce this type of work-related injuries (Lundberg et al, 1989; Kvarnström, 1983; Kilbom et al, 1986). Both technical elements such as tools, techniques, knowledge and skills, and the social system, i. e. the individuals working in the organization and their interrelationships, must be taken into account.

A successful work organization can only be achieved through joint optimization of technical and social conditions (Robbins, 1987). The socio-technical perspective recognizes the fact that both the technology and the social system are essential for the completion of a good working environment. From what we know today about the emergence of work-related illnesses and their dependence on ergonomic and organizational factors, it is clear that problems concerning work load injuries can be solved only by acting on both organization and work place design.

The Husqvarna Forest & Garden company in Sweden is one of the world’s largest producers of chain saws. In the factory, assembly-line work was carried out in 3- to 5-

minute cycles before the project described in this paper started, and each worker repeated one cycle continously.

In the mid 1980s, absence rates were analyzed within the company. It was then found that 70 per cent of the absence time was due to work-related musculoskeletal disorders.

In spite of individually adjusted work places designed according to modern ergonomic principles these problems did not show any signs of decreasing.

In 1989, a new chain saw assembly plant for nearly 300 employees was build. The management had made it a strategic objective to base the new factory on existing ergonomic know-how and to introduce organizational changes that would help prevent musculoskeletal disorders. One of the goals was to create a work environment that would attract employees even in the 90s. Another goal was to curb production costs by reducing the high rate of sick-leave, by diminishing the need for extended rehabilitation efforts and by bringing down the high labour turnover.

The purpose of this paper is to describe how theoretical knowledge was called on when planning the new factory and to show how the results achieved corroborate this knowledge.

METHOD

After the strategical aims were decided by the management, the practical implemetation was made by the company Health Service in cooperatin with department of Production Engineering. Improvements compared with the old factory were introduced concerning the following factors: working technique, work pace, wage system, working hours, work organization and rehabilitation. To monitor the effect of these changes, labour turnover, sick leave, production costs and production errors were followed during the initiation of the new factory and up to 18 month after production started. All figures such as sick leave and labour turnover were compared to figures from the old factory still in operation.

All workers were trained to use a working technique that keeps muscular effort at a level below 15–20 percent of the MVC (Maximum Voluntary Contraction). This level was chosen based on the practical coclusion made in previous in-house studies (Parenmark et al, 1988).

Chain saw production has been increasingly streamlined over the years. Extensive use of prefabricated components from external suppliers has eliminated a number of tasks such as regulating and adjusting sub-assembly units. Assembly work has thus lost some of its previous contents. It has grown more monotonous and there are fewer natural pauses. As a result, exposure to muscular load has increased, multiplying the risks of locomotor disorders (Hagberg, 1987). Field studies within the company have shown that muscular strain were increacsed when the work pace becomes higher (Parenmark et al., 1987;). The same study indicates that a monotonous task calls for a remarkably high working speed in order to feel comfortable.

By carefully examing the production plans for the new factory, it was possible to calculate the probable working pace in each sector. With these estimates as reference points, adjustments were made that allowed the work to be performed at a pace not causing undue muscular strain. The working pace thus assessed corresponded to 70–80 per cent of that in the old assembly plant. The reduction of individual working pace averaged 20–25 per cent.

Our efforts to develop the work organization started out from a “lean production” concept meaning that a number of duties were transferred to the assembly-line workers from other categories of employees in order to create a flat organization similat to the one that have been described in car industry (Womack, J.P.Jones, D.T. and Roos, D., 1991). These duties included keeping track of incoming deliveries from sub-contractors, quality checks, monitoring delivery plans and performing certain supervisory tasks.

The assembly workers were organized in self-controlling teams including a supervisor. These groups were to assume responsibility also for external contacts, production planning and quality checks. Each team should also provide on-the-job training for its own newcomers. They were also trained how to use computers in the internal communication system. The employeers also participated inwork-place design. Using a sketch of a re-designed work place, production engineers and workers discussed the practical implications in detail before the layout was finally approved. The workers were also to participate in installing new work places and in buying and adjusting the tools.

The new work organization adopted made it necessary to increase the number of work places and to enlarge the plant compared to the original plan. The main difference in work tasks compared to the organization in the old plant was that part assembly tasks as well as quality controls were handled within the groups.

From a production engeneering point of view the new organization also called for a different way of dividing the work tasks comparing to the old plant. This ment more alike working cycles as time is concerned than in the old factory.

Persons with less than full capacity have been difficult to fit into today’s tight work organizations. In a full employment situation, such as was the case in Sweden until recently, absent workers are hard to replace, which means that those present are burdened with extra work and overtime. This leads to more workers contracting illnesses or quitting. This creates new vacancies which in turn strain the remaining work force further.

In order to break this vicious circle, greater organizational flexibility was aimed for in the new factory. The work organization was to take care of tempoarily reduced individual capacity as well as partial work handicaps of a permanent nature. One of the challanges we faced was to design suitable work places for disabled persons.

RESULTS

The sick-leave rate in the new plant decreased by 5 percentage points compared to the old plant (Fig. 1). This ment a decrease by 20–25 per cent on the sickleave level.

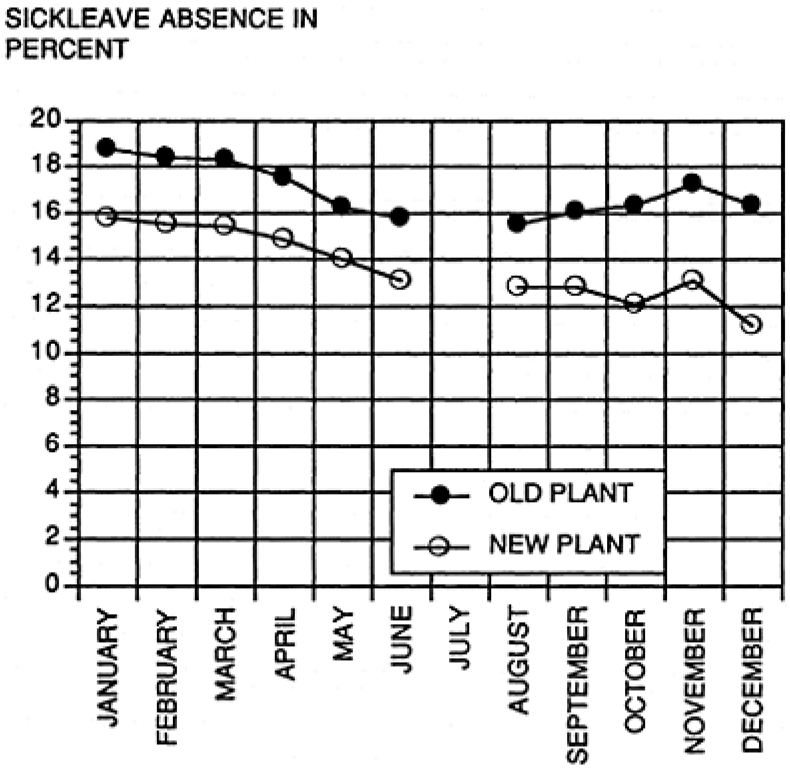

Figure 1: Comparasion of sickleave in percent of working time available between the new and the old plant.

Labour turnover dropped from about 35 per cent to about 10 per cent (Fig. 2).

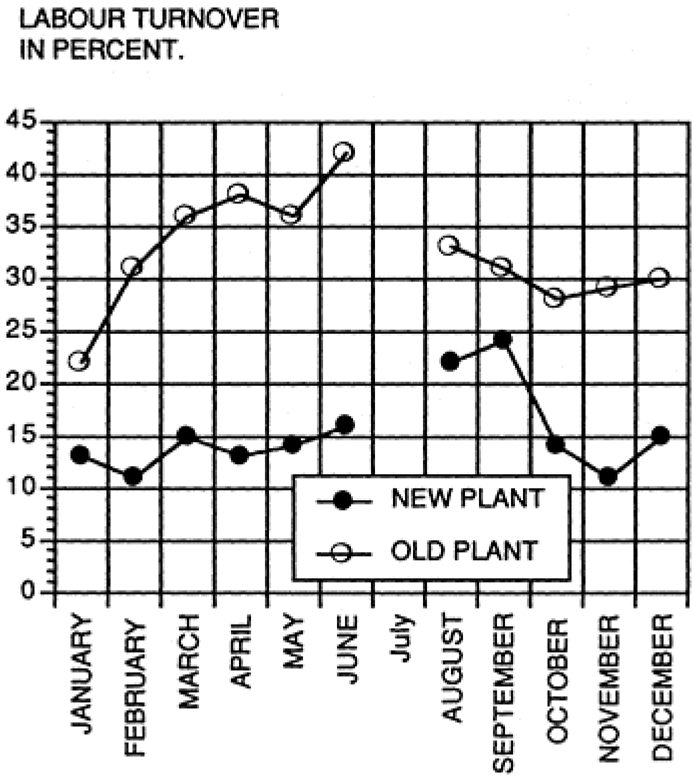

Figure 2; Labour turnover in the new and old factory one year after invention.

Overtime became practically non-existant, yet production output unfailingly met the plans.

Work-related deviations from quality norms decreased by several per cent.

Total production costs fell by about 10 per cent from the cost level of the old plant.

The new plant proved attractive as a place of work, as testified by the many applications for tansfer from workers in other units.

DISCUSSION

In this intervention study we found that by a systematic implementation of ergonomic knowledge it is possible to lower sickleave rates and labour turnover. It is also possible to achive financial benefits from these changes. Attendance ratio, quality outcome and observance of delivery commitments improved as well. Absence rate and staff turnover decreased compared to the situation wich is at hand in the old plant. In the new plant a number of tasks previously performed by specialized staff were included in the duties of the assembly teams. In the total working time, the share of repetitive assembly work was reduced by over 30 per cent.

It has been shown in several studies that the individual motor programme in terms of neuromuscular function is widely scattered. Learning a correct working technique is one way of reducing the muscular load. It is especially important for persons with less physical aptitude for manual labour such as assembly work to adopt a good working technique. This type of training might even prevent muscular disorders from developing or att least from growing severe.

Industrial engineers still use the MTM (Method Time Measurement) System, which means that they make movement analyses for each work task. In order to influence individuals to abstain from working at a harmfully fast pace, a “speed limit” was created in the new plant. This was done without leading to any loss in productivity compared to the old factory. A decrease in work pace seems thus to be able to take place without the consequense of loss in productivity. This fact is important when it comes to organizational and ergonomical changes with the aim to lower muscleloskeletal disorders among industrial workers.

An advanced manufacturing system is supposed to preclude production disturbances and to solve problems as they arise. Our new assembly line lived up to these expectations, which allowed the workers to abandon the habit of stepping up the speed at times in order to catch up on production. In manufacturing industry with piece-rate wage systems it is common to work at a highly intensified pace in order to compensate for a reduction in earnings caused by hitches in the production flow. This exaggerated pace, which multiplies the muscular strain, was eliminated by the new work organization.

As pointed out by Edgren (1986), the work organization greatly influences perceived exertion, motivation and health among workers. Creating a well functioning organization that will affect these factors favourably, involves both social and technical modalities (Ulich et al, 1990). These are the underlying principles of our new organization based on teams. So far, ergonomic efforts to reduce overload disorders have been mostly focussed on individual work places. Disappointment has been felt in many places where measures aimed to individuals have failed to produce a noticeable effect on the frequency of work-related injuries.

It is becoming generally acknowledged, that not only work places but also work organization and psychosocial interaction patterns must be considered when combatting musculoskeletal disorders. This widens the scope of ergonomics. In this study we set out to apply the accepted ergonomical knowledge in a wider sense to influence production engineering and industrial planning.

In rehabilitation it is important to identify the factors that enable each individual to carry on an occupation regardless of possible problems. Hagberg (1987) has shown that increasing the number of work places and breaking the monotony of assembly work by adding new tasks and changing the work pace can permit workers to take up their job again even if suffering from locomotive disorders. This involves organizational changes such as staff increase and job rotation.

Thanks to lessening demands on individual performance, employees manage to stay on their jobs in spite of minor declines of their working capacity. Furthermore, in this type if organization persons with permanet work handicaps can be employed without becoming subject to undue physiological exertion. In our case this has called for somewhat larger investments in work places and premises than those required by traditional designs.

All these measures together lower the exposure to both musculoskeletal and mental stress. The results greatly interested employees in other departments and made them ask for transfer to the new factory.

A major problem when studying work-related muscular diseases is the difficulty of finding a direct dose-response correlation between muscular strain, pathogenetic process, clinical symptoms and industrial interventions (Larsson, 1988; Kilbom, 1986; Edgren, 1986). Maybe that is the reason why the cause-and-effect debate tends to overstatements even doubting the very existence of workrelated muscular disorders (Ferguson, 1986).

The financial results yielded by the new plant substantiate studies showing that production economy benefits from ergonomic improvements. Costs were drastically reduced and deliveries were almost infallibly accomplished on schedule. In this context, the importance of organizational interventions at shop-floor level must not be underestimated.

Basing further planning on the results accounted for in this paper and other reports, the management for the company has made it a strategic aim to reduce harmful environmental influence on musculoskeletal disorders throughout their manufacturing departments. Some of the goals set up can be attained at the existing work places, while other require further research.

CONCLUSION

Modern ergonomic knowledge in a wider sense, when allowed to influence several aspects of a sociotechnical system, makes it possible to minimize risks of musculoskeletal disorders. In so doing, it also produces beneficial economic effects. Absence rate decreases, quality outcome improves and delivery plans are fulfilled more accurately than before. In other works, a work organization which prevents work-related disorders also increases the effectiveness of the production system and thus comtributes positively to the financial result.

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PRACTICAL APPROACHES TO ERGONOMIC PROBLEMS AND ISSUES IN AN AT&T MANUFACTURING LOCATION

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INTRODUCTION

An AT&T manufacturing location experienced an increasing number of ergonomically related injuries. The Corporate Ergonomist surveyed the location and developed a practical report. This paper analyzes ergonomic issues at the location, and makes recommendations.

This paper's outline entails the following: historical studies pertaining to the location, occupational injuries, contributing factors, ergonomic observations, personal protective measures, and survey recommendations.

The survey recommendations include detailed analyses of different manufacturing operations and ergonomic solutions. Preventive measures are addressed, and a redesign of the work environment is analyzed.

This project was undertaken by the Corporate Ergonomist and the local human factors specialist to establish the status of the facilities at the various workstations within the context of currently applicable ergonomics principles. This was to be accomplished by evaluating the equipment, physical surroundings and work habits typical of the functions performed in the facility. The ultimate goal was to reduce the risk to employees in this workarea who have been experiencing repetitive motion injuries (RMIs), e.g. carpal tunnel syndrome (CTS).

BACKGROUND INFORMATION

This AT&T manufacturing location is the headquarters for design, development and production of the microelectronics printed circuit boards (PCBH). During ergonomics inspection of this location and careful evaluation of its various workstations it became evident that some of the employee complaints were related to poor physical workplace design and/or tasks assigned to the workers. Throughout the Corporate Ergonomist's visit, and after detailed analysis of these workstations, and discussions with both employees and their managers, it was evident that workstation adjustments and modifications could substantially decrease the complaints, reduce the number of injuries, and improve the work environment.

HISTORICAL INFORMATION

A number of classic ergonomics studies conducted throughout AT&T recommend that workers who perform repetitive manual tasks should be educated as to the occupational type of repetitive motion injuries (RMIs) that may be caused by their work environment. RMIs occur when the tendons, bones, muscles, and/or ligaments of a joint press against the median nerve, impairing the nerve function. These types of injuries may result in backaches, CTS, and other work related disorders.

Some of this location's employees, have experienced symptoms that may be evidence of improper workstation design such as: pains in various parts of the body, general physical weakness, intermittent numbness, and a tingling or pins-andneedles sensation in the joints.

BACK, NECK AND SHOULDER INJURIES

Cases of back, neck, or shoulder injuries, such as muscle strains and pulls, are some of the most common injuries observed amongst the employees. Contrary to employees belief, these problems are not always the result of lifting heavy objects. Although in most cases the rectangular printed wiring boards are not heavy, excessive and repeated lifting of them can cause RMIs.

In few workstations employees had to overreach to either position heavy round objects or remove them to other workareas. This overexertion, turning and twisting could result in back, shoulder, neck and general aches and pains in the employees.

The injury records indicated that the greater distance an emplyees' body part is extended during a manual material handling operation, e.g. lifting, and the longer the duration of the extension, the greater the strain. And, the greater the strain, the more severe the pain and the greater the frequency at which various injuries can occur.

As was observed at this location, these types of problems are often the result of poor workstation design or stressful positions. For some of the employees, it can also be the result of poor body mechanics or work techniques. Many of the employees' occupational and work-related tasks involve a high frequency of repetitive motion. Each of these has a cumulative effect on the employee's body, and can contribute to various body part disorders.

CARPAL TUNNEL INJURIES

Among a few of the employees interviewed, mild cases of CTS symptoms were evident. In cases of CTS, symptoms usually begin with the index finger or the thumb and the middle finger. At night, when the body tones down, these sensations may appear to become more severe and annoying to the person. If not cared for, the pain may radiate to other joints. And, a lack of proper treatment may result in severely choking off of the nerve impulses and blood nutrients. This can cause the nerves of the joints to "starve" and the muscles to atrophy. Eventually, in extreme cases, some patients may lose the use of their joints. It is also important to note that CTS disorders can also become a significant contributing factors to body parts pain and injury.

OTHER CONTRIBUTING FACTORS

Our Human Factors experience indicates that contributory factors other than work are critical and may answer some of the questions asked by the employees.

1. Women are twice as likely to become victims of RMI-types of injuries than men. This is due to women having smaller joint structures (in comparison to men) and therefore, more prone to these types of injuries.
2. Other contributing factors can be: diabetes, a lack of vitamin supplements, and menopause, all of which can increase an employee's risk of RMI. Also, there are a few arcane disorders that may contribute to RMI's such as: Myxedema (thyroid condition), quervian disease (syndrome affecting the tendons).
3. Pregnant women may be more susceptible to these disorders, because of their body's fluid retention during pregnancy.

STATEMENTS OF THE PROJECT PERSPECTIVE

This analysis should be viewed as a reflection of the AT&T Corporate Ergonomists evaluation of the environmental condition of the existing facility. It does not take into consideration any proposed moves, rearrangements, or reorganizations. It is acknowledged that there are other considerations that have significant effects on the procurement and arrangement of workstations, such as new machines and/or tools. If, however, ergonomics principles are implemented and the recommendations are followed within the constraints intrinsic to the operation of this facility, the disabilities, inconvenience, and cost associated with repetitive strain injuries can be greatly reduced if not eliminated.

SURVEY RECOMMENDATIONS

The following reviews is divided into workareas of the location:

Pin insertion

1. Weight of the "flat pack" trays: The kits of parts for the complex line has some trays that are too heavy for a major proportion of the working population. In addition, the size of these trays are large enough that the effective weight of the tray of parts is higher than the actual weight.

    Reduce the weight of parts in trays, replace trays with roll around carts, etc., are recommended solutions.
2. Repetitive pinching of pin combs at manual shuttle load: These manual pin loading positions are designed with good considerations for the people but the pinching of pin combs to obtain and place these with the high degree of repetition is a potential problem area. After reviewing the automatic shuttle loading system it was clear that most reasonable solution is to automate most of the pin insertion tasks. The existing work position is ergonomically designed. The degree of repetition involving pinching, calls for the implementation of administrative controls such as rotation of personnel until automation is complete.
3. Insertion complex repetitive motions: The Winchester Press and Body Carrier Removal machine allows a full range of motion, but individual stress points still exist. The pinching of the shuttles with arms outstretched at the Winchester Press is a combination that should be avoided. The wrist position when inserting and removing shuttles from the body carrier removal machine is another stressful upper extremities body position. These two examples with the degree of repetition exhibited are potential stressors to be avoided from an ergonomics viewing. Corrective short terms measures include administrative actions of rotating people. If body positions can be improved by machine changes, this would reduce the potential but replacing the stressful human actions by machine efforts is a definite plus with a strong potential to improve the work environment.
4. The automatic shuttle loading (ASL) lines: The ASL machines were very impressive. These state-of-the-art machines are a direct replacement for the physical and mentally stressful tasks of manual shuttle loading. It was recommended to increase the utilization of this highly technical concept. Machine use in situations where employees fail, due to mental or physical stress, is an important element in ergonomic considerations at any facility.
5. Inspection and holding of boards: The inspection positions require the employees to use their hands as holding fixtures. This may not be overly stressful until the holding and moving of the pinned product exceeds the capabilities of the individual person. No known measurement system exist to determine in advance what weight, degree of wrist/arm manipulation or inspection duration should be avoided. Injury statistics from this area indicate that the inspection tasks, especially for larger than single wide boards, are outside the expected capabilities of the working population.

    This will be an ever increasing problem. The accumulation of small trauma disorders is how cumulative trauma disorders (CTDs) are caused. These types of disorders may not show their symptoms immediately, but because they have a cumulative effect on an employee, if the process continues, symptoms will become more pronounced at a later time.

6. Work position for small vacuum press complex: This work position is not designed for seated employees. It is important to note that these seated positions should be modified. Changing the seated positions to a more ergonomically designed positions will alter the height and configuration and will increase the effectiveness of the employees while decreasing the physical stress of lifting and placing fixtures and products.

Tape pull

Tape pulling, as described but not viewed, is a stressful task that may easily be beyond the capabilities of workers. Especially, if the task is viewed as make-work or not important. If this is required, then replacing the tape with a machine removable barrier is the best long-term solution. As a short term administrative solution, the rotation of workers with awareness training in the potential problems and best methods to use to pull tape safely, is a recommended solution.

Chemicals

1. Too much manual loading and catching of panels: Workers were observed in many areas of the shop, but especially in the chemical area, loading or catching products at the end of a process. This task is not traumatic with one repetition, but all-day every day the body and the mind is exercised to repetitive trauma and boredom. This combination may result in injury and mishandling of the product. This appears to be an avoidable work situation that does not use the workers' abilities to their fullest and may contribute to CTDs.
2. Platers clamp work is too much repetitive motion: The platers operators were observed attaching clamps to panels at the platers. This task requires some force, and a twisting motion of a hand. Operations performing this task is a strong candidate for RMIs.

Lamination/stack-up

1. Stamping press requires repetitive motions that appear to be replaceable with new equipment: The stamping press is an impact stamping process where an employee has to handle multiple panels. This standing position requires foot pedal actuation and either multiple panel handling or repetitive panel lifting/lowering to identify each panel.

   This workarea is an excellent candidate for a more modern technology (such as bar coding) and automatic panel handling to decrease operator fatigue and increase productivity and quality.

Mechanical

1. Handling of layout plates: This task could be improved with a system that presents plates at operator chosen position. The existing system does not present a lifting trauma problem from a one time lift potential. The type of injuries that may be expected from this system is repetitive lifting at or above shoulder level. Over time this activity may cause CTD injuries to the arms or shoulders. The existing system is designed to minimize the potential lifting problems, but system improvements would reduce potential for injury.

AT&T CORPORATE ERGONOMIST'S FOCUS

Our efforts should be focused on assisting our employees in this facility to perform their responsibilities in the healthiest ways. As part of the AT&T's commitment to provide a safe and healthful work environment, the work-related safety problems should be placed on preventing injuries through vigilance on the part of employees regarding early warning signs such as discomfort, limitation of movement, complaints, and absenteeism.

There is a need to actively and regularly perform ergonomics evaluations of this location to optimize worksite design with the intent of preventing injuries and alleviating discomfort. Analysis of such surveys will aid our employees and their managers in adapting less risk-prone physical postures (environment) and by implementing ergonomically sound workstation designs. Appropriate ergonomics training should be implemented that adequately discusses practical solutions employees can use to improve the work environment and relieve fatigue and strain.

REFERENCES

In developing this ergonomic analyses of the AT&T location no outside references were used. Therefore, this paper is original and a state-of-the-art evaluation of an existing AT&T high-tech manufacturing environment.

ERGONOMIC JOB ROTATION IN POULTRY PROCESSING

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Jerome Foods, a fully integrated turkey growing and processing company, initiated random job rotation programs in 1987. Employee and supervisory support for the concept of job rotation was high. In early 1989, a comprehensive ergonomics program was imple-mented. One of the goals of this ergonomics program was to reduce the incidence of cumulative trauma disorders through ergonomically sound rotations. The resulting method of job rotation design has proven quite successful and is outlined in this paper.

INTRODUCTION

Rotating workers between jobs of differing physical and mental demands has been recommended as a means to manage fatigue. Error reduction (Rodgers, 1983), increased employee job satisfaction (Grandjean, 1988), and reduced incidence of cumulative trauma (Rodgers, 1983; Putz-Anderson, 1988) are reasons for implementing a job rotation program. However, caution must be taken in the design of job rotation programs since poorly designed job rotations can increase worker stress levels (Putz-Anderson, 1988; UFCW, 1989.)

At Jerome Foods, random supervisor-designed job rotations, which had been in place since 1987, had attained a high level of employee and supervisor acceptance. In 1989 efforts were undertaken to ensure that all individual employee rotations met basic ergonomic requirements. The goal was to design a systematic approach to job rotation that would:

1. Involve employees and improve understanding of ergonomic principles.
2. Prevent employees from performing job rotations that actually increase stress.
3. Maximize stress reductions for as many employees as possible.

4. Encourage changes in the areas of job design, workload balance, and departmental boundaries.

JOB STRESS EVALUATION

The first requirement of the job rotation and general ergonomics program was to obtain estimates of the physical stresses inherent within each job. In order to accomplish the job evaluation phase within a reasonable time period (six months), a standard job evaluation technique was developed. This "Ergonomics Job Survey" provides numeric values for stress estimates in seven joint locations, specifically the shoulders, elbows, wrists, and back. Thirty-four employee Ergonomics Specialists from departmental safety committees were trained on using the "Ergonomics Job Survey Form" (see attached Exhibit A). This four-page evaluation form was completed for every job by these employee Ergonomics Specialists. Each department's safety committee then ranked the jobs within each of the joint locations and decided on numeric levels to define stress estimates as "high, moderate, or low" (see Table 1: "Example of Job Survey Results"). The final stress estimates (see Table 2: "Ergonomics Stress Summary") were then presented for verification by the entire employee group within each department.

Table 1

EXAMPLE OF JOB SURVEY RESULTS

Left Wrist		Right Wrist			
Position	**Stressor**	**Position**	**Stressor**	**Ergo Scale**	
Wing Deboning	26.94	Thigh Deboning	21.68	10	—High
Wing Harvest	11.14	Wing Deboning	13.61	9	
Thigh Deboning	9.08	Wing Harvest	8.68	8	
Tall Cutter	4.92	Thigh Breaking	3.14	7	
Thigh Breaking	-0-	Tall Cutting	2.23	6	
Bird Hanger	-0-	Bird Hanger	1.64	5	
				4	
				3	
				2	
				1	

Table 2

Ergonomic Stress Summary By Position Title		Faribault Pack & Box	September 1990		Steve S.		
		Stress location & Level					
Line	**Wrists:**		**Elbows:**		**Shoulders:**		**Back:**
Position	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	
Bag Stuff	High	High	Mod.	High	High	High	Mod.

Baster	Low	Mod.	Low	Low	Low	Low	Low
Dumper	Low	Low	Low	Low	Low	Mod.	Low
Giblet Stuff	High	High	Low	High	Low	Mod.	Low
Palletizing-Box	Mod.	Mod.	Low	Low	High	High	High
Pop Up Timers	Low	High	Low	Low	Low	Hlah	Low
Quality Check	Low	Low	Low	Low	Low	Low	Low
Roto Operator	Low	Low	Low	Low	Low	Low	Mod.
Scale Push	Low	Low	Low	Low	Low	Low	Low
Scaler	Low	Low	Low	Low	Low	Low	Low
Scaling-Box	Low	Low	Low	Low	Low	Low	Low
Tall Cutter	Mod.	Mod.	Low	High	Mod.	Mod.	Mod.
Throwing-Box	Low	Low	Low	Low	Low	Low	Low
Trusser-Hens	Low	Low	Mod.	Mod.	Low	Low	Mod.
Trusse-Toms	High	High	High	High	Low	tow	High

The weight factors and formulas used within the survey process were based on the opinions of the author. The results of the survey must therefore be considered subjective estimates of the job stresses and not detailed ergonomic evaluations. Employee acceptance of the stress estimates was high. Only five of the over 300 jobs surveyed needed reevaluation due to failed acceptance by the employee group. The stress estimates have proven sufficient to enable safety committees to target “high” stress jobs for correction and to aid in the redesign of job rotations. Some departments are also using the survey results as a basis for training and work-hardening procedures.

JOB ROTATION DESIGN

Keeping with the systematic approach used to survey job stress, a standard technique for job rotation design was developed. The objective was to provide the departmental safety committees with a method to develop formal job rotation programs that were based on the results of the “Ergonomics Job Survey”.

The first step involved placement of all jobs within the department on individual “3×5” cards, with the stress estimates located along the cards’ edges (see Figure 1: “Job Stress Card”). The safety committee could then arrange jobs into all conceivable rotations and evaluate for ergonomic acceptability. The initial determination of rotation acceptability was based on the total daily accumulation of stress as measured by the Job Survey. To accomplish this, “stress points” were assigned to the jobs based on the job stress estimate and the length of time the job was to be performed (see Table 3: “Rotation Design by Stress Accumulation”). Points for each stress location could then be summed for the day’s cumulative stress level at each joint by simply lining up the “Job Stress Cards” (see Figure 2: “Using Job Stress Cards”). The rotation stress levels were then graded based on the stress totals as either “moderate, high, or unacceptable” (see Table 4: “Rotation Design by Stress Accumulation”).

Figure 1 JOB STRESS CARD

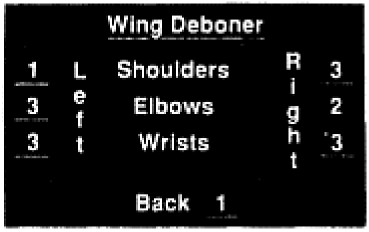

Table 3 ROTATION DESIGN BY STRESS ACCUMULATION (POINT SYSTEM)

1. Assign Approprlate Points To Each Stress Category in The Rotation:

Stress Category	Rotation: Quarterly	Points Hourly	1/2 Day
High	3	1.5	6
Moderate	2	1.0	4
Low	1	.5	2

Figure 2 USING JOB STRESS CARDS

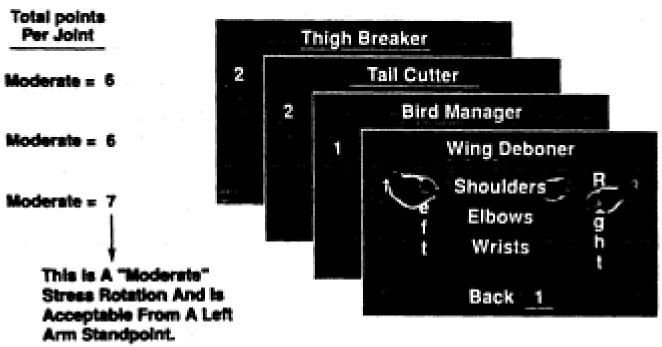

Table 4 ROTATION DESIGN BY STRESS ACCUMULATION (POINT SYSTEM)

1. Add Entire Days Points For Each Joint.
Grade Rotate Stress Level:

Total Points (Per Joint)	Stress Level	Who May Perform
4 To 7	Moderate	Anyone
8 To 9	High	Experlence And Capable
10 Or More	Unacceptable	No One

The specific order in which the jobs of an acceptable rotation were to be performed was then determined by the following general guidelines:

1. No back-to-back high stresses within an individual's rotation.
2. No more than three moderate and/or high stress positions for any individual per day.
3. Only one high stress position for any individual per day.
4. Precede and follow each high stress position with a low stress position.
5. No back-to-back moderate and/or high stress positions within any individual's rotation.

Since the guidelines are progressive in nature, the safety committees applied the guidelines in order, one at a time, to all seven joint locations. The goal was to get all rotations within the department to meet the first guideline before proceeding to the second, then the third, etc. Committees were then able to define the success of their efforts by which guidelines they were able to meet. To date no safety committee has been successful in achieving the fifth guideline. This would require a job rotation scheme in which all "moderate" and "high" stress positions were preceded and followed by "low" stress positions for all joint locations.

IMPLEMENTATION

All affected departments were able to design, write, and implement the new rotations within the allotted six-month period (one year following the initiation of the Job Survey process.) Exact methods of implementation varied, which resulted in varying levels of success. The departments that found the program of most benefit developed formal written guidelines that included a generic list of all acceptable rotations. This allowed those responsible for the daily assignment of individuals some flexibility, yet still maintained the ergonomic intent. Those departments, usually smaller in nature, that made specific rotations for individuals, experienced great difficulty in adhering to their program due to production and personnel changes. Finally, those departments which developed just formal guidelines to be followed when putting together daily rotations experienced the greatest flexibility, but found it difficult to maintain the program due to the daily complexity. As a result, it was recommended to departments, during program audits, that they develop formal guidelines that include a list of all acceptable job rotations.

The existence of unavoidable "high" stress rotations was a predictable implementation problem. Most departments required within their rotation guidelines that only "experienced and capable" employees would be allowed to work in such positions while job improvements are being made. Changes in department boundaries, pay structures, and other factors were encouraged to provide an opportunity for expanded rotations. As part of the overall ergonomics program, "high" stress rotations, as well as "high" stress jobs, are targeted for stress reduction on a systematic basis.

RESULTS

The specific effect of the job rotation program on injury and illness rates cannot be determined, since the larger ergonomics program was implemented simultaneously. Rate declines have been noted and are continuing. It is difficult, however, to segregate the effects of program elements, such as mandatory engineering controls for “high” stress jobs, from any possible effects resulting from the job rotation program. These other ergonomic efforts are not, however, seen by all employees on a daily basis as is the rotation program. The evidence that fellow employees are designing daily job rotations to account for ergonomic issues supports employee confidence in the overall program. This employee belief in the rotation concept has spread to other parts of the Company which have less repetitive jobs. As a result of employee requests, the ergonomics program is currently being implemented in areas that have not historically experienced cumulative trauma disorders.

The high degree of employee involvement in stress evaluation and rotation design not only helped to sell the job rotation program, but also increased awareness of basic ergonomic principles. Since in many jobs the worker has personal control over work techniques and body postures, a jobs actual stress level may vary greatly with individual work methods. The understanding of what makes a job stressful allows employees to make a conscious effort to select less stressful techniques.

CONCLUSIONS

The described method of using basic ergonomic principles to improve job rotation has been very successful. This success, however, must be recognized as only an interim step on the way to improved workplace design. A threshold of exposure for cumulative trauma disorders has not. yet been identified. It is possible, perhaps likely, that rotating a group of employees through a “high” stress position will, given sufficient time, produce illnesses throughout the entire group (Putz-Anderson, 1988). Using job rotation to manage the daily exposure to physical stress must be considered a means of delaying the onset of illness while ergonomic improvements are being developed.

The concept of job rotation as a means of job enhancement and fatigue reduction is here to stay. Providing an opportunity for employees to vary daily activities reduces both physical and mental fatigue even in “low” stress positions (Grandjean, 1988; Rodgers, 1983.) A more alert employee is of significant value in the areas of quality, safety, and job performance. Even when all “high” stress positions have been eliminated, the job rotation concept will continue to have an economic foundation.

REFERENCES

Grandjean, E., 1988, Fitting the Task to the Man, 4th ed., (London: Taylor & Francis), pp. 194–195.

Putz-Anderson, V., 1988, Cumulative Trauma Disorders—A Manual for Musculoskeletal Diseases of the Upper Limbs, (London: Taylor & Francis), p. 83.

Rodgers, S.H., 1983, Ergonomic Design for People at Work, Vol. 2, (N.Y., N.Y.: Van Nostrand Reinhold Co. Inc.), pp. 224–225, 256.

UFCW Office of Occupational Safety and Health, August 1989, Analyzing Ergonomic Programs; Making Sure They Are The Real Thing, (Washington, D.C.), pp. 3–4.

Exhibit A

Jerome Foods, Inc.
Ergonomics Job Survey

This form is to be used by trained Ergonomics Specialists only.

Dept. ________ Job Title ________

Job Description ________

Evaluator(s) ________

A. Cycle Rate. Time five complete job cycles and calculate cycles per minute.

1. Time for 5 cycles = ______ seconds
2. Rate = 300/(time for 5 cycles) = ______ cycles/minute

B. Force. Estimate the maximum upper body force needed to perform one job cycle.

1. Score: 1 = light force (10% of maximum strength - can easily do task for entire shift)
   2 = moderate force (25% of maximum strength - can do task for entire shift but will suffer from "fatigue")
   3 = high force (50% of max. strength - can not do for entire 8 hours)
   4 = extreme force (75% of maximum strength - can do for short time periods, i.e. ½ hour)
   5 = MVC (Maximum Voluntary Contraction - can only be held for short time)

Note: If a force is static (held for more than ½ the cycle time) then double the force score.

2. Force Score:

Score	0	1	2	3	4	5
Force	None	Light 10%	Moderate 25%	High 50%	Extreme 75%	MVC

left hand ______ left arm ______ back and
right hand ______ right arm ______ legs ______
(+1 for each glove use)

C. Posture. Observe each joint during work activity and count number of aggravating postures per cycle or the time in seconds per cycle for static postures. Multiply the number of aggravating postures by the "Stress Points" to obtain a "Stress Score" for each posture. Sum scores for each joint.

1. Shoulder	Stress Points	Joint Posture/Stress Score Left	Right
a. Hand above head	4 x	___=___	___=___
b. Hyperabduction	5 x	___=___	___=___
c. Elbow at shoulder level	5 x	___=___	___=___
d. Elbow beyond 45° from the body	4 x	___=___	___=___
e. Reach behind	3 x	___=___	___=___
f. "Shrug" up or back	2 x	___=___	___=___
g. Reaching more than 18"	2 x	___=___	___=___
TOTAL STRESS SCORE		___	___

2. Elbow	Stress Points	Joint Posture/Stress Score Left	Right
a. Hand rotation w/ flexion or extension	5 x	___=___	___=___
b. Extreme rotation of hand (up or down)	4 x	___=___	___=___
c. Lateral force	3 x	___=___	___=___
d. Resting on hard surface	2 x	___=___	___=___
e. Hands at chest level	2 x	___=___	___=___
TOTAL STRESS SCORE		___	___

Exhibit A

3. Wrist	Stress Points	Joint Posture/Stress Score Left	Right
a. Flex	5 x	___=___	___=___
b. Extend	4 x	___=___	___=___
c. U./R. deviation	3 x	___=___	___=___
d. Pinching	3 x	___=___	___=___
TOTAL STRESS SCORE		___	___

4. Back/Legs	Stress Points	Joint Posture	Stress Score
a. Lifting more than 50 lbs	25 x	___	___
b. Lifting between 20 & 50 lbs	15 x	___	___
c. Lifting ≤20 lbs	10 x	___	___
d. "Pick-up" or place below knees	20 x	___	___
e. "Twisting" of torso	10 x	___	___
f. Bending over (30°)	10 x	___	___
TOTAL STRESS SCORE			___

D. Environmental Factors

1. Air Temperature

a.	above 90°F	10
b.	above 80°F	5
c.	below 50°F	10
d.	below 32°F	20

2. Product Temperature

a.	below 50°F (cold)	5
b.	below 32°F (frozen)	10

3. Tools

a.	"sharp" edges	10
b.	vibration	20
c.	gloves	5

4. Total Environmental Score ______

E. Ergonomic Score. Use the formulas below to calculate the ergonomics scores for each joint.

Left Shoulder:
______ x (______ x ______ + ______)² ÷ 10,000 = ______
Cycle Rate, Force, Posture, Environ.

Right Shoulder:
______ x (______ x ______ + ______)² ÷ 10,000 = ______
Cycle Rate, Force, Posture, Environ.

Left Elbow:
______ x (______ x ______ + ______)² ÷ 10,000 = ______
Cycle Rate, Force, Posture, Environ.

Right Elbow:
______ x (______ x ______ + ______)² ÷ 10,000 = ______
Cycle Rate, Force, Posture, Environ.

Left Wrist:
______ x (______ x ______ + ______)² ÷ 10,000 = ______
Cycle Rate, Force, Posture, Environ.

Right Wrist:
______ x (______ x ______ + ______)² ÷ 10,000 = ______
Cycle Rate, Force, Posture, Environ.

Back/Legs:
______ x (______ x ______ + ______)² ÷ 10,000 = ______
Cycle Rate, Force, Posture, Environ.

Exhibit A cont.

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05/30/91

ERGONOMIC IMPROVENENT BY AUTOMATING THE APPLICATION OF ADHESIVE-BACKED LABELS TO 3.5″ DISKETTES

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In 1988 a Hewlett Packard employee was diagnosed with severe carpal tunnel syndrome in one wrist. The main cause of the injury was traced to the manual application of adhesive-backed labels to 3.5″ diskettes. To prevent further incidence of this injury, the entire printing and labeling process was automated. This was accomplished by integrating off-the-shelf hardware and software. The result of our effort was the elimination of future repetitive motion injuries (RMI's). Productivity gains were also realized by a 65.5% decrease in the cycle time of diskette labeling.

INTRODUCTION

One of the manual assembly processes that existed at Hewlett Packard's Signal Analysis Division involved the application of adhesive backed labels to 3.5″ software diskettes. The process consisted of the following steps:

1. Peel off one of the printed labels from a sheet of 10. One hand would hold the sheet in a pinch grip while the other would peel off the adhesive backed label, again using a pinch grip.
2. Center the label on the diskette.
3. Ensure the label is completely seated by pressing one's fingers along the surface of the label.
4. Place the labeled diskette into a box and repeat the process.

On a typical day, one assembly worker would label approximately 75 to 100 diskettes with an average cycle time of 8.12 seconds per diskette. There were days, however, when he/she would be expected to label several hundred diskettes, taking up to 1.5 hrs to accomplish this task. After one particularly long day of labeling diskettes, an assembly worker felt sensations of numbing and then later tingling in her right hand. These sensations persisted for several weeks and the symptoms were later diagnosed as Carpal Tunnel Syndrome. Carpal Tunnel Syndrome is a hand/wrist disorder resulting from the irritation of the median nerve as it is compressed by surrounding tissue and bony structures in the wrist (The Joyce Institute, 1988). In this case the damage was so severe that surgery was required to relieve the compression on the median nerve. The total cost of the injury including surgery, rehabilitation, and lost-time wages was approximately $20,000.

An analysis of the labeling process showed that the frequency of damaging wrist motions (DWM) incurred by the assembly worker was 2483/hr in the hand that was peeling and pasting the label on to the diskette. This value is greater than the maximum safe level of 1000 DWM’s per hour (The Joyce Institute, 1988) and was the primary reason that the worker sustained the injury. Our challenge was to find a way to continue applying labels to diskettes without further risk of cumulative trauma injury to our assembly employees. The solution had to be cost effective, flexible, and simple enough to be run by an assembly worker on the line. Also, if a new printer was going to be used, it had to be able to print clear, crisp labels and have barcoding capability as well.

NEW LABELING SYSTEM

The label creation, printing, and application system that has been implemented consists of the following three components:

1. A Zebra 90 Thermal Transfer printer with options for additional font capabilities; manufactured by Zebra Technologies Corporation of Vernon Hills, IL.
2. An Accraply 350F Pressure Sensitive Labeling System; manufactured by Accraply Inc of Minnetonka, MN.
3. Label Master software; created by StrandWare Inc. of Eau Claire, WI.

The new process of applying a label to a 3.5″ diskette is now done in the following sequence:

1. Labels are fed from the Zebra 90 printer into the Accraply Labeling System. A Hewlett Packard Vectra PC is cabled to the printer and is used to start the print sequence and to specify the quantity of labels to print.
2. A piston is activated, causing a 3.5″ diskette to eject from a hopper on to a moving conveyer.
3. When the diskette gets to a defined position along the conveyer it triggers the stepper motor that controls the take-up reel for the label backing. This reel pulls the label backing around a 100 degree bend, removing the label from its backing and depositing it on to the conveyered diskette.

4. The take up reel stepper motor is disengaged when an upstream label passes by a light sensor. This action of starting and stopping the take-up reel is what dispenses labels on to the diskettes.
5. The process continues until the hopper runs out of diskettes to feed on to the conveyer.

Although this labeling process is highly automated, an assembly operator is still required for a few operations. First, the operator must ensure the supply of diskettes in the hopper does not run out. Also, he/she must gather and sort the labeled diskettes as they pool within a box at the end of the conveyer. Finally, and most importantly, he/she must deactivate the piston when all of the printed labels have been applied to the diskettes. This is critical because it is diskettes on the conveyer that drive the take up reel, and problems can occur if labels are not being fed from the printer when the take up reel is operating.

LABEL CREATION

Once the printer and labeling system were calibrated and working in unison, the next challenge was to set up all of our 350 current labels to print on the Zebra 90 printer. There was no way that we could automatically convert any of our existing label files into the Zebra Programming Language (ZPL) format. This meant it was necessary to recreate all of our existing labels. To accomplish this task we took a two step approach:

1. Utilizing the Label Master software, we created a family of 5 generic label files each containing information regarding text font, text size, barcode size, and all of the necessary spacing and layout details.
2. Using one of the generic label files as a starting point, an assembly operator would simply edit the existing text to design the label they desired.

This process provided two important benefits for us. Not only did it allow us to very efficiently recreate all of our existing labels into the ZPL format, but the 5 family label files gave us a standard we could distribute to the R&D designers for future labels. This application of Group Technology will save considerable time and effort in the design of all future labels.

The final step required to implement our automated labeling system was the development of a friendly DOS based interface that would allow the assembly operator to easily print out specific quantities of different labels from the printer. Although the Label Master software does have the capability to start the print sequence, we had difficulty using this software to print out labels that required a copyright symbol. To solve this problem, we created a simple DOS batch file that allowed the operator to print labels using a 2 step process. First, they invoke the batch file by typing P, followed by the filename of the label they want to print. The batch file will automatically place them in the DOS line editor EDLIN. Next, the operator types in:

1,99 RPQ1^ZPQ?^ZE

where ? is the quantity of labels that need to be printed. The replace command in EDLIN will replace the print quantity of 1 (PQ1) to the desired print quantity and then return the operator back to the DOS prompt. Using this method, the operator can queue up a total of 7 jobs to print out. When the operator is finished queuing up all of the labels they need to print, the final step is to invoke a batch file that signals the printer to print out 20 blank labels. This is required to feed the last set of printed labels to the label attaching portion of the labeling system.

RESULTS

A breakdown of the costs involved in the set up, implementation, and operation of the automated labeling system is as follows:

One Time Expenses;		Cost
Supervisor Time for process set up (4 weeks):		$ 2,000.00
Engineering Time for process set up (4 weeks):		$ 6,000.00
Accraply 350F Labeling Machine,		
Zebra 90 Thermal Transfer Printer,		
Label Master Software:		$22,153.00
	Total	$30.153.00
Ongoing Expenses (per printed label);		
Label & Ribbon:		$ .04
Preventative Maintenance (estimate):		$ .03
Direct Labor		$ .04
	Total	$ .11

The primary goal of this project was the elimination of risk for Carpal Tunnel Syndrome associated with the attaching of labels to 3.5″ diskettes. We feel this goal was achieved with the implementation of our automated labeling system. The Accraply system has proven to be a reliable, repeatable process that eliminates any stressful hand or wrist motions. The economic payback of this system is in the elimination of future RMI's, especially those requiring surgery which can typically cost the company $15,000 per case. It took approximately 3 months to implement this system, with 1/3 of our time dedicated to this project.

As with most ergonomic improvements, we also realized a productivity gain when this process was implemented. The production line lowered its production cost per label from $.21 to $.11, a decrease of 47.6%. This was achieved by combining the printing and label attaching process into one automated step which produces labeled diskettes at a rate of 21.4 per minute. The utilization of this system has changed our labeling process from being tedious and ergonomically dangerous to a process that is risk free and very efficient.

REFERENCES

The Joyce Institute, 1988, Applied Industrial Ergonomics—Reference Manual, pp. 20, 92.

BIOGRAPHICAL SKETCHES

Tim J.Lazaruk is a Process Engineer at the Signal Analysis Division of Hewlett Packard Company. He has been with the company for 3.5 years and is involved in the areas of quality control, tooling and fixturing, process improvements, and ergonomics. Tim holds a B.S. in Mechanical Engineering for the University of Notre Dame and a M.S. in Industrial Engineering from the University of Arizona.

John Kirk is a Production Process Supervisor at the Signal Analysis Division of Hewlett Packard Company. He has been with the company for 14 years and is involved in the manufacturing of silicon devices, microelectronics, instrument assembly and test, software reproduction, and systems integration. John holds A.S. degrees in both Business Management and Electronics Technology from Santa Rosa Junior College.

SIGNIFICANT IMPROVEMENTS FROM PROVIDING ERGONOMICALLY DESIGNED FURNITURE TO AT&T CORPORATE MANAGERS

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INTRODUCTION

This project analyzed the impact of ergonomically designed furniture on work performance, morale, productivity, costs and the number of occupationally related complaints. Sixty AT&T corporate managers were randomly given four different ergonomically designed chairs for evaluation. Each manager selected one chair type for three weeks. A comprehensive questionnaire was developed to compare the previously used chair with the ergonomically designed chair. At the end of the third week, each manager completed the questionnaire.

This paper evaluates the results, and concludes that ergonomically designed furniture significantly increased work performance, morale, productivity, and work effectiveness. It also decreased total costs e.g., work delays, injuries, and number of occupational related complaints.

BACKGROUND

All sixty randomly selected managers were performing most of their job-related activities either using telephones or video display terminal (VDT). Types of activities involved consisted of three basic categories of VDT tasks. These were:

1. Information entry, e.g., MARS (Mechanized Accident Reporting System), CHEMICAL (Chemical Management Information System)
2. Dialogue e.g., ASSET (AT&T Source System Employee Checking), Email, (AT&TMAIL)
3. Information inquiry e.g., LINUS (Library Network System), OLGIES (On-Line General Information Exchange Systems).

For information entry tasks, the most important items were the keyboard and the source document, which could be either on line or on paper. The manager reads information from the source document and enters it via the keyboard. The screen is less important for keypunch work since it is used mostly to check the accuracy of entries. The screen can be more important, however, for information entry work that makes extensive use of computer-generated forms.

For dialogue tasks, the flow of information was a continuous one, from the keyboard to the data or text that was displayed on the screen. Source documents were rarely used for this task, since additional data input were seldom required.

How often the VDTs were used also depended on the job. For some jobs, the VDT was rarely used, whereas for others, it was in constant use throughout the work hours. As might be expected, minor ergonomic deficiencies in the design of the workstation and the VDT could be very crucial for jobs that consisted a variety of tasks for a prolonged period of time, and day after day.

FURNITURE USED

Conventional office furniture designed at these offices were to primarily suit office equipment and activities of a traditional office, most of which involved printed paper documents. Such office furniture was not, of course, designed with VDTs in mind. Although VDTs could be used to perform many conventional office jobs, such as word processing or information retrieval, these tasks were often done quite differently with a VDT. Neither the unique physical characteristics of the VDT nor the tasks for which it was used were envisioned by the designers of conventional office furniture. As a result, VDT operators often found that they could not used conventional office furniture comfortably.

The above conditions and increase in number of complaints e.g., back injuries, repetitive motion injuries (RMIs), encouraged me to conduct this study.

SOME COMMON PROBLEMS

Our experience indicated that one fundamental principle of ergonomics is that a healthful work environment requires ergonomically designed workstations. Proper workstation design is especially important if the operator spends many hours doing the same repetitive tasks. Although individuals may be able to compensate for poor worksation layout, this is often accomplished only at the expense of personal physical comfort.

QUESTIONNAIRE

At the beginning of the third week after using one of the four ergonomically designed chairs, the following questionnaire was given to each manager to complete:

Age ------------------ Sex -----------------

Time employed at AT&T -----------------

Years sitting on (AT&T) previous arrangement chair ---------

Note: The following assumptions should be made to answer this questionnaire:

a. The "new arrangement" refers to the new chair and new work conditions.

b. The " previous arrangement" refers to the period prior to the new chairs and new work conditions.

Please Circle an Appropriate Word:

1. Are you physically comfortable working at the new arrangement?

a. Always Usually Somewhat Rarely Never

Answer the same question pertaining to the previous arrangement.

b. Always Usually Somewhat Rarely Never

2. How often do you need to make adjustments at your work routine to be more comfortable (new arrangement)?

a. Always Usually Somewhat Rarely Never

Answer the same question pertaining to the previous arrangement.

b. Always Usually Somewhat Rarely Never

3. How comfortable do you feel working with the new arrangement compared to the previous office arrangement?

a. Much More More Similar Less Much Less

4. With the previous arrangement, did you have to change your work routine due to fatigue?

   a. Every 1/2 Hour   Every Hour   Several Times   Rarely   Never

5. Is the new chair causing you any problems?

   a. Never   Rarely   Somewhat   Frequently   Always

   The same question for the previous work arrangement.

   a. Never   Rarely   Somewhat   Frequently   Always

6. Do you presently experience muscle fatigue (using the new chair) in your neck, shoulder, back or wrists?

   a. Never   Rarely   Somewhat   Frequently   Always

   The same question for the previous work arrangement.

   a. Never   Rarely   Somewhat   Frequently   Always

7. In which area of your body (using the new chair) do you presently experience fatigue?

   a. Neck   Shoulders   Back   Lower Back   Wrists

   The same question for the previous work arrangement.

   a. Neck   Shoulders   Back   Lower back   Wrists

8. Have you recently seen a physician (at the new work environment) because of work related physical discomforts?

   a. Yes --   Why? ---------------------------------
   Indicate the problem area (s)

   b. No --

   Are these discomforts similar to the previous work discomforts experienced?

   a. Yes --   Why? ---------------------------------
   Indicate the problem area (s)

   b. No --

9. Is physical stress related to your new work arrangement a problem?

   a. Yes --   Why? ---------------------------------

   b. No --

10. Other comments please: ---------------------------------

PERCENT RESULTS, ANALYSES AND EVALUATION OF THE QUESTIONNAIRE

<u>Question number 1.</u>

a. For the new arrangement, tabulated answers indicated the following results in percent form:

– Always: 47 %
– Usually: 23 %
– Somewhat: 11%
– Rarely: 14%
– Never: 5%

b. For the previous arrangement:

– Always: 5%
– Usually: 17%
– Somewhat: 8%
– Rarely: 42%
– Never: 28%

The above results indicate that the new ergonomically designed chairs greatly improved employees comfort.

<u>Question number 2.</u>

a. For the new arrangement, tabulated answers indicated the following summary of references in percent form:

– Always: 27%
– Usually: 38%
– Somewhat: 24%
– Rarely: 11%

b. For the previous arrangement.

– Always: 1%
– Usually: 8%
– Somewhat: 10%
– Rarely: 81%

The above results indicate that the employees did not attempt to adjust their chairs due to the fact that these chairs were not ergonomically designed and either were not adjustable or difficult to adjust. However, since the new arrangement was fully adjustable, employees felt comfortable adjusting their ergonomically designed chairs for different types of jobs and time of day.

<u>Question number 3.</u>

– Much More: 46%
– More: 34%
– Similar: 11%
– Less: 4%

– Much Less: 5%

The above results indicate that in general employees felt more comfortable with the new arrangement than the previous one.

Question number 4.

– Every 1/2 hour: 37%
– Every hour: 28%
– Several times: 16%
– Rarely: 4%
– Never: 15%

The above result indicated that with the previous arrangement most employees had to frequently change their work routine due to fatigue. Previously poor work environment could be the primary reason for increase in absenteeism, injuries, and decrease in productivity and morale.

Question number 5.

a. For the new chair, tabulated answers indicated the following results in percent form.

- Never: 27%
- Rarely: 38%
- Somewhat: 16%
- Frequently: 7%
- Always: 12%

b. For the previous chair

- Never: 9%
- Rarely: 7%
- Somewhat: 8%
- Frequently: 18%
- Always: 58%

The above results indicate that the in general new ergonomically designed chair caused less problems than the previous chair. Since problems correspond to waste of time, lack of concentration, and poor work environment, then it is important to note that an ergonomically designed chair will significantly improve productivity and quality of work.

Question number 6.

a. For the new arrangement, tabulated answers indicated the following results:

- Never: 44%
- Rarely: 28%
- Somewhat: 5%
- Frequently: 12%
- Always: 11%

b. For the previous work arrangement:

– Never: 3%
– Rarely: 8%
– Somewhat: 17%
– Frequently: 43%
– Always: 29%

The above results indicate that most employees tested experienced less muscle fatigue using the new chair in comparison to the previous chair. Our experience has proven that prolonged muscle fatigue if not cared for will eventually cause injuries e.g., back injuries, that constitute more than 45% of the AT&T on the job injuries. Injuries if not taken care of will result in disabilities, and increase in overall production costs.

Question number 7.

a. For the new arrangement, tabulated answers indicated the following results in percent form:

– Neck: 9%
– Shoulders: 7%
– Back: 41%
– Lower back: 29%
– Wrists: 14%

b. For the previous arrangement:

– Neck: 8%
– Shoulders: 8%
– Back: 36%
– Lower back: 37%
– Wrists: 11%

The above results could be misleading because of the following reasons:

1. These results are in percent form. Therefore, they do not accurately show that employees working in new arrangement experienced much less neck, shoulders, back, lower back, and wrists aches and pains.
2. Employees' comments indicated that, they experienced less problems using the new chairs than the old ones.
3. Most employees did not answer "part a" of this question because they felt no fatigue working at the new arrangement.

Question number 8.

For the new arrangement, tabulated answers indicated the following results:

a. Yes: 17%
b. No: 83%

For the previous arrangement:

a. Yes: 6%
b. No: 94%

The above results and comments indicate that the previous work arrangement was the primary reason that some employees visited a physician because of work related physical discomforts. Their comments also state that, they felt much better and number of visits to a physician were decreased working at the new arrangement.

Question number 9.

a. Yes: 18%
b. No: 82%

The above answers and comments indicate that most employees who responded did not attribute physical stress to their new work arrangement. The majority of the comments highlighted the fact that they felt much less physical stress working at the new arrangement in comparison to the old arrangement.

Question number 10.
More than 89% of the employees who commented preferred working at the new arrangement than the previous one, and did not want to return their new ergonomically designed chairs.

SUMMARY

Our study concluded that even minor ergonomic changes in a work environment will significantly increase work perform-ance, morale, and work satisfaction. It also decreases total costs, and the number of occupational related complaints.

REFERENCES

In developing this project, no outside references were used. Therefore, this study is original and presents an approach to developing a healthful work environment throughout AT&T.

ERGONOMIC AND PRODUCTIVITY IMPROVEMENTS IN AN ASSEMBLY CLAMPING FIXTURE

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A manufacturing assembly process requires that a shield be compressed to fit into a recess in a cast housing. The compression fixture used two handwheel screws which caused discomfort to assembly personnel due to the large number of damaging wrist motions with excessive pinch-grip forces required. After a detailed videotape analysis, a new fixture was designed using pneumatic cylinders to replace the hand wheel screws. All excessive pinch-grip forces were eliminated, and the number of damaging wrist motions was greatly reduced. Additionally, a 50 per cent reduction in cycle time was achieved.

INTRODUCTION

The "CRT Insertion" process selected for this study, was chosen based on a real-time observation of an electronic instrument assembly situation involving what initially seemed to be high power-grip forces coupled with extreme shoulder flexion. However, this turned out to be a comparatively minor concern. Analysis of the process and operator interviews revealed that the real ergonomic concern was the large number of damaging wrist motions coupled with high pinch grip forces which were experienced in a different step of the process. No known ergonomic-related injuries have been directly attributed to this process; however, the reported discomfort was such that it was felt worth while to make improvements as a preventive measure.

Tendon damage can occur if the wrist is frequently bent while holding something (Tichauer, 1966). An accumulation of tendon damage inside the carpal tunnel can result in carpal tunnel syndrome. The higher the repetition rate, the greater the chance of injury (Silverstein et al, 1987). There is a clear relationship between high force grasps and carpal tunnel syndrome (Smith et al, 1977). For example: the wrist in ulnar deviation with a pinch grip causes severe stress on the tendons in the carpal tunnel (Armstrong, 1983).

Description of the Operation

The CRT (or display tube) insertion process consists of two steps:

1) The clamping operation in which a sheet metal shield, which has been positioned over the CRT, is clamped in both axes and compressed dimensionally so that it will physically fit into a recess in the die-cast front frame. See figure 1.
2) The pressing operation in which the display assembly is pressed into the front frame.

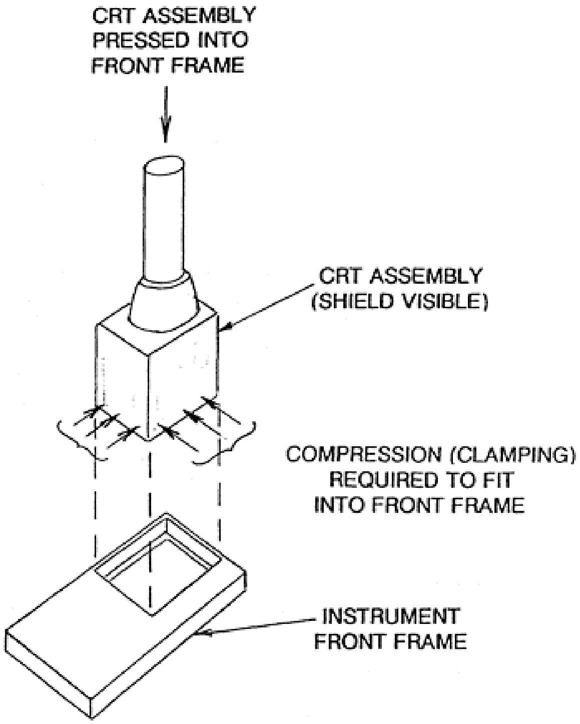

Figure 1. CRT Insertion Process Description

After being pressed into place, the clamp is removed and positioned for use on the next unit. With the clamp released, the CRT sub-assembly is held in the housing by friction until a later part of the assembly process secures it permanently.

Personnel in this section are regularly rotated through the various assembly jobs. Therefore, any of at least eight workers are familiar with this process.

METHOD

The CRT insertion process was analyzed using the detailed task analysis methodology described by Drury and Wick (1984). It is a quantitative methodology for evaluating the ergonomic risk of a work station, with emphasis on a frame-by-frame detailed analysis of videotapes; evaluating the results against established criteria; and the design, implementation and validation of a solution.

Data Collection

The CRT insertion process was videotaped from two sides so that both the left and right profiles of the operator could be observed and studied. The operators were interviewed and their comments noted.

The videotape was reviewed, and the critical portions were studied on a frame-by-frame basis. During this review, a task analysis form was filled out which noted all task steps, and corresponding body positions which could be potentially damaging. The maximum power grip and pinch grip forces used in the operation were determined by asking the operator to actuate a power or pinch dynamometer to simulate the maximum force felt during the operation (Yonda, 1986). These forces were also noted on the data sheet.

Data Evaluation

An evaluation sheet was compiled from the collected data which summarized position, force and frequency. All extreme positions and forces were noted and highlighted. The upper limit criteria were considered to be 1000 damaging wrist motions (DWM) per hour (Hammer, 1934), a maximum pinch grip force of eight pounds, and a maximum power grip force of 25 pounds.

The greatest initial concern, based on visual observation, was the power grip force required to press the CRT assembly into the front frame, as well as the shoulder flexion required as the operator reached for the lever. However, analysis of the videotape data, and interviews with the operators, led to the revised conclusion that, by far, the greatest problem was the number of damaging wrist motions and excessive pinch-grip forces associated with tightening the clamp on the CRT shield before pressing it into place.

Based on this analysis, a tentative decision was made to concentrate on an ergonomic solution to the clamping operation only. Just to be sure, however, some additional tests were conducted to measure pressing forces. In order to get a reasonable sample size, thirty (30) tests were conducted with tubes from the two major suppliers. Three operators participated in the tests, the extremes of which were a strong stocky male, and a petite female. Results of these additional tests were interesting. The only forces which exceeded the established guideline of 25 pounds for a power grip were exerted by the strong male operator. The lightest forces were exerted by the petite female. In all cases the mechanical integrity of the assembly was satisfactory, suggesting that the maximum force was a function of operator style, rather than a force which was demanded for proper assembly. Therefore, it was felt that any ergonomic complaints arising from the pressing operation (none have been reported) could be addressed as a training issue. The decision, then, to concentrate on an ergonomic solution to just the clamping operation was felt to be entirely justified.

Solution Design

The initial attempt was to compress the shield by using mechanical over-center clamps mounted to a simple clamping frame. This was unsuccessful in that far too much force was required. While it would have eliminated many damaging wrist motions, the force required to actuate the clamps was beyond any reasonable comfort level. In order to reduce the forces to an acceptable level, the levers would have to be very long which, in turn, would make the clamping frame very unwieldy.

The second attempt was to use a power driver to turn the screws to actuate the clamp. The requirements of the power driver were three-fold: (1) enough power to always ensure adequate clamping force, (2) a very low or variable speed to retain control, and (3) light weight for easy handling. Finding a power driver which would meet all three of these requirements simultaneously proved virtually impossible, so this approach was abandoned.

This, then, led to consideration, and eventual implementation of pneumatics as the design approach which resulted in a satisfactory solution. For simplicity, and to avoid the proverbial re-invention of the wheel, the same basic design of the existing clamping frame was retained. The frame members were redesigned only where necessary to accommodate the short-stroke double-acting pneumatic cylinders which were used in place of the hand-wheel screws. See figure 2.

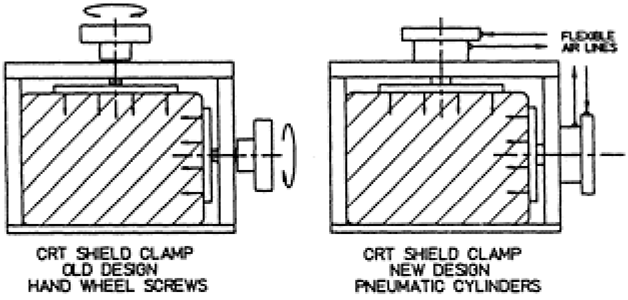

Figure 2. Old and New CRT Clamping Frames

The operator now clamps or releases the CRT assembly by simply stepping on a two-position foot control valve. The only required modification to the facility was to run an air line to the work station. A regulator was installed in the line so that the air pressure could be optimized and controlled. Flow control valves were installed in the pneumatic circuit to regulate the actuation speed and avoid the problem of "slamming shut." The only apparent disadvantage of the pneumatic design is that the air lines "tether" the clamp to a particular location. You cannot arbitrarily move this operation to another location across the room unless you go to the expense of relocating all the pneumatic circuitry. A subsequent modification was made after a few months of use; one of the pneumatic cylinders which actuated against the long side of the CRT shield was replaced with a cylinder of the next highest capacity rating. This was desirable to ensure adequate clamping force in the worst case situation.

Validation

After implementing the pneumatic solution, the process was videotaped again. The dramatic differences in eliminating damaging wrist motions were readily apparent upon first visual observation, even before videotaping. This was confirmed by analysis of the videotape as well as by the comments of operators.

RESULTS

Results of the analysis are summarized in Table I. Of special significance was the reduction in damaging wrist motions from 1375/hr to 480/hr (right side), and elimination of all pinch grips with excess force. Also note the reduction in cycle time.

Table 1. Results of the Analysis. The cycle time includes both the clamping and pressing operations.

MEASURE	BEFORE Hand-wheel	AFTER Pneumatics	COMMENTS
CYCLE TIME	2.5 min	1.25 min	50% reduction
DAMAGING WRIST MOTIONS	600/hr L 1375/hr R	680/hr L 480/hr R	Increase due to shorter cycle time. Reduced to <1000
PINCH GRIPS	18/cy L 43/cy R	17/cy L 12/cy R	
PINCH GRIPS w/ EXCESS FORCE	2/cy L 15/cy R	None	All pinch grips w/forces >8 lb were eliminated.
SHOULDER FLEXION	19/cy L 45/cy R	17/cy L 16/cy R	Both profiles had one extreme position, before & after.
SHOULDER ABDUCTION	3/cy L 40/cy R	no change L 11/cy R	
SHOULDER ADDUCTION	6/cy L 9/cy R	43° no change R	
ARM PRONATION	7/cy L 35/cy R	5/cy L 6/cy R	
ELBOW EXTENSION	16/cy L 42/cy R	14/cy L 12/cy R	Both profiles had one extreme position, before & after.
MAX TRUNK ∡	43°	13°	

MAX NECK ∠	80°	27°	

CONCLUSIONS

The pneumatic solution to the CRT clamping problem was first completed and installed in the production area on 1 May, 1991. It has been in continuous use since then except for a brief maintenance period in December 1991. Operator comments, particularly from petite females, have been very favorable.

There are still some ergonomic concerns with the press portion of the operation which should ideally be addressed. For now, however, there are other ergonomic concerns in other areas of manufacturing which are higher priority. When we are again able to look at the press operation, pneumatics may be a very viable solution here also.

ACKNOWLEDGEMENTS

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The training in Applied Industrial Ergonomics (AIE) by my co-author, John L.Wick of J&J Consulting, greatly stimulated my interest in this subject. John's availability as a resource of information has been invaluable. I was privileged to be one of six engineers from Signal Analysis Division selected to receive this training in January 1991. Part of the training was to select a problem for a detailed task analysis. This project was chosen for division focus by a group decision by the AIE-trained engineers based primarily on the results of a risk/cost justification analysis. All of them participated in prioritizing the problems, and in brainstorming possible solutions.

I would also like to especially acknowledge the help of Bob Fassbender, a Facilities Department supervisor. His working knowledge of pneumatics and available hardware greatly expedited arriving at a quick solution.

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DEVELOPMENT OF AN ERGONOMIC ASSESSMENT CHECKLIST AND ITS USE FOR EVALUATING AN EG&G IDAHO PRINT SHOP: A CASE STUDY

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The Idaho National Engineering Laboratory (INEL) is a multifaceted Department of Energy facility that performs a variety of engineering and research projects. EG&G Idaho is the prime contractor for the laboratory and, as such, performs the support functions in addition to technical, research, and development functions. As a part of the EG&G Idaho Industrial Hygiene Initiative, an ergonomic checklist was developed and ergonomic assessments were conducted at selected work places. This paper concerns the development of the comprehensive ergonomic assessment checklist and its use for assessing the EG&G Idaho Print Shop.

INTRODUCTION

The Idaho National Engineering Laboratory (INEL) is a 2472-square kilometer U.S. Department of Energy site where nuclear reactors and support facilities have been built and tested to demonstrate the applications of reactor technology, to conduct safety research, and to support defense programs. The existing facilities include a number of research and experimental reactors, waste management facilities, and a chemical processing plant that serves as the primary facility for the recovery of uranium, plutonium, and other isotopes from U.S. Government-owned or -controlled reactor fuel.

EG&G Idaho, Inc. is the prime contractor for the INEL and, as such, performs support functions in addition to technical, research, and development functions. These support functions include operating print shops, laundry facilities, bus service to the reactor sites, and cafeteria services.

EG&G Idaho, Inc. is required to comply with federal Occupational Safety and Health Administration (OSHA) and Department of Energy (DOE) health and safety regulations and requirements. The effective management of worker health and safety protection includes all work-related hazards, whether or not they are regulated by specific federal standards. DOE Order 5480.10 "Contractor Industrial Hygiene Program" (1985) specifically identifies ergonomic stressors to be addressed as part of the contractor Industrial Hygiene (IH) Program. EG&G Idaho's Human Factors Research Unit (HFRU) was asked to conduct ergonomic assessments in selected work places in order to determine whether or not poor ergonomic conditions existed. The HFRU ergonomics team was made up of ergonomic specialists, with backgrounds in industrial engineering and safety.

The objectives of this work were:

1. Develop an ergonomic checklist(s) in conjunction with the IH Program for recording observations and potential ergonomic risk factors. The checklist was required to be tailored to the specific needs and conditions of the work places assessed.

2. Perform the ergonomic assessments using the ergonomic checklist(s).

3. Develop joint recommendations with the IH(s) for controlling ergonomic exposures as applicable and provide these to management.

In late 1990 the scope of work, objective, schedule, and budget were determined. Work began in late January, 1991. Six departments of EG&G Idaho, Inc. (Administration, Information Resources, Facilities and Maintenance, Science and Technology, and Power Reactor Programs,) participated in the ergonomic assessments. The areas that were to be assessed had been identified by industrial hygienists as potential areas of risk due to ergonomic stressors. From the list of work places and input from the IHs, a schedule of ergonomic assessments was determined. An initial walk through survey of the work places was made by the HFRU ergonomics team during January 1991. This initial walk through provided information about the types of work activities that are done in the work place and the equipment and instrumentation that would be needed when the actual ergonomic assessments were conducted. It also provided an opportunity to meet supervisors and some employees of the facilities.

During February and March, 1991 the ergonomic checklist was developed by the HFRU. In mid-March the ergonomic assessments were begun by the HFRU ergonomics team and they continued until early June, 1991. As the initial step in the assessment process, job hazard analyses (JHAs) were conducted The work place was then assessed using the ergonomic checklist The results of the assessments were documented using the JHA and the copy of the completed checklist. Recommendations were developed, reviewed and agreed upon by the department IH(s) and then communicated to management

The checklist approach of conducting the assessments was chosen for several reasons including: ensuring the assessments were conducted consistently, assessments were well documented, and so that a central source of ergonomic information was developed that could be given to industrial hygienists for their future use.

CHECKLIST DEVELOPMENT

As an initial step in the development of the checklist, a thorough literature search was conducted to find references of other existing ergonomic checklists. During this step, the *OSHA Ergonomic Program Management Guidelines for Meatpacking Plants* (OSHA, 1990) was thoroughly reviewed to ensure all applicable guidelines were incorporated into the checklist and assessment process. Although several checklists were found, none were as comprehensive as what was needed. Most dealt with a single area, such as the causes of cumulative trauma disorders (CTD) (Calisto, et al, 1986). For some areas of ergonomic concern, such as the proper design criteria of lifting tasks, checklists did not exist.

The best concepts of the existing checklists were utilized in the development of the checklist, and new questions and sections were developed for those areas without existing checklists. Graphics were utilized to help explain more difficult concepts as well as to increase the usability of the checklists. For instance, instead of trying to describe verbally how a VDT work station should appear, a figure of a properly designed VDT work station was provided with the proper dimensions superimposed on the drawing.

The new checklist (Ostrom, Gilbert, and Wilhelmsen, 1991) addresses 8 areas. These included, Accident/Injury information, General Office Requirements, General Industrial Requirements, Lifting, Repetitive Motion, Workstation Design, Vibration, and Glove Box/Laboratory Hood Design. The first section of the checklist is a set of questions formatted as a flow diagram that aids the user in deciding which sections of the checklist need to be completed in order to conduct a thorough assessment of each specific and unique work place. Each of the eight checklist sections are briefly described:

Accident and Injury Information

This section of the checklist was adapted from *Ergonomics Program Management Guidelines for Meatpacking Plants Guidelines* contained in OSHA Bulletin 3123. The purpose of this section is to alert the IH or a physician to a potential musculoskeletal problem area. (OSHA, 1990)

General Office Requirements

The General Office Requirements section is designed to provide information concerning the office environment such as lighting, noise level, housekeeping. This section was developed using information contained in Rodgers (1983) and McCormick and Sanders (1982).

General Industrial Requirements

The General Industrial Requirements section is designed to provide information concerning the industrial environment such as lighting, noise, heat stress, housekeeping, etc. This section was developed using information contained in Rodgers (1983), McCormick and Sanders (1982) and NIOSH (1973).

Lifting

The Lifting section is designed to provide an indicator of the manual materials handling stresses found in the work place. This section is based on the NIOSH lifting guidelines (NIOSH, 1981) and Ayoub and Mital (1989).

Repetitive Motion

The Repetitive Motion section of the checklist is designed to provide information concerning the level of upper extremity and wrist stress found in the work place. This section was developed using information contained in Putz-Anderson (1990), Kroemer (1989), and Calisto, et al. (1986).

Workstation Design

The Workstation Design section of the checklist is designed to provide information concerning the work place design. This section primarily concerns items such as work heights of computer desks, work benches, and machinery. It is for both standing and sitting tasks. This section was developed using information contained in Rodgers (1983) and McCormick and Sanders (1982).

Vibration

The Vibration section concerns occupational exposure to vibration. This section concerns both segmental and whole body vibration. This section was developed using information contained in NIOSH (1973).

Glove Box and Laboratory Hood Design

The Glove Box/Laboratory Hood Design section is designed to provide information about the arrangement of glove boxes and laboratory hoods. This section was developed using information contained in Rodgers (1983).

Rather than rely solely on qualitative descriptions, it was decided to assign a point value to each question in the checklist The point value represents the relative risk of injury if the desirable condition described in the question is not met with the lowest value (i.e., 1) associated with the lowest risk and the higher values (i.e., 10) associated with the higher level of risk. The point values were developed by using information contained in the references for the particular sections. The point value system was found to be useful in making comparative judgements of potential risk. It should be noted, however, this point value system has not been rigorously validated.

An initial version of the checklist was developed before the first, Information Resources Department, ergonomic assessments. Feedback from the utilization of the checklist for these assessments was used to improve the checklist’s structure and content. The checklist was originally designed so that there were not separate sections. Therefore, when the checklist was used one needed to complete the whole thing. The first assessment showed that the checklist needed to be divided into sections and the person completing it would decide upon the initial walk around of the work place what sections needed to be completed. This approach decreased the amount of time needed to complete the checklist and the amount of paper that would be generated for each work station.

The checklist was further refined as other assessments were made. Comments made by the industrial hygienists were also included in the checklist. An excerpt from the Work Place Design section is presented in Figure 1.

EG&G IDAHO PRINT SHOP ERGONOMIC ASSESSMENT

The EG&G Idaho, Inc. print shop provides xerographic, offset lithographic printing, process camera work, metal and electrostatic platemaking, and diazo (blueline) printing services to INEL. Other services provided include cutting, drilling, perforating, numbering, folding, assembling, laminating, shrink wrapping, comb and perfect binding, and stapling of paper publications such as reports, newsletters, etc. Twenty-three employees currently work in the print shop.

The print shop was the first work place assessed using the ergonomic checklist. The sections of the checklist used to assess this area were the General Industrial Requirements, the Lifting, the Repetitive Motion, and the Work Station Design sections. The following is a description of the ergonomic concerns found in the print shop and the recommendations made to improve the situation.

In numerous cases the heights of the workstations were not correct for the workers. It was found that military surplus tables were being used for work tables. The work height of these tables was 74cm. This height was identified as too low; for the average worker this work height should have been approximately 100 to 112 cm. When the employees were observed working, they were in a stooped posture. Depending on the height of the stack of paper the employee was working on, the employee might start a task in an erect posture, As the height of the stack of paper decreased, the employee’s posture became more stooped. It was recommended that tables with adjustable work height be purchased.

Another example involved a blueline machine. In this case, the operator was of short stature and the place where paper is fed into the machine was approximately at the operators shoulder height. It was determined that this situation was a potential cause shoulder stress for the operator. It was relatively easy to lower the paper feed height of the blue print machine by removing the wheels. Removing the wheels lowered the work height by 10cm and resulted in a less extreme shoulder posture.

Related to the inappropriate work heights found in the print shop was a lack of adjustable chairs. The heights of the various work stations varied greatly in the print shop. In certain cases, employees would move from work station to work station and since most of the chairs lacked adjustability, there were often mismatches between the seated employee and the various work heights.

The print shop utilized carts to move stacks of paper from work station to work station. The carts had two shelves. It was a general rule that only the top shelf of the cart was to be used. During rush periods where a great deal of work was required in a short amount of time, however, the bottom shelf on the push carts was utilized. The employees had to get into an awkward posture in order to place stacks of materials weighing up to 7 kg onto the bottom shelf. It was recommended that the employees never use the bottom shelf of the push carts.

There were numerous tasks requiring repetitive motions in the print shop. These included sorting tabbed pages, collating documents, comb binding, and placing documents in three-ring binders. Automated machinery currently does not exist for performing some of these tasks. For instance, there are no machines currently available for placing tabbed pages in documents. Currently the print shop only can collate a document up to 30 pages. Manual collating is required for documents over 30 pages.

This involves printing packets of 30 pages each and then manually assembling them into a complete document The act of manually assembling a document requires several stressful wrist motions. The print shop already had administrative controls designed to limit the number of hours an employee could perform this task per day. However, during rush periods, these controls were not always enforced. It was recommended that these controls always be enforced with no exception.

The comb binding operation was especially interesting because each employee performed this task differently. Some employees set up their work place in a organized fashion intuitively using the principles of economy of motion (Barnes, 1980). Other

7.2.2 Posture

1. Can the employee attain a sitting posture as depicted in Figure 7.1? YES __ NO __

IF: NO, then add 5 pts.

FIGURE 7.1: Sitting Posture.

a. Spine is slightly arched and leaning forward.
b. Knee joint is at 90 degrees.
c. Head is not tilted forward greater than 20 degrees.
d. Elbow joints can be held at 90 degrees.
e. No twisting of the head and/or trunk.

NOTE: The posture depicted above is desirable: however, it is not necessary that the employee remain in this posture. The employee should have the ability to attain a variety of postures and not be crowded; this ensures a full range of motion.

Figure 1: Example from the Ergonomic Checklist

employees appeared to do everything opposite to these principles. It was recommended that employees who were observed performing this task in an organized manner should train other employees who perform or might potentially perform this task in order to benefit from the economy of motion principles.

Since the assessment, the print shop has implemented all the recommendations. No formal evaluation has taken place, but informal observation suggests that employees recognize the changes made and feel they are beneficial. These feelings may result from both reduced physical stress as well as the emotional and motivational benefit of evidence that the company is concerned and willing to change things to promote employee health and safety.

CONCLUSIONS

The checklist approach was chosen to ensure consistency among ergonomic assessments, to ensure the assessments were well documented, and so that a central source of ergonomic information was developed that could be used by industrial hygienists in the future. Feedback from the first assessments was used to streamline the checklist and make it more usable. The checklist approach proved to be a good method of assessing the print shop for ergonomic concerns. The ergonomic concerns found in the print shop included mismatches between the heights of the work tables and worker stature, lack of adjustable chairs, and tasks requiring repetitive motions. Recommendations have been implemented and they have had immediate beneficial impact on employees in the print shop.

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A PRACTICAL EVALUATION METHOD FOR QUANTIFYING ERGONOMIC CHANGES AT L.L. BEAN

Implementing Ergonomics With Total Quality Management

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In response to increasing cumulative trauma disorders of the upper extremities and back in the mid to late 1980's, L.L.Bean implemented many initiatives to reduce their incidence and severity in its Manufacturing division. In 1989 L.L.Bean also began to implement Total Quality Management as a way of doing business. The combination of good management and effective health and safety programs resulted in a -79% reduction in lost-time incidents. In order to evaluate the effectiveness of the ergonomics program in the reduction, a practical evaluation method for quantifying ergonomic changes was developed.

INTRODUCTION

Like many companies in Maine and the nation in the mid to late 1980's, L.L.Bean experienced a rising incidence of cumulative trauma disorders (CTD's), predominantly of the upper extremities and back. Our worksites had always been clean, well lit, and apparently safe. However, the emergence of these "new" occupational illnesses, CTD's, changed our perspective on workplace health and safety. Ergonomics became a key strategy to prevent workplace injuries/illnesses, as well as to return partially disabled employees to the work force.

During this period, the practical definitions of workrelated conditions seemed to broaden. In its meatpacking guidelines, whereas OSHA defines occupational injuries as, "caused by instantaneous events in the work environment", OSHA's definition of occupational illnesses includes the statement, "unless the illness was caused solely by a non-workrelated event or exposure off-premises, the case is presumed to be work related" (OSHA, 1991).

Workers' compensation case law in Maine gradually incorporated definitions like these over the 1980's. Cumulative trauma disorders like tendonitis, carpal tunnel syndrome, bursitis, and epicondylitis seemed to come out of the woodwork as employees, doctors, employers and others realized the potential connection of CTD's with work. We aggressively developed and implemented health and safety programs to address the increasing incidence of CTD's.

During the same period our company adopted Total Quality Management (TQM), a quality improvement philosophy and management system based on the work of Deming (1986), Juran (1964), and Crosby (1979) in the 1950's. Until then, like many good manufacturing companies, we had utilized Frederick Taylor's (1923) scientific management principles to achieve high production rates. With TQM's focus on quality and overall productivity, it allowed us to re-examine the way our 400 employees had successfully produced shoes and canvas luggage in the past. New management in our Manufacturing division proactively adopted TQM and focused a lot of time and energies on improving workplace health and safety.

Total Quality Management at L.L.Bean is based on five principles:

1. Customer focus (both internal and external);
2. Top down support and commitment;
3. Total involvement of everyone;
4. Effective measurements upon which improvements can be based;
5. Continuous improvement of all processes.

TQM effectively places responsibility for workplace health and safety with area management and the responsibility for providing innovative and effective programs with Employee Health and Safety. Employee Health's mission and objectives are aimed at helping area management and employees to achieve and maintain a healthy and safe workplace. To achieve that mission and objectives, the "right things" (programs or processes) needed to be developed (see Figure 1). Through "customer-supplier" alignments, the Health and Safety Department helped our "internal customers" (area management and employees) in our Manufacturing division implement the right programs to help reduce the incidence of CTD's.

From 1988 through 1990, 70–90% of Manufacturing's losttime claims were classified as CTD's, occupational illnesses. Our focus became not only preventing as many injuries or illnesses as possible, but also accommodating employees with CTD's that might have only partially been caused or aggravated by work activities. Ergonomics was a cornerstone of our focus. Essential elements of our programs were:

- Management Support
- Front Line Supervisor Responsibility
- Employee Involvement
- Applied Ergonomics
- Worksite Stretch Program
- Work hardening/Fitness Program
- Early Medical Management
- Onsite Physical Therapy
- Preplacement Physical Exams

From 1989 through 1991, with the help of Employee Health and Safety, Manufacturing was able to achieve a −78.8% reduction in lost-time incidents. (see Table 1.)

Table 1. Lost-time incidents by year for Manufacturing division.

Year	Lost-Time Incidents Per 200,000 Hrs. Worked	Percent Reduction
1988	14.9	
1989	15.6	4.7%
1990	10.1	−35.3%
1991	3.3	−67.3%
1989 to 1991		−78.8%

Because of the multi-disciplinary approach to reducing injuries/illnesses, it was impossible to quantify the specific contribution of each program to the subsequent reduction in lost-time incidents. However, as part of TQM, we try to measure the contribution of our programs in order to make sure we are doing the "right things right" to achieve our objectives. We subsequently developed a practical method to objectively quantify the improvements in acknowledged risk factors for CTD's.

ERGONOMICS HISTORY

Ergonomics in Manufacturing moved through three phases from the mid-1980's to today.

Phase 1: Ergonomics was typically focused on improving jobs in which employees had an injury/illness. Emphasis was on reacting to problems as they developed. Training of supervisors, engineers, budget analysts, human resource specialists, and others was accomplished, but there was not yet an effective system to implement changes.

Phase 2: Ergonomics was applied to jobs more proactively in the late 1980's. Ergonomic design teams included health and safety specialists as well as engineers and employees to look at jobs for ergonomic improvement. There was now a more formal framework to implement changes, but focus was still on justifying ergonomic changes in relation to overall productivity.

In this period, an external expert was brought in to intensively train six people to videotape, analyze, and use a team approach to make changes in jobs. The method helped us learn how to make sound, objectively evaluated, ergonomic changes ourselves. (Wick, et al., 1990) However, whereas we began to see some immediate benefits from this training, the management framework was not yet in place to maximize the effect of ergonomics.

Phase 3: Ergonomics became a part of the overall job and work flow design just like productivity and quality. In TQM, workplace health and safety is an integral part of management and employee performance expectations and rewards. Ergonomics has become an integral part of manufacturing and is included in all workplace planning and changes.

METHODOLOGY

Since we could not measure the effect of ergonomics changes on the reduction in lost-time incidents independent of other factors, we decided to measure the improvement in risk factors that experts in the literature feel contribute to cumulative trauma disorders. We would evaluate our program based on percent improvements in those risk factors and the number of jobs and employees affected by the improvements. The two key questions would be:

1) Are we applying ergonomic changes to the right jobs? and
2) Are the ergonomic changes actually resulting in improvement?

The basic framework of our methodology evolved to closely follow the proposed OSHA ergonomics guidelines and other recommended approaches (Keyserling et al., 1991; OSHA, 1991), utilizing an ergonomics design team approach. The core team included the ergonomics specialist, standards analyst/engineer, occupational health nurse, and a member of our Maintenance Department. In looking at any jobs, the affected employee (s) and supervisor were always included and were an integral part of the process.

Worksite Analysis

The program started with worksite analysis. We used a combination of methods including: monitoring OSHA-200 logs and workers compensation claims; measuring incidence rates; conducting plant surveys; studying reports from supervisors, employees, and health and safety personnel; and other methods. Data collected by the Health and Fitness Specialists as they implemented worksite stretch programs provided additional information on what parts of the body employees felt the most fatigue and soreness. Our ergonomics specialist became closely involved with any planned changes in products or work processes.

In jobs where quick fixes (e.g. obvious postural changes) were needed, changes were implemented immediately. However, in situations requiring a more thorough analysis, a seven step process was used: (Drury and Wick, 1984)

1. Obtaining buy-in and support from the supervisor and employee(s).
2. Videotaping the job.
3. Analyzing the job and quantifying repetitions, angles of the body, and forces used.
4. Presenting the videotape analysis and results to a team including the employees doing the job, the supervisor, occupational health nurse, standards analyst or engineer, a Maintenance Department employee, and other interested personnel. Using brainstorming and other facilitation techniques, practical solutions were recommended.
5. Cost-justifying the recommended changes.
6. Building a prototype for testing.

7. Implementing the approved prototype.
8. Remeasuring the job to make sure improvements were achieved.

Our goals for changes were (Wick et al., 1990):

Angles:	As close to neutral position as possible.
Forces:	Grip—less than 25 pounds. Pinch—less than 8 pounds.
Repetitions:	Less than 1,000 damaging motions per hour.
Posture:	Upright seated or standing posture, with reach zones close to the body. Support for upper extremities.
Lifting:	Within NIOSH guidelines. (NIOSH, 1981)

Hazard Prevention and Control

Our concern was with new types of hazards: excess force, angle, repetitions, and awkward unsupported postures. Typical conditions that created these were identified:

- incorrect workstation height
- incorrect tool angle
- poor grip surfaces
- improper machinery design
- lack of automated machinery
- lack of jig/fixture use
- lack of upper extremity support
- excess repetitions
- excess lift loads

Initially many modifications consisted of 2×4's, 1/2 inch plywood, and angle iron. These modification materials, though simple, were inexpensive, easy to install, and very effective. After implementation employees almost always felt the improvement. If not, we would keep working at it.

As awareness and support increased, department budgets for ergonomic improvements also increased. Our solutions became much more creative:

1. Instead of raising/lowering a bench to fit an employee, operator adjustable workstations were developed to reduce reaches, lifting, and to allow operators to adjust to proper work heights.
2. New jig fixtures were developed to "hold" work pieces, reducing the forward angle required to perform the task.
3. We found air! We became more knowledgeable about air cylinders and the related controls, allowing partial automation of processes not warranting full robotic automation. Air is used to push, pull, grip, twist, and tilt, addressing some seemingly unsolvable problems.
4. Instead of allowing the unavailability of tools to limit us, we designed and fabricated our own when necessary.
5. Anti-skid surfaces were installed on many tools, fixtures, and handles to reduce grip forces.

6. Poor machinery design, or information, was no longer a limitation. Using machine operators as a resource, we developed new machinery. These were built from the ground up to incorporate all desirable features and allow a safe productive work environment. New technology was incorporated into old machinery to automate when others said it “couldn’t be done”.
7. New machinery purchases were not limited to productivity pay backs. Ergonomic benefits justified purchase of computerized machinery to reduce repetitiveness.
8. Ergonomics became a part of doing business at L.L.Bean Manufacturing. New products, revisions, and work area layouts are all analyzed for problems before implementation. All areas of employee population flag ergonomic concerns and have input into their solutions.

Medical Management

The Ergonomics Specialist worked closely with the Occupational Health Nurse and onsite Physical Therapist to help return partially disabled employees to the workplace. Aggressive medical management included early reporting of symptoms, onsite physical therapy, an active modified work program, work hardening that transitioned employees into our health and fitness program, and close follow-up of employees with symptoms.

Joint evaluations of the worksite by the affected employee, the supervisor, the ergonomics specialist, physical therapist, and occupational health nurse helped tailor the worksite specifically to fit the employee’s capabilities and restrictions. Engineering and work practice controls, administrative controls, and personal protective equipment were used to return the employee to work in his or her own or modified job. Any ergonomic changes made for partially disabled employees were evaluated for transfer to other similar jobs.

Education and Training

In the first two years of the ergonomics program, education and training was focused on the ergonomics team, managers, and supervisors. Employees were brought into the process and educated as changes were made to their jobs. Employee insights, participation, and buy-in to any changes were critical.

Overall ergonomics training for all employees in the plant is being conducted in 1981 and 1982.

EVALUATION

In order to evaluate the effectiveness of ergonomic changes independent of the other programs, assessment of the improvement was made for each intervention. Categories of 0–10%, 11–25%, and 26+% were established. Force was measured in pounds using grip and pinch meters or a scale if it was a lift. Repetitions were counted using slow motion video analysis. Angles (i.e. ulnar deviation) were measured in degrees with a protractor using slow motion video analysis. Posture was measured in degrees and was estimated visually.

Since one person performed all the measurements, reliability was somewhat controlled. However there was no independent check of the evaluator's measurements. Overall, in 1990 there were 373 modifications of the risk factors to 214 workstations. (Many jobs had more than one risk factor modified.)

Table 2: Percent improvements in selected CTD risk factors.

Percent Improvement	Force Reduction Changes	Angle/Repetitions Changes	Posture Changes	Totals
0–10%	66	48	46	160
11–25%	59	66	3	128
26+%	47	27	1 1	85
Totals	172	141	60	373

DISCUSSION/CONCLUSION

There are some limitations to our system. We do not actually know that the risk factors we are measuring are the cause of the lost-time incidents. Likewise, we also do not know that the improvements in those risk factors are actually contributing to the reduced lost-time rates. Postural measurements were somewhat subjective. And there were also no independent verification of any of the measurements.

To make sure that what we are measuring is valid, we rely on expert opinion and the literature. That is, that the posture, angle, force, and repetition improvements will lead to improved ergonomics and decreased CTD's. (Keyserling, et al., 1991) We continually watch the literature for validation of the risk factors on which we focus.

As we expand the measurement system company-wide and involve others in the measurements, we are beginning to quantify postural improvements to improve their accuracy. We are systematically training persons taking the measurements and are performing periodic audits to ensure accuracy and reliability.

Although not perfect, what we end up with is a reasonable system to make sure we are doing the right things right; that we are changing the right aspects of the jobs looked at; and that the changes result in improvements. Although lacking in scientific rigor, it is a system that works well for us. It enables us to effectively work with area management and employees to carry out our mission to improve the health and safety of the workplace.

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Figure 1: Employee Health mission statement

Employee Health Mission Statement

To work with area management and employees to achieve and maintain a healthy and safe workplace, and promote the health, safety, and fitness of employees.

OBJECTIVES:

- Reduce injuries and illnesses.
- Reduce time lost from work due to injuries/illnesses.
- Increase overall health, fitness and related quality of life of employees.
- Reduce workers compensation and health care costs.

“RIGHT THINGS” TO ACHIEVE OBJECTIVES.

Prevent Occupational Injuries/Illnesses by:

- Ergonomic Design of Work Stations and Work Processes
- Health and Safety Education and Training
- Worksite Stretch Programs
- Safety/Industrial Programs
- Preplacement Physical Exams

Manage Occupational Injuries/Illnesses by:

- Case Management of Disabled Employees
- Onsite Physical Therapy
- Transitional Work/Permanent Reassignment for Disabled Employees
- Claims Handling

Prevent and Manage Those Non-Work Related Injuries/Illnesses with Greatest Negative Impact on Employees and L.L.Bean through:

- Health Risk Appraisals
- Health Classes and Programs
- Health Education and Counseling
- Benefit Bonus Credits

Provide Health and Fitness Programs for General Health Improvement:

- Health and Activity Classes
- General Fitness Assessments
- Four Regional Fitness Centers

Customer-Supplier Alignments with Key Areas
Compliance with Governmental Regulations

ERGONOMIC DESIGN

DESIGN FOR ERGOABILITY—A CASE STUDY

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A neoteric method for the inclusion of ergonomic principles in the design process called Design for Ergoability (DFE) was tested on a limited basis to evaluate three product design options with respect to CTD risk factors. DFE uses of a comprehensive database and the Decisive Dominance Heuristic (DDH) to assess the ergonomic aspects of product designs. Preliminary results indicate that the DFE method can introduce ergonomic factors into the product design cycle before finalization of a design, and thus help minimize CTDs in assembly operations.

INTRODUCTION

Incorporation of ergonomic principles into the design of both new products and downstream manufacturing operations has seldom been practiced on a proactive basis. In the majority of cases, ergonomics/human factors engineers have not been consulted until the cost of industrial injuries (mostly due to CTDs) has skyrocketed. Moreover, ergonomic input has been limited to downstream operations. Thus, the product design process has traditionally been performed in an isolated environment, utilizing the "throw-over-the-fence" method. Manufacturing must accept the product as designed, and develop an assembly process that meets both design and managerial constraints. When injuries begin to increase at a high rate, and productivity and quality have been severely reduced, the ergonomics/human factors engineer is called in on an ad hoc basis.

In the 1990's, U.S. manufacturers are shifting their focus from advanced manufacturing systems to the product development process. Industrial data shows that roughly 80 to 90 percent of the total life-cycle cost 01 a product is established during the design phase. In addition, gains from improvements in the product development process can range between 40 to 60 percent. Existing techniques which include design for X (DFX), concurrent engineeering, and cross-functional teams will be enlarged, and offer a realistic vehicle for the practice of proactive ergonomics.

Interjection of ergonomics into the product design cycle can be accomplished through an expansion of DFX parameters. Currently, the "X" in DFX represents testability, manufacturability, assembly, maintainability, reliability, and additional downstream factors. It has not specifically included ergonomics as a unique design element. The primary function of all "X's" in the design phase is to assist the designer in understanding the effects of a design upon all other "X's" to ensure that one DFX factor is not optimized at the expense of other downstream elements (a satisficing approach).

A new variable for the DFX family, termed "Design for Ergoability", is introduced which offers design engineers a quantitative method for evaluating the ergonomic impact of a design before it has been frozen. DFE goes beyond the concepts of "Design for Simplicity" and "Design for Assembly", by examining simplfied and efficient designs with respect to their potential for causing CTDs in line operators. Designs which appear optimal from the standpoint of the number of parts and ease of handling (as determined by the "Boothroyd Design for Assembly Rating System", or other assembly rating scales) may in fact be suboptimal from an ergonomics point of view. Although projected design and manufacturing costs may appear optimal, costs associated with increased medical and insurance outlays, along with reduced productivity and quality stemming from assembly-related injuries can turn an apparent cost-effective design into a losing proposition.

DFE implementation begins with the creation of a database, which may be accessed by all members of the design team. Information on ergonomic, quality, reliability, maintainability, and other problems associated with previous designs is collected in order to "red-flag" troublesome parts, subassemblies and assembly methods. Data can be gathered from numerous sources, including medical records, design engineers, purchasing, manufacturing, quality control, customers, and line operators. Ergonomic data collected on an electronic part might include the following:

Table 1. Example of ergonomic data collected on a troublesome electronic part.

Ergonomic Data for Part No. 1357
1. Manual insertion of part
2. Chuck pinch grip used (F=7 Kg.)
3. ~20 deg. wrist flexion required
4. Average task frequency=400 times/day
5. Seven female operators who performed the manual insertion task have developed carpal tunnel syndrome
6. Medical costs to date=$75,000

Once the database (which should be updated on a continuous basis) has been established, parts, subassemblies and assembly methods can be ranked via use of the Decisive

Dominance Heuristic (DDH) developed by Iyer (1988), which can be used to measure the capability of a design alternative to dominate other design options in as many of the design goals as possible. The DDH offers an efficient procedure for assigning priority ranks to a set of decision alternatives in the presence of multiple design objectives. In addition, the DDH permits design parameters to be explored without the imposition of resource constraints (which can be added later), thus providing a clearer picture of the relative merits of each design option. This is important with respect to the inclusion of ergonomics in the design process, since quality, reliability and cost factors often arbitrarily override ergonomic considerations.

As an illustration of the DDH (see Table 2), suppose that four options for the redesign of an existing product are being evaluated by a cross-functional team with respect to ergonomics, quality, reliability, and assembly. Team members reference relevant information from the database, and provide ordinal rankings for each design option within their area of expertise (e. g. Human factors/ergonomics engineers rate ergonomic factors; QC people rank quality considerations, etc.). This stage produces four ordered sets of options. Next, the sum of ranks is computed for each option. This step results in an R-Score for each design alternative, which is calculated as follows:

R-Score=(No. of Objectives)
X (No. of decision parameters)
+(No. of Objectives)−(Sum of ranks) (Iyer, 1988)

Table 2. Use of the Decisive Dominance Heuristic (DDH) to rank design options by objectives (including ergonomics).

	Ranks of Design Options by Objectives			
	A	B	C	D
Ergonomics	1	3	4	2
Quality	2	1	3	4
Reliability	2	1	3	4
Assembly	1	2	4	3
Ranks	A	B	C	D
1	2	2	0	0
2	4	3	0	1
3	4	4	2	2
4	4	4	4	4
R-Scores:	6	7	14	13

Priority ranks are then assigned to each design, and ordered by sorting R-Scores (from high to low). The priority rankings for the four design options are: C>D>B>A.

Violations of the DDH priority ranks from the original ranks assigned by design team members can also be calculated. Priority ranks determined via the DDH are used to compute the absolute deviations of these ranks from the individual ranks. The lower the value, the smaller the deviation (see Table 3).

Table 3. Comparison of individual ranks and absolute deviations (violations). Note: E=Ergonomics; Q=Quality; R=Reliability; & As=Assembly.

Options/ Rank		Individual Ranks E	Q	R	As	Violations E	Q	R	As	Total
C	1	4	3	3	4	0	1	1	1	0
D	2	2	4	4	3	1	1	1	0	3
B	3	3	1	1	2	2	1	1	0	4
A	4	1	2	2	1	0	1	1	0	2
										9

The DDH is a flexible alternative to scales and rating methods used to evaluate designs which assign penalty points to macro assembly operation elements. These assignment of penalty points associated with straight or circular movement within the x, y or z planes, which only provides a limited estimate of possible ergonomic problems.

The potential for the development of industrial injuries (especially CTDs) has not traditionally been considered during the design phase. In addition, input from experienced assembly operators with respect to possible injury problems has also been noticeably absent, since line operators are not usually included as members of cross-function design teams. A case study is offered which illustrates the use of the DDH to assess CTD risk factors in three design options. Input from operators based upon their experiences assembling the new product was also used to assess CTD risk.

METHODS

Three proposed product designs were evaluated by use of the DDH to determine which option minimized the risk of CTDs in line operators, and to evaluate the use of the DFE concept. Each design was based upon previous product designs (a common practice), which meant that some historical data was available. Collection of relevant ailable. Collection information was performed manually, since a complete database (the initial implementation factor in DFE) did not yet exist.

A physical analysis of each design was performed to assess obvious problems associated with parts and subassemblies. In addition, a task analysis was conducted while experienced line operators assembled each product design (the preliminary layout and tooling for each option had already been set up). Detailed notes were taken 01 operators' comments concerning assembly procedures which could cause a CTD (use of the "think-aloud" method).

Based upon both the physical and task analyses, as well as operator input, job and body activities required by each design option were compared with those stated by Putz-Anderson (1988), and Kroemer (1989) to be associated with certain CTDs. A list of CTDs that could result from each design option was then prepared and ranked. The DDH was used to obtain an R-Score for each design,which was then equated with the amount of risk for the development of each type of CTD (see Table 4).

Table 4. Use of the DDH to determine CTD risk for the three design options. Note: CTS=Carpal tunnel syndrome; E=Epicondilitis; T=Tendinitis; PTS=Pronator teres syndrome; DEQ=De Quervain's disease; RTS=Radial tunnel syndrome; UNE=Ulnar nerve entrapment; and RTE=radial tunnel syndrome. DO_1=Design option 1; DO_2=Design option 2; and DO_3=Design option 3.

Ranks of Design Options by Type of CTD			
	DO_1	DO_2	DO_3
CTS	1	3	2
E	1	2	3
T	1	3	2
PTS	1	2	3
DEQ	1	2	3
RTS	1	3	2
UNE	1	2	3
RTE	1	2	3
RANKS	DO_1	DO_2	DO_3
1	8	0	0
2	8	5	3
3	8	8	8
R-Score	24	13	11

RESULTS

As the data in Table 4 indicate, design option one (DO_1) received an R-Score that was approximately two times better than either design options two (DO_2) or three (DO_3) In addition, each option had an absolute deviation of zero. This corresponds to the qualitative choice of both the authors and the line workers. Furthermore, if a design engineer had to select one of the options based upon the individual ranks made by the human factors/ergonomics engineer, and the resulting R-Scores, he/she also would have chosen DO_1.

Table 5. Comparison of individual ranks and absolute deviations for each CTD.

	Individual Ranks							Violations								
	C	E	T	P	D	R	U	RT	C	E	T	P	D	R	U	RT	Tot
Options/ Rank																	

DO_1 1 1 1 1 1 1 1	1	0	0 0 0 0 0 0 0	0	0
DO_2 3 2 3 2 2 3 2	2	1	0 1 0 0 1 0 0	0	3
DO_3 2 3 2 3 3 2 3	3	1	0 1 0 0 1 0 0	0	3

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CONCLUSIONS

The DFE method, which utilizes a comprehensive database and decision support system (DSS) via the DDH, provides a simple quantitative technique to assess and priortize ergonomic risk factors in design options. The concept also allows the consideration of ergonomic elements in the presence of multiple design objectives. Additional studies are needed to test the use of DFE in the design environment.

European project on standardization of *Structures and function of computer manikins for design and evaluation of work space at machinery*

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Many computer programs for graphic planning and vizualization and ergonomic evaluation of work space using anthropometric body models, manikins, have been presented during the last few years. The differences between them makes it difficult to compare results. Before there is a general agreement on principles for analysis and models, it is necessary to specify programs and body models together with the results. When models and principles have been validated, it will be possible to work with a limited number of standardized manikins and biomechanical and other models. The aim of this project is to create a basis for standardization of computer manikins by gathering information on the characteristics of the available programs and in particular the manikins used.

INTRODUCTION

Achieving free movement of goods between the member countries is one aim for the European Community (EC). All the EC countries have laws on product safety and so on which can cause technical barriers to trade. In 1985 European Community Ministers agreed on a *New Approach to Technical Harmonisation and Standards* to tackle this long standing problem for business. The *New Approach* is based on *Directives,* i.e. Community laws, which set out *essential requirements,* e.g. for safety, which must be met before products may be sold in the Community. European standards fill in the detail and meeting them is the main way for businesses to fulfil the essential requirements. The Directives also say how manufacturers are to show that products meet the essential requirements. Product meeting the requirements are to carry the CE mark, which means that they can be sold anywhere in the Community.

The *Machinery Directive* (1989) is one of the first directives; it covers a wide range of products. Through the *European Economic Space* (EES) treaty also the EFTA countries will become included (with others to come) thus forming the world's largest inner market with a population of more than 350 million.

The New Approach is based on the principles that the content of the directives is limited to essential safety requirements and general principles and that necessary technical specifications are given in standards. Thus standards has been given a new, much more important role than before as they will replace existing national regulations.

The European Committee for Standardization (CEN) has proposed a work plan to produce a complex of European standards in support of the Directives. The standards are divided in three categories, levels. Under the Machinery Directive the first level A comprises general principles and requirements common to all machinery, terminology, etc. The second B level covers ergonomic aspects and specific safety devices, safety distances, control actuators, etc. common to several types of machinery. The third level C deals with specific classes and units of machinery by calling up specific standards from the first two levels and addressing requirements specific to the class. The extent and the intensity of the standardization work in Europe is very high at present as the target date for the market is the first of January, 1993.

Ergonomic issues within CEN are handled by Technical Committee 122 *Ergonomics* which has several working groups. Relevant in this context are Working Group 1 *Anthropometry,* Working Group 2 *Ergonomic Principles,* and Working Group 4 *Biomechanics*. The purpose of this communication is to give a report from a project in Working Group 1 *Anthropometry,* the aim of which is to create a standard for computer manikins. Other projects in WG 1 concern dimensions of passages and access openings at machinery, standing and sitting working postures at machinery, compilation of anthropometric data for the European population, etc.

SOFTWARE DEVELOPMENT

The technical development of computer software, methods and procedures for graphic planning and vizualization is very fast at present. Many new, commercially available programs have been presented during the last few years and more work is going on in research and development laboratories around the world. Programs are available for workstations as well as PCs and Macintosh computers. The programs are of many different types and the quality and the capacity varies. Some programs are designed only for vizualization, others permit biomechanical calculations in static body postures or different types of work space evaluation. Some programs are easy to learn and work with while others are more difficult to use.

FIELDS OF APPLICATION

Computer models of the human body have been available in many shapes since the FIRST MAN was developed by Fetter in 1967 for studies of reach distances in aircraft cockpits. The use of the computer models has a very wide range from making of drawings and pattern design to film animation, movement studies and performance optimization in sports. Surveys of model characteristics and applications have been given by Hickey et al (1985) and Aune and Jürgens (1989).

The early applications in the aircraft industry have been followed by the automobile industry where computer models of the human body are used in the product development process more or less rutinely. Despite the development in computer graphics hardware and software, routine use is still hampered by, for example, difficulties in handling models with many degrees of freedom and slow response of the computers available to designers (Verriest et al., 1991).

The development of computer manikins for use in ergonomics was also early. The well known SAMMIE (Bonnie et al., 1969) took shape at about the same time as FIRST MAN. But, in the field of ergonomics the use has been quite limited due to high system costs in combination with low interest in working environment control. Today the situation is different and the number of applications reported in the literature is increasing rapidly, see for example Karwowski et al. (1990). The structural body models are now also combined with biomechanical models to enable the evaluation of stresses on different body parts due to posture, materials handling and other work activities. It is interesting to note the change of focus from ergonomic evaluation of product function to analysis and control of the production environment that has occurred in recent years.

VALIDITY OF MODELS AND INTERPRETATION OF RESULTS

The interpretation of results of ergonomic evaluation of work stresses based on direct observation and measurement can be difficult and ambiguous. The situation does not become simpler when the evaluations are based on computer models which are roughly specified if specified at all. In some cases the evaluations are done within companies using models developed in house; in other cases the evaluations are made by means of models in commercially available software or by consultants using own software. For the end user it is important to know how the results have been arrived at because this enables him to judge the validity of the used models and the weight to attach to the results. To satisfy the end user in this respect, it is necessary to specify the presumptions and the conditions under which the results have been obtained. The models used must be specified to ameliorate and if possible simplify the possibilities to interpret the results.

Different manikins have different features and before standardization, it is adequate to let the inventors present all important features. When enough experience of work with computer manikins and biomechanical models have been gathered, standardization can take place in the area and the number of models confined to just a few. The first step will be to require specifications together with the results in each application and to standardize the specification. A tentative scheme is given below.

Part of the work in this project is to gather information on the characteristics of the available programs and in particular the manikins used. It is also of interest to know which computers are used, in which applications the programs are used and also to obtain an evaluation of or comments on how useful the existing programs are found to be. All users, developers, manufacturers and marketers of these types of programs are invited to contact me in any appropriate way, the sooner the better. A report of the current status of the project will be given at the conference.

SPECIFICATIONS

For characterization, the man model, the software, and the applications as well as the methods for user control must be specified. The software can be classified according to geometric representation either 2-D or 3-D and further according to category: animation, anthropometric, and biodynamic.

In 3-D the man models can be represented either by a stick figure, a surface or a volume model. In the latter case it is of interest to know whether an endoskeleton is incorporated or not. The number of segments, links, of the model and the construction of the joints should be given as well as the type of coordinate system used to describe the link orientation and whether any constraints are imposed. Also the hierarchial structure of the manikin is of interest, if it can be changed by the user for a specific application, and the resulting number of degrees of freedom. A description of the design of more complex joints of the body such as the shoulder should be included when applicable as well as the way to handle vision. It must be specified how the anthropometric geometry of the model is given, if a data base of the anthropometric measurements of a specific population is provided, if other data bases can be incorporated as well and if it is possible to specify the measurements of a certain individual. When the model is used in biomechanical analyses, data on segment weights, locations of points of gravity and moments of iertia must be given as well as their origin. If some of these data are based on calculations, the method for that must be given together with the underlying assumptions.

The types of analysis the model is intended for is of importance. The evaluation can be by judgement based on a visualization of the model in an environment as a still picture or as an animated sequence of movements. Specific analyses can focus on geometric relations, e.g. reach, reach interference, clerance, ingress, egress etc., or on strength requirements and calculations of loads on specific joints or segments of the body. In the latter case, principles and details of the design of the biomechanical model must be made available to the user as must the origins of any data bases of physical strength and criteria for load restrictions which are used.

Requirements on hardware and software necessary for using the man model and the accompanying software must be given. It is of great interest to know if geometries from for example a CAD program can be imported, or if the man model can be exported and used as part of other programs, or if it can be used in a Computer Aided Engineering environment.

The output of the modelling software depends on whether the analyses done are parametric or not. In most cases the output is graphical as scenes are presented on the display screen togehter with tables and diagrams. Plotters and printers can be used for recording of still pictures and video recorders in the case of animation.

The methods to control posture of the man model should be stated. The possibilities here are numerous ranging from command language control and use of mouse and potentiometers to call of preprogrammed postures from a library. Similarly, the method for controlling and specifying movements in animation should be given: key-frame technique, gesture control, solution of dynamic equations, etc. The availability of procedures to control the interaction between the man model and the environment such as kinematic or other constraints and collision detection are very helpful.

A statement concerning the intended users is recommended. In most cases the user has to be be fairly experienced in anthropometry, workplace design and computing techniques to utilize the full power of software designed for complex applications. For inexperienced users, however, software can be designed to provide guidlines for decision making and interpretation.

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THE APPLICATION OF TWO-DIMENSIONAL MANIKINS FOR DESIGNING FURNITURE FOR CHILDREN AND YOUTH.

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INTRODUCTION

In recent years the number of people with faulty posture has grown rapidly and their average age is constantly decreasing. An organism that is young and not fully developed is especially sensitive to exterior environmental influences. Furniture, furnishings, and toys which are not properly designed and adjusted to the characteristics of the young lead to faulty postures and strengthen pathologic states. In order to prevent these one should apply ergonomics in designing objects.

Ergonomics should be applied in designing all objects earmarked for the younger generation. The Institute of Industrial Design in Warsaw deals with problems connected with the ergonomics of children and youth environment. The concept of developing anthropometric data of children and youth for the design of elements for the furnishings of flats, nurseries, schools and hospitals belongs to basic projects undertaken by the Institute. As the result of the study a set of anthropometric characteristics of children and youth aged 4 months 18 years was obtained. The set contains 69 somatic features, and was published in two monographs presenting physical development of children aged 4 months 3 years (Nowak, 1986), and of children aged 4–18 (Nowak, 1985). These monographs include data represented in tables and expressed as percentiles (5th, 50th and 95th percentiles).

In order to facilitate the work of designers several methodological aids including a set of flat manikins were developed, besides anthropometric data presented in tables. These present the shape of a child’s body changing with age in two dimensions and properly scaled.

TWO-DIMENSIONAL MANIKINS OF CHILDREN AND YOUTH

The following criteria were taken into consideration while preparing the manikins; conformability of functional measurements with current anthropometric data, simplicity of the use of models, of their removal and storing, and the lowest costs of production. In order to meet these criteria it was necessary to reconcile many factors important both for anthropometry and design. It is obvious that even the best model is a static arrangement—it cannot present fully the dynamics of the human body, and especially the dynamics of a child's body changing in the ontogeny. To achieve data synthesis the idea of differentiating manikins in respect of sex was given up. The analysis of the development of body height as well as of other height features of boys and girls indicates that the development of these features of boys and girls up to 10 years of age is similar and that differences of somatic features are statistically insignificant (up to 8 mm) and can be neglected for the need of design.

The manikins were not prepared for each age class but were divided into groups consisting of several age classes. It was very difficult to separate the above groups since it was impossible to take into account the dynamics of development with the division resulting from the necessity of designing furnishings separately for children of kindergartens, primary schools and secondary schools simultaneously. The period between 11 to 15 years of age was the most controversial one. This is a period of rapid changes in a child's body due to puberty. This period differs slightly in case of boys and girls. The pubescent leap is a sign of puberty resulting from hormonal, functional and morphological changes occurring in a child's body that prepare him or her for puberty. The pubescent leap is common to boys and girls, but differs in intensity and persistence in particular children.

In the case of boys the leap occurs at the age of 14 on average, and about 2 years earlier in girls and is less intensive. Differences in dimensions of adult males and females results to a certain extent from the differences of their pubescent' leap. As the girls pubescent leap starts earlier it is less intensive and as a result the process of body development is completed earlier. In practice girls reach puberty at the age of 16 and their body stops growing, while the process of developing body dimensions of boys can occur up to 21 years of age.

Considering the above the groups of boys and girls manikins were divided differently. The manikins, however, were divided with regard to successive stages of child development embracing post-infantile age (1–3 years), pre-school age (4–6 years), younger school age (7–10 years), puberty (11–14 years), and juveniles (15–18). This division complies with the age of children attending nurseries, kindergartens, primary and secondary schools. Considering the above 7 following groups were selected; I—age 1–3 years [x/], II—age 4–6 years [x/], III—age 7–10 years [x/], IV—age- 11–14 years boys, V—age 15–18 years boys, VI—age 11–13 girls, VII—age 14–16 girls. The set of manikins was prepared using the values of 5th and 95th percentiles, to allow the application of threshold percentiles in design. The set consists of 26 models presented in two views: a side view, where figures are in the sagittal plane, and a top view, where figures are in the transverse plane. Each model gives the information on sex, age and its percentile value.

(Fig. 1). The manikins are made of a stiff material, plexiglass, and are of 1:5th scale. There are holes in them which make possible to place the figure in a given position or to move a given segment of the body. The manikin is fixed by sticking a compass leg or a pin into a

x/ without division in respect of sex

hole on the top of head or on foot. Motion capacities are possible thanks to holes representing the axis of rotation of a joint. Motion capacities for the following joints are provided: shoulder, elbow, wrist joints (upper limb), hip, knee, ankle joints (lower limb), as well as head motions (upper

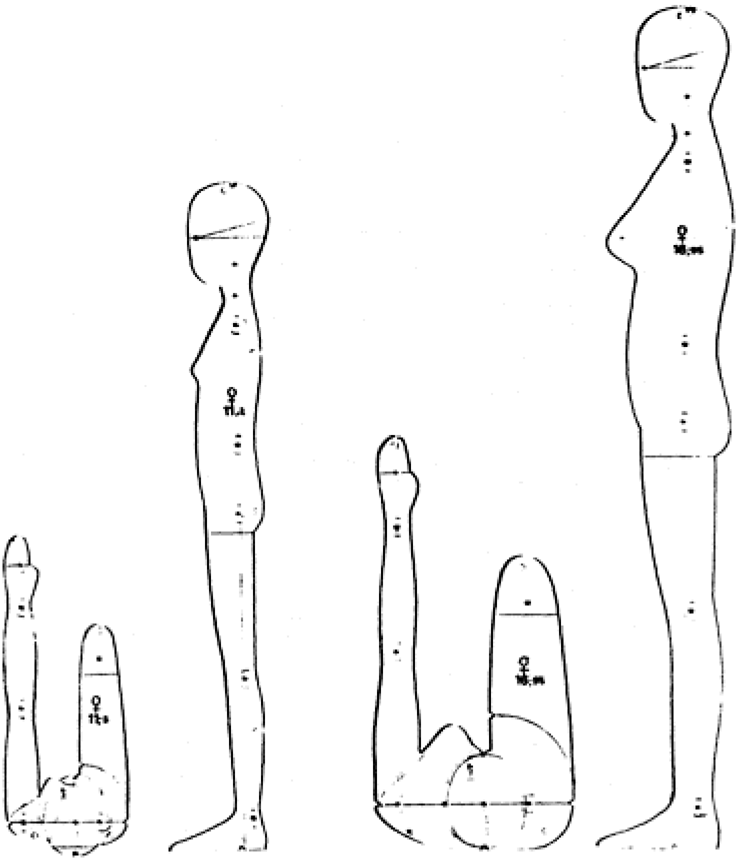


Fig.1. The example of manikins models of youth.

and lower joints of head), neck motions (junction of neck and thoracic segments of spine) and trunk motions (junction of thoracolumbar segment). Flexion and extension movements in all the above mentioned joints can be obtained by means of the manikin developed in the sagittal plane, while the manikin developed in the transverse plane allows us to determine abduction and adduction movements of limbs and head movements. Angular values of the movement range of limbs were obtained on the basis of surveys carried on by the Institute in 1987/88 (Pacocha, 1990). The model in transverse plane is a simplified shape of a child's figure seen from the top. The left side consists of the shoulder, upper limb and breast; the right side consists of the thigh, hip and abdomen. Rotating the manikin along the axis of symmetry one can obtain the contour of the whole body. Contours of upper limb and reach dimension are obtained by putting the model for the transverse plane onto the model of the sagittal plane. Fig. 2 shows, in a simplified form, the ways in which manikins can be used directly on the drawing board; using a drawing pen one can

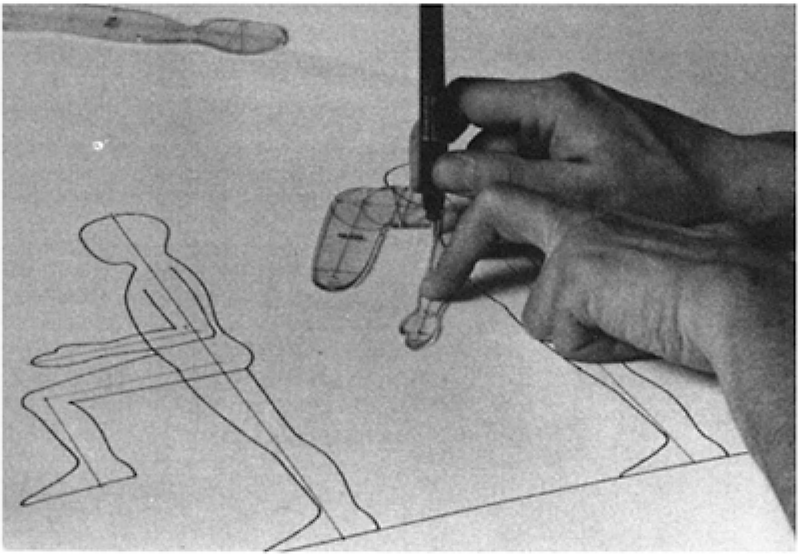


Fig. 2. How to use models.

obtain body contours in different stages of a given movement and determine functional dimensions in the sitting and standing positions.

DESIGNING AND ERGONOMICS ASSESSMENT OF FURNITURE

As it was shown in practice the set of manikins is useful both for design and ergonomics assessment of products. In both cases the manikins allow us to find irregularities in furnishing adjustments to the somatic structure of children and to define the necessary changes. The models should be used mainly at the design stage, and would allow us to avoid further errors. At this stage one can properly adjust furnishings to the somatic structure and needs of a child and thus one can influence indirectly the stimulation of its development.

The prototype set of furniture designed for children aged 0–18 is an example of the application of manikins to the design process. The set was designed by Anna Molag, a designer who cooperates with Ergonomics Research Department of the Institute of Industrial Design. The set was prepared so that it could perform the following tasks:

– storing articles,
– resting,
− working and playing

While preparing furniture basic ergonomics principles were used in order to achieve its:

– functionality (possibility of using furniture by children aged 0–18),
– simplicity of setting,
– adjusting furniture dimensions to the dimensions of children aged 0–18,
– safety and hygienics.

In order to achieve the task the idea of furniture division, based on combining elements according to the task was adapted. This will be discussed in details in the further part of the article. Each piece of furniture was analyzed ergonomically with great care by means of the models of manikins described earlier.

All the basic seat parameters were tested by means of the models of manikins. At the same time desk height was tested as well as measurements of seat height and back rest height. By putting the models of manikins onto designs of seats, referring to measurements of children aged 3–18 (Nowak, 1985, 1986) corrections of the measurements of chair parameters were made. At the same time appropriate desk height for a given seat height was determined. Three types of seats A, B and C and measurements of desks heights referring to them were determined as a result of the analyses carried out. The measurement of popliteal height was adopted as a criterion of seats differentiation, and the measurement of elbow height was used to determine desk height.

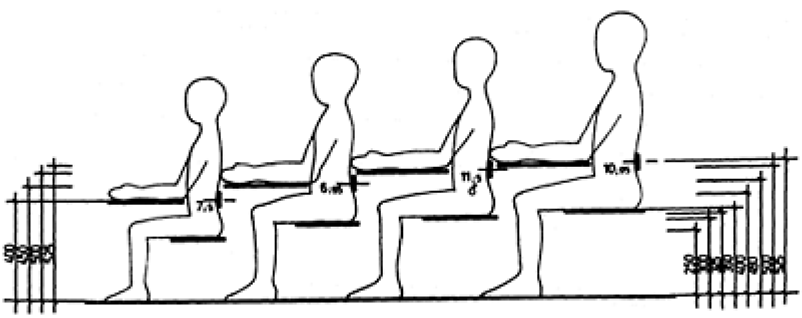
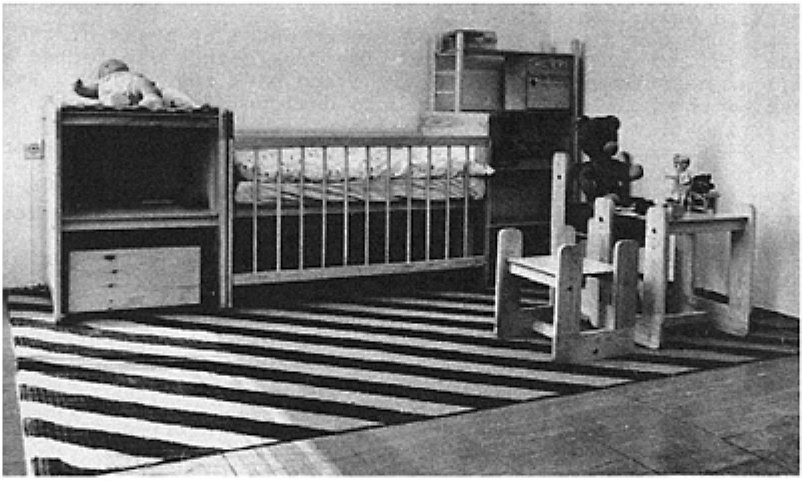


Fig. 3. The application of manikins in determining seat and hight measurement.

In Fig. 3 the analysis of seat height, back rest height and desk height for chairs of type B was given. The adjustment range for height measurements of chair of type A, which can be used by a person up to 18 years of age, measures 350 mm to 460 mm. The desk height recommended for this type of chair varies from 525 mm to 730 mm. The seat height for chair of type B measures 250 mm to 350 mm. The desk height for these type of seats should measure 400 mm to 525 mm. Chair of type C is designed for the youngest children and its adjustment range for height measurements measures 158 mm to 250 mm.

As it was stated previously, the main advantage of the furniture described is that it is multifunctional—it can have several functions. The first possibility of arranging furniture is shown in Fig. 4. This type of furniture arrangement allows to play and relax for children aged 0–3. By changing bed height the bed can be used both by an infant and by a child of 3 years of age. As the child develops furniture change its function. The bed which is no longer useful can easily be changed into a desk and book shelves (Fig. 5). Appropriate adjustment of desk height and chair measurements allows the furniture to be used by children up to 18 years of age.



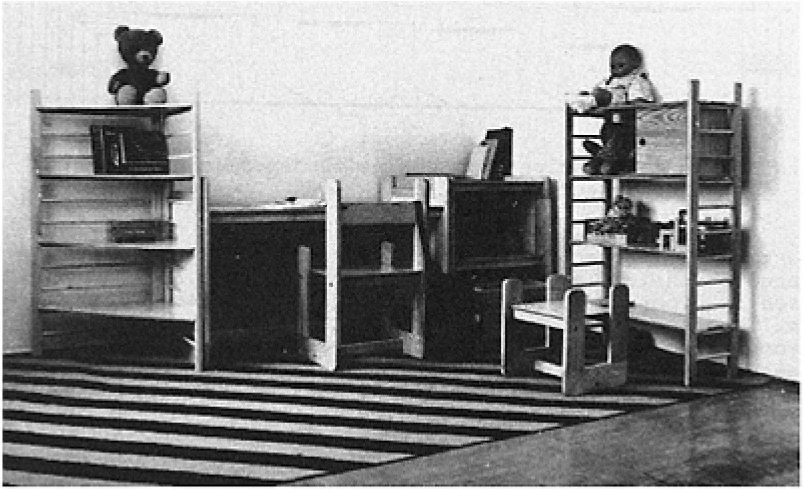


Fig. 4, 5. Multifunction furniture.

One of the main problems is for parents to adjust furniture to the body dimensions of a growing child. It should be stressed, that the set of furniture is made of wood, and is thus safe and hygienic.

CONCLUSIONS

The application of the set of two-dimensional manikins of children and youth (aged 1–18) at the design stage was proved. The designer, besides using anthropometric data, was able to assess necessary changes and make final adjustments at the design stage of an article. This is of great importance, since it allows us to avoid errors that could occur if manikins were not used.

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FORMULATION OF PHYSIOLOGICAL RESPONSES DURING INTERMITTENT WORK UNDER TEMPERATE ENVIRONMENTS

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Relationships were devised based on empirical data of heart rate (HR), tympanic (T_{ty}) and oral (T_{or}) temperature, aiming at developing a predictive method for determining the suitability of work-rest regimes under hot environments. Four males performed sets of four cycles (at 108 W) through pedalling on a cycle ergometer, in testing work-rest ratios of 6/6, 8/4 and 9/3 min./min. under three different controlled temperatures namely 20, 25 and 30 °C WBGT. Trends of HR, T_{ty} and T_{or} values obtained during the latter part of the work periods were tested and found to conform with a general formula.

INTRODUCTION

The combinations of factors affecting the work-heat load in any study are very large and no single investigation can take all of them into consideration. There is an urgent need for intensive studies on the effect of various controlled combinations of work and environmental heat (WHO, 1969; and NIOSH, 1986). This assignment should include a large population of subjects of different physical characteristics such as age, sex, and body build; different task conditions (e.g. the way of doing task, work-load and work-rest regime); and environmental factors. Exchange of information on this subject and cross-checking of conditions from laboratory to laboratory, and from laboratory to industry, are essential (Brain, 1980; Mairiaux and Mal chaire, 1985; and Lee and Ramsey, 1987). Physiological monitoring is limited by the methods that can be used without impairing the worker health or his performance (Brouha, 1967). This consideration, also, reduces substantially the kind of measurements that can be made directly during physical work performance. Therefore, physiological strain imposed due to work-heat stressing factors upon worker can be estimated at a certain degree of accuracy using rational functions. In other words, subjective data, work load level, type of task, work-rest regime and physical environment can be used to plot relationships for assessment of the stress a certain individual is subjected to.

METHOD

Four male healthy subjects aged between 20–22 selected from larger population were participated in this study (Table 1). They were neither athletes nor having regular physical training programmes. All subjects were dressed in T-shirt and trousers during any of the experimental runs. A constant physical work load of 108 W (equivalent to approximately 50% VO_{2max} of subjects) was conducted throughout leg pedalling on a cycle ergometer. The rate of pedalling was kept constant at 50 r.p.m. Such task was performed at repeated cycles under one of three different work-rest regimes for a total work-rest session of 48 minutes. Three work/rest levels (6/6, 8/4 and 9/3 min./min.) were selected to represent the work-rest ratios of 1/1, 2/1, and 3/1 respectively. Four levels of cycle order effect (C_1, C_2, C_3 and C_4) were considered for conducting the three work/rest ratios. A recovery session of 16 minutes was scheduled immediately after the 48 minutes work/rest. Heart rate (HR) in beats/minute, tympanic temperature (T_{ty}) and oral temperature (T_{or}) in C were the measured dependent parameters in this investigation. Experimental data of HR and T_{ty} were averaged for the last two minutes of each work or recovery periods, while oral temperature data were taken as the measured values after work stop and for every 4-minutes during the recovery session.

Table (1) The Physical Characteristics of the Subjects

Sub. No.	Age (yr)	Height (cm)	Weight (kg)	HR* (bpm)	VO_{2max} (lpm)	HR_{max} (bpm)	T_{ty}** (°C)	T_{or} (°C)
1	22	170	68	60	2.8	189	36.05	36.08
2	20	176	68	62	2.8	190	36.33	36.16
3	22	178	75	72	2.9	189	37.12	36.98
4	20	172	71	60	3.3	190	36.80	36.56

* Measured at resting under 20 to 22°C room temperature.
** measured 12 min after resting under 20°C WBGT.

RESULTS

The independent variables of the ambient temperature (A), work/rest ratio (W) and cycle order (C) were subjected to statistical techniques of analysis of variance. The results were extensively described in a previous work (El-Nawawi et al., 1990), where HR, tympanic and oral temperatures were found to be significantly affected by the ambient temperature, the work/rest ratio and the cycle order. The empirical models developed from this study is presented in this section.

Heart Rate

The change in heart rate, as a function of time for the submaximal loading adopted in this study, can be divided into four patterns: the steep rise during the early minutes of work period (about 2–3 minutes), the slight increments (or steadiness) occurring during the last part of work period (last 2–3 minutes), then the quick drop after work cessation (2–3 minutes at the beginning of the rest or recovery) and the slower decrements at the latter parts of rest or recovery.

The latter parts of work periods and the subsequent early segment of rest were of interest in this investigation for the development of rational HR functions. Formulae were expressed to represent the different combinations of work/rest and ambient temperature (6/6, 8/4 and 9/3 min./min. work-rest ratios and 20, 25 and 30°C WBGT ambient temperatures). Four different mathematical expressions were tested to find the best fit for HR curves (as function of time expressed starting each working or resting period): the Power function ($HR=at^{b}$), the exponential function ($HR=ae^{bt}$), the polynomial function of first order ($HR=a+bt$) and the polynomial function of the second order ($HR=a+bt+ct^{2}$). The curve fitting technique of least squares was used to derive the coefficients for these equations using a designated software programme. The power function yielded the best fit for the experimental HR data in either work or rest. Figures (1), (2) and (3) illustrate the plots, best fitted, for the different combinations, based upon the tested functions. These plots expressed the pattern of the HR levels reached during the last part of work (last three minutes) and the first segment of recovery (first three minutes).

The trends of the HR peaks obtained over the last two minutes of work periods were significantly affected directly by the factors involved in this study (ambient temperature, work/rest regime and cycle order), as well as a common effect attributed by the controlled variables mentioned earlier (subjects, task and clothing) or some uncontrolled random variables e.g., psychological state, circadian rhythms,.. etc., (Cohen and Muehl, 1977). The heart rate maximum averages $HR)_{max}$ peaks showed successive increments with cycle order (C). Such increments were determined by the ambient temperature (A) and the work-duration/cycle-duration ratio (R). The trends of such peaks were examined and f ound to be conformed with the following general equation:

$$HR)_{max}=\alpha\, A^{\beta}\, R^{\mu}\, C^{\delta} \qquad (1)$$

where:

A=ambient temperature, (°C WBGT).
R=work-duration/cycle-duration ratio.
C=cycle order.
α, β, μ and δ are constant coefficients.

The HR measured data were averaged over the last two minutes of each work period for all combinations of work/rest and ambient temperature levels. The equation obtained was thus expressed as:

$$HR)_{max}=52.959\ A^{0.2820}\ R^{0.054855}\ C^{0.074308} \quad (2)$$

A high correlation between the experimental and the calculated $HR)_{max}$ values was found (r=0.91). The set of curves obtained for the calculated $HR)_{max}$ values is shown in Figure (4).

The constant work performed in this study was about 50% VO_{2max} of the subjects and the expected HR was about 130 bpm in comfort environments (Astrand and Rodhal, 1970; and AIHA, 1971). Considering a HR value of 140 beats/minute as a critical limit, the following equation could be extracted from equation (2):

$$A=[140/(52.95924\ R^{0.54855}\ C^{0.07430785})]^{3.5459} \quad (3)$$

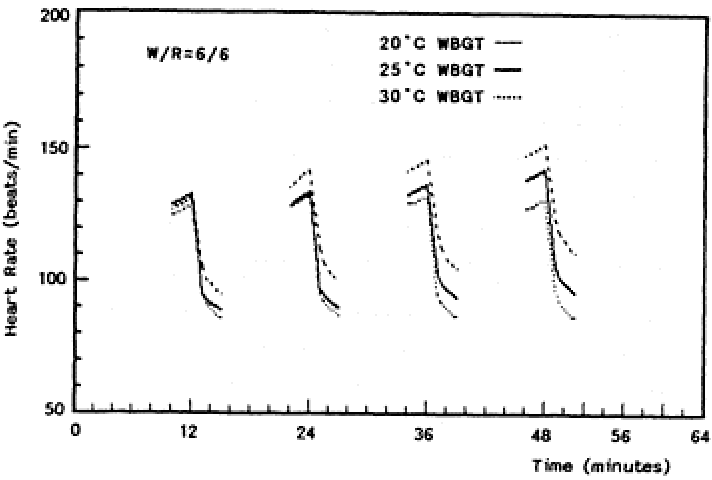

Fig. (1) Fitting Curves for the Heart Rate Data Based on the Tested Empirical Formulae (Data of the 6/6 W/R Regime)

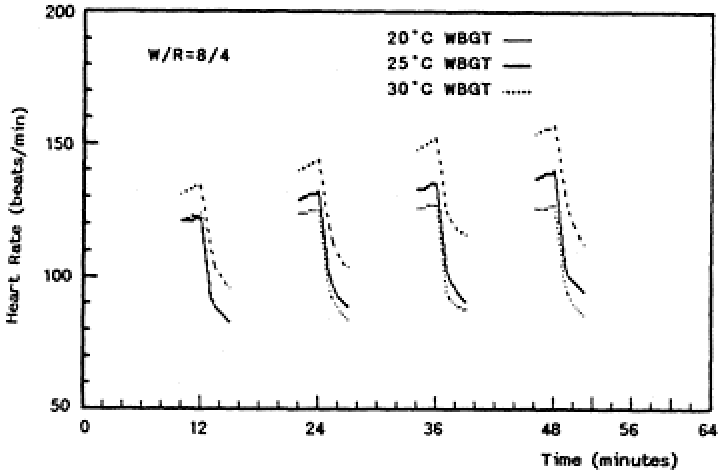

Fig. (2) Fitting Curves for the Heart Rate Data Based on the Tested Empirical Formulae (Data of the 8/4 W/R Regime)

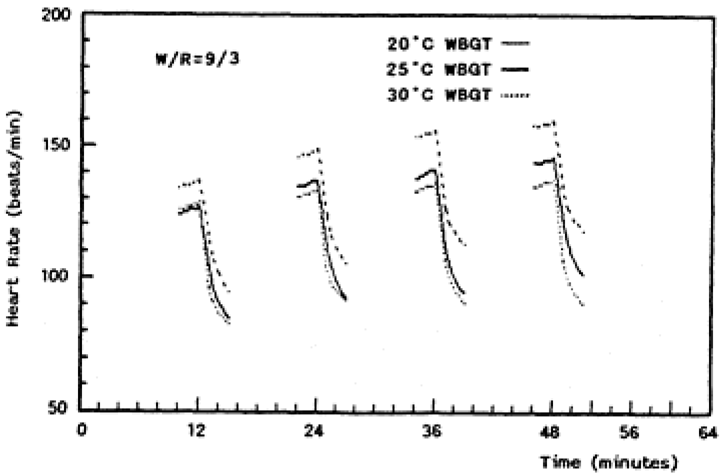

Fig. (3) Fitting Curves for the Heart Rate Data Based on the Tested Empirical Formulae Data of the 9/3 W/R Regime)

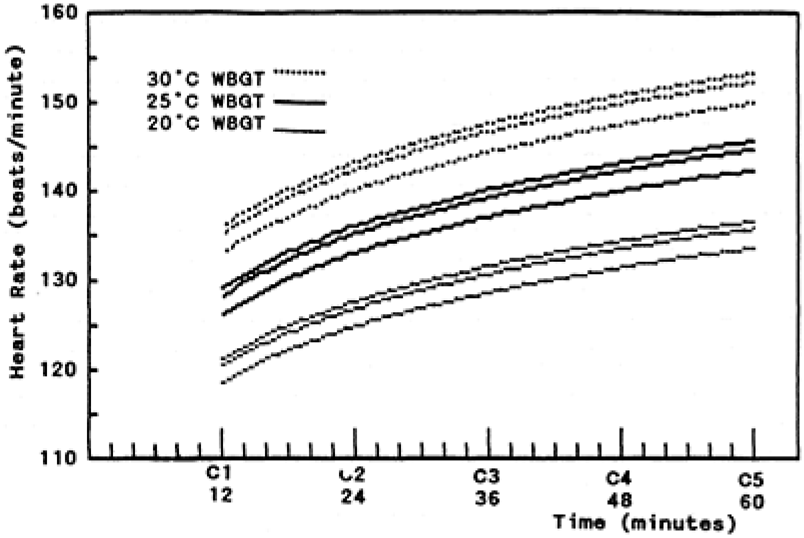

Figure (4) Fitting of Curves for the Maximum Heart Rates Obtained from the General Empirical Formula

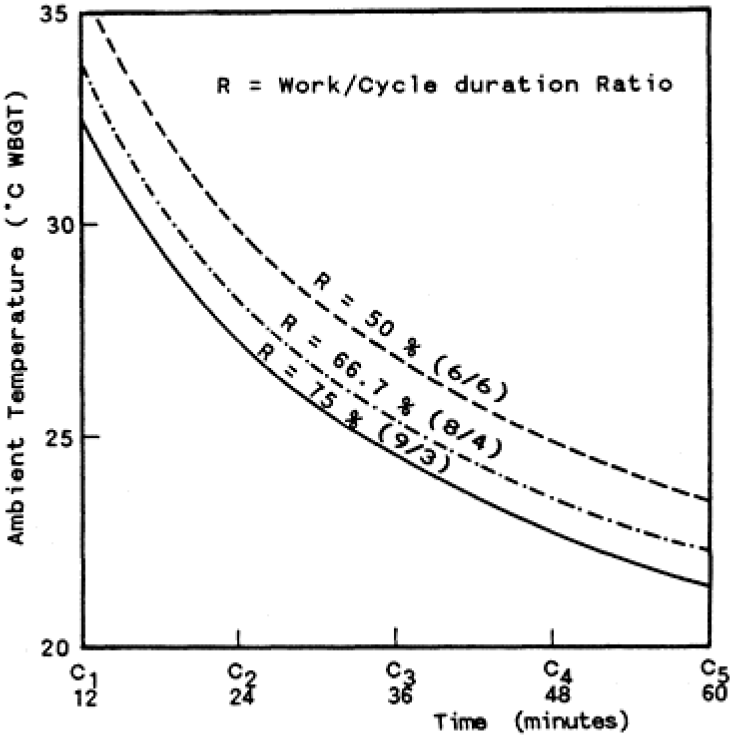

Figure (5) Time Limit Curves Based on Heart Rate Maximum Values of 140 bpm During Cyclic Work Performance

Figure (5) shows a plot of curves determining the ambient temperature—cycle-order/time limits for the different work-rest regimes. These curves were characteristic of the particular experiments carried out in this investigation. However, it can be modified using correction factors for age, sex and other experimental conditions to provide a reasonable estimate for HR when performing work-rest cycles under worm or hot environments.

Tympan Temperature

The average T_{ty} measured values implied significant differences due to the work/rest ratio effect as well as the ambient temperature effect. Such differences were detected starting in the early phase of work-rest sessions. The averages of T_{ty} for the three work/rest ratio levels had consistent close differences compared with those obtained for the ambient temperature, which may suggest higher sensitivity of tympanic temperature to the ambient temperature levels selected in this study. A progressive rise for the T_{ty} with the cycle order was also obtained under the prescribed experimental conditions. Most of the

T_{ty} increments took place during the first cycle, while less increments were observed during subsequent ones.

The cyclic changes in tympanic temperature did not show remarkable drop in values as in case of the HR. However, similarity of the patterns of change for maximum levels of HR and T_{ty} were observed. Tympanic temperature values corresponding to the $HR)_{max}$ (The averages of the last two minutes of work periods) were used to fit a similar mathematical form and the following function was obtained:

$$T_{ty})_W=31.263\ A^{0.054423}\ R^{0.17225}\ C^{0.01568} \quad (4)$$

Figure (6) shows a plot of the curves for the estimated tympanic temperature values resulted by the above formula. Such plots were made for the performance at the three levels of work-duration/cycle-duration ratio (R) under each of the environmental temperature (A). The experimental and estimated T_{ty} average values were tested and found to be highly correlated (r=0.95).

Oral Temperature

The trends of oral temperature measured values were found to be inferior to that corresponding of tympanic. Also, the differences between oral temperatures under the three levels of ambient temperature were closer as the work/rest ratio level was lower. A progressive rise for the oral temperature with the cycle order was also obtained under the prescribed experimental conditions. Stabilization of oral temperature was almost to be observed during the last two cycles' phase (C_3 and C_4) especially under the two lower levels of ambient temperature (20 and 25°C WBGT). Such stability was not observed under the higher ambient temperature level (30°C WBGT).

The oral temperature values measured after each work cycle were used in order to fit curves in a similar manner to that of tympanic temperature. The same model was also used to develop a formula for the estimation of the oral temperature based upon the working conditions (work-duration/cycle-

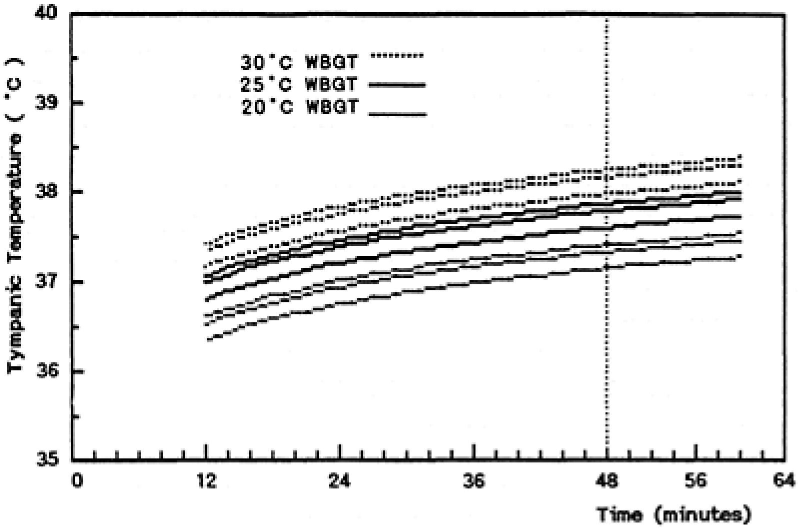

Figure (6) Fitting of Curves for the Tympanic Temperature Trends Obtained from the General Empirical Formula

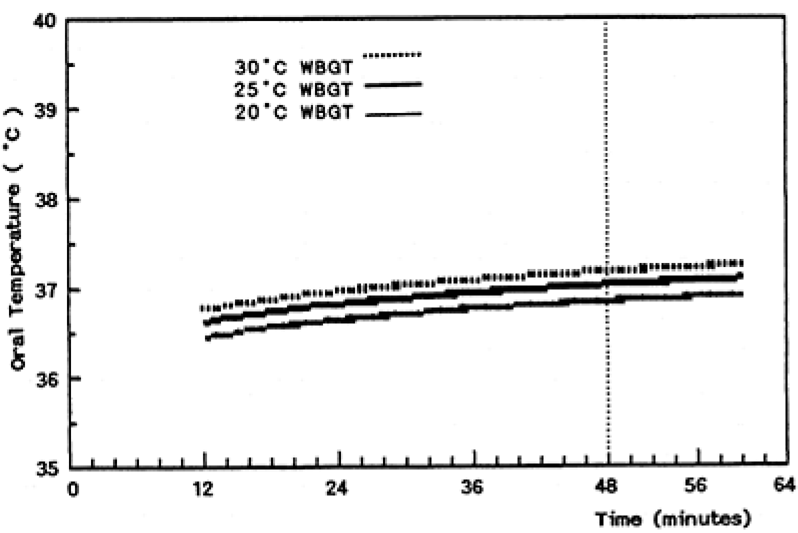

Figure (7) Fitting of Curves for the Oral Temperature Trends Obtained from the General Empirical Formula duration, ambient temperature and cycle order):

$$T_{or})_W=34.215\ A^{0.021523}\ R^{0.002403}\ C^{0.008401} \quad (5)$$

Figure (7) shows a plot for the estimated oral temperature values obtained from the developed model. Such plot explored the direct progressive effect of temperature which could be detected through the experimental session. The experimental and the estimated T_{or} average values were found to be highly correlated (r=0.91).

CONCLUSIONS

1) The outcome of the results indicated that the evaluation of work-heat stress effect on humans is a particularly complex problem. No specific trend can be generalized using one single response to evaluate the combined stressing factors. The need to acquire a mean of relationship description between measures such as HR, T_{ty} and T_{or} is still imminent.

2) The HR, T_{ty} and T_{or} formulae and charts developed in this study, although, they were characteristic of the particular experiments carried out. However, they can be modified using correction factors for age, sex,…and other experimental conditions to provide a reasonable estimate for such physiological responses when performing physical work-rest cycles under warm or hot environments.

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DESIGNING MACHINES FOR MAN: ANALYZING AND OPTIMIZING A CNC CYLINDRICAL GRINDING MACHINE IN THE DESIGN PHASE

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The following article reports on a research project which was carried out in cooperation with industry. A CNC cylindrical grinding machine which was still in the design phase, was analyzed and designed from an ergonomic point of view. The method of videosomatography was used to achieve this end.

INTRODUCTION

The rate of innovation in mechanical engineering in the face of the ever-increasing pressure of industrial competition is becoming faster and faster. It is thus of increasing importance that besides developing a high flexibility in the technical functions of a machine, the customer’s demands for a good ergonomic design of the machine operator’s workplace should be taken into account.

Proper dimensional and movement-oriented workplace design is an essential prerequisite for low-stress working in manual work systems. A lack of the necessary ergonomic design results in the machine operator having to work under unfavourable conditions which can involve severely strained body posture and position. As experience has shown in industrial practice, the negative effect of an ergonomically unfavourable workplace on the machine operator can result in a reduced efficiency of the whole work system.

The planning and designing of an industrial workplace can be a very time-consuming process. Since the time required is usually unavailable within a firm’s development and construction departments the result is that often only a fraction of the workplaces can be systematically designed according to ergonomic principles. In addition to this, many small and medium-sized firms lack the appropriate ergonomic know-how.

Therefore a well-known German manufacturer of grinding machines has decided to implement the design of a planned CNC circular grinding machine in cooperation with the Department of Ergonomics at the IAO. The goal of the joint venture was to monitor the machine for ergonomic deficits and to test different design solutions during the early stages of the design process. The technique of videosomatography was to be used to this end.

Videosomatography is a technique well fitted for the ergonomic analysis, evaluation and design of machine workplaces. Using this method, new designs or alternative design solutions can be checked and revised at a very early stage in the design process thus reducing the risk of incurring costly corrective measures at a later date. Another benefit of the method is that it works on the basis of initial drafts without having to build costly test prototypes.

METHOD

CNC cylindrical grinding machines are used for the external, internal and contour grinding of turned parts. The testing of the planned machine was limited to the manual activities of the operator. Any programmable or automatic regulation of the machine controls were disregarded during the testing.

Testing Procedure

The testing was divided into the following steps:

Step 1:
The tasks of the machine operator were discussed with the manufacturer and, using both the available drafts and machines of older design, were then analyzed and noted down. During this process, all those manual activities were determined which were subsequently to be investigated using videosomatography.

Step 2:
Each individual activity of the machine operator was simulated in the laboratory with the help of videosomatography. The simulation was based on the available drafts of the planned CNC circular grinding machine (see fig. 1) and the test subjects were formed by the members of an operating crew whose body size covered the range of 5th to 95th percentile (height, arm reach). A video recording was made of the simulaton for subsequent assessment.

Step 3:
Using the video recording, the single actions were checked for any possible ergonomic deficiencies.

Step 4:
Alternative design solutions were suggested and implemented to remedy the deficits, these were then likewise checked using videosomatography.

The technique of videosomatography

The method is based on the principle of blending a video image of a scale drawing of a workplace with a video image of a test subject in such a way that a scale representation of the workplace and the working individual is reproduced on a monitor.

To achieve this the videosomatography laboratory at the IAO is divided into three areas, a layout area, a studio and a control panel (fig. 2). In order to reproduce the blend of two images, two video cameras film two areas simultaneously, i.e. the scale drawing of the workplace is filmed in the layout area and the living test subject is filmed in the studio. The signals generated by the respective video cameras are then electronically mixed at the control panel using a vision mixer.

The test subject is selected on the grounds of suitability with regard to the user group or body proportion. The body size

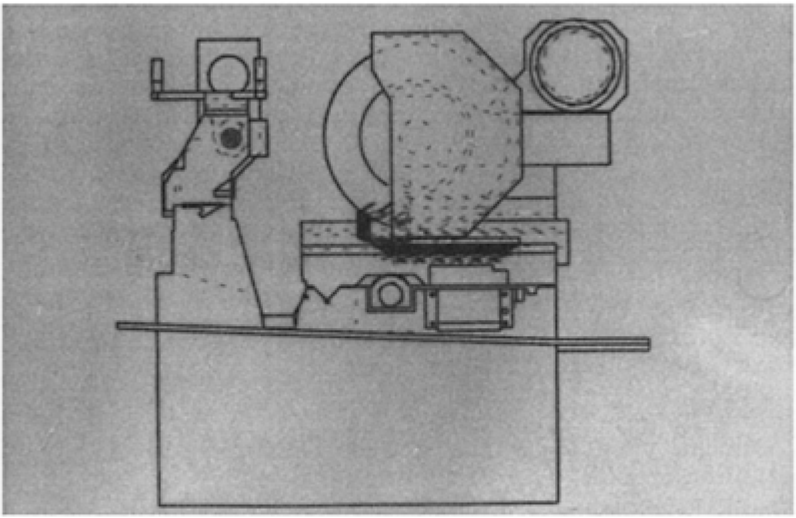

Fig. 1: Draft of the CNC circular grinding machine used for the videosomatography (side view without machine housing)

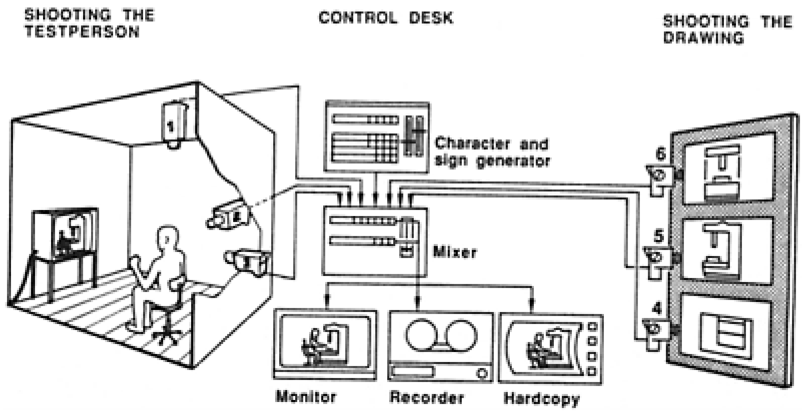

Fig. 2: Configuration of the videosomatography laboratory

of the test subject can be adapted to the scale drawing of the workplace by using zoom lenses. This means that the total adaptation range of percentile body size can be covered by smooth gradation from the 5th to the 95th percentile.

In the studio, the test subject is provided with a dummy reconstruction of the workplace built of simple geometric forms and a control monitor within field of vision. These enable the test subject to coordinate and monitor the necessary sequence of movements more easily. The image of the dummy reconstruction can be deleted from the recordings using the “blue box” method.

Finally, the resulting videosomatographic analysis is documented using a video recorder and a hardcopy device.

TEST RESULTS

The videosomatographic investigation of the CNC circular grinding machine included the following manual activities:

– operating the part-loading door
– exchanging the part (parts of different lengths)
– shifting the part headstock
– adjusting the tailstock spring
– changing the grinding wheel
– changing the grinding wheel surface planer
– adjusting the grinding headstock

The results of the videosomatographic investigation will be represented in the following by the two activities, shifting the part headstock and changing the grinding wheel surface planer.

Shifting the part headstock

The machine operator stands in the open door at the front of the machine during this activity. By shifting the part headstock the distance between the centres can be adjusted to accommodate a part of a different length. In order to do this the fastening screws on the font of the part headstock (facing the front of the machine) must be loosened using a spanner. An air pressure valve on the left hand side of the part headstock is then turned by hand. The air thus released forms a cushion between the part headstock and the guideway which enables the operator to shift the part headstock manually (max. displacement force ca. 100 N.). When the part headstock has been moved to the required positon the air pressure valve is closed and the fastening screws are tightened.

Adjusting the part headstock became difficult when the length of the part exceeded 300 mm. Fig. 3 and 4 show operators of the 5th and the 95th percentile adjusting the part headstock to accommodate a part 600 mm in length (top view). The unfavourable body posture of the operators can be clearly seen. Only by bending, at the same time twisting the torso and stretching far forwards can the operators reach the screw points on the part headstock. This is an extremely strained body posture which a machine operator can hardly be reasonably expected to assume. The cause lies in the fact that the door's width of opening is too small. This prevents direct frontal access to the screws and to the valve. Instead, the operator which stands on the right hand side of the part headstock can only reach them from the side which means that the reach access for head and arm movement

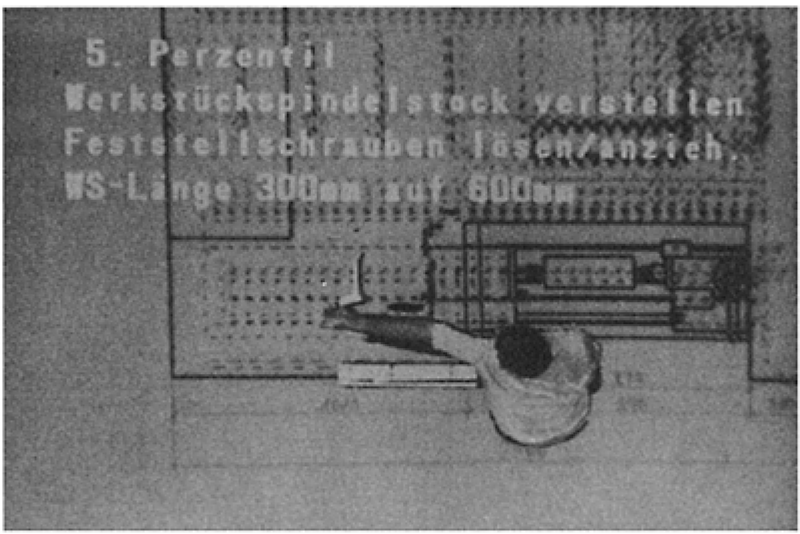

Fig. 3: Videosomatographic investigation of the activity of shifting the part headstock, 5th percentile

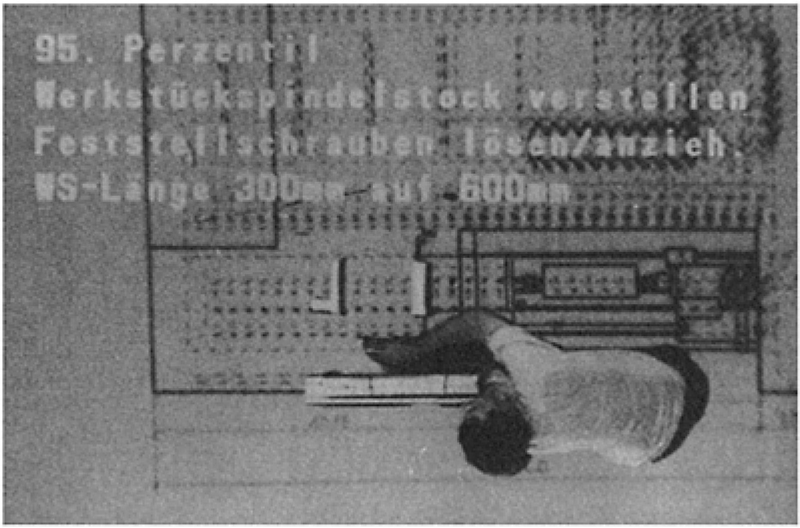

Fig. 4. Videosomatographic investigation of the activity of shifting the part headstock, 95th percentile

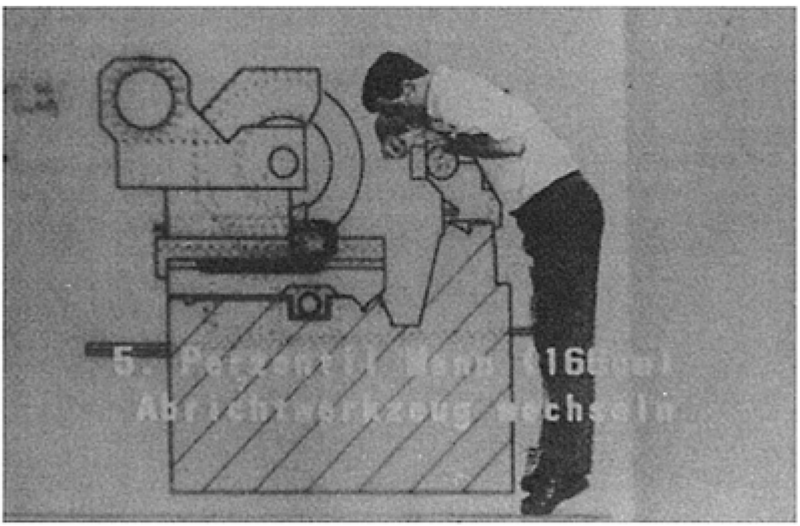

Fig. 5: Videosomatographic investigation of the activity of changing the grinding wheel surface planer, 5th percentile

is reduced to a narrow gap between the machine housing and the part headstock.

Changing the grinding wheel surface planer

The surface planer is situated on the tailstock which is on a level with the guill on the side of the machine facing the grinding wheel. In order to change the surface planer the operator has to loosen a number of fastening screws which can only be accessed from the grinding wheel side. The screw points are not directly visible from the operating position at the front of the machine. Fig. 5 shows that a 5th percentile man can only see the screw points by standing on tiptoe and bending deeply over the tailstock. This is also a case of a strained and severely tiring body posture. In addition, the operator’s knees knock against the water gutter which is attached to the front of the machine. What is more, this gutter also prevents the operator from being able to stand closely to the machine bed.

DISCUSSION AND DESIGN PROPOSALS

The follwing alternative design proposals give some examples of the measures which were prepared for the weak points revealed during the analysis of the operator’s activities on the machine. The corrective measures could be drawn directly onto the existent drawings and subsequently checked with the help of videosomatography.

Several alternative door designs were suggested to provide direct access to the headstock during the activity of adjusting the part headstock. A sliding door consisting of several separate sections was chosen as the most suitable solution. A door of this nature allows frontal access to the part headstock even when this has been adjusted to accommodate a part 1000 mm in length. In addition, a handle for the part headstock was suggested which would facilitate the application of tractive force on the part headstock and which would help prevent the part headstock from tilting while being shifted.

A new attachment module was developed for the grinding wheel surface planer in which the screw points are now to be found on the top of the tailstock. This means that the activity of changing the surface planer can now be performed in an upright stance. The width of the water gutter could be appreciably decreased in the area of the frontal door thus reducing the risk of injury through collision. Furthermore, in order to allow the operator to step up closely to the machine an adequate amount of foot room under the machine bed has been provided for.

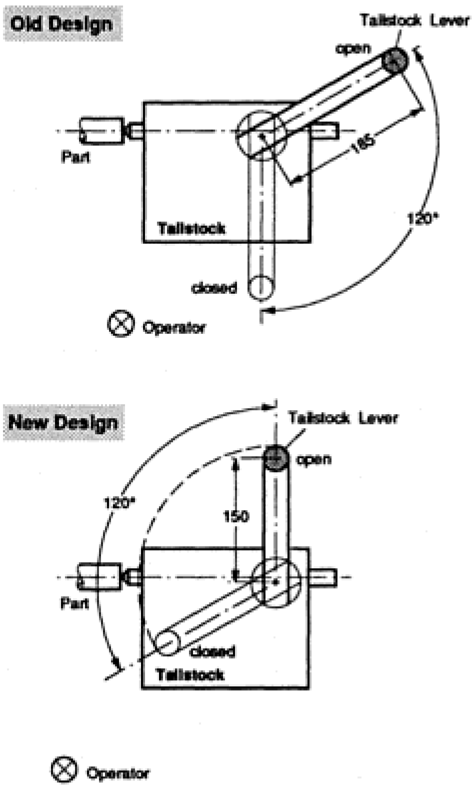

Fig. 6: Alternative design proposal for optimizing the operation of the manual lever (clamping the part)

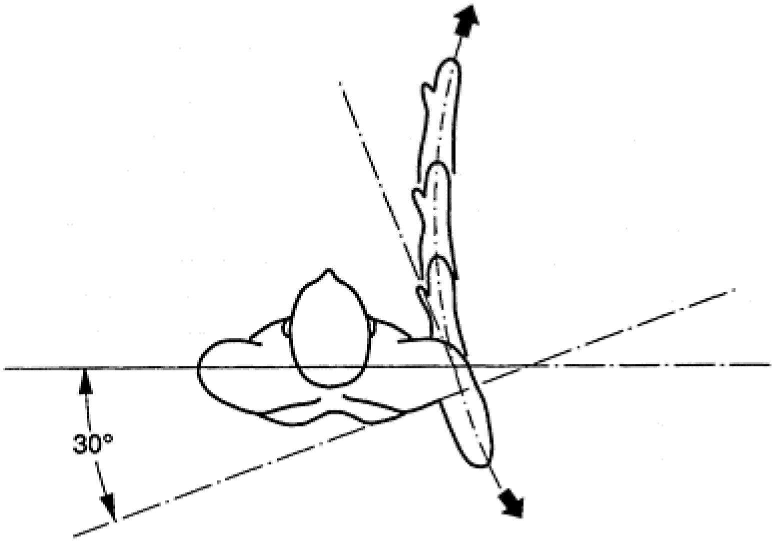

Fig. 7: Compulsory rotation of the human shoulder girdle

The manual lever on the tailstock which is used to clamp the part (during the activity of changing the part) has also been redesigned. Fig. 6a shows the original arrangement with the lever swivelling in a clockwise direction. The corrective measure (shown in fig. 6b) shows the lever now swivelling anticlockwise. Moving the arm in this direction is more compatible with the anatomically-determined compulsory rotation of the human shoulder girdle (fig. 7). Thus the distance between the manual lever and the part has been reduced. The operator can now hold the part closer to his body which makes clamping more easily. An additional advantage of this measure is that the operator is now able to bring up a higher arm force so that the length of the lever can be reduced.

The suggestions for improvements on the machine which were developed as a result of the videosomatographic analysis were discussed together with the manufacturer and adapted according to their compatibility with the peripheral technical conditions. In this way, the design solutions could be taken into account early in the detailing phase and incorporated in the structural drawings.

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SIMULATION OF TECHNIQUES USED TO POSITION RAILCAR DRAWBARS: A PILOT STUDY

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This study examined the maximal force that could be generated by four different techniques that are used to move a railcar's drawbar into proper alignment such that it can "make" with a drawbar of an adjacent railcar. The four techniques examined were; 1) anterior push, 2) posterior push, 3) anterior lift, and 4) posterior lift. The twelve subjects performed the four techniques following the Caldwell Regimen to determine the static Maximum Voluntary Contraction (MVC) for each technique. The results indicated that the lifting techniques were superior to the pushing techniques in terms of generating maximal strength. However, generating maximal strength should not be the only concern in selecting a drawbar alignment technique.

INTRODUCTION

Although there have been major advances in manual material handling over the last decade, there are still areas where these advances can not be made easily. For example, railroad yard workers may need to position a drawbar on a railcar so that two cars can be connected. Because of the random frequency of the task and the random location of the cars in the yard, it is difficult to carry a tool around which would give the worker a mechanical advantage. Therefore, the worker must physically move the drawbar into its proper alignment.

A drawbar can be found at either end of a railcar underneath the frame and above the wheel assembly. One end of a drawbar is pinned to the bottom of the car and it pivots laterally around the pin. The knuckle is found at the terminal end of the drawbar. It points away from the car. It is this part which couples or "makes" with the knuckle of another car.

McMahan (1988) looked at two popular solo techniques used by railroad yard workers to position the drawbar. The first technique has the worker stand with his/her anterior to the knuckle. The worker cups his/her hands and places them

Figure 1. Anterior Push

Figure 2. Posterior Push

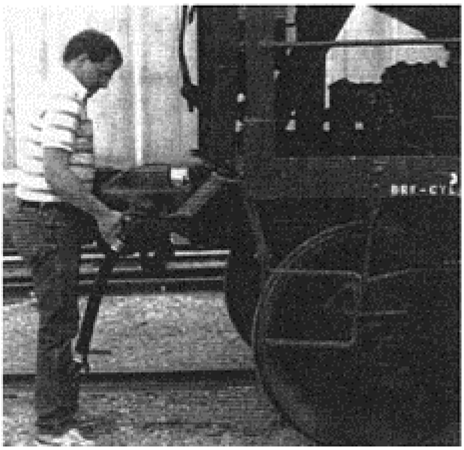

Figure 3. Anterior Lift

Figure 4. Posterior Lift

beneath the knuckle of the drawbar. The worker, then, slightly lifts the knuckle and slides it into position using the anterior push technique (Figure 1). The second technique has the worker stand with his/her posterior facing the knuckle. The worker cups his/her hands behind his/her back under the knuckle and slightly lifts while sliding the drawbar into position using the posterior push technique (Figure 2). Both of these techniques have the worker standing at the side of the drawbar. The results of McMahan’s (1988) study indicated that the posterior push (backing in) technique may be better, especially for smaller workers.

The objective for this study was to compare the two techniques which McMahan (1988) had studied with two alternative solo techniques. The first alternative has the worker stand anteriorly to the knuckle. Using both hands, the worker lifts the knuckle and side-steps it into position using the anterior lift technique (Figure 3). The second alternative has the worker stand with his/her posterior to the knuckle where upon the worker lifts the knuckle and side-steps it into position using the posterior lift technique (Figure 4). Both lift techniques have the worker standing at the end of the knuckle with his/her frontal plane perpendicular to the long axis of the car. The worker's hands are separated in the two lift techniques so the worker can grasp the edges of the U-shaped knuckle which opens toward him/her. It is hypothesized that if the worker is capable of generating a higher amount of force by using the alternative techniques, then a smaller amount of energy would be required to perform the task of positioning the drawbar. Secondly, if the two alternative techniques are shown to be better force producers; then, the safety and visual concerns need to be addressed to know if the lifts are the most appropriate techniques to use in positioning a drawbar.

METHOD

Subjects

Twelve college students participated in this study. They were all healthy males who had had no history of back disorders. Their ages ranged from 22 to 36 years of age (mean=27.2, sd=5.2) and their stature ranged from 66 to 75.5 inches (mean=69.7, sd=3.2).

Apparatus

The study was conducted within the lab; therefore, it was necessary to simulate the drawbar for the four techniques used in the study. To conduct the simulation, two separate apparatuses were built. The first (LIFT) apparatus was built to measure the static MVC for the anterior and posterior lifts. The second (PUSH) apparatus was built to measure the static MVC for the anterior and posterior pushes. Both apparatuses were built out of wood. The four techniques and the apparatuses are shown in Figures 5–8.

The LIFT apparatus used a Dillon Load Cell (Model Z), which was placed in a tension mode, to measure the static MVC exerted in the lifting techniques. It was wired to a Dillon Force Meter (Model SGCN). The load cell in conjunction with a steel cable connected the bottom of a 14 inch wide box to the floor. The width of the box was similar to the width of a standard drawbar knuckle and the height of the box (10 inches) represented the height of a drawbar knuckle. The distance between the bottom of the box and the floor was approximately 34 inches and was controlled by the length of the cable. The 34 inch distance represented the maximum distance between the bottom of the knuckle and the top of a tie. It should be noted that ballast (rock or dirt) on top of the tie could reduce the distance below 34 inches.

In the PUSH apparatus, a load cell was connected to the apparatus at a fixed location behind a freely moving lever arm. The load cell (Model USB-25100) was placed in a compression mode and was wired to a load cell meter (Model

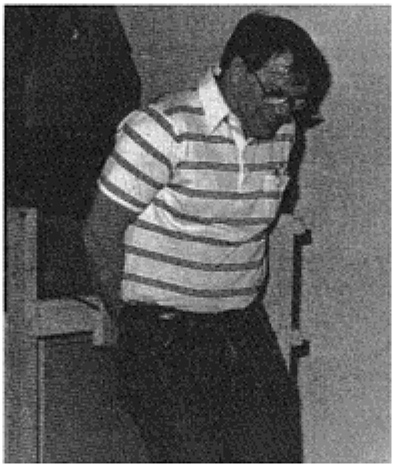

Figure 5. Anterior Push

Figure 6. Posterior Push

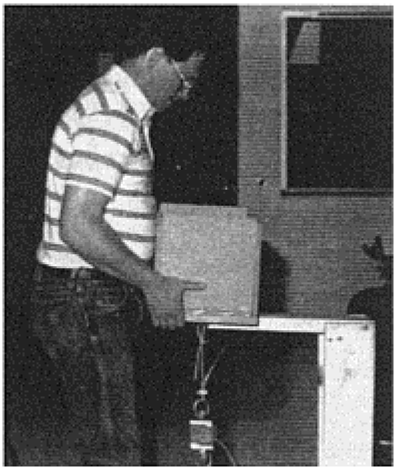

Figure 7. Anterior Lift

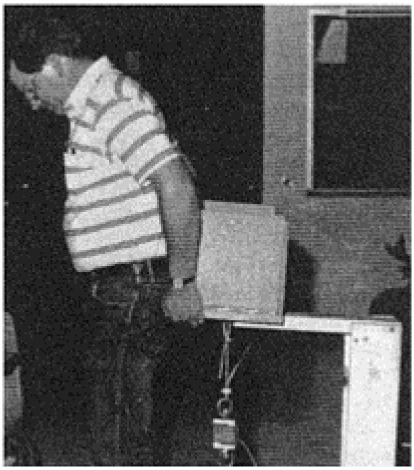

Figure 8. Posterior Lift

SG1000P). Force was applied by the subject to the load cell. This was accomplished by pushing on a pad which was connected to the freely moving lever arm. The pad had the same approximate dimensions as a standard drawbar. The bottom of the pad was located 34 inches above the ground. The PUSH apparatus was attached to a cabinet in order to absorb torque which was developed in the static pushing techniques.

Procedure

The method of determining the differences between the four techniques consisted of using the Caldwell Regimen (Caldwell et al., 1974) to determine the static Maximum Voluntary Contraction (MVC) of each trial. The four techniques were tested in a random order with each technique being performed three times.

The procedure for the study consisted of; 1) explaining the purpose of the study to the subjects, 2) having them sign an informed consent form, 3) collecting anthropometric data (stature and age), and 4) showing them where to locate their hands and how to properly apply force to the two apparatuses in order to standardize the standing postures for the four techniques. There were expected differences, however, in style (ie., use of legs, bracing, individual differences in method due to stature).

RESULTS

An analysis of variance, using a general linear model procedure on SAS, was used to test for the dependent variable of peak force. The independent variables were trial, technique, subject height, and their interactions. The trials were the three repetitions performed using each technique. The techniques were the anterior push, posterior push, anterior lift, and posterior lift. Subject height was categorized as above the mean or below the mean. The mean was 68.3 inches (Kroemer, et al., 1986). The resultant design was a 3 (trial)×4 (technique)×2 (height) mixed factor model with blocking on subjects nested within height.

An analysis of variance performed on SAS demonstrated that the significant effects were; 1) technique and 2) technique by height (Table 1). A post-hoc Tukey test was performed on the main effect of technique as shown in Table 2. A simple effects F-test was performed on the four techniques by each of the heights. For the people who were below the mean in height, there was no significance for techniques (p=0.0625). There was, however, a significant difference for techniques by those people who were above the mean in height (p=0.0001).

Table 1. The results of the F-test conducted in the ANOVA using GLM with confidence interval of 95% and alpha=0.05 where subject is the error term.

Source	DF	Anova SS	Mean Square	F Value	Pr>F	Sig
Trial	2	5941.464	2970.732	3.44	0.0518	
Technique	3	380124.1	126708.0	25.19	0.0001	X
Height	1	56013.93	56013.93	1.04	0.3312	
Trial X Technique	6	3070.858	511.8097	1.00	0.4362	
Trial X Height	2	85.15447	42.57724	0.05	0.9519	
Technique X Height	3	66273.16	22091.05	4.39	0.0112	X
Trial X Technique X Height	6	1100.806	183.4677	0.36	0.9029	

Table 2. The results of the post-hoc Tukey test conducted in the ANOVA using GLM for Techniques with a confidence interval of 95% and alpha=0.05.

Tukey Grouping	Mean	Trial
█	260.73	Posterior Lift
█	256.66	Anterior Lift
█	156.28	Posterior Push
█	143.19	Anterior Push

A post-hoc Tukey test was performed on the main effect of technique for the subjects who were deemed to be above the mean height. The results are shown in Table 3.

DISCUSSION

From the results of the study, three topics need to be discussed. The first is the significance of the techniques for all of the subjects. The second is the significance of techniques for the subjects who were above the mean, and third the safety and visual concerns of the worker if he/she stands at the end of the drawbar. These topics are discussed in greater detail below.

In the post-hoc Tukey test (Table 2) for all of the subjects, it was indicated that the average static MVC for the two push techniques were equal (given a 95% Confidence Interval) to each other. These results differ from McMahan's (1988) study which indicated that there was a difference between the two pushes with respect to height. However, McMahan's study used a biomechanical model and the criteria of that study considered a push to be safe as long as the force of all the joints in the model were below 75% of maximum. Also, McMahan's biomechanical model was for the male extremes of 5% and 95%. The present study considered overall strength for the two groups of males; the first group

Table 3. The results of the post-hoc Tukey test conducted in the ANOVA using *GLM* for Technique by above average height with a confidence interval of 95% and alpha=0.05.

Tukey Grouping	Mean	Trial
█	292.75	Posterior Lift
█	292.02	Anterior Lift
█	151.50	Anterior Push
█	147.49	Posterior Push

consisted of individuals who were shorter than the mean of 68.3 inches (Kroemer et al., 1986) and the second group consisted of individuals who were taller than the mean. The variations between the two studies could be the cause for the different results.

The results in Table 2, also, indicated that the average static MVC for the two lift techniques were equal (given a 95% Confidence Interval) to each other. This would indicate that either lift could be conducted by the worker. It would be a matter of employee preference.

Table 2, also showed that there was a significant difference between the lift techniques and push techniques. This appears to indicate the superiority of the lift techniques with respect to the generation of maximal forces. This means that lifting would likely be easier than pushing and that the worker would likely use a smaller percent of his/her MVC in the lift techniques compared to the push techniques.

It was indicated by the analysis of variance (Table 1) that techniques by height was significant. This was clarified by a simple effects F-test analysis which indicated that there was only a significant difference for the subjects who were above the mean in height. Specifically, the lift techniques were better than the push techniques (Table 3). As previously stated, past research provided only biomechanical modeling for the 5th percentile male verses a 95th percentile male. It did not test heights in between the extremes to determine where the switch to a different technique might have occurred. This study looked at two ranges; but, it did not do much better at finding a break point due to the small number of subjects.

Finally, the static LIFT techniques were defined as having the worker stand at the end of the drawbar where upon he/she lifted the knuckle and (mentally) sidestep it into position. The LIFT techniques could create some problems because of this definition. For example, from a safety aspect the LIFT techniques could cause a worker to be pinned between two drawbars causing serious injury or death. A second problem with the LIFT technique is that it reduces the workers ability to visually see the alignment of the two drawbars. In order to reduce these concerns it might be best to have the worker stand to the side of the drawbar with one leg positioned below him and the other leg braced against the rail, so that he is able to lift and push simultaneously. With some alterations to the basic concept of the two apparatuses involved in this study, it could be possible to study both the horizontal and vertical forces simultaneously. This may be useful in determining a proper technique for moving the drawbar.

Further study should include subjects who regularly do this task, a fixture that can measure both horizontal and vertical forces and biomechanical analysis of the compression forces especially in the lumbar area.

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AN ERGONOMIC APPROACH TO DEVELOPING SUPPORTING EQUIPMENT: FOCUS ON AN ASSEMBLY LINE WHERE POOR WORK POSTURES ARE COMMON

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In this project, a practical Ergonomic approach based on three key methods—asking/listening, observation and scientific approach was drawn up for an assembly line in a flexible manufacturing system. The project's focus was to implement an ergonomical scientific approach to support the workers on the assembly line through the development and introduction of supporting equipment, robots for example, to reduce the workloads while enhancing productivity. This paper, however, discusses only an ergonomic approach in industrial management field which we called the "Ergoma" approach for the above purpose.

INTRODUCTION

Thirty years have passed since the first ergonomic activities were organized on an international level. During that time, the number of ergonomists and the amount of research in the field have increased greatly. Today, the term ergonomics, or human factors, is well-known throughout the world.

Unfortunately, even today, few in the industrial world has fully accepted and put into actual use the concepts of ergonomics at the work place. Also, while previous research was based on ergonomics as a practical field of study, today's researchers face resistance from those who can implement these ideas, creating a gap between the themselves.

For example, ergonomists' plans for creating smaller work loads are always rejected by corporate managers and owners. A reason for this stems from the different attitudes ergonomists and management have toward labor cost and health-cost efficiency in relation to corporate profits.

If ergonomists were in position as corporate managers and owners and were to propose a plan to increase productivity, it would encompass areas for coping and intervention, factors that would make the plan more acceptable.

In other words, ergonomists should not limit their thinking. Rather, they should expand it to include the overall concept, systematic concept, balance of productivity, health and safety, which concerns the structure that envelops the work force—the main concern of ergonomists. Such thinking for action programs should also consider industrial engineering.

In recent years, ergonomics has begun to include systematic concepts. Amid this historic flow, Hendric stressed macroergonomics (1986), whose purpose is to consider the overall structure in creating the most appropriate structure for an ergonomic system (1991). Hendric's theory of macroergonomics emphasizes organizational design and management (1991).

There has been, however, no universally valid approach established, detailing how ergonomists should offer concrete solutions to problems.

Another field is participatory ergonomics (1984) which has broadened of theories on interpersonal relationships (Brown, 1991), but whose approaches have proved to be no more than details of circumstances.

Kumashiro and Kumashiro et al illustrated an ergonomic approach to industrial management (ergoma) taking into consideration the corporate side and deals concretely with each, individual problem (1987 1991). Compared with Hendric's macroergonomics, this approach still has a narrow target, but yet addresses as a whole the corporate organization.

This paper seeks to reconfirm the importance of the ergoma approach by redeploying Kumashiro's methods at the same work place where he conducted his research. While the approach in this paper is a circumstantial one, it is a step in the direction for a more universal approach.

The ergoma approach has revealed no new methods but rather it has strongly reaffirmed the implementation of the basic concept of applied ergonomics. It calls for setting goals that will be easily acceptable by the corporation and assembling systematically conventional methods reflecting various points of view.

Furthermore, combining the three basic elements of most practically—asking/listening, observation and scientific approach—the ergoma approach yields a new thinking, known as adhocracy. Adhocracy allows people in the corporation to participate in considering the problems and their solutions.

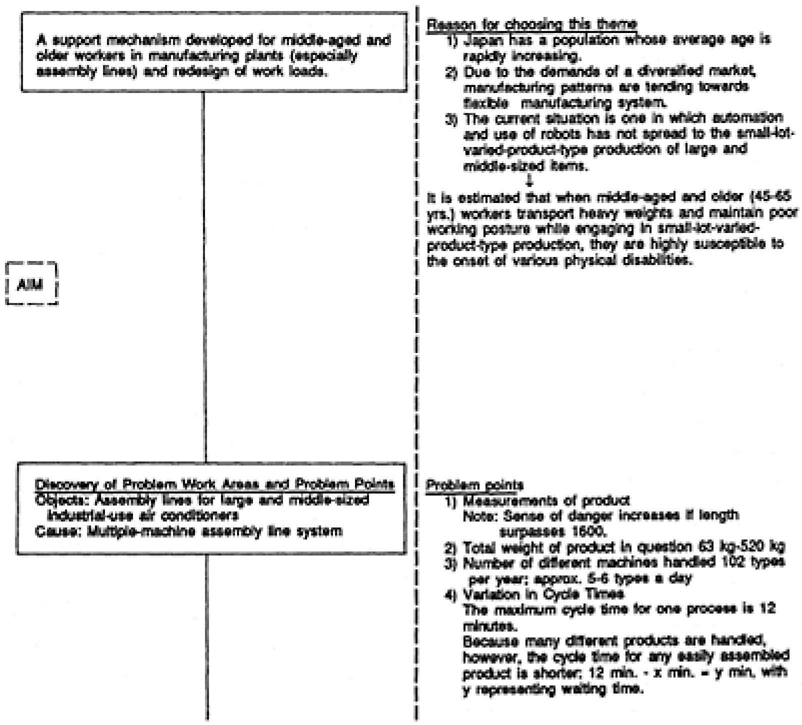
ERGOMA APPROACH

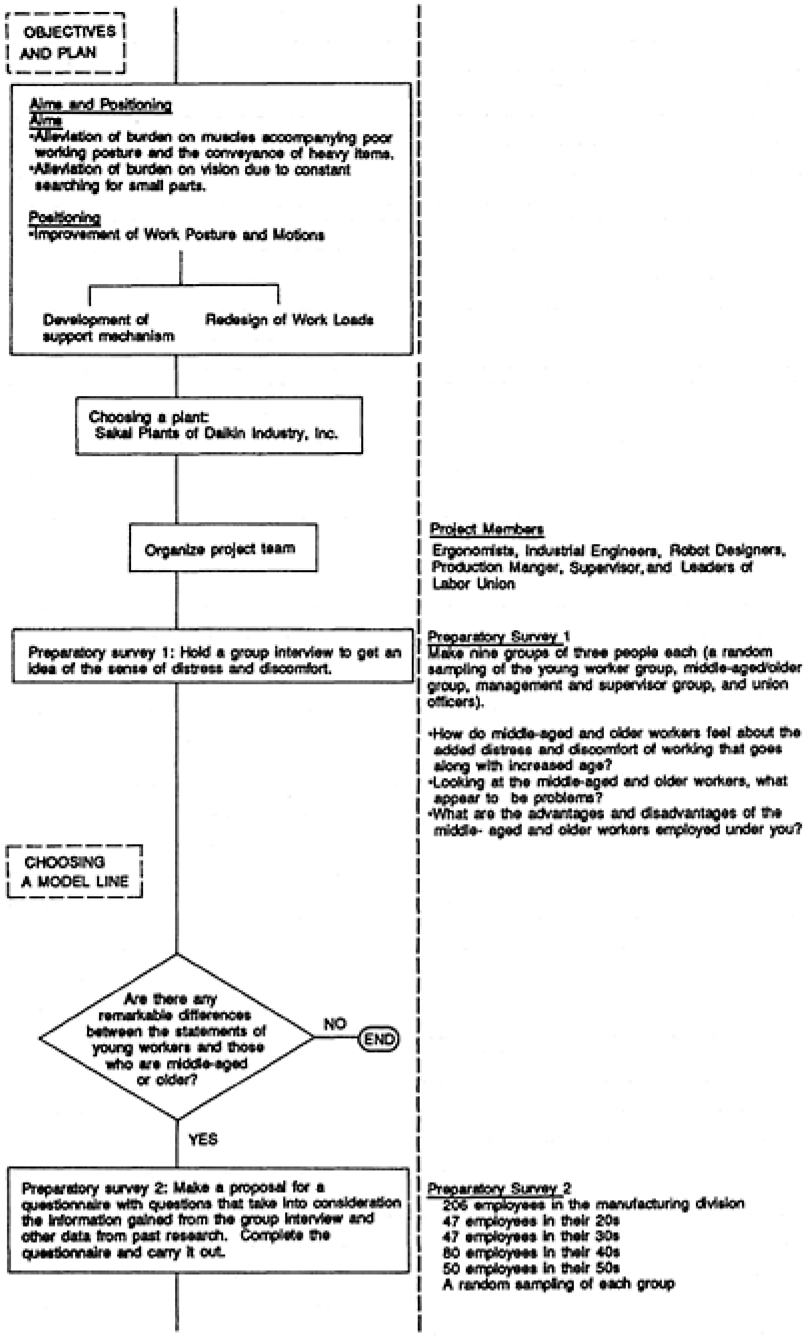
There are three basic ergoma concepts: Ramazzini's on occupational health, F.W.Taylor's on industrial management and the base of ergonomics from an appropriate labor management perspective. The aim is to increase industrial production form a health-cost and productivity view point——the merging of production and humanity.

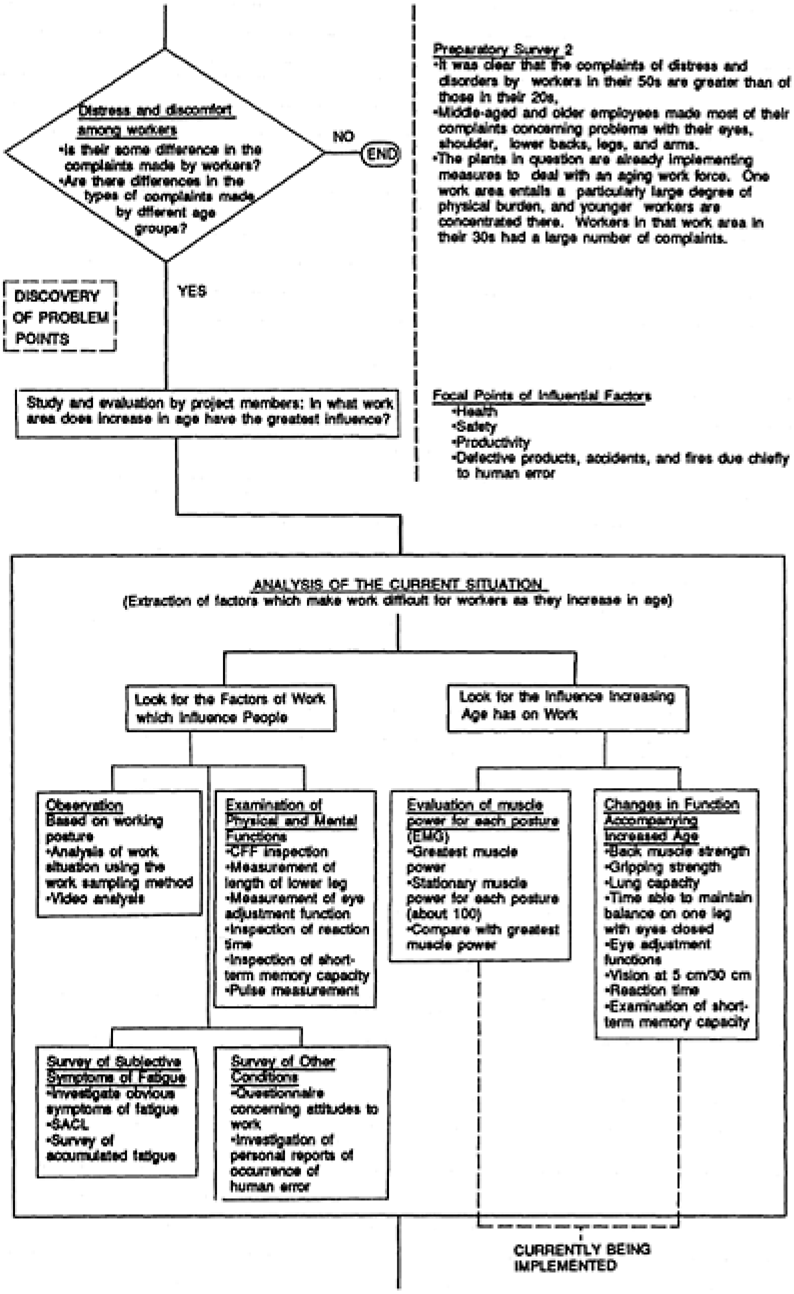
The basic, concrete approach is a scientific one which is used in the industrial engineering field. Based on this approach, the techniques, all within range of the above concepts, are chosen and applied case by case.

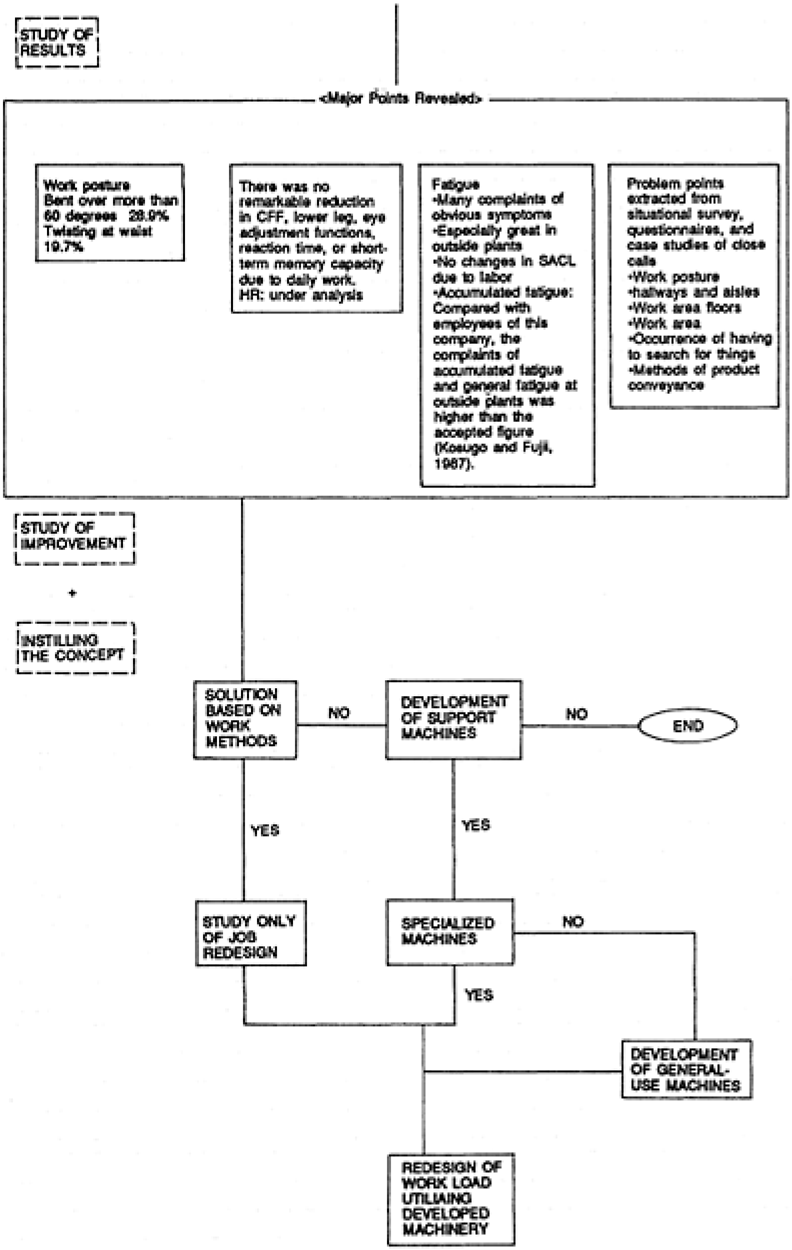
The focus of this case study is on work postures, a subject which has generated many reports in the past detailing methods to analyze these positions. The basic analysis method (methods used for the research of this paper are illustrated in the accompanying flow chart) used here is OWAS (1980), with the original observation points developed.

Table: Flow chart for "Ergoma" approach




OBJECTIVES AND PLAN
Aims and Positioning
Aims
•Alleviation of burden on muscles accompanying poor working posture and the conveyance of heavy items.
•Alleviation of burden on vision due to constant searching for small parts.
Positioning
•Improvement of Work Posture and Motions
Development of support mechanism
Redesign of Work Loads
Choosing a plant: Sakai Plants of Daikin Industry, Inc.
Organize project team
Project Members
Ergonomists, Industrial Engineers, Robot Designers, Production Manger, Supervisor, and Leaders of Labor Union
Preparatory survey 1: Hold a group interview to get an idea of the sense of distress and discomfort.
Preparatory Survey 1
Make nine groups of three people each (a random sampling of the young worker group, middle-aged/older group, management and supervisor group, and union officers).
•How do middle-aged and older workers feel about the added distress and discomfort of working that goes along with increased age?
•Looking at the middle-aged and older workers, what appear to be problems?
•What are the advantages and disadvantages of the middle- aged and older workers employed under you?
CHOOSING A MODEL LINE
Are there any remarkable differences between the statements of young workers and those who are middle-aged or older?
NO
END
YES
Preparatory survey 2: Make a proposal for a questionnaire with questions that take into consideration the information gained from the group interview and other data from past research. Complete the questionnaire and carry it out.
Preparatory Survey 2
206 employees in the manufacturing division
47 employees in their 20s
47 employees in their 30s
80 employees in their 40s
50 employees in their 50s
A random sampling of each group


Distress and discomfort among workers
•Is their some difference in the complaints made by workers?
•Are there differences in the types of complaints made by different age groups?
NO
END
YES
DISCOVERY OF PROBLEM POINTS
Preparatory Survey 2
•It was clear that the complaints of distress and disorders by workers in their 50s are greater than of those in their 20s.
•Middle-aged and older employees made most of their complaints concerning problems with their eyes, shoulder, lower backs, legs, and arms.
•The plants in question are already implementing measures to deal with an aging work force. One work area entails a particularly large degree of physical burden, and younger workers are concentrated there. Workers in that work area in their 30s had a large number of complaints.
Study and evaluation by project members: In what work area does increase in age have the greatest influence?
Focal Points of Influential Factors
•Health
•Safety
•Productivity
•Defective products, accidents, and fires due chiefly to human error
ANALYSIS OF THE CURRENT SITUATION
(Extraction of factors which make work difficult for workers as they increase in age)
Look for the Factors of Work which Influence People
Look for the Influence Increasing Age has on Work
Observation Based on working posture
•Analysis of work situation using the work sampling method
•Video analysis
Examination of Physical and Mental Functions
•CFF inspection
•Measurement of length of lower leg
•Measurement of eye adjustment function
•Inspection of reaction time
•Inspection of short-term memory capacity
•Pulse measurement
Evaluation of muscle power for each posture (EMG)
•Greatest muscle power
•Stationary muscle power for each posture (about 100)
•Compare with greatest muscle power
Changes in Function Accompanying Increased Age
•Back muscle strength
•Gripping strength
•Lung capacity
•Time able to maintain balance on one leg with eyes closed
•Eye adjustment functions
•Vision at 5 cm/30 cm
•Reaction time
•Examination of short-term memory capacity
Survey of Subjective Symptoms of Fatigue
•Investigate obvious symptoms of fatigue
•SACL
•Survey of accumulated fatigue
Survey of Other Conditions
•Questionnaire concerning attitudes to work
•Investigation of personal reports of occurrence of human error
CURRENTLY BEING IMPLEMENTED



CONCLUDING REMARKS

This project is intended to design ergonomic robots that would be used to minimize the problems which plague assembly line workers as they increase in age. This type of assembly line would be for large and middle-sized products produced from a flexible manufacturing system.

Initiated in 1991, the project is scheduled to be completed in 1995. Consequently, the project cannot include details of the robot or how the ergonomically designed robot should work in tandem with workers (job redesigning).

At this point, one of the weak points of the ergoma approach is dealing with temporary employees who have been sent by companies with poor operating situations.

The results of our study show that these workers have little sense of belonging to the organization under study, that their work attitudes is becoming more negative, and they complain frequently of fatigue. Concern has been expressed that such unproductive work attitude would affect the regular employees and pose a serious problem.

This is related to problems indicated by Brown in his participatory ergonomics (1991). In order to find a solution it will be necessary to absorb more of Hendric's macroergonomics before reorganize the ergoma approach.

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DEVELOPMENT OF (light wall) PARTITION-CONSTRUCTION TECHNIQUE

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Light walls (partitions) are commonly built from plaster boards (panels) screwed to metal crossbars (structural supports).

The main problems were: Heavy boardhandling, heavy monotonous screwing on metal crossbars, lack of handling equipment, heavy screwdriver-automaton and primitive trestles.

The following products have been developed in order to arrange the work ergonomically: A new panel (board) formatstandard, a light screwdriver-automaton, and a new screwpackage which eliminates manual screwcontact, a new crossbar, a new workingtrestle and some handling devices.

These new products have given the construction worker an improvment of ergonomics as well as an increase in productivity.

BACKGROUND

Constructing partitions is one of the heaviest and most monotonous jobs on the construction site. The main problems found are: Heavy handling of big plasterboards and monotonous screwing onto metal crossbars. Both these activities are known to be hazardous to the health. Most affected are workers permanently working with partition construction. Almost all of them show injuries after a few years on this type of work.

In order to reduce the required effort of screwing, a new metal crossbar has been developed.

The projects also developed handling equiptment reducing the manual efforts handling boards (panels).

A NEW BOARD FORMAT

A research to find the most ergonomic and productive board format was initiated. The ergonomic best format was found to have a width of 80 to 90 cm and the most productive *format was found to be 90 to 100 cm wide. All boards were at least 240 cm (8 foot) long, and 1, 3 cm (one half inch) thick.*

The width of the old standard format was 120 cm (4 feet). A good compromise could be a new format 90 cm (3 foot) wide. This format could also be adapted to the current standard in the construction industry. A possible smaller format of 60 cm (2 foot) width did not improve the ergonomic situation, nor the productivity compared to 90 cm. With 60 cm wide boards the worker will try to handle 2 or sometimes even three boards simultaneously. This handling increases the load and will also contribute to more accidents (damaged boards and lost balance) due to poor grip of the board package. The productivity decreases as the operator becomes exhausted. 60 cm panels will also make it difficult to build partitions straight.

A consequence-investigation of a new panel (board) format resulted in an introduction of a 90 cm (3 feet wide) board format. The new format was tested and proved to be more productive compared to the old. It reduces the handling time with about 25% of the handling time and also reduces the amount of waste material and physical load on the worker.

This new format has now become ***a Swedish standard*** *format for construction-boards.*

THE NEW CROSSBAR

A new crossbar *was developed. It is made from a single strip of galvanized steel expanded with meshes of different modifications, forming an advanced expanded metal construction. The flanges have meshes adapted to fit the screws. The waist has bigger meshes so that they can be penetrated by electric pipes and other installations inside the partitions.*

The new crossbar consists of only 50–60% of the metal in the standard crossbar. The new crossbar is equally strong. It will also reduce the contact between the two opposite sides of the partition. Thus it will reduce the sound- and heat-transmission.

When a screw has penetrated the plaster board, it will always hit a metalsurface angeled so that the screw will find its way into a mesh. This construction reduces the required force screwing from about 350 N to about 100 N penetrating the crossbar. The impuls for each screw is reduced from about 150 Ns to about 30 Ns, which is the same as for penetrating a plaster-board without a crossbar behind it.

THE NEW FASTENING TECHNIQUE

The work of the partition builders has become easier mainly due to the 3 feet wide boards and to the new crossbar.

To facilitate the handling and transporting of boards, a narrow ***transport carriage*** *was developed. The narrow transport carriage easily finds its way in difficult terrain.*

A new ***automaton for screwing-machines with corrugated board band,*** *eliminates contact between hands and screws.*

The automaton is light and aimed for one hand operation. It makes the screwingmachine only 2, 5 cm (one inch) longer than a screwingmachine without *automaton. In order to save required impulses, the screwfeeding is made in a new way. The screws are packed in a corrugated board band which holds 30 screws and is practical to use also when screwing with single-screw technique (without automaton). Thus it is necessery to buy only one single kind of screwpackage for partition construction, irrespective of screwing-tecnique. As wastematerial, the corrugated board is not harmful to the environment.*

***A new workingtrestle** has also been developed. It is sturdy, and gives support to the entire foot. It is equipped with casing for the screwingmachine, screws and other supplies. The sturdy trestle reduces the risk of falling. The casing reduces the need of climbing upp and down. The trestle is also equipted with electric sockets.*

RESULTS

*The new board format has reduced the load from lifting boards from 70 cm height, on the third lumbar vertebrae from 7285 N to 5069 N. The load on the third lumbar vertebrae is also reduced when mounting the panels to the crossbar frame. With the new 90 cm format the panels can be **handled by moving the arm only,** contrary to handling 120 cm panels which demands handling by turning and bending the back.*

The load on the hipjoint has also been reduced due to the reduction of the unsymmetrical weight.

The new format enables the operator:

to see over the edge of the board while carrying, which also reduces the risk of accidents

*to reach over the board edges and handling it with the arms, which eliminates unfavorable motions and positions. **to manage** to handle an unsymmetric load with low injury risk, the 120 cm plasterboard weighs about 26 kg, and the 90 cm board weighs only 19, 5 kg. The 90 cm board is also handled in more favourable positions.*

Introducing the 90 cm board in Sweden made the manufacturers charge the same price for a 90 cm board as for a 120 cm board. This increased the material costs by 25% using the 90 cm format. The workcost however was still more reduced building with 90 cm compared to 120 cm.

The total cost was although reduced by at least 5% constructing with 90 cm boards. In the future the 90 cm boards have become relativly cheeper. The price for 1 square meter will be about the same for both formats, until the 90 cm format totaly replaces the 120 cm.

Furthermore, the decrease of work-injuries and absence from work due to the working situation will save money and suffering for construction companies and their employies.

There is also less waste material using the 90 cm format. The 90 cm plasterboard can be mounted on crossbars at 45 or 90 cm interval. In industial- and office buildings you will get few more joints in the partitions with the smaller board format. In recidence-building the partitions are usually very short, so there will rarely be extra joints.

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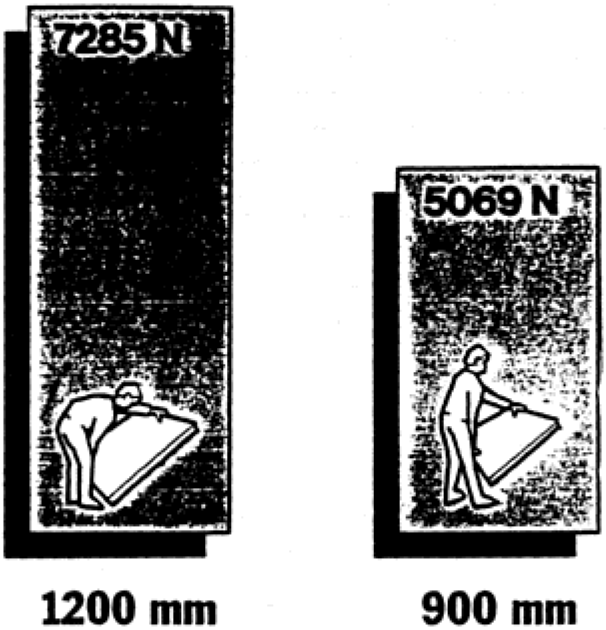

Figure 1. Reduced load on the lumbar spine.

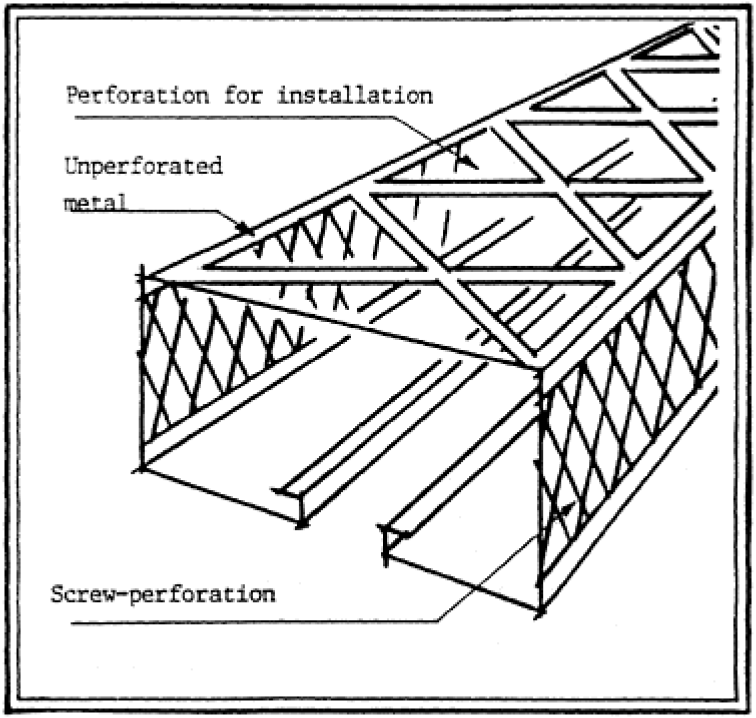

Figure 4. The expanded metal crossbar.

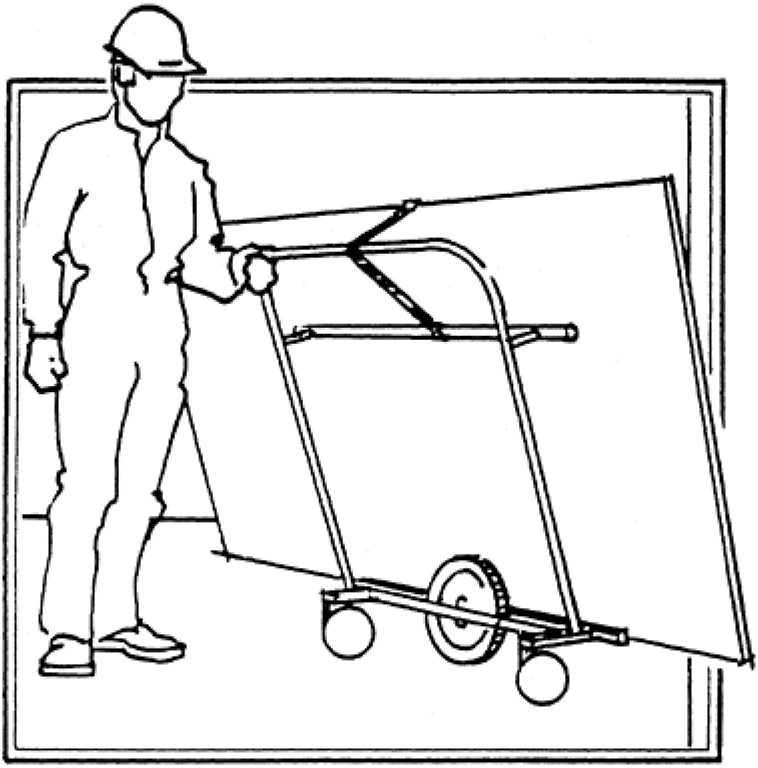

Figure 5. The narrow transport carriage.

Figure 6. The new working-trestle

KEYBOARD USE, DESIGN AND LAYOUT IN A NEWSPAPER EDITING JOB: A CASE STUDY

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A detailed analysis of hand and finger positions of a newspaper editor using one type of a keyboard revealed that the left hand was used more than the right hand; frequently used keys required awkward finger positions; and the most frequently used keys could only be used by a single finger. The prototype keyboard included repositioned frequently used keys; balanced left and right hand use; and the most frequently used keys designed for two fingers. Analysis of hand and finger movements showed that the prototype eliminated the stresses caused by the original keyboard.

INTRODUCTION

Newspaper editors use video display terminals (VDT's) to edit stories and fit them into the page space allotted. The keyboards are quite specialized and include many special function keys not found on more general purpose keyboards. Although keystroke rate could be high, the number of keys used may be small. The layout and design of the keys must be carefully considered to avoid creating fingering patterns that cause stress to the hands and wrists.

Stresses to the hands and wrists can result in cumulative trauma disorders (CTD's) such as tendonitis, tenosynovitis, De Quervain's disease and carpal tunnel syndrome. In the case of keyboard use, the stresses which can contribute to CTD's are position (Armstrong and Chaffin, 1979) and frequency (Silverstein, et al, 1986).

The stresses of the newspaper editor's job have been studied by others. For example, Buckle (1991) looked at the physical and psychological factors of the editor job and the effect on musculoskeletal disorders. The study described here focused on the effect key arrangement and use had on an editor's fingers, hands and wrists. The goal was to determine what stresses were a result of the keyboard and if relatively easy modifications to the keyboard would relieve the stresses.

METHOD

An editor was video taped using the original keyboard under normal work conditions. The camera view concentrated on the hands and the keyboard.

A detailed task analysis was done from the video tape. The task analysis methodology was adapted from that reported by Drury and Wick (1984). In this case, the video tape was used to record:

– The keys used by each hand;
– The number of times each function/control key was used by each hand;
– The time using the QWERTY section of the keyboard;
– The time spent with the hands "poised", or at rest.

From this data, the percent of keystrokes per hand could be calculated. Hand wrist positions such as the "poised" position between keystrokes could be identified. Also, any awkward hand or finger positions necessary to reach the keys could be observed and recorded. Percentages were used because of variations in the workload.

Ergonomics problems could be identified, such as unbalanced use of the hands; finger positions; and hand positions at rest. The data provided sufficient information to accurately quantify the problems. This allowed development of appropriate solutions.

A prototype keyboard was developed to address the ergonomics problems identified in the original keyboard. The keyboard had many programmable keys. This feature was important in the development of the modifications. Keys could be assigned to the appropriate finger or hand. The modifications were kept as simple as possible so they would be relatively easy to implement.

The original editor was video taped using the prototype keyboard and a detailed task analysis was done to determine the effect of the new design.

RESULTS

Original Keyboard

The original keyboard was the design provided by the manufacturer. The keys were programmed according to the manufacturer's recommendations and past practice. The editor was given no special instructions.

The analysis of the video tape showed that the locations and designs of the keys imposed significant stresses to the fingers, hands and wrists. Four problems were identified:

High frequency for the left hand;
Awkward finger positions;
Static hand positions at rest;
One finger operation of frequently used keys.

The assignment of the keys required the left hand to be used for 67% of the keystrokes. This is compared with 33% of the keystrokes for the right hand. The result was a high frequency rate for the left hand. Also, most of the editors were right-handed. Therefore, most of the work was done by the non-dominant, or weakest, hand.

Awkward finger positions were necessary to reach frequently used keys from the "home" position on the function key pads. This was also caused by poor locations of the keys compared to their intended use.

The hands were held in the position of wrist extension between keystrokes. The left hand was "poised" 70% of the time and the right hand was "poised" 61% of the time. The static loading placed high stresses on the tendons because of inadequate rest between exertions (Rodgers, 1987). The cause was the way in which the editor choose to hold the hands.

Very frequently used keys were those that were pressed repeatedly, sometimes as often as three times a second. These keys could only be used by a single finger. The resulting stress was concentrated on one finger and its associated tendons.

The editors reported pain or discomfort in the left wrists and forearms and the right forearms. Several had been diagnosed with tendonitis or tenosynovitis. The study clearly identified and quantified the ergonomics problems resulting from the keyboard and contributing to the complaints.

Prototype Keyboard

A prototype keyboard was developed to address the problems identified in the analysis. The intent was to make the changes as simple as possible so they did not require costly engineering by the manufacturer.

Keys were reprogrammed to shift some of the work from the left hand to the right hand. The goal was to have better balance, if not shifted in favor of the right hand.

Reprogramming was used to place frequently used keys in easily reached locations to prevent awkward finger positions. Either the key was moved under the finger when positioned at the "home" position; or the key was moved so far away that an intentional movement was required.

The problem of wrist extension during "poise" was solved by training the editor to relax the hands in the neutral wrist position to the side of the keyboard between keystrokes. This meant breaking an old habit and required concentration in the beginning.

The most frequently used keys were modified so they were wide enough for used by at least two fingers. This was accomplished by placing a cap across two single keys and programing one of the keys to be non-functional.

The prototype test was done by the same editor who used the original keyboard. She was allowed to become accustomed to the new design by using it for two days before the video taping. She received instruction on placing her wrists in the neutral position during the "poise" between keystrokes.

The analysis of the video tape revealed that the prototype solved all of the ergonomics problems identified in the analysis. The following are the results of the analysis of the prototype:

– The hands were better balanced: left hand—43%, right hand 57%;
– Awkward finger positions were eliminated
– The "poised" position was with neutral wrists;
– The most frequently used keys could be used by two fingers.

The editor who used the prototype reported that her forearms and hands felt better using the new design.

DISCUSSION

The keyboards used by newspaper editors are special purpose. They have been designed with many extra keys to do very unique things. Each newspaper has special requirements that the keyboard designer and the software designer must consider. Therefore, the basic design is very flexible and can be programmed to suit many different applications. A "one design can be adapted to fit all" design has emerged. The problem is, the "fit all" design may fit all newspaper needs, but not be compatible with the way human hands and fingers move. The result is potentially damaging stress—stress to the hands and wrists which could result in cumulative trauma disorders.

This study looked at the way one newspaper used one type of keyboard. There are many applications depending on the way each newspaper uses the equipment. Each application needs to be carefully designed to avoid injury. Key layout will depend on keying pattern and human hand limitations. The design must be carefully analyzed to be sure the keyboard can be used without imposing injury causing stresses to the fingers, hand and wrist.

Sellers and buyers of special purpose keyboards should validate the layout and use of the keys by using an actual operator and an appropriate analysis methodology. The only way to determine how the design really affects the user is through well designed user trials. Testing and validation during the design stage will avoid Workers' Compensation costs, pain and suffering, and law suits.

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DESIGN OF WORKPLACE: FOOTREST

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THE PROBLEM

The consequences of working in a sitting position with the feet above the floor are well known. However most of the products as VDT work station or secretary tables only offers as footrest a bar. This bar is there to structure the furniture not to support the feet. So the operator use as footrest empty boxes or the structure of the chair or of the table.

THE REQUIREMENTS

To be really comfortable a footrest must support completely the foot. Besides 1t must permit the operator change the position of the legs with continuous movements assuming a dynamic behavior instead of a rigid posture.

THE RECOMMENDATIONS IN THE LITERATURE

The literature about workplaces presents few guidelines about the subject—Pheasant, Cushman/Nielsen/Pugsley.

	Pheasant	Cusshman et al	Cakir	Tisserand
High				
front	3, 5–4, 5 cm		0–5 cm	
center				4–15 cm
back	10 cm			
Width	35 cm	30 cm		40 cm
Depth	45 cm	41 cm		30 cm
Angle	0–20	>30	10–15	

We must observe that a footrest with 30–41 cm of width is very restrictive. If we consider 45 cm for hip width, as in Diffrient, clearly almost everyone must maintain her upper and lower legs parallels with no movement of abduction when sitting.

Its easy to understand why so many people leave the footrest under the table without using it. They need motion—hip adduction and abdution and knee flexion/extension and rotation.

THE PROJECT

We have in ergonomics a lot of books with many recommendations for work surface considering arm reach envelopes. But there isn't any study after biomechanical angles of upper and lower legs.

In this application of newtonian anthropometry (see Grieve & Pheasant) we use the biomechanical angles that appear in Diffrient, Pheasant, Rohmert. For the linkage lengths the data come from Diffrient. Our principal tools are the anthropometric manikin of the 2, 5 and 97, 5 percentiles.

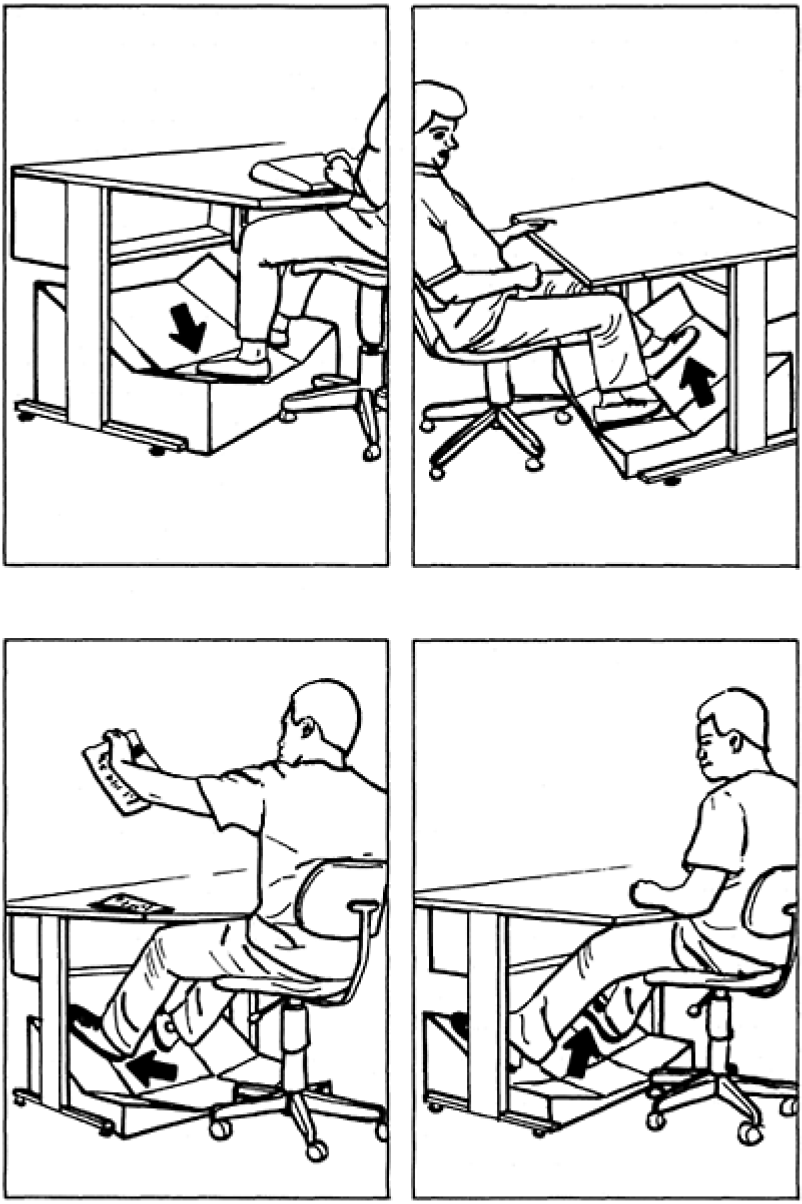
We define zones of convenient foot reach:

– with a vertical section in sagittal plane passing through hip and knee joints (flexion);
– with a horizontal section in transverse plane passing through hip joint (abduction);
– and with a vertical section in coronal plane passing through knee joint (rotation).

We have as result a foot rest that allows changing positions of legs whit the feet always supported by a surface in different heights and angles. So it is possible avoid a rigid posture that causes musculoskeletal disorders and improve the operators comfort and health.

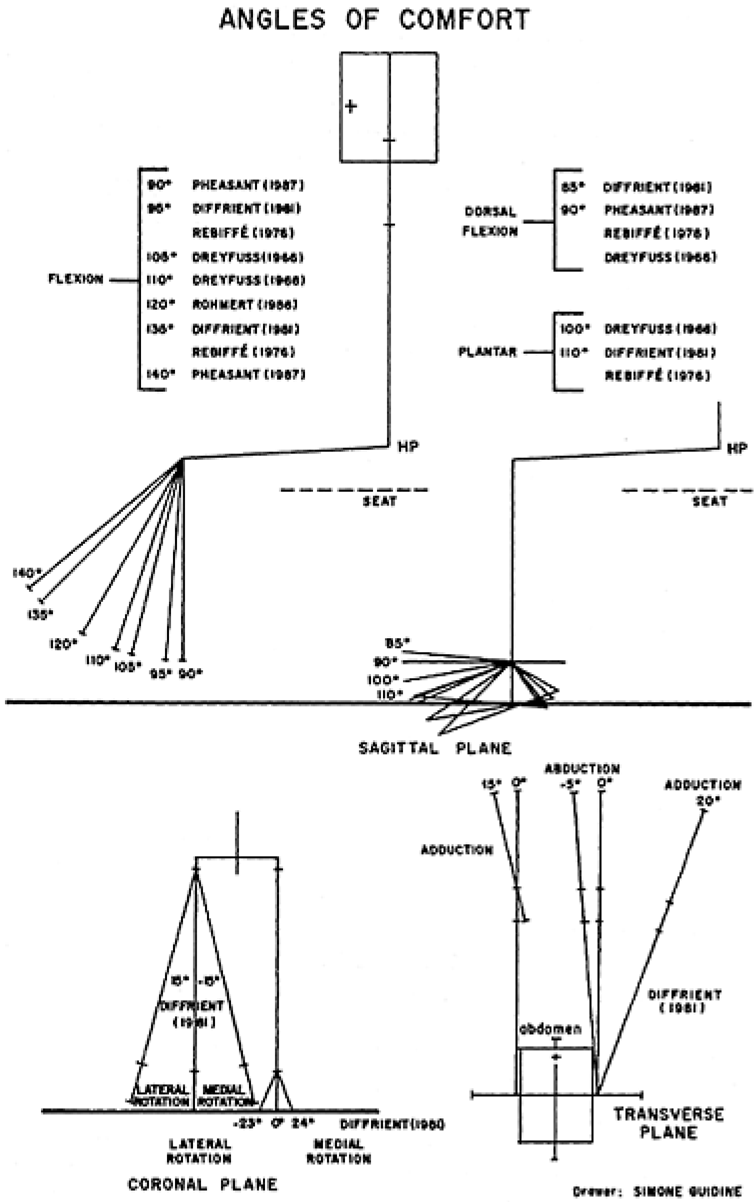
THE USERS OPINION

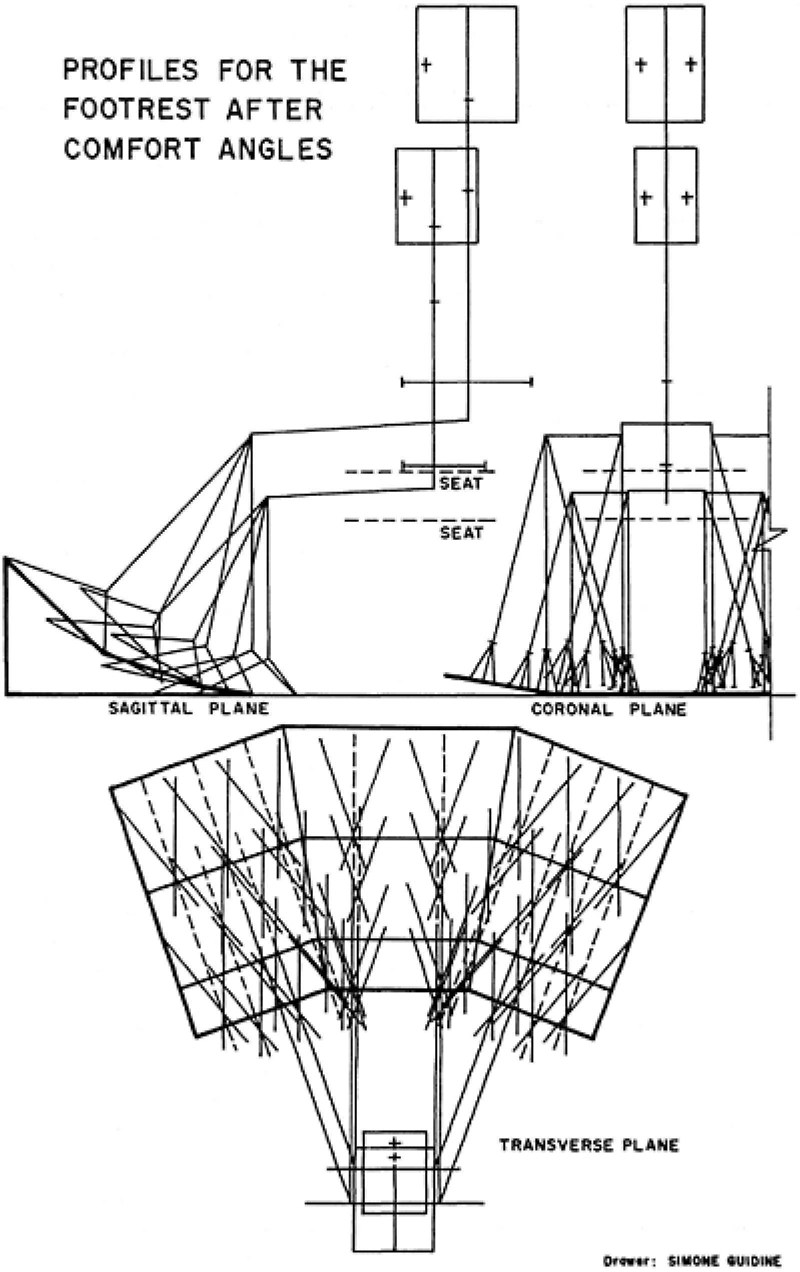
It was used a questionnaire to get the users subjective opinions about the footrest. Men and women of all percentiles approved it. They enjoyed the possibility of changing the position of the legs and found good have several surfaces with different angles, widths and highs to sustain their feet.



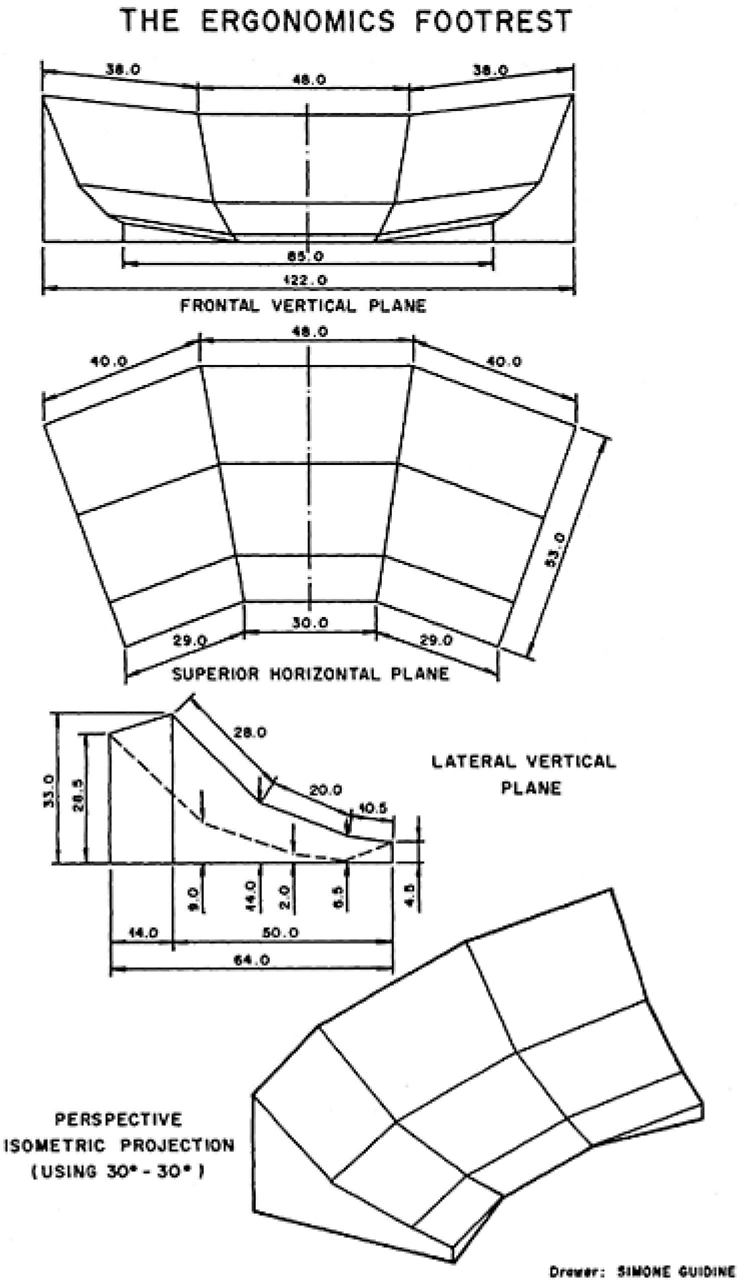
In the next pages we can see the application of newtonian anthropometry studies. After we show the relation between the comfort angles for hip pivot and knee joint in all the planes and movements we mentioned above and the footrest profile. Finally we present the footrest design.

ANGLES OF COMFORT





THE ERGONOMICS FOOTREST



At the moment the Health Department of the enterprise is doing the control of musculoskeletal disorders of operators who use the footrest and of a control group that continues working in the same old way.

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REDUCTION OF MUSCULAR STRAIN BY WORK DESIGN: ELECTROMYOGRAPHICAL FIELD STUDIES IN A WEAVING MILL

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INTRODUCTION

In a weaving mill one of the basic activities which has to be performed before manufacturing the weave on the looms is the production of 'warp beams'. In this the threads from several hundred bobbins are drawn together in a 'beamer' and wound onto a bobbin reel. The work physiological studies described in this paper deal with the determination of the muscular strain of persons involved in the production of warp beams ('creelhands'). Their main task is to fill the beamer with bobbins. Bobbins of a mass of 10 kg are used in the company in which the studies were conducted. They have to be transported into the beamer, lifted manually out of transport boxes and mounted on pegs arranged in 4 lines at various heights (30 to 190 cm).

The work flow was studied and the muscular strain of the workers during 'creeling' quantified in two field studies using the electromyograms (EMG) of several arm muscles. In the first study work sections inducing high muscular strain were identified and changes in the EMG signal in the course of the shift, indicating the occurrence of muscle fatigue during the work, were observed (Kylian et al., 1985; Luttmann et al., 1985; Laurig et al., 1987). Various recommendations for the redesign of the workplace and the work organisation were derived from the results of the first study. Most of the recommendations were implemented by the company and translated into practical measures of work design. In the second study, performed about 1 year after the redesign, analogous investigations were conducted in order to verify the success of the changes.

METHODS

In the first study the investigations were carried out during 3 entire shifts and involved 3 male creelhands aged between 22 and 48. The second study was conducted during 4 entire shifts on 3 male creelhands with ages between 21 and 49. One person participated twice in the second study. The EMGs were derived from the biceps and the finger flexor muscles of both arms using pairs of surface electrodes with an interelectrode distance of approx. 5 cm and an active diameter of 7.5 mm. The electrodes were taped to the skin over the belly of the muscles under test using double-sided adhesive rings and positioned according to Lippold (1967) and Zipp (1982).

After amplification (amplifier bandwidth 3 Hz–1 kHz), the raw EMGs were recorded on an analog magnetic tape (recorder bandwidth DC—1.2 kHz). The evaluation of the electromyograms requires exact assignment of the myoelectrical signal to the activity performed by the subject. To fulfil this requirement a method has been developed and applied in practice whereby an 'electronic protocol' is recorded together with the electromyograms on the same tape (Ballé et al., 1982; Luttmann et al., 1992). The electronic protocol is produced by an observer who accompanies the worker during the total data acquisition time. The observer uses a numerical keyboard to convert the current activity of the person under test into a code signal. Examples of the coded activity are: lifting a bobbin, mounting a bobbin onto a peg in the beamer, tying threads together, and transporting bobbins. In addition to the action code, the work flow was documented using hand-written protocols, video recordings and photographs.

In the data evaluation the Electrical Activity (EA) was formed from the raw electomyograms by means of rectification and analog continuous averaging over a time window of 140 ms. The averaged EMG was A-D converted with a sample rate of 20 Hz. In the computer-assisted data analysis the code signal was used to determine the myoelectrical activity during particular

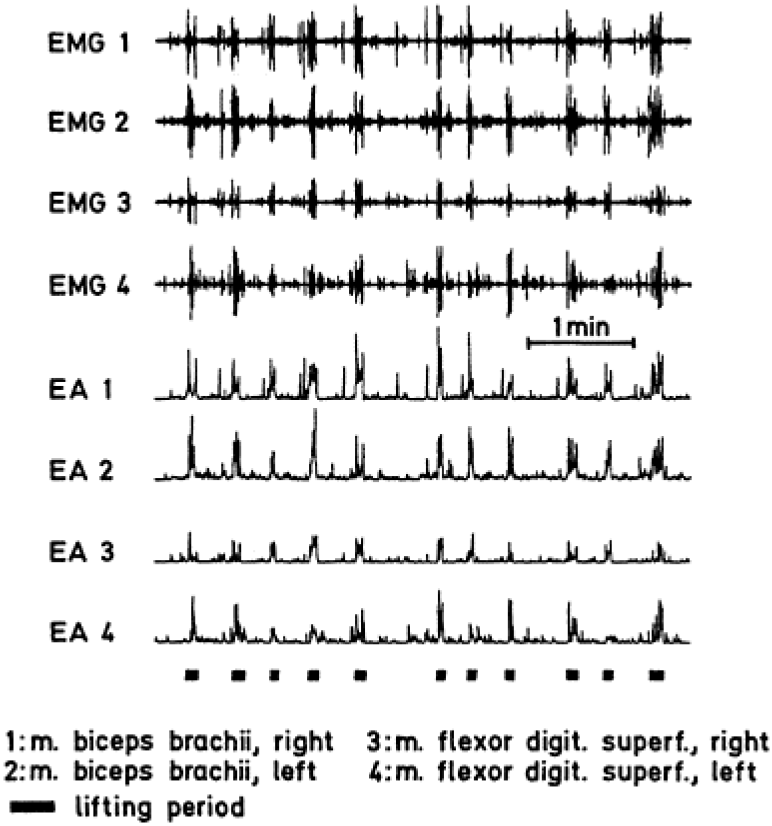

Figure 1. Original recording of the electromyograms and of the Electrical Activity signals of 4 arm muscles during the pegging of bobbins. The black bars below the recording indicate sections where the bobbins were removed from the transport box.

activities. The action code was additionally used to establish the percentage of the daily working time taken up by the various activities. In this the sum of all of the time sections which are characterized by a particular code was taken and related to the daily working time.

RESULTS OF THE FIELD STUDY BEFORE REDESIGN

Figure 1 provides an example of an original recording of the 4 electromyograms and of the accompanying time curves of the Electrical Activity. During the 5 min period, shown in figure 1, 11 bobbins were lifted out of a transport box and mounted on pegs. Markings below the recordings denote the time sections in which the bobbins were lifted. The point in time and the duration of the lifting periods were derived from the action code. As can be seen from figure 1, the highest myoelectrical activity occurs for all of the muscles under test during lifting. Consequently, this activity was of primary interest in the further data evaluation. The maximum EA during each lifting period was determined from the EA time courses for all of the muscles under test and plotted over time.

Figure 2 demonstrates a result of the data evaluation for a total shift in the first study. The work sequence is presented in the lowest diagram. The primary activity, called 'pegging', mainly consists of lifting the bobbins out of transfer carts, mounting them on the pegs in the beamer and tying the threads together. During the shift shown in figure 2, pegging is performed in 6 time sections each lasting between about 23 and 52 min (mean 40 min). The mean work rate in the pegging periods is indicated by the number of bobbins mounted per minute. It amounts to about 2 bobbins per min. The time sections between the pegging periods include several secondary activities such as transporting bobbins, removing empty bobbin reels, cutting off leftover threads, and taking work breaks.

In the upper diagrams the Electrical Activity of the four muscles under test is plotted over the total shift time. Each dot represents the maximum EA during one lifting period. The EA values scatter within a wide range due to the variation of both the grasp and pegging heights for the bobbins and different lifting techniques. In addition to the dots, regression lines have been included in the figure. For 3 of the 6 pegging periods shown in figure 2, the EA increases significantly for at least one muscle although the bobbin mass is constant. As described by Knowlton et al. as early as 1951, an increase in the myoelectrical activity in spite of a constant load indicates the occurrence of muscle fatigue during the work.

Similar results were found for all the shifts studied. In the first study before the redesign a total of 15 pegging periods were investigated. In 13 cases a positive slope was observed for at least one muscle, 7 of them being significantly larger than zero. The numerical values of the slopes are presented and discussed in a following section.

RECOMMENDATIONS FOR WORK DESIGN BASED ON THE FIRST STUDY

During the first study it was observed that the bobbins were delivered in transport boxes which were wider than the passageways between the arrays in the beamer. As a result, the boxes could not be moved into the passageways and the bobbins had first to be transferred from the transport box to a small transfer cart before being conveyed into the beamer. The transfer causes muscular and cardiac strain which is higher

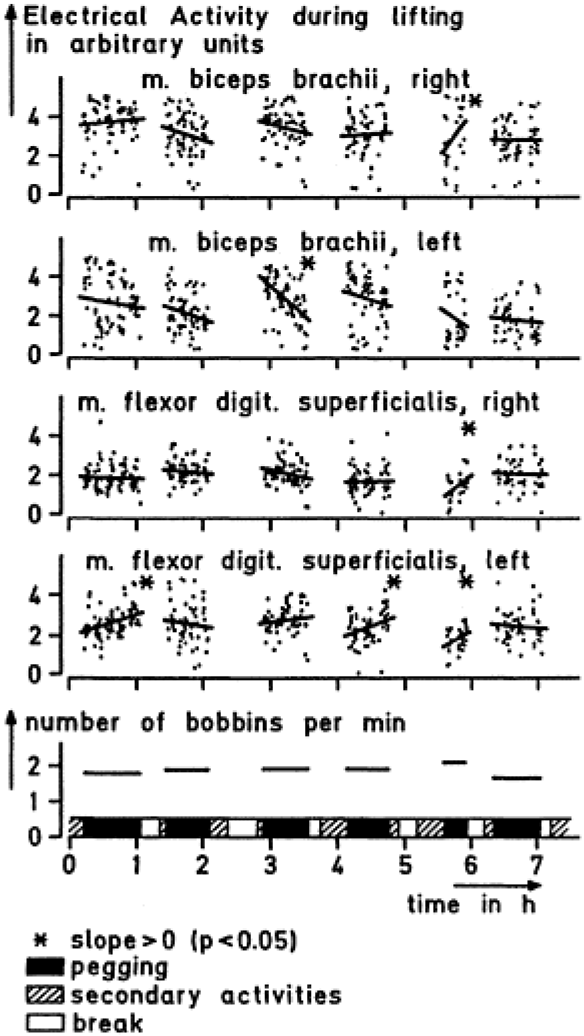

Figure 2. Muscular strain, work sequence, and work rate as a function of time for one total shift from the first study.

Upper 4 diagrams: Muscular strain indicated by the maximum Electrical Activity of 4 arm muscles during lifting for all of the lifting periods in the shift. Average time courses for 6 pegging periods are shown by regression lines.

Lowest diagram: Work sequence and mean work rate for 6 pegging periods indicated by the number of bobbins removed from the transport box and placed on pegs per minute.

than the strain during pegging (Luttmann et al., 1985, 1988). This means that the greatest strain does not occur in a primary activity but during a secondary activity which could be avoided if the arrays in the beamer were appropriately spaced. It was therefore recommended that the passageways between the arrays in the beamer be adapted to the width of the transport boxes. The bobbins could then remain in the transport boxes, thereby dispensing with the intermediate transfer step.

Before the redesign the bobbins were packed vertically in the transport boxes. The bobbins usually had to be lifted out of the boxes using one hand. During this action they were essentially held by the finger flexors. As a result, a high level of strain with consequent rapid fatiguing was observable in this muscle group in particular. To reduce the muscular strain and fatigue it was recommended that the bobbins be packed horizontally in order to allow bi-manual manipulation.

At first transport boxes with fixed sides and about 90 cm in height were used. To remove the bobbins from the lower layer the persons had to bend over the edge of the transport box and raise a load of 10 kg. They thereby adopted a posture which is associated with high spinal load. The use of transport boxes with detachable sides and the employment of hydraulic low lift platform trucks was recommended so that the bobbins could be removed at hip level, so reducing the spinal load.

In the above it was shown that the Electrical Activity increased during the pegging action in spite of a constant workload. Such an increase indicates the occurrence of muscle fatigue. Whenever work leads to muscle fatigue it can only be performed for a limited period of time and rest breaks must be provided. In fact, in the example shown in figure 2, the person stopped after an average working period of 40 minutes. The interruption of work was determined by the worker and did not coincide with the rest breaks planned by the company. Similar findings resulted for the other persons under test.

The relation between the fatigue-induced EA increase and the maximum possible duration of uninterrupted work ('endurance time') was investigated by Laurig (1975). It was observed that a shallow increase in the EA indicates a slow fatiguing process which is connected with a long endurance time whereas a steep increase in the EA is a sign of a fast tiring process and is associated with a short endurance time. Laurig (1975) established the functional relationship between the EA slope and the endurance time. This relationship had already been used in a previous investigation involving creelhands to examine whether the termination of the activity could be explained by the muscle fatigue (Luttmann et al., 1985). A fairly good correlation was found between the endurance times predicted from the slopes of the EA increase and the working times observed in the field study. It can therefore be concluded that the decision to interrupt pegging is influenced to a considerable extent by muscle fatigue and that the workers perform the work as long as possible in terms of muscular physiology.

Recommendations derived from the electromyographical studies are that pegging should not be performed uninterruptedly and that breaks are necessary to compensate for the fatigue which occurs. The breaks which have hitherto been taken arbitrarily should be legalized and a work-rest regimen ensuring that the length of working sections does not exceed 40 to 60 minutes should be introduced.

COMPARISON OF THE FIELD STUDIES BEFORE AND AFTER REDESIGN

The workplace was rebuilt on the basis of the recommendations mentioned above. In the new state of design the passageways between the arrays in the beamer are wider and transport boxes with detachable sides and low lift platform trucks are used. The latter allow the transport boxes to be moved easily into the passageways and permit continuously variable adjustment of the level of the transport boxes. Consequently, it is possible to grasp the bobbins at hip height and bending actions are no longer required in lifting the bobbins. The horizontal positioning of the bobbins in the transport boxes enables bi-manual grasping. Furthermore a work-rest schedule, implementing the aforementioned recommendations, was derived by the company. The schedule provided for a maximum working time between two rest breaks of 35 to 70 minutes. In the second study, conducted about 1 year after the redesign, analogous examinations of the work flow as well as of the muscle strain and fatigue were carried out. The results of both studies are compared in the following.

Work flow studies

Table 1 presents the results of the analyses of the code signal. The time taken for various activities is given as the percentage of the daily working time. Both studies are compared. The primary activity ‘pegging’ consists mainly of two parts, lifting the bobbins and mounting them on the pegs in the beamer, including the tying of threads. The activity associated with the greatest muscular strain is lifting the bobbins (cf. figure 1). In the first study the time for this activity amounts to 10.9 to 13.2 percent, this percentage declining to less than half after redesigning the work (5.3 to 5.5 percent). The time for mounting the bobbins and tying the threads together ranges between 22.3 and 27.2 percent before the redesign and between 28.9 to 29.6 percent afterwards. The total time for pegging amounts to between about 34 and 38 percent. Since the pegging time does not differ considerably between the two studies it is concluded that the time for the activity associated with the greatest strain, lifting, is reduced by the work design, this allowing the other necessary activities in the beamer, such as mounting the bobbins on the pegs and tying the threads together, to be performed under less time pressure.

The time for the other activities provided in the lower part of table 1 does not differ between the two states of work design since the design changes are mainly related to the pegging activity. About 21 to 30 percent of the time is needed for various secondary activities such as transporting bobbins,

Table 1. Percentage of the daily working time used for various activities

Activity	Study I before redesign			Study II after redesign	
	day 1	day 2	day 3	day 1	day 2
Lifting bobbins	13.2	12.8	10.9	5.5	5.3
Mounting bobbins on the pegs, tying threads	23.7	22.3	27.2	28.9	29.6
Secondary activities	29.1	25.5	20.9	29.7	25.7
Taking breaks	23.8	23.8	18.8	22.3	20.8
Miscellaneous	10.2	15.6	22.2	13.6	18.6

removing empty bobbin reels, cutting off leftover threads etc. The time allotted for breaks amounts to about 19 to 24 percent of the working time. The greater part of the time declared as miscellaneous was required for dealing with the subjects before and after the investigation periods, e.g., for affixing and removing the electrodes and for testing the equipment.

Electromyographical studies

Figure 3 demonstrates the time-dependent changes in the Electrical Activity during pegging. Before redesign a positive slope in the EA regression lines resulted for a large number of work sections. This is interpreted as a sign of muscle fatigue. Most of the slopes which differ significantly from zero (closed symbols) are found for the finger flexors. It can be assumed that this is mainly due to uni-manual lifting and to having to handle each bobbin twice. After redesign the horizontal position of the bobbins in the transport boxes and the elimination of the additional bobbin transfer has, as can

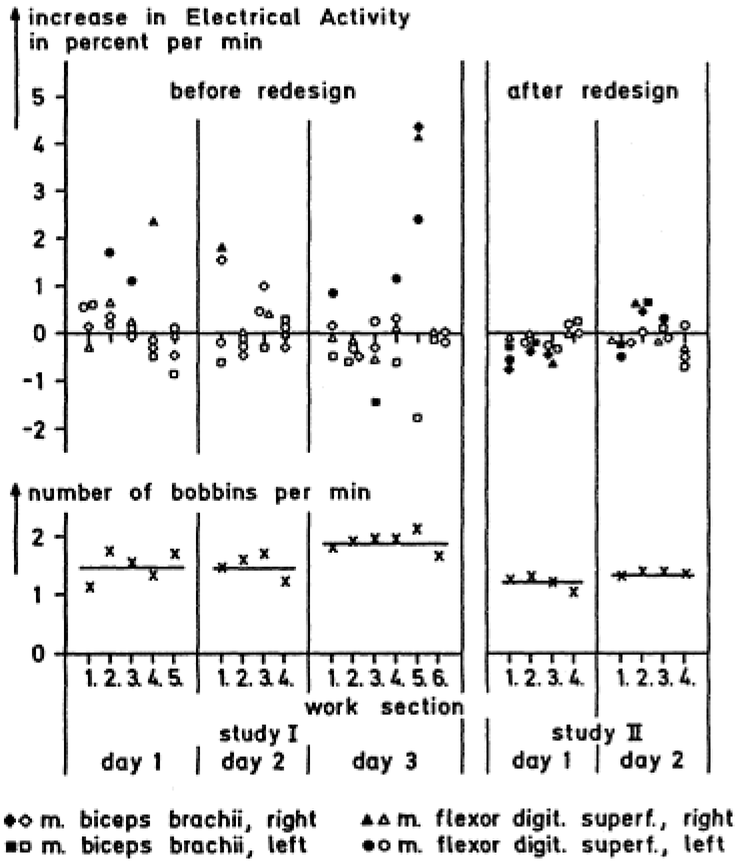

Figure 3. Slope of the regression lines for the maximum Electrical Activity during lifting (upper diagram) and work rate indicated by the number of bobbins pegged per minute (lower diagram) for all of the pegging periods in both studies Open symbols: Slope non-significantly different from zero Closed symbols: Slope significantly different from zero ($p<0.05$)

be seen by comparing the left and right-hand parts of figure 3, reduced the fatigue-related increase in EA considerably. The number of bobbins pegged per minute differs only to a small extent between both studies. For technical reasons, EMGs are considered for only 2 of the 3 subjects in the second study.

Economic aspects

In the previous state of work design the outer threads on bobbins were often damaged due to uni-manual removal of the vertically oriented bobbins from the transport boxes and the necessity of handling them twice. Such damage leads to breaks in the threads when creating the warp beam. Tying the threads requires stopping the beamer, thus extending the set-up time of the beamer considerably. The bobbins are handled much more gently as a result of the new work design. The number of thread breaks is drastically reduced and the time taken to prepare the beamer is considerably shortened.

CONCLUSIONS

Comparison of the results of the studies before and after redesign demonstrates a considerable reduction in the fatigueinduced changes in myoelectrical activity. This indicates a reduction in muscle strain and fatigue as a result of redesigning the work. In addition, the new design provides an economic benefit on account of the gentler treatment of the bobbins.

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A Psychophysical Method to Determine Ingress/Egress Dimensions for Mobile Underground Mining Equipment

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Sixteen male and sixteen female subjects were tested in order to determine appropriate ingress and egress opening dimensions for mobile underground mining equipment. Opening dimensions were determined for seating configurations used in five different seam heights: 81, 95, 123, 135, and 160 cm. A psychophysical methodology was used whereby each subject entered and exited a mock-up of a cab and adjusted the width of a sliding door to the minimum width that allowed for safe and comfortable ingress and egress. The mean opening widths, from lowest to highest seam height, are 132, 122, 112, 98, and 78 cm. The 95th percentile opening widths, from lowest to highest seam height, are 162, 149, 140, 122, and 101 cm.

INTRODUCTION

The confined environment of an underground mine creates severe restrictions and limitations that affect the design of mining machines. Often the focus on productivity has taken precedence over the consideration of human operators in the design of this equipment. Operator compartments, therefore, are frequently cramped and poorly designed with regard to ergonomics. Because the mining environment is hazardous, it is crucial to understand the interactions between the environment, the mining equipment, and the workers.

Incorporating human factors design considerations into underground mining equipment will undoubtedly improve safety and productivity. Currently, the Bureau of Mines is completing research on such human factors engineering aspects of operator compartment design as visibility, illumination, and operator reach. Another such human factors design consideration is the ingress/egress opening size necessary for workers to enter and exit the machine cab safely and comfortably.

Research on ingress/egress of surface mining equipment has previously been performed because of the large number of surface mining accidents attributed to slips and falls upon entering and exiting the equipment (Sanders and Peay, 1988). No such accident statistics have been gathered for underground equipment; but, Collier, *et al.* (1986) state, “The access path or corridor to the working position should give the operator easy access to his working position”, and they say that poor access to work spaces could result in delays in production. Furthermore, it is generally accepted that inadequate egress openings could delay exits in an emergency situation, thus creating a safety hazard. Collier, *et al.* (1986) also present access dimensions for continuous mining machines. However, the data are not valid for seam heights below 113.5 cm, and many United States underground coal mines are included in this range.

This experiment was conducted to provide mining equipment manufacturers with accurate, realistic data regarding appropriate ingress/egress dimensions. The ingress/egress dimension should be designed to accommodate the largest possible portion of the user population. A psychophysical methodology was chosen to accomplish this objective.

Psychophysics is a science which focuses on the “responses that organisms make to the energies of the environment” (Stevens, 1960). A practical application of psychophysics is the determination of scales for effective temperature, loudness, and brightness. Psychophysical methodologies also have been used in research on lifting and manual materials handling tasks. Snook (1978) reported acceptable weights of lift based upon psychophysical data. Often this methodology is used such that the subjects determine the frequency of lifts or the maximum weight which can be lifted comfortably. Since each individual’s strength and endurance varies, this method allows factors such as frequency and weight to be evaluated individually, since one level may not be acceptable to everyone.

A careful review of the literature suggests that a psychophysical methodology has never been used to determine the width of ingress/egress openings. There are many advantages to using a psychophysical approach for performing a study to determine the dimensions for an ingress/egress opening: it is flexible, realistic, and takes into account the human variation in anthropometric characteristics, psychology, and range of motion.

METHOD

A total of thirty-two subjects (sixteen male and sixteen female) were tested in order to determine appropriate ingress and egress opening dimensions for mobile underground mining equipment. Mean and standard deviation values for age, weight, and stature of the subjects are presented in Table 1. The subjects were volunteers who were employed at the Bureau of Mines Pittsburgh Research Center. Four of the male subjects did have experience working in underground coal mines and, consequently, had experience in entering and exiting mobile underground mining equipment. The remaining subjects were naive in this matter.

Table 1: Subject characteristics.

	mean	s.d.
Age (years)	33.4	7.46
Weight (kg)	75.0	18.0
Stature (cm)	171.4	9.06

Opening dimensions were determined for seating configurations used in five different seam heights: 81, 95, 123, 135, and 160 cm. These seam height values were chosen to correspond to the values used by an original equipment manufacturer when designing and building underground equipment. The seat back angle, seat pan angle, and the canopy height used in this study also correspond to the values currently used by an original equipment manufacturer. These seat configuration values are presented in Table 2.

Table 2: Seating configurations for five seam heights.

Seam Height (cm)	Canopy Height (cm)	Seat Back Angle (degrees)	Seat Pan Angle (degrees)
160	155	80	0
135	130	60	20
123	117	45	20
95	90	30	15
81	76	20	10

A psychophysical methodology was used whereby each subject entered and exited a mock-up of a cab and adjusted the width of a sliding door to the minimum width that allowed for safe and comfortable ingress and egress. Thus, the subject was given the control of one variable: the width of the door opening. Other variables, including the canopy height and the angles of the seat back and seat pan, were controlled by the experimenters. The entry height was fixed at the canopy height. In addition, the rear door was fixed to a position which corresponded to the 95th percentile male sitting acromial height value of 65.9 cm, as reported for U.S. Air Force flying personnel by Webb Associates (1978). The subjects were each read the same set of instructions which detailed the procedure prior to testing; these instructions are presented in the Appendix. During testing, each subject wore full mining gear, including boots, a hard hat, a mining belt, a cap lamp and battery, and a filter self rescuer. Each subject participated in two trials for each seam height. One trial had the initial opening width very narrow and the other trial had the initial opening width relatively wide. Thus, there were ten conditions per subject. The order in which each subject performed the conditions was randomized. An acceptable opening width was determined for each subject at each seam height by calculating the average opening dimension for the two trials at that seam height. Finally, the mean and 95th percentile opening widths were determined for each seam height. After each subject completed the testing, anthropometric data were collected.

RESULTS

The 50th percentile, standard deviation, and 95th percentile values are presented in Table 3, and the 50th and 95th percentile values are shown graphically in Figure 1.

Table 3: Ingress/egress opening dimensions for five seam heights.

Seam Height (cm)	50th Percentile Dimension (cm)	s.d. (cm)	95th percentile Dimension (cm)
160	77.7	13.7	101
135	97.6	14.9	122
123	112	17.3	140
95	122	16.0	149
81	132	18.2	162

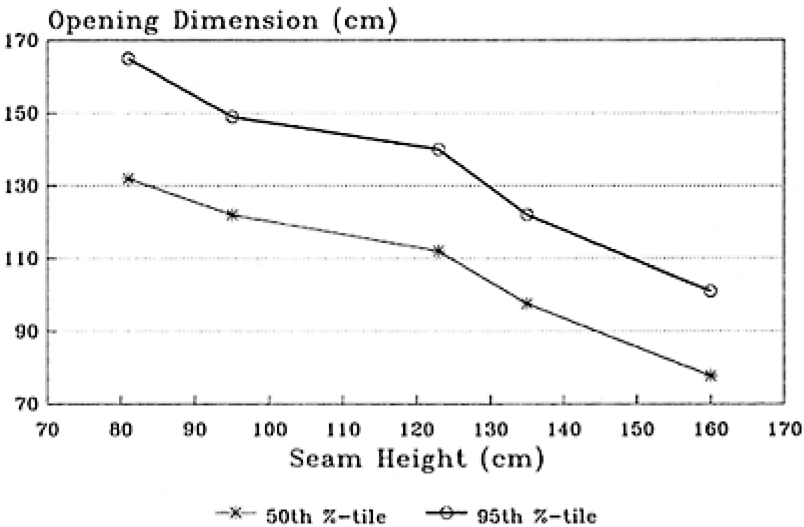

Figure 1: Opening Dimension vs. Seam Height

DISCUSSION

The data show that as the seam height becomes lower, a larger opening is needed for miners to safely and comfortably get in and out of the machinery. This is to be expected since as the seam heights became lower, the subjects must assume a more reclined posture. At the lowest seam height, the seat back was positioned at 20 degrees, thus causing most subjects to choose an opening width that was only slightly smaller than the individual's body length. In doing the experiment it was stressed to the participants that the appropriate width should not be an absolute minimum, but instead a width suitable for comfortable, everyday use.

Collier, *et al.* (1986) provide recommended entry widths for underground continuous mining machines for two different seam height conditions. These values are summarized in Table 4. Informal comparisons between the two studies indicate that the dimensions presented by Collier, *et al.* are generally smaller than those obtained in the current study, although their recommended width of 123 cm provided for seam heights below 159 cm but greater than 113.5 cm is comparable to this study's 95th percentile dimension of 122 cm for seam heights of 135 cm. The differences may lie in the fact that the dimensions provided by Collier, *et al.* are based solely upon anthropometry, and did not account for range of motion and psychological parameters.

Table 4: Ingress/egress opening dimensions suggested by Collier, *et al.* (1986).

Seam Height	Minimum Width	Preferred Width
>159 cm	25 cm (to 46 cm above ground level) and 45 cm (above 46 cm above ground level)	68 cm
<=159 cm and >113.5cm	123 cm (to 40 cm from cab floor) and 48.5 cm (above 40 cm from cab floor)	—

By using the psychophysical methodology to determine the opening dimensions, valuable information was obtained from each subject. Since miners have varying anthropometric characteristics and, hence, will enter and exit a compartment differently from one another, it is necessary to take into account the range of opening widths determined by the subjects.

These data provide numbers that can be used by design engineers when designing mobile underground mining equipment. It must be noted that these recommendations are based solely upon ingress and egress criteria; other safety and productivity factors may take precedence over these recommended dimensions. Design engineers are, however, encouraged to design equipment such that the largest feasible portion of the population can safely and comfortably use mobile underground mining equipment.

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APPENDIX

Instructions for Ingress/Egress Study

We are attempting to find out appropriate door width dimensions for mobile underground mining equipment.

We are not interested in the **absolute minimum** door width that can be tolerated, but only the minimum door width that allows **safe and comfortable movement** to and from the cab.

We want you to adjust the width of this doorway by sliding the frontmost door to the minimum position that allows you to move in and out of the cab in a safe and comfortable manner. (The rear door position will be set by the experimenters.) Please enter and exit the cab completely for each trial. We ask that you make **at least** three complete trials before your final determination is made, but make as many trials as you feel are necessary to make an accurate determination. When you feel that you have determined the appropriate width, please notify the experimenter.

Do not hurry, and enter and exit the cab carefully.

We encourage you to readjust the door width as many times as you want; only you can adjust the width. We feel that adjusting the width too many times is better than not adjusting the width often enough.

Remember, we are not interested in the absolute minimum door width that you can tolerate, but only the width that allows safe and comfortable ingress and egress.

This is your chance to help us determine appropriate door widths for mobile underground mining equipment.

Any questions?

The Effect of Product Design and Warning Salience on the Perception of Safety-Critical Product Attributes: A Case Study in Infant Carriers

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A field experiment was conducted to determine how the features of a product and the salience of its warnings affect potential purchasers' perceptions of a safety-critical product attribute. The experimental product was an infant carrier which represents a class of products known to be inappropriately used as infant car seats. Sixty-two subjects were asked to examine and select an infant car seat/carrier product from a group of four infant-carrying products. Dependent measures included the subjects' knowledge that the product was not designed to protect an infant in an auto accident and their attention to various warnings. Removing a potentially confusing product feature did not significantly reduce the proportion of subjects who mistakenly thought the product was designed for use as a car seat. However, increasing the warning's salience significantly increased the proportion of subjects who noticed and read it, but only in the most conspicuous condition was there an increase in the proportion of subjects who correctly recognized the product's limitations.

INTRODUCTION

Easily perceivable features of a product can provide users and potential users with a vast amount of non-verbal information from which they can make judgments about a product's structural composition, its method of operation, its basic functional and structural limitations, and its assembly or operational procedures (cf. Baggett and Ehrenfeucht, 1988; MacGregor, 1989; Norman, 1988; Rhoades, Frantz, and Miller, 1990). For many consumer products, features such as knobs, dials, textures, shapes, and structural composition (e.g., glass, plastic, wood, etc.) suggest, invite, or prohibit certain behaviors. Norman (1988) dubbed such features "affordances". According to Norman, affordances are those properties of objects, both perceived and actual, that suggest or imply how the object can be used. Essentially, product affordances allow people to draw upon previously learned skills, rules, and problem solving strategies to interact with a novel product, as opposed to relying on external sources of information such as written instructions or warnings.

From an accident prevention standpoint, product features that provide strong cues about the use of a product are advantageous provided they do not promote or instigate inappropriate and unsafe usage of the product. To investigate this product safety concern in a more formal manner, a field experiment was conducted to determine how potential purchasers' perceptions of a safety-critical product attribute are affected by the features of a product and the conspicuity of its warnings.

Description of product category

The type of product involved in this study was an infant carrier. Infant carriers are designed to hold an infant during activities such as feeding, napping, and shopping, however, they are not designed to restrain or protect an infant in an automobile. While an infant carrier is NOT designed to protect an infant in the event of an automobile accident, there are two other types of products that are designed for this purpose: 1) infant car seat/carrier combinations which carry infants and are also intended for use in automobiles, and 2) infant car seats (also known as child safety seats or child restraints) which are designed exclusively for restraining and protecting a child in an automobile. The latter two types of products have been designed to meet or exceed Federal Motor Vehicle Safety Standard 213 (U.S. DOT, 1981). The potential safety concern is that consumers may unknowingly purchase and use infant carriers as infant car seat/carrier combinations and subsequently have an automobile accident in which an infant is injured or killed due to the lack of protection provided by the infant carrier. This potential safety concern has been discussed in a variety of child passenger safety publications (Gillis and Fice, 1986; Jones, 1988; National Child Passenger Safety Association, 1985).

As opposed to examining the reasons and potential solutions for intentional misuse of infant carriers as car seats, this study focused on the problem of consumers unintentionally misusing infant carriers as car seats as a result of mistakenly believing the infant carrier to be an infant car seat/carrier combination. This confusion may arise from consumers not being aware that different categories of such infant products exist or consumers may be confused as to which product belongs in which category.

A final point regarding the infant carriers is that they often do not have obvious properties that distinguish them from car seat/carrier combinations. Generally speaking, products from both categories have straps for restraining the infant, a handle for carrying the product, a common shape, and a plastic shell construction. Readily observable features such as product weight, structural rigidity, shoulder strap design, in-store display characteristics, and price do not necessarily identify a particular product as a member of one of the two categories. In fact, the only reliable distinction between infant carriers and infant car seat/carrier combinations is that the car seat/carriers will be accompanied by a statement indicating that the product has passed the requirements of FMVSS 213. The potential confusion between infant carriers and car seats was noted in a 1986 consumer guide to buying children's products: "CAUTION: Some indoor baby seats look remarkably similar to infant safety seats. These are not crashworthy and should never be used as car safety seats." (Gillis and Fice, 1986).

Research objectives

Using a particular infant carrier as an experimental product, the specific objectives of this research were to determine: 1) The likelihood that potential purchasers would mistakenly perceive the subject carrier to be suitable for use as a car seat, 2) The extent to which a particular product feature might prompt purchasers to mistakenly perceive the carrier to be suitable for use as a car seat, and 3) The extent to which increasing the conspicuity of on-product warnings might reduce the propensity for consumers to incorrectly perceive the product to be suitable for use as a car seat.

METHOD

Subjects

Sixty-two subjects participated in the study. Fifteen subjects were assigned to each of three conditions and 17 subjects to a fourth condition (two extra subjects were interviewed in the fourth condition because there was some concern that difficulties with the audio/video transmission would result in missed portions of two interviews). Subjects were solicited from those attending or hosting one of the seven garage sales adjacent to which our experimental set-up was positioned for data collection. Approximately 90% of the people approached agreed to participate in the study. Generally speaking, after one interview was completed, the closest available person was approached and asked to participate. Subjects received $5 for their participation. Random assignment of subjects to conditions was not possible due to the inability to inconspicuously change from one condition to another at any given time.

The age of the subjects ranged from 16 to 76 with a mean of 37.4 years. There were 46 females (74%) and 16 males (26%). Twenty-three percent (23%) of the subjects had less than a high school education, 35% had completed high school, and 42% had at least some college education. Seventy-six percent (76%) of the subjects had used an infant car seat at least once and 60% had either purchased or helped to purchase an infant car seat or carrier.

Experimental setting and product display

Four infant carrying products were displayed on a table in the vicinity of a garage sale. Two of the products were infant car seat/carriers which met the requirements of FMVSS

213 and the other two products were infant carriers only (i.e., not designed to protect an infant in the event of an automobile accident). The products were displayed with their point-of-purchase advertising information but without their shipping cartons. Price tags reflecting typical consumer prices were placed in the upper right-hand corner of each product.

The display was erected and data collected at seven different garage sale locations in middle and lower-middle income neighborhoods in a midwestern community of approximately 25,000 residents. Data collection occurred within a two week period in the summer of 1991. To be selected as a data collection site, a garage sale location needed to have sufficient space for the display table and video recording equipment without endangering the subjects and without being too close to the garage sale merchandise (to prevent shoppers from overhearing the exchange between subject and experimenter).

A video camera recorded the subjects during their examination of the product and subsequent interview. The video camera and microphone were not concealed from the subjects in any way. The experimenter interviewed the subjects while another person controlled the video camera.

Overview of experimental protocol

Subjects were approached and asked if they would be willing to participate in a study to determine people’s preferences for different infant products. Once a person agreed to participate, the experimenter instructed the subject as follows:

> Imagine that you are shopping for an infant car seat that can also be used to carry an infant when walking from place to place. When you arrive at the store, this is the selection of products from which to choose. What I would like for you to do is select the one that you would purchase. Please take your time to inspect and handle the products just as you would if you were actually buying one of them, Keep in mind that I’m not asking you which one you like the most or which one you think is the most attractive, I’m asking you which one you would buy with your money. Let me know when you have made your decision.

The purpose of this introductory task was to allow the subjects to become familiar with the products. After subjects selected a product, they were asked if they noticed that the experimental product had a pouch in the back for carrying small baby supplies. For those subjects who did not notice the pouch, the interviewer picked up the product and held it so that the subject could look at the pouch. This was done to insure that each subject was at least exposed to an embossed warning on the back of the product which appeared directly above the pouch. This allowed for some measure of incidental attention to the warning on the back of the product.

Next, subjects were asked to concentrate on the experimental product and express their agreement or disagreement with several statements regarding the intended use of the product For example, subjects were asked to indicate their agreement or disagreement with the statement: “This product is designed for holding a baby while it is riding in a car.” If subjects agreed with this statement they were also asked to indicate their agreement or disagreement with the statement: “This product is designed to protect a baby in the event of a car accident”

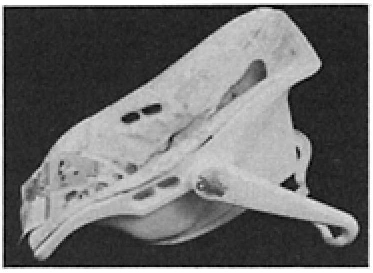
Subjects were then asked if they noticed any warnings or cautions on the product and, if so, what the warnings said and where they were located. Next, subjects were asked to find those warnings or cautions which they had not previously noticed. Finally, after all of the key data were obtained, subjects were asked to express their opinion regarding the noticeability of each warning and provide recommendations for changes to the warnings or the product itself that would make it less likely for people to think that the subject infant carrier was a car seat.

Experimental conditions and research hypotheses

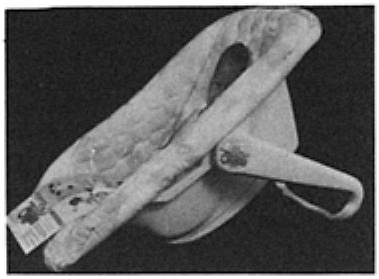
The experimental infant carrier was displayed in one of four conditions (see Figure 1).

Condition 1—Control Condition. In this condition, the subject infant carrier was presented as it is currently sold to consumers. No alterations were made to the product or its warnings other than the addition of a price tag in the upper right-hand corner of the product. The manufacturer’s point-of-purchase advertising, which was a cardboard insert in the shape and likeness of a baby, was strapped into the carrier as provided by the manufacturer.

Two warnings appeared on the product. One was located on the back of the product just above the storage pouch. It stated “WARNING: NOT APPROVED FOR USE IN MOTOR VEHICLES.” This warning appeared in raised white letters against the product’s white plastic shell (i.e., white-on-white format). The letter height was 3/16″. The second warning appeared in the lower left-hand corner of the cardboard baby insert in black print on a light blue background. It stated: “CAUTION: Not for use as a child car seat.” The letter height was 3/32″. The product had holes in the side which were designed as handholds for carrying the product, but they might also suggest a location for a seat belt to pass through. Although



Condition 1 - Side View



Condition 2 - Side View

Condition 3 - Front View

Condition 4 - Front View

Figure 1. Infant Carrier Conditions

the holes in the side of the product are too small for most automobile seat belt buckles, one of the seven car models we tested allowed for the seat belt to pass through the holes.

Given the characteristics of the warnings and the potential affordance for placing a seat belt through the handholds, this control condition was considered to have *low warning salience* and *high affordance* for use as a car seat relative to the other conditions.

Condition 2: Reduced Affordance for Use as Car Seat. This condition differed from the control condition in that a different model of the same infant carrier was used. In this condition, the product had a cloth lining that completely covered the holes in the side of the product, thus removing the appearance of a seat belt insertion point. The warnings were the same as in the control condition.

This condition was included to test the hypothesis that removing a design feature that might suggest an inappropriate use of the product would significantly increase the proportion of subjects recognizing the limitations of the product. More concretely, it was hypothesized that covering the holes in the side of the product would increase the proportion of subjects who recognized that the product was not designed for use as a car seat.

Condition 3: Moderate Warning Salience. This condition differed from the control condition in that the number and salience of the warnings was increased. The control condition warnings were modified in the following ways:

1. The raised letters on the back of the product, “WARNING: NOT APPROVED FOR USE IN MOTOR VEHICLES” were modified to appear in a red-on-white format instead of the initial white-on-white format
2. A professionally prepared label was added to the left shoulder strap. The label was printed in 1/8″ high red letters on a white background and presented the same verbiage as that used by a competitor’s infant carrier:

WARNING: DO NOT USE AS CAR SEAT
NEVER LEAVE BABY UNATTENDED. ALWAYS USE RESTRAINT
DEVICE. DO NOT SET WITH BABY ON TABLETOP OR COUNTER.

3. A 2–1/4″ diameter, circular warning symbol sticker was affixed to the upper lefthand corner on the front of the product. The sticker displayed a symbol of a blue car surrounded by the commonly used red circle with a slash through it. Around the circumference of the circle were the words: “DO NOT USE AS A CAR SEAT!” This sticker was also the same as that of a competitor’s infant carrier.

The features of the product were the same as in the control condition (i.e., the holes in the side of the product were exposed).

Condition 3 was included to test the hypothesis that increasing the salience of warnings against the use of the product as a car seat would increase the proportion of subjects who would recognize that the product was not suitable for use in a car. Note that relative to other carriers on the market, this condition represents a high level of on-product warning salience since the additional warnings were derived from warnings on competitors’ products.

Condition 4: High Warning Salience. This condition was the same as the control condition except that a 4 inch wide, white banner was placed across the front of the product which stated in 1–1/8″ high red letters, “NOT A CAR SEAT”. A by-product of such a large banner was that it somewhat obscured the holes in the sides of the product.

This condition was included to test the hypothesis that increasing warning conspicuity beyond that of the typical infant carrier would result in the highest proportion of subjects attending to the message and recognizing the product was not suitable for use as a car seat

RESULTS

Table 1 shows the percentage of subjects in each condition who agreed with each of the key statements. Collectively, the features of the product prompted a large proportion of the subjects to incorrectly assess the safety-critical limitations of the product. In fact, by combining the responses to Conditions 1, 2, and 3, in which the warnings were either of low or moderate salience, almost half of the subjects (47%) incorrectly agreed that the product was designed to protect a baby in the event of an accident.

Table 1. Percentage of subjects agreeing with the following statements.

	Condition			
	1 Control (Low Warning Salience/ High Affordance) (n=15)	2 Reduced Car Seat Affordance (n=15)	3 Moderate Warning Salience (n=15)	4 High Warning Salience (n=17)
This product is designed for holding a baby while it is riding in a car.	67%	60%	47%	12%
This product is designed to protect a baby in the event of a car accident.	60%	40%	40%	6%

Planned comparisons between the control condition and each of the other conditions were conducted using chi-square tests. Since the results of chi-square tests were the same for responses to both key statements, only the results for the statement “this product is designed to protect a baby in the event of a car accident” are presented.

Regarding the effect of visible holes in the side of the product, the proportion of subjects in Condition 1 did not differ significantly from Condition 2 (χ^2=1.2, N=30, p>0.10). As such, covering the holes in the side of the product did not significantly decrease the proportion of subjects who thought the product was designed to protect a baby in the event of an auto accident.

With regard to the effect of warning salience on the correct perception of the infant carrier, the difference between Conditions 1 and 3 was not significant (χ^2=1.2, N=30, p>0.10), however the difference between Conditions 1 and 4 was significant (χ^2=10.9, N=32, p<0.1) and the difference between Conditions 3 and 4 was significant (χ^2=5.4, N =32, p<0.1). Thus, increasing the warning salience did not increase the proportion of subjects who correctly recognized the critical limitations of the product, except in the most salient warning condition where the prominence of the on-product warning was well beyond that displayed by most, if not all, infant carriers.

Table 2 illustrates the percentage of subjects in each condition who noticed any of the warnings on the product and the percentage of subjects who read any of the warnings. With regard to the proportion of subjects who *noticed* any of the warnings in Conditions 1, 3, and 4, chi-square tests found the difference between Conditions 1 and 3 to be significant (χ^2= 8.9, N=30, p<0.1) as well as the difference between Conditions 1 and 4 (χ^2=15.2, N=32, p<0.1). However, the difference between Conditions 3 and 4 was not significant (χ^2=1.0, N=32, p>0.1). With regard to the proportion of subjects who *read* any of the warnings, Condition 4 resulted in a significantly higher proportion than Conditions 1 or 3 (χ^2=3.1, N=32, p<0.1 and χ^2=18.3, N=32, p<0.1, respectively) and Condition 3 resulted in a significantly higher proportion than Condition 1 (χ^2=7.8, N=30, p<0.1). Thus, increasing the salience of the warnings significantly and substantially increased the proportion of subjects who attended to and read at least one of the warnings against using the product as a car seat.

With regard to the attention to particular warnings on the infant carrier, 5 of the 62 subjects (8%) noticed the warning in raised letters on the back of the product and only 3 of them (5%) actually read it Only two of the 62 subjects (3%) noticed and read the CAUTION statement on the point-of-purchase cardboard baby insert, despite the fact that many of the subjects spent considerable time looking at the promotional information on the cardboard insert. In Condition 3, where a warning was added to the shoulder strap and a sticker was added to the upper left-hand corner of the product, none of the fifteen subjects noticed the warning on the shoulder strap and ten out of fifteen subjects (67%) noticed the warning sticker, however, only eight of the ten actually read it. Finally, in Condition 4, where a large white banner was placed across the front of the product, 14 out of 17 subjects (82%) noticed and read the statement on the banner.

Table 2. Percentage of subjects who noticed and read any warnings on the product.

	Condition			
	1 Control (Low Warning Salience/ High Affordance) (n=15)	2 Reduced Car Seat Affordance (n=15)	3 Moderate Warning Salience (n=15)	4 High Warning Salience (n=17)
Percentage of subjects who noticed any warnings on the product.	13%	13%	67%	82%
Percentage of subjects who read any warnings on the product.	7%	7%	53%	

Although warning comprehensibility was not specifically addressed in this study, it should be noted that all of the subjects who stated that they read at least one of the warnings correctly recognized that the product was not designed to protect a baby in an auto accident.

With respect to demographic considerations, chi-square tests found that gender, age, and previous use of an infant car seat were not significantly related to experimental condition ($p > 0.50$ for all three factors). Thus, the relationship between these subject attributes and knowledge of product limitations could be assessed by pooling responses across all four conditions. Gender and previous use of an infant car seat were not significantly related to subject responses regarding the limitations of the product ($p > 0.10$). However, age was related to knowledge of product limitations ($\chi^2 = 7.7$, N=62, $p < 0.10$). More specifically, across the four conditions, 60% of the subjects 40 years and older incorrectly thought that the infant carrier was designed to protect an infant in the event of an automobile accident, while only 35% of the subjects under 40 had this misconception. A potential explanation for this difference was provided by a middle-aged man who remarked that the current infant carriers are noticeably larger and sturdier than the infant carriers of 20 years ago.

DISCUSSION

Since one of the key features of a car seat is a place to insert or attach a seat belt, it is somewhat surprising that covering the holes in the side of the product did not significantly reduce the confusion regarding the limitations of this product. Subject comments during and after the interviews suggested several reasons for this finding: 1) during the session subjects may not have been thinking about how they would actually use the product in their car, 2) subjects may have realized immediately that the holes in the side of the product were not large enough to permit their seat belt buckle to pass through and therefore, dismissed the holes as seat belt anchoring points, and 3) subjects may have assumed that the product would be secured by some means other than the seat belt passing through the hand holes.

Although the presence of the holes did not significantly affect subject perceptions on the whole, there were several individuals who thought the holes were meant for a seat belt to pass through. These individual misperceptions suggest that, for a small proportion of consumers, the holes in the side of the product present a product safety concern because they may prompt or facilitate inadvertent misuse of the product as a car seat One possible solution to this problem would be to replace the holes with a closed, rounded ledge that still affords lifting but not the possibility of seat belt insertion. This solution stems from our more generic product safety recommendation which is: *Design products with features that afford and suggest intended uses of the product, but do not prompt or facilitate unintended and potentially unsafe uses*. Like verbal instructions and warnings, it is desirable that product features send unambiguous messages to product users.

Regarding the effect of increasing the conspicuity of the warning, the results of this study call into question some common assumptions about the ability of certain warning features to attract attention. Specifically, the presence of a bright contrasting color on the back of the infant carrier, as opposed to the white-on-white format, did not increase the proportion of subjects who noticed the warning on the back of the product. In fact, only 1 out of 15 subjects noticed the red-on-white version. This finding is contrary to commonly held beliefs regarding the effect of contrasting colors and contrary to the opinion expressed by many of the subjects exposed to the white-on-white warning (i.e., the warning would be more noticeable if it were presented in a contrasting color). Note that the subjects' assessment of warning adequacy is quite similar to that typically asked of jurors in failure-to-warn litigation where no human factors expertise is available and/or no specific testing or research has been conducted to determine the effectiveness of the warnings in question. This finding is certainly counter to Hardie's (1991) position that juror's are completely capable of determining the adequacy of warnings unaided by human factors engineers with specialized training and expertise in the design and evaluation of warnings.

The difficulty in getting people to process verbal or graphic product information when their attention is directed toward other types of information was also illustrated by this study. Specifically, 3 out of 17 subjects did not read the warning banner in Condition 4, and 5 out of 15 subjects did not notice the warning symbol on the front of the product in Condition 3. Note that, in this study, subjects who already had relevant criteria by which to judge the products did not need to process verbal or graphic information, but only to examine the physical features of the product. The infant carrier, like many other products and environments, presents the warning designer with the challenge of attracting the attention of individuals who are not planning on processing verbal or graphic information during their interaction with the product or environment. A methodology for dealing with this challenge and improving the effectiveness of warnings in such situations was successfully applied by Frantz and Rhoades (1992). Using a task analytic approach, they systematically examined the cognitive and behavioral elements of a particular task and used the analysis to identify temporal and spatial warning locations that effectively integrated or inserted the warning stimulus into the user's flow of information processing. With more knowledge of the behavior of individual's actually shopping for infant carrier products, this task analytic methodology could also be used to develop alternative warnings for infant carriers.

In closing, the nonintuitive nature of the findings regarding warning salience provides additional evidence that proposed warning solutions need to be evaluated in some manner. The importance of warning evaluation has been stressed by a number of authors (cf. Cunitz, 1981; Laughery and Brelsford, 1991; Miller, Frantz, and Rhoades, 1991; Robinson, 1986). Just as it is important to evaluate the physical design of a product along such dimensions as strength, reliability, and durability, it is important to evaluate proposed warnings along relevant dimensions such as attractiveness, comprehensibility, memorability, and behavioral effectiveness. Unfortunately, systematic evaluations of product warnings and instructions are not typically conducted (Moore, 1991). Our hope is that research efforts will continue not only in the general area of warning design, but also in the more specific area of warning evaluation methodologies so that systematic evaluations of warnings are more readily available and more widely conducted.

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UNINTENDED FORCE TRANSMISSION TO THE PEDAL DURING REACH AT DIFFERENT ANGLES AND HEIGHTS

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INTRODUCTION

The first studies of unintended acceleration highlighted the potential electromechanical basis for the problem, such as failures in cruise control mechanisms, fuel delivery systems, or onboard processors that control fuel mixtures and electrical performances (Schmidt, 1989; Pollard & Sussman, 1989). Some studies have shown evidence that unintended acceleration is the result of driver error rather than a malfunction of the automobile (National Highway Traffic Safety Administration [NHTSA], 1987; Rogers & Wierwille, 1988; Schmidt, 1989). The NHTSA (1987) engineering analysis report examining unintended acceleration compiled a list of drivers' risk factors, suggesting that this issue is related to human factors. Vehicles most frequently involved in accidents are those with which the drivers are relatively unfamiliar.

Schmidt's (1989) reviewed human factors contributions to unintended acceleration and presented a rationale to explain the phenomenon. He noted that during unintended acceleration there was strong support that the right foot does, in fact, contact the accelerator, even though the driver fully intended to press the brake. This inconsistency in foot trajectory is believed to be generated by spinal or muscle-level variability. According to Schmidt (1989), the inherent variability and inconsistent processes that initiate muscular forces and their timings are the source of these errors, and the outcome of these movements regarding the environmental goal can be measured as errors.

There is a sparsity of data regarding the possibility of drivers error, unintended acceleration, during the task of reaching, i.e. keying some information on the farebox by a bus driver. The purposes of the study were: a) to determine the effects of height of reach and angle of reach on the maximum reach, maximum comfortable reach, and forces transmitted to the pedal; and b) to determine the relationship between the magnitude of reach and forces transmitted to the pedal.

METHOD

A mock-up simulated the RTS bus seat-floor-accelerator pedal configuration. Subject's movement and foot pressures on the pedal were quantified and recorded by three separate TV cameras and a force plate interfaced with a computer. This study utilized the VICON motion analysis system with a Kistler force plate (model 9861A, Kistler Instruments AG, Kistler Instrument Corp., Amherst, New York). The population consisted of 13 male and 10 female professional bus drivers volunteering from the New York City Transit Authority with no previous history of neurological and orthopaedic problems. The height and weight of the subjects were 170 (12) cm, and 78 (45) Kg respectively. Data relative to one subject was lost. due technical problems. Therefore, twenty-two subjects were used in the analyses.

The independent parametres were angle of reach (A) and height of the plane of reach (H). The dependent variables were maximum reach (MR), maximum comfortable reach (MCR), and normal peak force transmitted to the accelerator pedal (Fz). There were four angles of reach ranging from 0 degree (lateral reach in the coronal plane) to 90 degree (forward reach in the sagittal plane). The angles were 0, 37, 57 and 90 degree (Fig. 1). The 37 degree angle was chosen because it represents the exact radial line pointing to the farebox keypad on the RTS bus which are largely used by the New York City Transity Authority. The location of the farebox was marked on the 37 degree line of reach. The 57 degree angle was chosen since it represents the radial line pointing to the transfer ticket cutter. The origin of the angles was established by the middle of the seat backrest. with the seat adjusted to the midpoint of the fore-aft range of motion.

The height of the plane of reach was the measured distance of the four lines of reach relative to the floor (Fig. 1). Three heights were represented: 69 cm (dashboard height); 43 cm (farebox keypad height); and, 56 cm (midpoint between the extremes). Maximum reach and maximum comfortable reach were measured from metacarpophalangeal joint III (MCP III) to the middle of the seat backrest at SRL.

In order to accurately measure the forces transmitted to the force plate, the pedal must be mechanically stiff. The real accelerator pedal, however, is compliant and the position of ankle-pedal interface is regulated via the central nervous system. In an attempt to limit variations in the initial force values on the pedal prior to performing the reaching task, the resultant force as measured by the force plate was displayed on the monitor of an IBM-PC. The driver was then instructed to maintain the value within the tolerance limit (±5 N) of a reference line (50 N).

Upon arrival at the Motion Analysis Laboratory of the Hospital for Joint Diseases Orthopaedic Institute, the participants were first asked to read and sign a consent form and to fill out the medical questionnaire. After the subjects were properly screened, the experimental procedures were explained, and the driver's weight and height were measured.

A marker was attached to the participants' right hand over the metacarpophalangeal joint of the middle finger (MCP III). Each subject was then asked to sit and adjust the seat so that the right foot was positioned as it would be for driving. The subjects were asked to place their right foot on the accelerator pedal and rest the left foot on the floor alongside the pedal in a normal driving position. Visual feedback of the forces transmitted to the pedal were provided to the subjects. After maintaining the force within the target

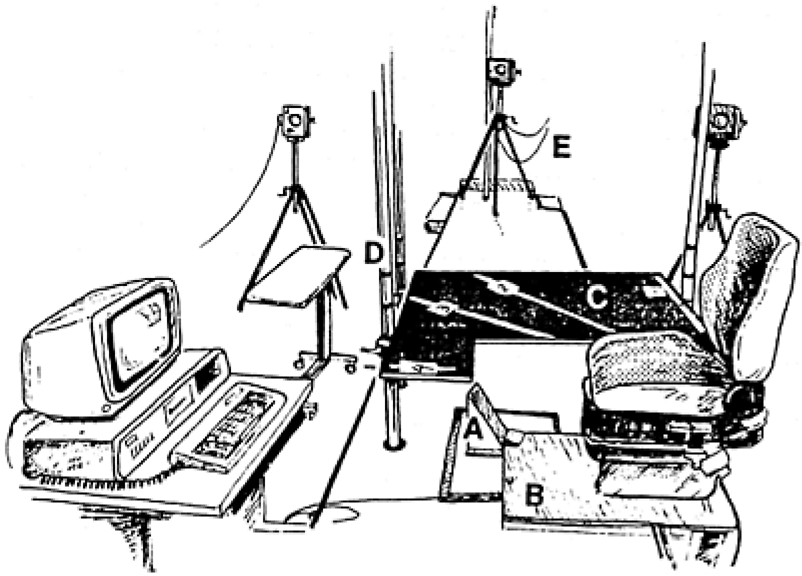

Figure 1. The Schematic Diagram of the Experimental Set-up in the Hospital for Joint Diseases Motion Analysis Laboratory A: Pedal fixed to the Kistler forceplate, B: The base of support for the ISRI 6500 air cushion seat, C: The radial lines 1–4 representing the four different angles of reach on the panel, D: Three different height positions of the panel, E: TV cameras (VICON System)

of 50±5 (N), the feedback was withdrawn and the drivers were instructed to initiate the reach task by a verbal command.

The subjects were first asked to perform their maximum reach and maximum comfortable reach along the horizontal panel for each radial line and for each adjusted height. The subjects then returned their hand to the initial position on the thigh. The maximum reach trial consisted of using the right hand to reach the most forward position along each one of the established radial lines along the horizontal panel. To perform a maximum comfortable reach trial, the participants moved to achieve a perceived position of maximum comfortable reach. Finally, the subjects were required to reach specifically toward the point on the panel representing the spatial position of the farebox keypad.

All subjects performed five practice trials to familiarize themselves with the experimental procedure. The experiment consisted of two reaches, one maximum reach and one maximum comfortable reach for each of the four established angles located at three heights plus the farebox keypad point (height 43 cm and angle 37 degrees). All trials were randomized with respect to the angles and heights to minimize learning effect and repeated twice.

At the initiation of the verbal command, the VICON system was activated to track the marker on the subject's hand and on the seat backrest. The A/D converter interfaced to the force plate was simultaneously triggered to collect the components of the force on the pedal during the reach. The program also calculated the length of the vectors MCR and MR with respect to an origin in the middle of the seat back at the seat height.

The main effects and interaction of angle (A) and height (H) on maximum reach (MR), maximum comfortable reach (MCR) and normal force transmitted to the pedal (F-MCR and F-MR) were tested using a multivariate analysis of variance (MANOVA) procedure with a repeated measure design (SPSSX, 1986; Tabachnik & Fidell, 1989; Norusis, 1990). The Pearson Correlation Coefficients were obtained between driver's height and MCR, MR, F-MCR and F-MR (Table 3). Lack of significant relationship between driver's height and the dependent variables excluded the use of subject's height as covariate in the statistical analysis. The statistical significance for every test was assumed at $p<.05$. The multiple comparison test (Post-hoc Test of Tukey) amongst different levels of the main effects was computed where the main effect yielded statistical significance.

RESULTS

Descriptive statistics consisting of the means and standard deviations (SD) for each angle and height for MCR, MR, F-MCR and F-MR are presented in Tables 1 and 2.

Based on the results of MANOVA, both angle of reach ($F(3, 19)=4.01$, $p<.024$) and height of reach ($F(2, 20)=8.53$, $p<.003$) presented significant main effects on MCR. However, the interaction effect of height and angle was not significant ($F(6, 16)=.75$, $p>.619$). The outcomes for MR showed significant main effects of angle ($F(3, 19)=.88$, $p<.001$) and height ($F(2, 20)=.43$, $p<.005$). The interaction effect was not significant ($F(6, 16)=.44$), $p>.109$). With respect to normal peak force transmitted to the pedal during maximum comfortable reach (F-MCR), neither the main effects nor the interaction were significant. F-MR presented significant main effect of angle ($F(1.42, 29.82)=4.85$, p<.025). No main effect of height and the interaction were found significant for the F-MR. The results of Post-hoc Tests of Tukey for the main effect of angle and height are presented in Tables 3 and 4.

DISCUSSION

The findings of this study with respect to the reach measurements are in agreement with those of reachability studies (Chaffee, 1969; Kennedy, 1978). The results indicate that individuals present larger right hand reach measures in the space delimited between the angles 30 and 60 degrees on the horizontal plane for locations at the right side and the heights of the plane of reach ranging from the seat reference level (SRL) to about 30 cm above. The reach measures decreased for 90 degree (forward bending in the sagittal plane) and for angles posterior to the plane of the seat backrest.

The length of reach depends on the direction of reach (Galer, 1987). The results of this study regarding the height of the plane of reach are in agreement with the findings of previous studies (Chaffee, 1969; Kennedy, 1978). The amount of

Table 1. Maximum Comfortable Reach (MCR) and Maximum Reach (MR), in cm, for Three Different Heights (H1=43, H2=56, H3=69 cm) and Four Angles (Angle 1=0, Angle 2=37, Angle 3=57, Angle 4=90 Degrees)

N=2	MCR		MR	
	Mean	SD	Mean	SD
Angle 1				
H1	64.0	6.0	81.4	13.0
H2	66.9	9.7	84.9	10.8
H3	71.7	9.6	88.2	14.6
Angle 2				
H1	67.6	10.7	97.7	15.6
H2	73.6	10.7	100.4	14.2
H3	75.5	12.7	104.7	14.1
Angle 3				
H1	70.7	13.3	100.8	16.8
H2	73.1	14.9	104.4	13.0
H3	75.2	14.9	107.5	14.2
Angle 4				
H1	69.1	15.0	87.1	16.4
H2	72.1	13.8	86.9	15.5
H3	77.3	12.8	88.6	17.2
Total	71.4	9.2	94.4	10.0

Table 2. Normal Peak Force (N) on the Pedal During Maximum Comfortable Reach (F-MCR) and Maximum Reach (MR) for Three Different Heights (H1, H2, H3) and Four Angles

(N=22)	F-MCR		F-MR	
	Mean	SD	Mean	SD
Angle 1				
H1	49.0	8.9	67.6	19.5
H2	48.9	10.6	62.4	12.5
H3	49.7	10.2	61.3	10.7
Angle 2				
H1	48.8	10.1	74.6	35.3
H2	48.5	9.7	68.6	18.7
H3	48.8	10.8	71.2	26.9
Angle 3				
H1	47.9	7.4	71.1	26.5
H2	48.3	10.1	69.5	21.4
H3	48.9	9.4	71.0	24.6
Angle 4				
H1	48.2	10.2	61.2	15.5
H2	48.4	10.4	59.5	11.6
H3	47.5	10.7	60.5	15.7
Total	48.6	9.0	66.5	16.5

Table 3. Post-hoc Tukey Test Results for MCR, MR, and F-M at Different Angles

Variables	Angles					
	1–2	1–3	1–4	2–3	2–4	3–4
MCR	<	<	<	–	–	–
MR	<	<	–	–	>	>
F-MR	–	–	>	–	>	>

<, > significant difference p<.05;—no significant difference

Table 4. Post-hoc Tukey Test Results for MCR and MR at Different Heights

Variables	Heights		
	H1–H2	H1–H3	H2–H3
MCR	–	<	–
MR	–	<	–

<, > significant difference p<.05;—no significant difference

reach, for both MCR and MR, increases from height 1 to height 2 and from height 2 to height 3.

These results can be explained by the kinesiology of the movement and restrictions on the range of motion due to the body linkages, joints, and muscle systems. The reach movement is characterized by elbow extension coupled with shoulder and trunk flexion. Reach is also function of the contributions of arm length, shoulder breadth, and trunk length. For instance, since the arm pivots on the shoulder, it: is easier to reach ahead of the shoulder than ahead of the nose (Konz, 1990). During the performance of a reaching task with pure lateral bending or forward flexion, the limiting factors could be the shoulder itself or trunk rotation. The stability requirement is also important since the margin of safety for stability is reduced during extreme forward or lateral bending. The drivers were capable of a significantly greater reach along the radial lines 37 and 57 degrees. These results were evident for both maximum comfortable reach and maximum reach.

An important finding of this study was the lack of significant correlation of the height of the driver and the reach (MCR, MR) with the normal peak forces transmitted to the pedal.

Regarding the forces transmitted to the pedal, the results of this study revealed no significant differences on the force measurements due to height of the plane of reach. Angle of reach presented a significant main effect on the results of normal peak force during maximum reach. Angle 4 presented smaller forces than angles 1, 2, and 3. This might be a consequence of the relative position of the driving seat and the pedal, which requires that both legs be flexed to 90 degrees at the knee. Therefore, when the drivers reach forward maximally (angle 4), it is easier for the left foot to balance the forces transmitted as a result of the movement.

The findings of this study reinforce the results of studies that considered unintended acceleration a human factor consequence, i.e., that it may not be a effect of malfunction of the vehicle (NHTSA, 1987; Rogers & Wierwille, 1988; Schmidt, 1989). The results of this study direct attention to the design of the driver’s workstation. A poor design can also be the cause of unintended acceleration. It was shown in this study that the drivers increased the amount of pressure on the pedal when they reached beyond their comfortable reach limits. In particular, when the drivers reached for the farebox keypad location, a rise in the transmitted normal force to the pedal occurred. The difference between the initial and peak normal force values during the farebox reach showed a mean value of 4.83 N, enough to activate the accelerator pedal.

One of the practical results of this study, indicates the need for further analysis of the design objectives during placement of the farebox keypad or other controls within the reach envelope of the seated operator, i.e., the bus driver. The present location of the farebox keypad might be unsafe and could lead to unintended accereleration of the bus. The results for the normal peak forces transmitted to pedal during maximum reach were significantly higher than during maximum comfortable reach. The accidents do not occur very frequently because the drivers receive constant feedback regarding position of the pedal. The quasi-isometric plantar flexion at the ankle joint regulates the amount of force on the pedal and the drivers are constantly receiving feedback from sources such as afferent signals from the joint receptors and muscle spindles (Brooks, 1986), their subjective perception of the pedal position (Corlett, 1965), the possible displacement of the vehicle, and engine noise.

CONCLUSION

This study determined the effects of angle of reach, height of reach, and driver's height on the maximum comfortable reach (MCR), on the maximum reach (MR), and the normal peak force transmitted to the pedal. Angle of reach showed significant main effect on the values of MCR, MR, and F-MR. Height of reach presented significant effect on the results of MCR and MR. There was no significant correlation of the height of the driver on the reach and on the F-MR and F-MCR. Based on the multivariate analysis of variance, the F-MR was significantly higher than F-MCR. The study indicates that locating the controls within the maximum comfortable reach envelope, the possibility of unintended force transmitted to the pedal will be smaller.

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POSTURE

A COMPUTER-BASED METHOD FOR RECORDING THREEDIMENSIONAL BODY POSTURES

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This paper reports on the development of a computer tool to record three-dimensional postures. The program attempts to provide a high resolution technique that is easy to use and not overly time consuming. It incorporates two- and threedimensional graphics and allows the representations to be manipulated to the same perspective as the subject being recorded. Postures can be selected from one of six different views (left, right, front, back, top, and three-dimensional). Separate views are coordinated to force a consistent representation for later analysis or storage.

INTRODUCTION

Posture measurement and recording is essential to most ergonomic assessment techniques. Videotape is commonly used to record work activity and postures are recorded and digitized from the tape. Methods of recording posture range from simple paper and pencil methods to very complex computer-aided video digitization techniques. Paper and pencil techniques, although inexpensive and readily available, either provide a inadequate description of posture or are difficult to use and time consuming. Computer-aided methods offer increased speed of data input, but often lack the complexity necessary to adequately record posture for ergonomic analysis.

This paper presents a computer-based method for recording three-dimensional posture that is intended to be both accurate and easy to use. The program currently runs on a PC compatible computer system and has been designed to assist the analyst in recording postural information from a videotape or still picture record of the work posture. The method uses relatively simple two- and three-dimensional graphics to represent the position of the subject. Spatial compatibility is increased by providing views in all three planes, and presenting a threedimensional figure that can be directly compared to the recorded image. The program attempts to provide a relatively simple user interface and incorporates known limitations in human perception and information processing. At the present time, the method has been developed, and validation work is in progress.

BACKGROUND

Posture recording methods were originally developed to allow the user to directly observe and record work postures as the work was being performed. Paper and pencil techniques were developed to provide the user with a template to rapidly capture postures for future analysis. One of the first methods described in the literature was the Ovako Working Posture Analyzing System or OWAS method (Karhu, Kansi, and Kuorinka, 1977). This was developed as a short, practical method for identifying potentially harmful postures. Simple categories of body position are presented to the user for quick, easy classification of working posture. Corlett, Madeley, and Manenica (1979) developed a more detailed technique termed posture targeting that focused on accurate posture recording. In posture targeting, a template provides concentric circles (targets) for each moveable part of a body shown in standard anatomical position. By selecting the appropriate location on each target, the user can specify the angle of a body part as it deviates from standard position in all three planes.

In general, most paper and pencil techniques have either been designed to be fast and easy to use (similar to OWAS), or are designed to be highly accurate (similar to posture targeting). Methods focusing on quick and easy posture recording produce only a vague description of body position. This lack of specific postural information makes it difficult to perform an accurate ergonomic assessment of the work. The more accurate methods tend to be difficult to use because of their minimal consideration for the cognitive and perceptual limitations of the user. As a result, these methods require an extensive training period (>1 hour) and a somewhat lengthy time to complete (>30 seconds).

The speed of data input and encoding has been increased through the use of computers. Identifying specific postures as keys on the keyboard speeds the input of postural information and there is no encoding time from paper to computer format. Keyserling (1986) developed a method designed to record very general postures and the length of time each posture was held. This method was similar to OWAS, but video and computer technology were used to facilitate data input. A problem with this method is that although it provides a measure of the time spent in the general posture categories, the information recorded is too general for most other ergonomic assessments.

In response to the lack of accuracy and excessive time required to record posture, Malone (1991) developed a paper and pencil technique designed to be highly accurate, but easier to use than the previous methods. The method referred to as posture taxonomy specifically considered the cognitive, perceptual, and anthropometric characteristics of the user. Targets surround each link and identify possible positions a link can adopt. By using a graded range of 15 degree intervals, the sensitivity of the method is reduced to a level that matches the cognitive and perceptual abilities of the user. Each link was also represented in all three planes to increase the spatial compatibility of the method. Although this method accounts for the cognitive, perceptual, and anthropometric characteristics of the user, Malone found that time to complete the posture recording was extensive, ranging from 4 to 6 minutes. The extensive number of targets that needed to be completed maintained a high level of accuracy, but most likely caused the extensive time requirements.

The method presented in this paper is based upon the work of Malone (1991). It places similar emphasis on the perceptual and cognitive issues underlying the recording of human posture. In an attempt to reduce the recording time and increase the accuracy of posture taxonomy, the present method has employed computer technology.

MODEL DESCRIPTION

This project was concerned with the development and validation of a computer program to facilitate the input of three-dimensional postural information by non-experienced users. The method was designed to be as comprehensive as possible, while still maintaining a user-friendly interface.

The program provides the user with six different views of a stick figure representation of the posture of the subject. To present these views, the computer screen is divided into seven sections (See Figure 1). Along both sides of the screen the six views are presented as small boxes with labels. The three views presented on the left are the three-dimensional view, and the right and left side views. The remaining views—front, back, and top—are positioned on the right side of the screen. The central box, or zoom box, is much larger and contains the template where the views can be enlarged and manipulated.

Each view is a stick figure viewed in the saggital, transverse, or frontal plane, except for the three-dimensional view which can be viewed in all three planes. Each stick figure is divided into links separated by 13 joints, with the back divided into two links by a joint at the L5/S1 region. Dividing the back into two links provides the opportunity for greater accuracy by allowing twisting of the spine and bending of the back. This is essential in the analysis of postures related to low back injuries.

A user can select a view to be enlarged with a mouse click anywhere inside the box containing the desired view. When the view is enlarged and centered in the zoom box, the user can manipulate the stick figure using the mouse. The threedimensional view can be rotated by clicking arrows at the bottom of the screen that appear when the view is enlarged (See Figure 1). Spatial compatibility is increased if the posture being manipulated is also represented in the same orientation as the videotaped model.

When the other views are enlarged, the stick figure can be manipulated by selecting a joint with a mouse click. This activates a circle of 24 dots around the selected joint (See Figure 2). The 24 dots provided 15 degree intervals around the joint to represent possible link positions. It has been shown that observers can only reliably discriminate between joint angles of 15 degrees or greater (Gil and Tunes, 1989). By clicking on one of the dots, the user can move a link to various positions around a selected joint. After a joint is rotated, other joints can be selected and rotated until the user achieves the desired posture for that particular view. When another view is selected for manipulation, all views reset to incorporate the changes made in the previous view.

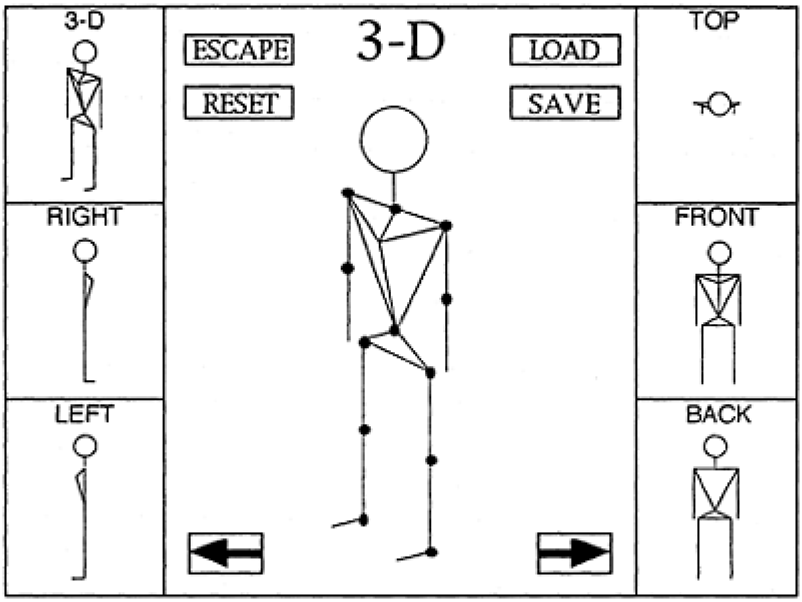

Figure 1. Posture recording template with six views represented and three-dimensional view expanded.

As adjustments are made, the posture of the computer representation changes, providing spatially compatible feedback for comparison with the videotaped posture. In the paper and pencil techniques, a limb position is simply identified by its location or angle of rotation, but the representation is not altered to appear in a different posture. In the computerized method, when the shoulder is rotated to a new position, the forearm and upper arm are also rotated and the representation actively takes on a new posture. Because of this a user can easily check and readjust any link that appears inconsistent with the videotaped posture. It is hypothesized that increasing the spatial compatibility in this manner will increase recording accuracy.

PROCEDURES FOR USE

Specific procedures have been developed to assist the user in recording postural information. First, the threedimensional view is selected and rotated to the correct perspective. By comparing this view to the videotaped posture, the user can manipulate the three-dimensional view until it is presented in the same orientation as the videotaped model. Next, the user selects one of the five views and attempts to recreate the posture as it would look in that view only. For example, if the user selected the "right" view, the videotaped posture would have to be mentally rotated so that it could be seen from the right in the saggital plane. Other views are then selected and manipulated to recreate the videotaped posture. Although only two correctly positioned views are necessary to recreate the videotaped posture, the user can select and manipulate as many views as are desired.

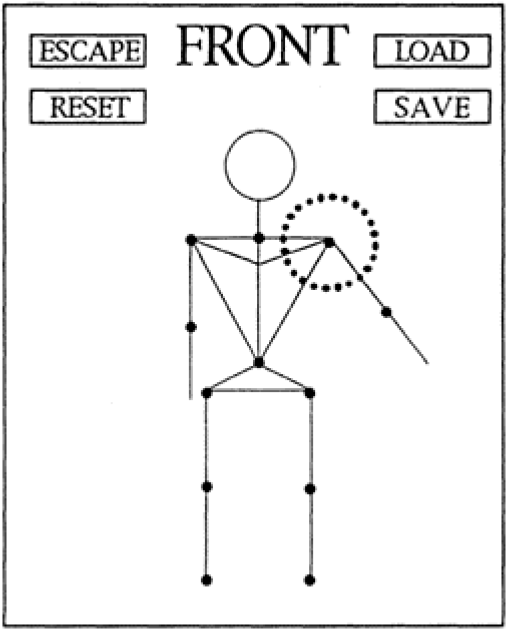

Figure 2. Front view expanded with graded range surrounding the left shoulder.

A reset button is included to allow the user to erase all postural manipulations and start from scratch. Also, an escape button is available that allows the user to leave an enlarged view without incorporating any of the postural changes completed in that view. Save and load buttons are also included to save postural information and recall previously recorded information. Data is stored as three-dimensional points for each joint and reference point. This format facilitates the retrieval of postural information and the subsequent analysis of that information.

The proposed method incorporates many of the advantages of the previously developed methods, and attempts to remove some of the disadvantages. By increasing the spatial compatibility to a greater degree than Malone (1991), it is hypothesized that the accuracy of the method will increase. Using a computerized format for the input of postural information, it is hypothesized that the speed of data input will increase, reducing the overall recording time.

VALIDATION

A validation experiment is planned to determine if the objectives of the method have been met. A range of fixed ergonomic postures will be recorded on videotape and presented from several different angles. Subjects will view and record these postures using the computerized method. The accuracy and reliability of the method will be tested by comparing the postures recorded to those recorded by other subjects and the known values. Recording times will also be measured and compared to previously developed methods to determine if the method is efficient.

In addition, each subject's spatial ability will be measured using standardized tests. Spatial abilities will be compared to performance for the posture recording task. It is hypothesized that subjects with superior spatial ability will perform this task more quickly and accurately than those with poor spatial ability.

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POSTURAL STABILITY WHILE HOLDING LOADS USING VARIOUS STRATEGIES

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INTRODUCTION

Load-carrying is common in industrial, military and recreational activities. The major ergonomic concerns in load-carrying are injuries due to slips which result in falls, musculo-skeletal overexertion injuries due to slips with recovery of balance, and overexertion injuries from the load itself. This preliminary research investigated the effects on postural stability of holding loads in various postures while standing upright. Load-carrying is the focus of ongoing work and the correlation between holding and carrying will be explored.

Only one previous study referencing standing stability while holding loads was identified. Davis (1983) measured voluntary sway angles and reported that stability was reduced in laden as compared to unladen standing. The loss was nearly linearly related to the magnitude and height of the load. Although interesting issues in postural stability while holding and carrying were highlighted, the source of data presented is unfortunately unclear.

Research addressing load-carrying is somewhat more prevalent, however, contradictory conclusions have sometimes been reported. For example, Pierrynowski et al. (1981) and DeVita et al. (1991) found minimal load effects on temporal and kinematic gait parameters. Others, including Martin and Nelson (1986) and Nottrodt and Manley (1989), concluded that load conditions did significantly affect these measures. Another concern pertains to carrying modes which have been investigated. Modes have varied widely and often apply to a specific population or task, frequently military applications.

In this study, standing stability while laden and unladen was assessed. Holding postures representative of those used in industry were chosen for evaluation. Variables derived from foot force measurements were the primary criterion for evaluating stability but limited human motion data was recorded as well. The hypothesis that postural stability is negatively affected by load-holding as compared to unladen standing was tested. Effects of varying postures on stability were quantified. It was theorized that two-handed postures, symmetric in the frontal plane, were unstable compared to one-handed asymmetric modes. The hypotheses that stability was reduced by holding loads at higher vertical heights and holding heavier external loads were also examined. Another goal of this study was to identify quantitative measures and experimental conditions relevant to the hypotheses of interest. These results will be useful in designing subsequent experiments to further understanding posture and balance control mechanisms employed while manipulating an external load. Ergonomic load-holding and carrying strategies may eventually be recommended.

METHODS

Protocol

Two young adults of average anthropometry, one female and one male, were tested while standing upright holding a 10x10x13 inch wood box, empty or loaded, in one of several positions. The box had a smooth metal handle attached to the top and cutout handles on the sides. Adequate finger clearance was assured. Trials with no external load were also performed. Three-dimensional foot forces were recorded while the subjects stood on an EquiTest System posture platform (NeuroCom International, Inc.). Unexpected forward horizontal translations of the supporting surface were induced in two magnitudes. Practice trials familiarized the subjects with the protocol. Trials requiring the subjects to stand quietly with no perturbation were also performed. Reflective markers were taped on the subject's left side at the following landmarks: ankle (lateral malleolus), knee (lateral femoral epicondyle), hip (greater trochanter) and shoulder (acromion process). Human movement was video-recorded and analyzed in the sagittal plane using the Peak Performance Motion Measurement and Analysis System (Englewood, CO).

Experimental Design

Table 1 summarizes the independent variables and levels tested. Six holding postures were chosen for investigation based on frontal plane symmetry and vertical height of the load (high, mid or low). The postures are defined as follows.

(1) 1-HAND-AT-SIDE: load held at subject's side with dominant hand using handle on top of box, elbow fully extended (asymmetric & low)
(2) 2-HANDS-AT-SIDES: as 1-hand-at-side but half of load is held by each hand in identical boxes (symmetric & low)
(3) 1-HAND-AT-WAIST: load held with dominant arm at waist level, resting on iliac crest (asymmetric & mid)
(4) 2-HANDS-AT-WAIST: load held against the torso at waist level using side handles, elbows flexed 90 degrees (symmetric & mid)

(5) 2-HANDS-LOW: as 2-hands-at-waist but elbows are fully extended (symmetric & low)
(6) 1-HAND-HIGH: load held on shoulder with dominant arm (asymmetric & high)

The perturbation variable was tested at four levels. The magnitude of small perturbations was 0.5 * subject height in inches/72. Large perturbations were 2.25 * subject height in inches/72. Static standing trials involving no perturbation were conducted with eyes open and eyes closed. Lastly, the box was either empty or contained a 25 pound sack of lead shot.

Table 1: Independent Variables

POSTURE	PERTURBATION	LOAD
1-hand-at-side	small	box
2-hands-at-sides	large	box & lead
1-hand-at-waistt	none/eyes open	
2-hands-at-waist	none/eyes closed	
2-hands-low		
1-hand-high		

Each subject was tested in a combination of randomized full and half-fraction factorial designs. The 1-hand-at-side, 2-hands-at-sides, 1-hand-at-waist and 1-hand-high postures were tested at all combinations of perturbation and load levels in a full factorial design. For the 2-hands-at-waist and 2-hands-low postures, an additional independent variable indicated whether the load was grasped above or below its center of gravity. Half of all possible experimental conditions were tested for these two postures. Finally, trials with no external load were conducted at all perturbation levels. Due to the configuration of the EquiTest System, three trials of each posture, perturbation and load combination were conducted in succession. Six repeated trials were obtained by running two groups of three. All groups of three were randomized separately for each subject.

Analysis

A large number of dependent variables were analyzed and all were defined such that increased magnitudes were interpreted as indications of reduced postural stability. Emphasis was placed on variables derived from the foot force data. The center of pressure (COP) was calculated over time and used to determine root mean square sway amplitudes and average velocities for the medial-lateral and anteroposterior directions and their resultant (ml_sway, ap_sway, res_sway, ml_vel, ap_vel, res_vel). The COP maximum absolute deviation from its initial location was calculated for the medial-lateral and anteroposterior directions (ml_dev, ap_dev). The last dependent variable derived from foot forces was the maximum anteroposterior shear force, normalized by body mass (ap_shear).

Dependent variables derived from the human motion data included sagittal plane joint ranges of motion and maximum angular accelerations of the ankle, knee, hip and shoulder. Range of motion was defined as the difference between the maximum and minimum measured angles and indicated the extent of joint flexion and extension resulting from induced perturbations. Angular acceleration was calculated as the second time derivative of the joint angle. Since flexion versus extension was not of concern, the maximum absolute acceleration was analyzed.

The human motion data was collected under restrictions and therefore interpreted with discretion. It was analyzed only for trials involving large or small perturbations. The accuracy of the measurement system available precluded motion analysis of trials without perturbations. Also, only the two-handed symmetric postures and the trials involving no external load were considered. The asymmetric postures were excluded since only two-dimensional motion data acquisition was possible and the responses elicited from one-handed postures were expected to be nonplanar.

Laboratory space limitations required that the camera be placed at a 45 degree angle to the plane of movement rather than the optimal orthogonal positioning. The data were translated into the sagittal plane using the method developed by Holbein and Redfern (1991).

In the half-fraction factorial design chosen for the 2-hands-at-waist and 2-hands-low postures, the interactions confounded with main effects were assumed to be insignificant and subsequent statistical analyses supported this assumption. The grasp condition did not have a statistically significant effect on any of the dependent variables defined. Therefore, it was eliminated from further analyses and all six postures were analyzed as a full factorial experiment.

The order within each group of three perturbations was initially treated as an independent variable. Order was found to periodically affect some dependent measures derived from foot forces, mainly for small perturbations. This result was taken into account when comparing holding postures.

Various statistical techniques were used in analyzing the data. A liberal 0.1 significance level was applied throughout to avert premature elimination of any experimental conditions. Linear regression models were employed to determine if the independent variables affected the dependent variables defined. Least-Significant-Difference tests were used to determine significant differences in pairwise main effect means. Significant differences in the postures and loads tested from the control condition of unladen standing were estimated using Dunnett's two-tailed t-test. All statistical analyses were conducted separately for each subject and perturbation level. Perturbation conditions were not combined since initial investigations confirmed that this variable had a large effect on the magnitude of subject responses. An exception was the eyes open and eyes closed variations of the no perturbation condition. Few differences were noted with eyes closed compared to eyes open for the purposes of this study.

RESULTS

Foot Force Data

Table 2 presents the combined means and standard deviations across all postures and loads of the dependent measures calculated from the foot force data. Large differences between subjects were not evident and they were combined for brevity. All variables shown were positively correlated with each other (R=0.7 to 1.0, except ml_dev). To provide a more general measure of instability in further analyses, they were weighted equally and combined in various manners.

Table 2: Results Derived from Foot Forces by Perturbation [means and (standard deviations)]

	NONE		LARGE	
ml_sway (mm)	0.03	(0.02)	0.16	(0.08)
ap sway (mm)	0.06	(0.03)	0.59	(0.21)
res_sway (mm)	0.07	(0.03)	0.62	(0.21)
ml_vel (mm/s)	14.56	(2.50)	31.08	(5.62)
ap_vel (mm/s)	16.04	(2.27)	50.43	(8.96)
res_vel (mm/s)	24.10	(3.67)	65.65	(10.51)
ml_dev (mm)	3.82	(2.04)	5.84	(2.57)
ap_dev (mm)	6.50	(3.39)	28.33	(4.29)
ap_shear (% body weight)	0.34	(0.24)	5.29	(1.66)

The statistical analysis of the above dependent variables for the defined holding conditions yielded the following significant findings:

(1) Standing unladen was not more stable than holding an empty or loaded box. In fact, the sway velocity measures indicated that holding was more stable than unladen standing. This was true especially for the 1-hand-at-side, 2-hands-at-sides and 2-hands-low postures and the loaded box.

(2) When each posture was individually compared to the group of remaining five others, 1-hand-at-waist was the most unstable. 2-hands-at-waist was also unstable with large perturbations. 2-hands-at-sides and 2-hands-low were more stable than the other postures tested.

(3) When postures were categorized based on symmetry, asymmetric postures were less stable during quiet stance for both subjects. During a perturbation, the male's medial-lateral measures (ml_sway, ml_vel, ml_dev) were less stable for asymmetric holds. However, the symmetric group was less stable for the female during a large perturbation.

(4) When categorized based on load height, those postures with the box at waist level were less stable than holding the box either high or low.

(5) Holding the loaded box was less stable than holding an empty box with respect to sway magnitude, COP deviations and, for quiet standing, ap_shear. However, the heavier load condition resulted in increased stability with respect to sway velocity during quiet stance and ap_shear during large perturbations.

Human Motion Data

Human motion data involving only symmetric postures or no external load and with perturbations were investigated. Table 3 summarizes the ankle, knee, hip and shoulder ranges of motion for each subject from large perturbations, combining all postures and loads. The female's ranges of motion were approximately twice as large as the male's. These data were all positively correlated (R=0.7 to 0.9) and hence were again used collectively to indicate the overall extent of body movement.

Table 3: Joint Ranges of Motion for Large Perturbations [means and (standard deviations)]

	FEMALE		MALE	
ankle range (deg)	7.80	(1.55)	3.49	(0.75)
knee range (deg)	16.23	(2.18)	5.80	(1.79)
hip range (deg)	9.22	(3.02)	5.83	(1.30)
shoulder range (deg)	5.41	(1.77)	3.71	(1.30)

For large perturbations, the lowest angular accelerations were in the shoulder, followed in order by the ankle, hip and knee. The values for the shoulder and ankle were similar as were those for the hip and knee. Subjected to a cut-off frequency of 8 Hz, the female's shoulder and knee accelerations were 1809 and 3914 deg/s^2, respectively. These same results for the male were 1325 and 2612 deg/s^2. However, the acceleration data was found to be sensitive to the cut-off frequency chosen.

Similar to the foot force measures, increased magnitudes of the kinematic data were interpreted as indications of reduced stability. Comparing holding with unladen standing, few consistencies with respect to significance occurred. When differences were noted, symmetric holding was more stable than unladen standing, especially for the female. Also, comparing the external loads with no load, laden was occasionally more stable than unladen standing and especially for knee and hip kinematics. Considering the three postures analyzed, the few instances of significant differences indicated that 2-hands-at-waist was less stable than 2-hands-at-sides or 2-hands-low. Finally, holding the loaded box resulted in increased ankle and knee movement when compared to the empty box, especially for the female.

DISCUSSION AND CONCLUSIONS

Many of the variables derived from the foot force data are commonly used to assess the postural stability of balance-impaired patients and to rehabilitate these individuals. The application of this experimental paradigm to ergonomic issues is somewhat new, as is the incorporation of human motion analysis.

The limited number of subjects in this study prevented definitive conclusions from being drawn. However, trends in the data were evident and conclusions suggested by any one statistical test were often supported by other separate tests.

When the trials requiring a box to be held were compared with the unladen standing trials, the hypothesis that holding a load decreased postural stability was not supported. The foot force and kinematic data suggested that the addition of an external load actually improved stability for the holding postures with the load held closest to the ground (1-hand-at-side, 2-hands-at-sides, 2-hands-low). These postures lower the center of gravity of the body-and-box system as compared to the other postures or unladen standing. It is possible that the vertical height of the center of gravity is crucial when recovering from a moderate balance disturbance as was induced in these experiments. However, the accelerations of an external load may worsen one's ability to recover from a more severe balance disturbance.

Comparing the empty box and the box with lead, it was unclear whether increased loads affect postural stability. Holding the box with lead did not consistently result in reduced stability. It is possible that the position and availability of the upper extremities to assist in balance recovery is more significant than the amount of mass held.

The 2-hands-at-sides and 2-hands-low postures provided the most stable holding strategy of those tested, probably a result of the low load height rather than the frontal plane symmetry of the holds. When all postures were categorized based on the vertical load height, those nearest the ground were more stable than those with the load either at waist level or on the shoulder. The most unstable method was 1-hand-at-waist and 2-hands-at-waist was the next worst.

One-handed asymmetric postures were generally less stable than two-handed symmetric ones although this result was not conclusive. Symmetric postures were more unstable for the female subject during large perturbations and, therefore, were not invariably superior. However, two symmetric postures were labeled superior overall and an asymmetric posture was considered the worst. Also, asymmetry was not favored in the quiet standing trials nor according to some medial-lateral measures in trials involving a perturbation. The center of gravity of the body and box system was moved away from the frontal plane center line in the one-handed holds. Diminished stability may be expected when minimizing movement of an external load is a large portion of the overall task, such as during quiet standing, and only one limb is used to do so. When the task requires minimizing movement of both the body and a load, such as during perturbations, it may be advantageous to have one arm free to help recover stability. Although medial-lateral stability may be reduced by using only one arm, the increase in anteroposterior stability may be more crucial in recovering from perturbations, similar to a slip, induced in that plane.

These conclusions did not all agree with Davis' (1983). He reported that holding loads decreased stability compared to unladen standing, with the worst conditions being heavier loads held higher. Experimental conditions were similar in the studies. He tested males and females with loads held at the waist, on the shoulder and on the head. However, one reason for the disagreement in conclusions may have been the different dependent measures used. His measure, sway angle, was not calculated here. Furthermore, Davis reported only trends and not statistical results.

The results of this study suggest that further experimentation is warranted to better understand postural stability during laden standing. The vertical height of the external load appears to be critical and the frontal plane symmetry of the hold may be a factor. The magnitude of the load does not appear as an important consideration although testing a larger range of loads may indicate otherwise. The minimal differences between quiet standing trials with and without eyes open were not expected since vision is known to play a major role in postural stability and control. Further testing of this condition may be performed if vision is considered a factor in the situations of interest. Finally, the foot force measures were sensitive enough to detect statistical differences among the postures and loads tested. The limited human motion data was also somewhat sensitive; three-dimensional analysis of all postures is recommended to support the conclusions.

Conducting similar experiments while carrying loads would provide a means for comparing standing stability with stability during gait. A high correlation between holding and carrying would justify recommendations of ergonomic load-carrying strategies based on the results of much simpler standing experiments.

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A NOVEL APPLICATION OF POSTUROGRAPHY TO THE EFFECTS OF ASYMMETRICAL LOAD HANDLING

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INTRODUCTION

The study of human posture is of interest to many different scientific disciplines. According to Johansson and Magnusson (1991) important applications of posture and gait research include: orthopaedics and physical therapy, occupational and sports medicine, otorhinology and neurology, and biomedical engineering. The postural problems important to occupational medicine and ergonomics include slipping, tripping and spinal loading. Many factors are involved when a person slips and falls. It appears that a person's ability to maintain their posture and regain their balance may be a major factor. Investigators have used several different techniques to study posture: one of the most widely used today is the moving platform, which will be employed in this study. The majority of the studies that have used the moving platform have examined the electromyographical (EMG) responses of the leg muscles (quadriceps and hamstrings) and lower leg muscles (gastrocnemius and tibialis anterior). Many of these studies have concentrated on the lower leg muscles because these are the muscles that will make the initial adjustment to the perturbation. However, according to Nashner (1977) the multijoint sway dynamics of the body also creates movements about the knee and the hip. Nashner and McCollum (1985) have proposed two postural synergies that are used during translational perturbations: an ankle synergy and a hip synergy. During backward translation the muscles on the posterior surface of the body (eg. gastrocnemius, hamstrings and erector spinae) contract to help maintain balance. Nashner (1977) found that the gastrocnemius, hamstring and erector spinae produced movements to compensate for the forward antero-posterior (AP) sway that occurs during posterior translation. He concluded that the rotation at the ankles caused by the AP sway caused the trunk and leg muscles to respond to the perturbation. Responses in the leg muscles to perturbations have been shown to exhibit stereotyped temporal organization (Woollacott et al., 1988, Nashner and McCollum, 1985). It appears that the ankle muscles are activated first and then the muscles of the upper legs and trunk on the same side of the body. A study being done in our laboratory at the University of Massachusetts has consistently shown that during backward translation the posterior leg muscles are activated in a distal to proximal sequence which is in agreement with other studies (Woollacott et al., 1988, Nashner and McCollum, 1985). The effects of carrying a load on the postural responses have yet to be examined in the current literature.

Of the current published studies only one examines the EMG activity of the muscles on both sides of the body (Duncan et al., 1990) while others assume that the muscular responses are symmetrical. The validity of this assumption has yet to be examined. A recent study by Mizrahi and Susak (1989) examined the bi-lateral reactive force patterns in postural sway activity of normal subjects. This study used two force plates placed adjacent to each other and measured ground reaction forces during postural sway. It was stated that the force traces were synchronous, however the vectorial force patterns were found to be different possibly indicating that the levels of muscular activity were different for each leg. They recommend that when examining postural sway the activity of each leg should be taken into account.

There have been two studies that have examined the effect of asymmetric load carriage on erector spinae EMG activity. A 1987 study by Cook and Neumann compared the erector spinae EMG activity during loads carried anterior to the chest, loads carried backpack style and loads held in the hand. This study only examined the erector spinae activity on one side of the body; they found that there was a comparable increase in the EMG activity during both the anterior loading and contralateral hand held loading. Both of these increases were significantly different from the no load and the backpack loaded conditions. This study also showed that although there tended to be an increase in the erector spinae EMG during contralateral loading, there was actually a decrease in erector spinae EMG when the load was held ipsilaterally. This result should not be unexpected since asymmetric loading causes a lateral flexion moment and thus increased activity in the contralateral erector spinae. It was concluded from this study (Cook and Neumann, 1987) that one handed carrying causes a decreased muscular activity ipsilaterally but an increased muscular activity contralaterally; they also concluded that the anterior carrying position needs the most muscular effort bilaterally. A 1986 study by Burton examined the EMG activity of the erector spinae during the carrying of two different types of grocery bags, one with handles, which could be carried in one hand, and one without handles, which had to be carried anteriorly. This study found that when comparing the two bags there was no significant difference between EMG activity of the right and left lumbar region erector spinae groups. However, they found that there were two distinct groups of subjects, one which exhibited a difference between right and left erector spinae EMG activity and one that did not. It was hypothesized that the one group that showed no difference may have used their abdominal muscles to take the load. It was also concluded that the bag without the handles created a lower and more even load on the erector spinae muscle group than the bag with the handles. From the results of these studies it appears that more research on this topic must be done.

The purpose of this current experimental method is to examine the effect of symmetric and asymmetric loading on EMG responses of the hamstrings and erector spinae muscle group during postural perturbations; the bilateral activity of those muscles will be examined to determine the symmetry of responses. This protocol will also examine the foot pressures during the various conditions.

METHODOLOGY

Subjects

Ten college aged male volunteers will participate in this study. Each subject will be cleared by University Health Services prior to participation. In addition, each subject will read and sign an informed consent document that is consistent with University guidelines for the protection of human subjects. All subjects will be screened for low back problems and postural abnormalities.

Stimulus Delivery System

A translating platform will be employed to cause the postural perturbation. A block diagram of the equipment setup can be found in Figure 1. The platform will translate posteriorly at 30 cm/sec for 1.0 second. The system was originally designed by Andres (1979) and has since been modified. The platform is powered by a DC motor (Electrocraft E703–01) which is controlled by a servo amplifier (Electrocraft 6200AP) which is triggered by an IBM-XT computer. Position and velocity feedback are monitored by an Electrocraft 110 tachometer.

Electromyography

Bipolar surface electromyography (EMG) will be used to assess activity of the right and left hamstring and erector spinae muscles. Two reusable electrodes will be applied to the skin over the belly of each muscle being examined. An additional pre-gelled, silver-silver chloride surface electrode (Hewlett Packard 14445C) will be placed on the lateral condyle of the femur and serve as a ground. Prior to application of the surface electrodes the area of application will be shaved and cleansed vigorously with isopropyl alcohol to remove hair and layers of dead epithelial cells. Raw EMG will be preamplified (Analog Devices AD524, CMRR=120 dB, input impedance=10^9), integrated with a 55 millisecond time constant by an RMS integrator (Analog Devices AD536A) and amplified (Analog Devices AD524), then converted to root mean square (RMS) EMG. The RMS-EMG will be sampled with a 16 channel analog to digital converter (Data Translation DT-2801A) at a rate of 600 Hz using a Zenith 386 computer running data acquisition software and stored on floppy disk for further analysis.

Center of Pressure Measurements

Tekscan (Boston, MA) sensors will be used to determine foot pressure data during each trial. The subject will stand on the sensor sheet and data will be collected during translation of the platform. An Epson 386 computer will be used for data acquisition. Data will be collected at 20 Hz for 5.0 seconds.

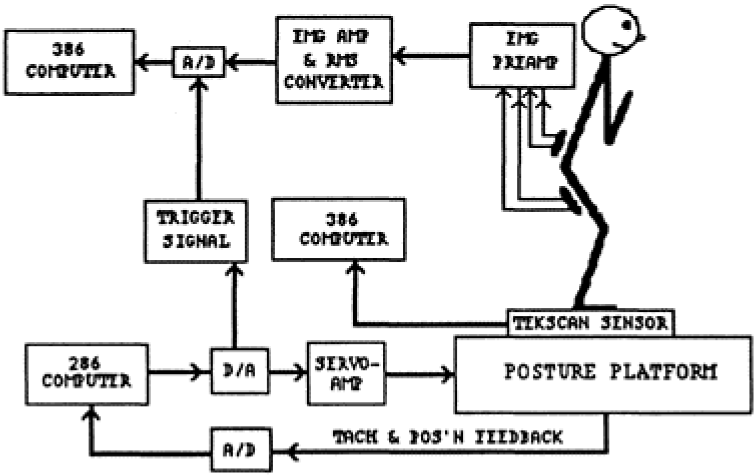

FIGURE 1. Block diagram of equipment setup.

Experimental Protocol

The experimental protocol will consist of three sessions for each subject; the first session will be treated as a learning session and no data will be collected. Each session will consist of 30 trials; the subject's eyes will be closed during all trials. Six trials will be conducted at each of five conditions: 1) unloaded, 2) symmetrically loaded holding a box in front of the body, 3) asymmetrically loaded holding an asymmetrically weighted (weight on the right side) box in front of the body, 4) asymmetrically loaded holding a box in the right hand (suitcase style), 5) symmetrically loaded holding a box in each hand. The order of the conditions will be randomly selected. The first trial at each condition will be used to collect quiescent data for the EMG and foot pressure measurements. During the loaded conditions the subject will hold a mass that is equivalent to 20% of their body weight. The length of the box used for the anteriorly loaded conditions will be 2 times the subject's shoulder width.

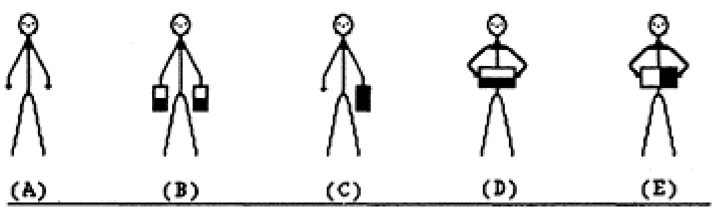

FIGURE 1. Stick figures of the five conditions. (A) unloaded, (B) symmetrically side loaded (suitcase

style), (C) asymmetrically side loaded, (D) symmetrically front loaded and (E) asymmetrically front loaded.

<u>Criterion Measures</u>

Researchers have used many variables in an attempt to quantify postural sway. Hufschmidt et al. (1980) have developed several measures of postural stability, among these are the Sway path (SP) and Mean Amplitude (MA) which will be calculated from the foot pressure data:

$$SP = \sum_{i=1}^{n-1} \sqrt{(AP_{i+1}-AP_i)^2 + (LAT_{i+1}-LAT_i)^2} \quad (1)$$

$$MA = \sum_{i=1}^{n} \sqrt{(AP_i^2-LAT_i^2)} \quad (2)$$

In both equations 1 and 2, AP=Antero-posterior location of center of pressure and LAT=Medio-lateral location of center of pressure.

Electromyographical measures used in this study include: latency which is defined as the time interval between the onset of the perturbation and the beginning of the reflex response, peak amplitude which is defined as the value of maximum activity of the muscle during each trial expressed as a percentage of the maximum activity for that day. Duration of muscle activity and the average activity over a particular window of time (pre, post and during translation) will also be calculated from the EMG data.

<u>Statistical Procedures</u>

An analysis of variance (ANOVA) for repeated measures will be used to evaluate differences between conditions. Sheffe's multiple comparison test will be used to analyze any significant differences between conditions. The intraclass correlation will be used to determine the reliability of the criterion measures.

CONCLUSIONS

The results of a pilot study indicate that a hip strategy may be used when a subject is anteriorly loaded; however, during side loading an ankle stategy may be used. Nashner and McCollum (1985) have suggested that a hip strategy may be used when the support surface is too narrow, causing the ankle to be unable to exert sufficient force to regain balance. Increasing the load above the center of gravity may also cause a hip strategy to be used because of the inability of the ankle to exert enough force to overcome the loss of balance without help from the hip and trunk. Further analysis is necessary to determine the exact strategy used in each condition.

During the asymmetrically loaded cases the center of foot pressure was shifted towards the load and the muscle activity of the contralateral erector spinae was increased, thus it appears that during asymmetric loading both the EMG and foot pressure responses are asymmetric. The lateral moment created by the load causes the contralateral erector spinae to counteract this by bending the trunk laterally away from the load. This asymmetric response of the erector spinae may lead to injury, further investigation may provide insight into the mechanisms involved in this asymmetric response.

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NIOSH WORK PRACTICES GUIDE OR MANUAL LIFTING: SIGNIFICANCE OF POSTURALLY-BASED DIFFERENCES IN PERCEIVED STRESS IN LIFTING TASKS OF EQUIVALENT DESIGN MERIT.

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Examination of postures assumed when performing symmetrical lifts in the sagittal plane, showed that subjects preferred to limit extensor activity about the knee and flexor activity at the shoulder, and to rely more upon the strong extensors of the back to initiate and complete a lift or lower operation. This strategy markedly reduced perceived strain even though it insidiously increased the magnitude of mechanical stress acting upon the lumbar spine. High-frequency lifting appears to negatively reinforce use of stoop lifting strategies; extinguishing use of mechanically-preferable squat-lifting strategies. If confronted with an array of design options that provide equivalent Action Limits, select the option that presents the least mechanical risk if the worker chooses to use a stoop lift.

INTRODUCTION

The National Institutes of Occupational Safety and Health (NIOSH) has and continues to construct guidelines for the design and conduct of manual lifting (NIOSH, 1981). Current NIOSH guidelines are based upon concomitant consideration of epidemiological, biomechanical, physiological, and psychophysical criteria. The objective of the guideline is to reduce the risk of an overexertion injury by improving the match between the physical demands of a lifting job and the worker’s physical work capacity. Practitioners applying the NIOSH Work Practices Guide for Manual Lifting (NIOSH WPG) attempt to increase the Action Limit for a lift by adjusting horizontal, vertical, distance, and frequency discounting factors. In short, the NIOSH WPG's structure allows a designer to select from a wide range of design options that in many cases offer equivalent degrees of risk reduction. Careful review of the basis of the NIOSH WPG shows that it is heavily dominated by biomechanical factors and, to progressively lesser degrees, by aerobic demands and psychophysical criteria. If a worker elects to use postures that are not consistent with those recommended by the NIOSH WPG, then risk of injury to the low-back could be much greater than that suggested by the WPG.

The literature contains a few reports that subjects or workers fail to gage muscular tension or other cues of intervertebral disc compression within the low-back when performing lifting tasks (Freivalds et al., 1984; Karwowski, 1991; Waikar, Lee, Aghazadeh, and Parks, 1991). If workers are insensitive to high-levels of mechanical stress in the low-back when performing lifting or lowering tasks, then one would expect other cues to influence selection and use of lifting behaviors (e.g., postures, exertion strategies, etc.). NIOSH (1981) argued that workers may consider aerobic and production demands when choosing between stoop and squat lifting postures; squatting postures increase aerobics demands, challenge the extensor strength capabilities of the knee, and are less time-efficient (Garg, et al., 1985). If so, one could expect: a) a knowledgeable worker might use squat lifts when lifting rates are low, and to transition into stoop lifting when aerobic demands increased to intolerable levels, or b) that workers might always elect to use stoop lifting strategies to minimize aerobic, strength, and other demands given past experience.

The objective of this paper is to test the argument that workers prefer to use postures that minimize perceived strain, that such postures are at times contradictory to those recommended in the NIOSH WPG, and that failure to consider this phenomenon when designing or evaluating lifting tasks can subject workers to greater than necessary risk of low-back injury.

METHODS AND MATERIALS

Subjects. Fifteen males and three females ranging in age from 18 to 26 years, served as subjects in this experiment. Acceptance for participation in the study was based upon a subject's willingness to continue participation in the study after progressively lifting 7.5, 10.0, and 12.5 Kg loads at a rate of 9 lifts per minute while assuming a posture that had been found to be most stressful during pilot experimentation. All subjects participated in the study on an informed consent and paid basis.

Apparatus. Subjects were asked to lift and then lower a wooden box of 22 cm in width, 19 cm in depth, and 37 cm in height. The box contained predetermined numbers of plates of steel to adjust its weight as needed to meet experimental requirements. Cylindrical handles of 3 cm in diameter were attached to the box to enable subjects to perform an underhand cylindrical grasp and lift. Subjects lifted the box from a custom-built shelf that was adjusted to meet required initial horizontal and vertical positioning of the box relative to the standing height of the subject.

Procedures. Subjects reported to the laboratory on 16 separate days across a 6 week period following a session of familiarization and practice with the lifting task and equipment. A subject, on each test day, was asked to perform a cyclical stand, assume a pre-specified posture, grasp box, lift box to waist height in a standing posture, return or lower box to shelf again while assuming the prespecified posture, release the box, return to a standing posture, and stand until signaled to repeated the cycle. The cycle of lifting and lowering was repeated at a rate of either 3 or 9 per minute.

Each subject's heart rate was recorded, along with a cross-modal estimate of perceived strain, every three minutes during the trial. The procedure used to cross-modally match perceived strain to a visual line-length is described elsewhere (Wiker, Chaffin, and Langolf, 1989). Subjects were asked to anchor their matches such that a zero length line represented no symptoms of strain, while a maximum visual line length would represent either a sense of exhaustion or intolerable musculoskeletal discomfort.

The set of fixed-stance test postures assumed, shown in Figure 1, were designed to orthogonally-vary combinations of estimated lumbar L5/S1 intervertebral disc compression and back extensor force requirements, load torque: isokinetic strength ratios for flexion at the shoulder and extension at the knee determined by pre-experimentation strength tests, and estimated abdominal pressure. The particular postures and frequencies of cyclic lifting and lowering experienced during a given test day were randomly-sequenced. Unless subjects reached 75% of maximum heart rate or an equivalent report of strain, trial performance continued for 20 minutes. Upon completion of a trial, subjects were allowed to rest before departing the lab and did not return on subsequent days for further testing until all residual signs and symptoms of localized or systemic fatigue had waned completely.

RESULTS

At the start of each test session, subjects were asked to place their feet in a test position and then to use a "free-style" lift of the box. Subjects performed this lift as a warm-up and did so prior to learning of the day's scheduled test posture. Each subject was exposed to the same lifting geometry (i.e., equal horizontal and vertical locations of the load) twice; once each for the two lifting rates. The figure below plots the postural orientation of the major links of the body at the beginning or initiation of the "free-style" lift. Foot placement relative to the load differed for each condition. The plot shows, however, that subjects employed equivalent postures for across all eight lifting conditions. Subjects tended to keep the upper arm and lower leg aligned vertically, while using torso, knee, and, to a much smaller degree, elbow flexion to position the body for the lift. The plot also shows that torso flexion was often matched by a concomitant degree of knee flexion or squat.

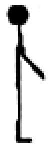
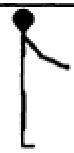
L5/S1 Disc Compression	Shoulder Moment	Knee Moment	Test Posture
Low	Low	Low	
		High	
	High	Low	
		High	
High	Low	Low	
		High	
	High	Low	
		High	

Figure 1. Experimental postures assumed by subjects when performing the cyclic lifting and lowering task at either 3 or 9 lifts per minute.

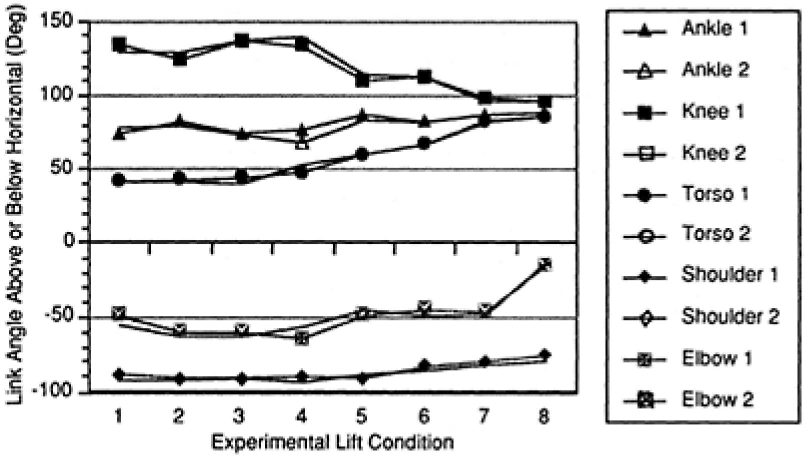


Figure 2. Plot of ankle, knee, hip (torso), shoulder, and elbow angles, above or below the rightward horizontal, produced when subjects performed a semi-freestyle lift of the tote box on two separate test days.

Average cross-modal matching estimates of perceived strain and heart rates recorded at the eighteenth minute of testing are plotted in Figure 3.

Standardized regression of cross-modally-matched perceived strain (PS) reported during the 18 th minute of testing showed that reports were significantly affected by lifting frequency, stress in the lumbar region and the moment about the knee ($F=47.7$; $MSE=305$; $p<0.001$; $R^2=0.48$):

$$PS=0.59F+0.35C+0.15K+0.11S-0.13FCK$$

where:

PS = Cross-Modal Matching Report of Perceived Strain
F = Number of Lifts Per Minute
C = L5/S1 Disc Compression
K = Load Moment at the Knee
S = Load Moment at the Shoulder

Similar analysis performed on heart rate produced an equivalent outcome.

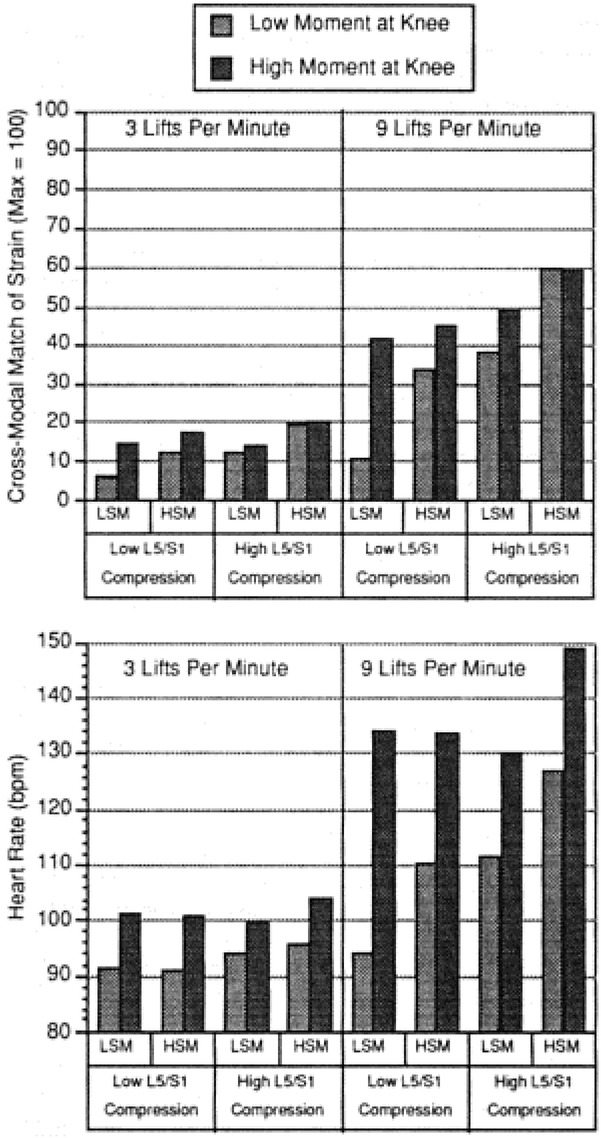


Figure 3. Plots of average cross-modal matching reports of strain and average heart rates recorded during the eighteenth minute of each trial. Means are plotted across all experimental conditions. Note that LSM refers to a

low shoulder moment, and HSM refers to a higher shoulder moment.

DISCUSSION AND CONCLUSIONS

Descriptive models showed that postures which increased tension in the extensors of the knee, markedly diminished any change in perceived strain associated with elevations in mechanical stress within either the shoulder or low-back. However, if the moment about the knee was reduced toward zero, then subjects showed that they were able to detect elevations in stress acting upon either the low-back or the shoulder. Based upon the differences in the ranges of moments experienced about the shoulders and low-back in this study, it is clear that the shoulder produced comparatively more discomfort for a given level of moment that did the lumbar region.

Comparable findings obtained with descriptive modeling of heart rate showed that increases in extensor activity at the shoulder, the low-back, and the knee produced successively greater elevations in heart rate. The model suggests that one can reduce aerobic demands, indicated by heart rate, for a given lifting task by keeping the moments at the knee and shoulder as low as possible and relying upon the extensors of the back to perform the lift. This finding is supported by the work of Garg and Saxena (1985) who found that performance declined and that oxygen uptake and heart rates increased when squat lifts were employed in lieu of stoop-lifting.

Collectively, the findings suggest that workers would prefer to limit extensor activity about the knee and flexor activity at the shoulder, and to rely more upon the strong extensors of the back to initiate and complete a lift or lower operation. This strategy markedly reduced perceived strain even though it insidiously increased the magnitude of mechanical stress acting upon the lumbar spine.

In either case, high-frequency lifting appears to negatively reinforce use of stoop lifting strategies; extinguishing use of mechanically-preferable squat-lifting strategies. If so, one should design repetitive lifting tasks with the expectation that workers will elect to use stoop lifting techniques. If confronted with an array of design options that provide equivalent Action Limits, select the option that presents the least mechanical risk if the worker chooses to use a stoop lift.

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BODY POSTURES, AIR VELOCITY VARIATIONS, AND THERMAL COMFORT

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Human body regional air velocity and the effect of body posture on the air velocity were studied using manikins. Air velocities were measured at six body sites and for two postures: standing and sitting. Large variations were found in the regional air velocities. Posture-induced differences were smaller than expected. The free stream air velocity was found to give a good approximation of the whole body mean air velocity. However, work place designs based on whole body parameters cannot accommodate the effects of localized thermal comfort level variations that a worker's body may experience.

INTRODUCTION

Air velocity is one of the basic physical parameters that define the thermal environment and govern heat exchange between the human body and the environment [ISO, 1985]. In the heating, ventilation and air conditioning field, air velocity is a critical variable in the evaluation of the air diffusion performance index (ADPI) or thermal comfort indices such as "predicted mean vote" (PMV) or "predicted percentage of dissatisfied" (PPD) [ISO, 1984]. PMV and PPD are whole body indices. A work environment designed with the aid of PMV and PPD attempts to balance the whole body thermal comfort level of the workers within the work place. However, the design does not account for localized thermal comfort level variations that a body may experience. Also, the indices do not-have appropriate mechanisms to account for any posture-induced difference in the air velocity levels.

This study looked at the regional and whole body air velocities encountered by the human body. The effects of body posture on air velocity were also studied. Two postures: standing and sitting were compared. Regional air velocity were measured at six selected body sites: Head, Chest, Upper Arm, Lower Arm, Thigh, and Lower Leg. These six sites are affected differently when the human body changes from a standing to a sitting posture. The limb segments of the Lower Arm and Thigh change from a vertical to a horizontal orientation when the body sits down. The Upper Arm and Lower Leg limbs tend to keep their approximately vertical orientation. The Head and Chest experience almost no change in orientation except in their heights relative to the ground. Because of the varieties of effects, the regional air velocity profiles at these sites can be expected to differ between the two postures. Regional air velocity variations were examined as a potential source of inadequacy in whole body thermal comfort indices such as PMV and PPD.

METHOD

The study was conducted in an environmental chamber at the U.S. Army Research Institute of Environmental Medicine. Two life-size, unheated, stationary manikins were used to simulate the human body posture of standing, and sitting on a chair (see Figure 1). The manikins offered anthropometric human body features and contour, and the advantage of absolutely reproducible postures. Both manikins have the same body surface area of 1.68m^2. Data from the standing and sitting manikins were measured separately.

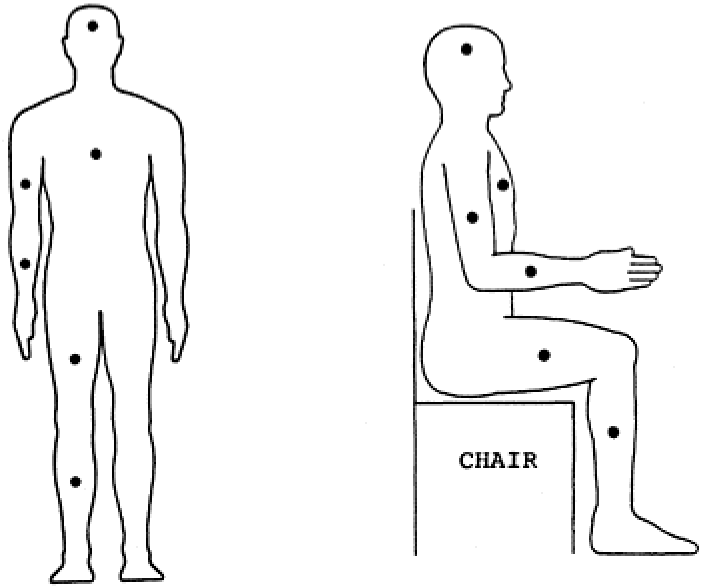

Figure 1. Standing and sitting manikins.

The environmental chamber has precise temperature, humidity, and airflow control. The chamber temperature was set to 21°C, with relative humidity at 50%. Two chamber air velocity settings were used: 0.447m/s (1 mph), 0.894m/s (2 mph). The chamber free stream air velocity was measured with a unidirectional thermal anemometer, placed at a height of 1.7m from the chamber floor and a distance of 2.2m in front of the manikin. The manikins faced directly into the chamber airflow.

Air velocities were measured at six selected body sites using omnidirectional thermal anemometers. The approximate positions of the six sites are depicted in Figure 1. A set of six anemometers was mounted on a telescoping tripod support (see Figure 2). The air velocities were measured with the anemometer probe placed 1.0 cm from the designated body sites. As much as possible, the anemometer probes were orientated at a 90° angle to the direction of the chamber airflow to minimize the yaw angle and roll angle effects. The omnidirectional probes have a range between 0–3.00 m/s. The time constant of the anemometer is 2 seconds. The air velocity data were linearized, analog-to-digital converted and collected using a desktop personal computer.

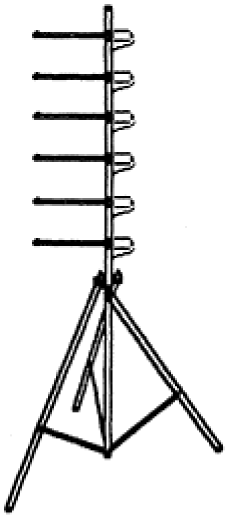

Figure 2. Schematics of anemometers on supporting tripod.

At each of the six body sites, the regional air velocities were measured at eight equally spaced radial positions around the site: 0° (front), 45°, 90° (right side), 135°, 180° (back), 225°, 270° (left side), and 315° (see Figure 3). For the sitting manikin, the limb segments of the Lower Arm and the Thigh are in a horizontal orientation. For these horizontal limbs, the 0° position represents the top (rather than front) of the sites, and the 180° position represents underneath (rather than the back of) the sites. At the Chest site, for the 45° and 315° positions, the anemometer probes were placed above the pectoral muscle in the vicinity of the nipples. For the 135° and 225° positions, the probes were placed in the vicinity of the scapulae.

The actual data collection procedure was a repetitive process. At each chamber air velocity setting, one

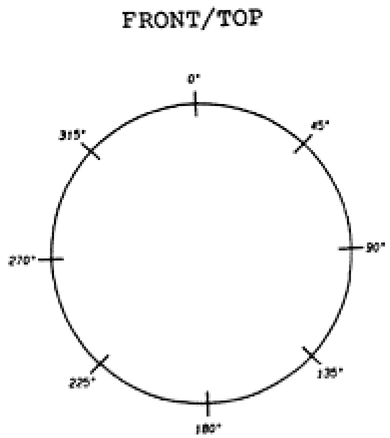

Figure 3. Anemometer radial positions.

anemometer was placed at each body site, with all six at the same radial position. Air velocity data were collected at 3-second intervals, for a continuous 10-minute period. After the 10-minute collection period, the chamber air velocity was changed to a new setting. Another round of 10-minute data collection was initiated. After both chamber air velocity settings had been employed, the six probes were then moved to the next radial position to begin another round of 10-minute data collection. This process continued until all eight radial positions were completed. Therefore, each complete set of data contained 2 rounds of measurement, with each round composed of data from all 6 body sites, at 8 probe positions.

RESULTS and DISCUSSION

A total of nine data sets from the standing manikin and six data sets from the sitting manikin were collected. At each of the six measurement sites, the eight radially positioned measurements were averaged to produce a site mean value. It is assumed that each body segment acts as a natural integrator that averages the eight radial position data and that the site mean represents the air velocity level experienced by the body segment as a whole. The site means in Table 1 were each produced from the entire set of standing (9 sets) or sitting (6 sets) manikin data.

In Table 1, the air velocity levels at the Head site were from two to five times higher than the other sites. A probable explanation may involve a shape factor. The head may be described as an approximate sphere whereas the limbs are cylindrical in shape.

The differences in the site mean air velocities between the two postures were not as remarkable as expected. The Head and Chest regional air velocities showed minimal change between standing and sitting. The limb segments that changed orientation from vertical (when standing) to

TABLE 1. Site mean air velocities (in m/s)

	STANDING MANIKIN						
Free Stream		Head	Chest	UpArm	LoArm	Thigh	LoLeg
0.447	–	1.01	0.570	0.270	0.355	0.423	0.184
0.894	–	1.89	1.01	0.585	0.782	0.815	0.405
	SITTING MANIKIN						
Free Stream		Head	Chest	UpArm	LoArm	Thigh	LoLeg
0.447	–	1.02	0.510	0.414	0.422	0.340	0.205
0.894	–	1.68	0.915	0.694	0.838	0.730	0.475

horizontal (when sitting), the Lower Arm and Thigh sites, showed only minor differences in the site mean air velocity levels between postures. In fact, the largest posture-induced site mean dif ference occurred at the Upper Arm site, where the limb kept its orientation between standing and sitting. It is worth noting that even though the mean air velocities at the Lower Arm and Thigh sites were similar between postures, the air velocity profiles at these sites were prominently different between standing and sitting. For example, in Figure 4, the air velocity profile of the Lower Arm was quite irregular in the standing (vertical) posture, but much more circular, i.e. with nearly equal magnitudes around the limb, for the sitting (horizontal) posture. Figure 4 is a two-dimensional profile, where higher air velocities are represented radially outward from the center. The center circle represents the cross-sectional top view (for the vertical orientation while standing) or back view (for the horizontal orientation while sitting) of the Lower Arm. The symbols O and Δ were used to represent air velocity data measured at the two chamber settings of 0.447m/s and 0.894m/s, respectively. On the radial (polar) plots, each unit represents 0.05m/s. The curves that connect the eight data points around the body segment were only used to aid visualization. The curves do not represent continuous data points.

In Table 1, no relationship can be found between the site means and the chamber free stream air velocity. In both postures, no site mean resembled the free stream air velocity. However, the situation became quite different when the overall means were examined in Table 2. The overall mean is an equal-weight average of the site means. From Table 2, it is apparent that the overall means give a good approximation of the chamber free stream velocity in both postures.

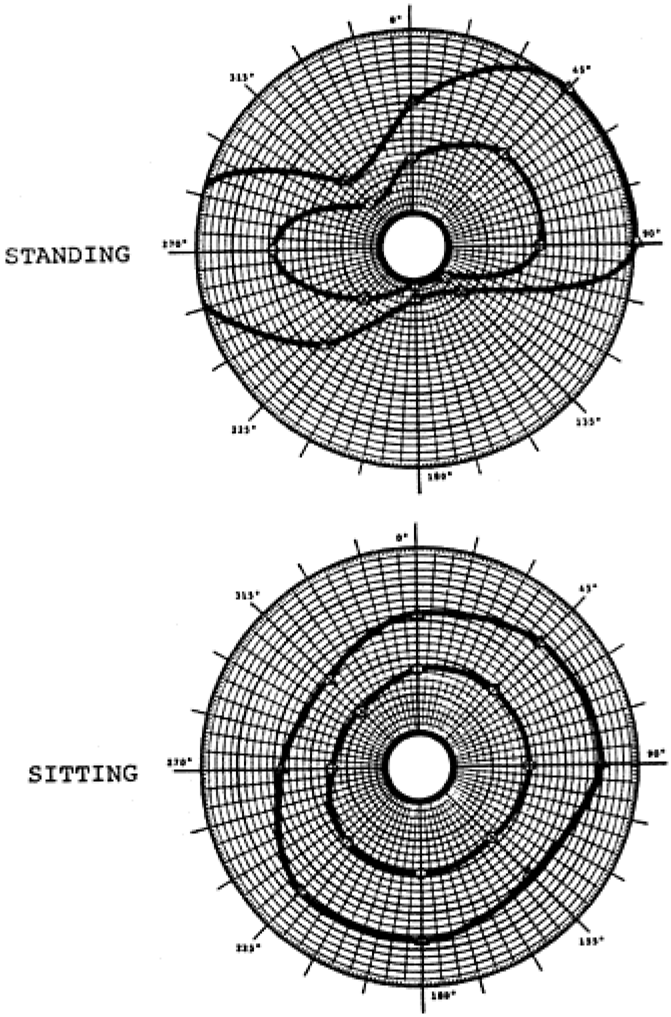

Figure 4. Lower Arm air velocity profiles of standing and sitting postures.

A weighted mean was also computed and included in Table 2. The weights were adopted from the ratios of body segment surface area to the total body surface area [Nishi and Gagge, 1970]. The weights used were: Head 8%, Chest 35%, Upper Arm 8%, Lower Arm 9%, Thigh 20%, and Lower Leg 20%. The surface areas of the hands and feet were grouped with the Lower Arm and Lower Leg sites, respectively. The weighted mean contained a disproportionally large contribution from the Chest data, because the large body trunk area is attributed entirely to the Chest site. Remarkably, Table 2 shows the weighted means in close

TABLE 2. Overall and weighted mean air velocities (in m/s)

STANDING MANIKIN

Chamber Free Stream	Overall Mean	Weighted Mean
0.447	0.468	0.455
0.894	0.914	0.864

SITTING MANIKIN

Chamber Free Stream	Overall Mean	Weighted Mean
0.447	0.486	0.440
0.894	0.888	0.826

agreement with the overall (equal weight) means. The chamber free stream air velocity proved to be an adequate approximation of both whole body mean data, for both postures.

It is not immediately apparent why the overall mean and the weighted whole body mean should agree and that the chamber free stream air velocity offers a good approximation of whole body mean air velocities in both body postures. Perhaps the fact that both manikins have the same total body surface area is one important factor. Rapp [1973] did find that convective heat transfer of a standing, sitting, and reclining nude man can be very uniquely modelled by a sphere having the same Dubois surface area as that of the nude man.

It was assumed earlier that each body segment acts to average the surrounding air velocity. This assumption is certainly not applicable to the whole body. Within an asymmetrical thermal environment, it is possible to feel localized discomfort while the whole body is thermally neutral [Gonzalez, 1983]. The human body is sensitive enough to experience localized conditions. Therefore the free stream air velocity may approximate the whole body mean air velocity, but it may not represent the conditions experienced by the body at various skin sites.

Thermal comfort indices such as PMV and PPD are whole body indices, and are calculated using a single air velocity value. Usually, the free stream air velocity is applied. It may appear fortuitous that the free stream air velocity is a good representation of the whole body mean air velocity. However, since the regional air velocities can be quite disparate as Table 1 showed, and since the human body is subject to localized discomfort, the comfort indices such as PMV and PPD may not be adequate to represent conditions experienced by the human body. The large variations found in the regional air velocities will likely elicit disparate localized thermal comfort responses. As the PMV index is formulated presently, no mechanism is available to account for any localized thermal discomfort.

The posture-induced difference between standing and sitting apparently has only a minor effect on thermal comfort scale. The small variations in air velocities found between postures in Table 1 would make only a 0.10–0.15 point difference in the PMV index [ISO, 1984], which may not be large enough to alter a person’s thermal comfort sensation.

CONCLUSION

This study looked at the regional and whole body air velocities encountered by the human body, and the effect of posture, standing and sitting, on the air velocity. The regional air velocities were measured at six selected body sites. Large variations in the regional air velocities were found among sites. The two postures caused only minor differences in the regional site mean air velocities, even though the air velocity profiles were markedly different between standing and sitting. The free stream air velocity gave a good approximation of the whole body mean air velocity. However, whole body indices such as the PMV and PPD cannot properly account for local thermal comfort level variations that the workers within a work environment may experience. The human body is susceptible to localized discomfort even though the whole body is at a theoretically thermal neutral condition.

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PERCEPTION

Application of Stochastic Catastrophe Models to Visual Perception

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This paper presents a stochastic catastrophe model for perception of ambiguous objects in sensory test. Fisher's ambiguous man/girl figure was extended to a sequence of continuous figures. The subjects' perception of the ambiguous figure was measured as a function of figure size and amount of vibration of a hand-held disk.

Our hypothesis was that a bistable perception phenomenon would be found in the subjects' judgemnet of the ambiguous man/girl figure as the details of the figure changed smoothly from man to girl and back.

In the expereimental design the stimuli consisted of 21 distinct figures in the sequence from man to girl, with 15 levels of detail. Nine size of figures were used, ranging from 1.8 ×1.0 cm to 7.0×3.9 cm. The strength of the vibrations in the hand-held disk ranged from $5 m/sec^2$ to $35 m/sec^2$ in increments of $5 m/sec^2$.

The median age of the 20 subjects was 20 years old. Our experiment led to the following conclusions:

1. Variations in the occurrence of changes in perception was not influenced by vibration or figure size, but was influenced by detail and by individual differences within the subjects themselves. A stochastic catastrophe model explained the bistable perceptions experienced by the subjects.

2. A statistical test of the fit of a stochastic cusp catastrophe model to the jugements recorded in this experiment leads to the conclusion that such bistable phenomena can be explained by a cusp catastrophe.

INTRODUCTION

A few researches (Fisher, 1969, Attneave, 1971, Poston and Stewart, 1978) explain multistable or ambiguous perception by catastrophe models. For example, in Fisher's work (1967), it is clarified that man face and girl shape are perceived with almost same probability in the case of seeing Fisher's figures. Also, Attneave (1971) describes that the different perception for Fisher's figure is occurred by seeing from man face to girl shape and reverse using a sequence of continuous figures in which Fisher's figure is interpolated in the middle of the sequence.

In this paper, Attneave's figures were extended to a sequence of continuous figures by means of computer graphics. Using the sequence, the effect of the size of figures and localized vibrations on a bistable perception phenomenon seeing the ambiguous man/girl figures is investigated.

Next, a sequence of continuous figures with the details of the figure changed smoothly from man to girl is drawn by an improved interpolate method.

In order to examine the relationship among the physical quantity of the figure changed smoothly from man face to girl shape, the details of the figure and the psychological quantity for human, scaling of sensation is performed. And an application of cusp catastrophe models to a bistable perception phenomenon with a splitting factor of the details of figure and a normal factor of the changes of figure from man face to girl shape is tried.

EXPERIMENTAL SPECIMEN AND METHOD

In experiments, the extended Fisher's ambiguous man/girl figures shown in Fig. 1 of which the changes from man face to girl shape are 21 kinds of figures and the details are 15 kinds of figures are used experimental specimens. Also, in the size of figures, 9 kinds of figures shown in Table. 1 from 1.8×10 cm to 7.0×3.9 cm are used. The acceleration of localized vibrations exposed to the fingers tip of subjects are changed from $5 m/sec^2$ to $35 m/sec^2$ by $5 m/sec^2$. Subjects are 20 men before and after 20 years old.

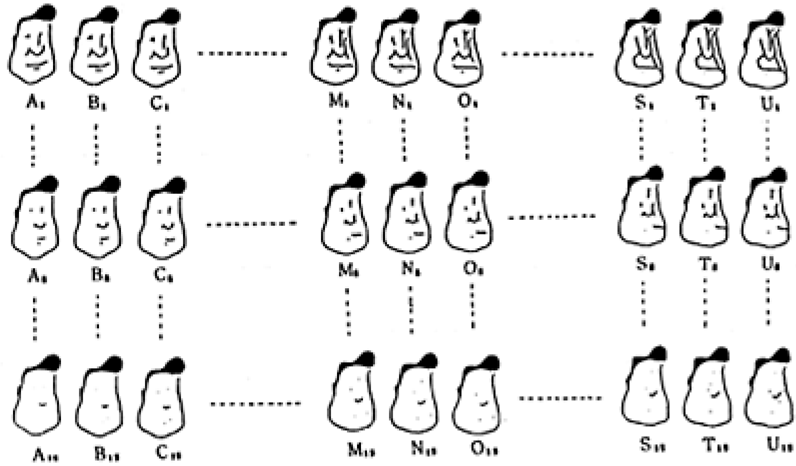

Fig.1 A sequence of continuous fingers extending Fisher's ambiguous man/girl figure with detail

In the next experiment, the figures 4.0×2.2 cm in size is used. In the detail of figures, the code numbers 1, 3, 5, 7, 9, 10, that is, 6 kinds of the size, are selected, and the experiment of the size is performed at random. The subjects look at these figures in sequential order from man face to girl shape and judge the figure in which the change of their visual perception occurs, and the reverse is also performed. One sequence is repeated 8 times. Subjects are 43 men before and after twenty years old. Also, the experiment for scaling of sensation is performed. The degree of man face and girl shape become lower, as the detail of figure is lost. In order to calculate the degree of man face and girl shape for each figures series, the scaling of sensation for the series A_1 to A_{15} and U_1 to U_{15} is performed respectively.

For the series A_1 to A_{15}, 15 figures from A_1 to A_{15} are shown the subjects and assigned numerical values from 1 to 100 by them.

In addition, for the series U_1 to U_{15}, the experiment is performed in much the same way as that for the series A_1 to A_{15} and the degrees of man face and girl shape are calculated. The scaling of sensation for 21 figures of the series A_1 to U_1 is also carried out and the relation of the physical quantity of the change from man face to girl shape and psychological quantity of human is investigated. There are 20 male subjects before and after 20 years old.

EXPERIMENTAL RESULTS

There are no effects of localized vibration to finger tip on the change of visual perception. It is seemed that the behavior of visual perception is influenced by subject. First, for each subjects, the data is analyzed by the one-way layout. Factor is the size of figures. The factor has nine levels and four observations. The result of this analysis is shown in Table

2. Also, the result of correlation analysis for the numerical values of the size of figures and of the change of visual perception is shown in Table 3. This table does not show the correlation of the size of figure and the change of visual perception. Second, factor is subject. The factor has nineteen levels and 36 observations. The result of this analysis is shown in Table 4. As a result, the significant difference in subjects is discriminated in numerical values in the figures at which the perception is changed. The

Table 1 Figure size

code	figure size (ratio)
1	1.8 cm×1.0 cm (0.7)
2	2.2 cm×1.2 cm (0.86)
3	2.5 cm×1.4 cm (1.0)
4	3.1 cm×1.7 cm (1.22)
5	3.5 cm×2.0 cm (1.41)
6	4.3 cm×2.4 cm (1.72)
7	5.0 cm×2.8 cm (1.99)
8	6.1 cm×3.4 cm (2.43)
9	7.0 cm×3.9 cm (2.8)

Table 2 Change of visual perception from man face to girl shape by figure size (subject 1)

factor	mean square	degree of freedom	variance	F ratio
figure size	0.065	8	0.008125	1.79
error	0.1225	27	0.004537	
total	0.1875	35		

Table 3 Correlation analysis

	correlation factor	
factor	change of perception from man to girl	change of perception from girl to man
1	0.401*	0.557*
2	0.097	−0.184
3	0.239	0.151
4	−0.170	−0.166
5	−0.215	0.240
6	0.164	0.045
7	0.452**	0.424
8	0.520**	0.068
9	−0.144	−0.150
10	0.33	0.224
11	0.470**	0.288
12	0.384*	0.223
13	−0.150	−0.084
14	0.436**	−0.054
15	−0.203	−0.394*

16	0.296	0.401*
17	−0.098	0.135
18	0.175	0.275
19	0.107	0.195

Table 4 Change of visual perception

factor	mean square	degree of freedom	variance	F ratio
subject	7.63364	18	0.424091	61.79**
error	4.56389	665	0.006863	
total	12.19753	683		

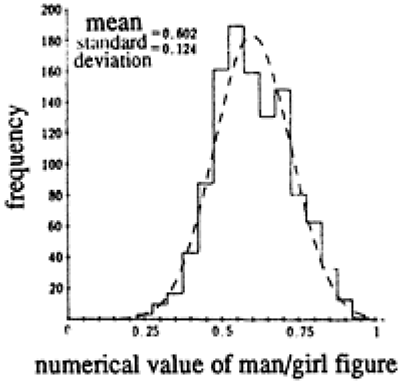

Fig. 2 Figure of the occurrence of changes in perception

effect on the change of visual perception is not discriminated in the size of figure, but discriminated in subject. Finally, pooling the data of the size, stochastic catastrophe models (Cobb, 1978, 1981, 1985) is used. The number of judging to man face in the 18 data is the degree of judging to man face. And the four observations of the degree of judging to man face is analyzed.

The occurrence of changes in perception is not influenced by figure size and is influenced by individual differences within the subjects themselves.

In addition, a frequency distribution shown in Fig. 2 is obtained from the data of all subjects in the case of A, B, ---, T, U and of U, T, ---, B, A. The curve shown by broken line in Fig. 2 is approximate to normal distribution. Also, the figure L(0.55) or M(0.6) is very ambiguous figures. In order to apply stochastic catastrophe model to a bistable perception phenomenon found in the subjects' judgment of the ambiguous man/girl figure, the data obtained in the experiment is processed as follows. As mentioned above, pooling the data of each subject is regarded that the figures is observed 18 times its observation is repeated 4 times. As shown in Fig. 3, the frequency distribution for the number of judging to man face is obtained from the data of all subjects.

In the experiment of finger tip subjected to localized vibration, the result is the same as mentioned above.

The coordinates of A_i between A_1 and A_{15} for the sequence of continuous figures A_1 to A_{15} is based on the data1 of coordinates of A_1 and A_{15}. The coordinate of a dividing point is i-1:15-i. If the physical quantity of A_1 is 1, and that of A_{15} is 0, the physical quantity for Ai(i=2, ---, 14) may be determined by (15-i)/14. The relationship between physical

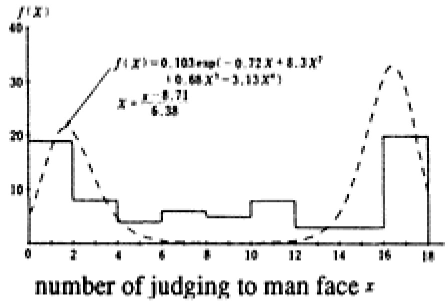

Fig. 3 Frequency distribution for the number of judging to man face and its estimated curve, M(0.6)

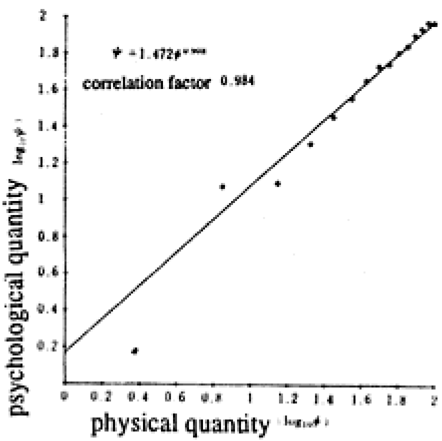

Fig. 4 Scaling of sensation (A_1–A_{15})

quantities and psychological ones for human is shown in Fig. 2. So, the psychological quantity ψ is the geometrical mean value of evaluated values and this quantity is the mean values of 20 subjects. In another, the physical quantity $\Phi$is 100 times of the value determined for the detail figure.

The relationship between the physical quantity of stimulus $\Phi$and its psychological quantity ψ is given by Stevens.

$$\psi = k\,\phi^{n} \tag{1}$$

where k and β denote constant. Equation(1) is reduced to

$$\log_{10}\psi = \log_{10} k + \beta \log_{10}\phi \tag{2}$$

When $Y=\log_{10}\psi$, $X=\log_{10}\phi$, $K=\log_{10}k$ from equation(2),

$$Y=\beta X+K \tag{3}$$

was obtained. The constant β of equation(3) obtained from the least square method is the important value for the definition of sensory scale. As shown in Fig. 4, the relation of $\log_{10}\psi$ and $\log_{10}\phi$ is linear. Therefore, the equation(1) is satisfied in this experiment. Similarly, for the sequence of continuous figures U_1 to U_{15}, the physical quantities that $U_1=1$, $U_{15}=0$ and $U_i=(15-i)/14$ (i=2, ---, 14) are determined. In this case, the relation of physical and psychological quantity is also satisfied equation(1) shown in Fig. 5.

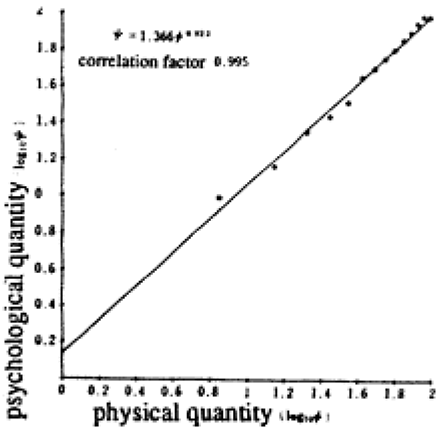

Fig. 5 Scaling of sensation (U_1–U_{15})

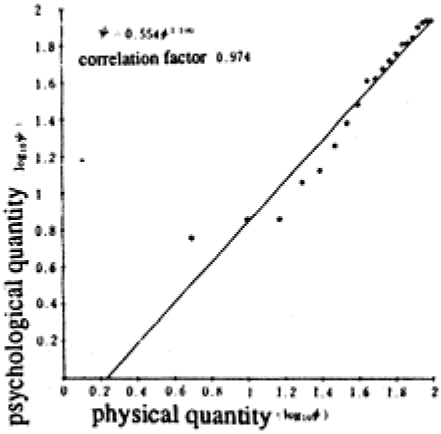

Fig. 6 Scaling of sensation (A_1–U_1)

For the sequence of continuous figures A_1 to U_1, the physical quantities are determined by numerical values ranged from 0 to 1.0 in increments of 0.05. $\dot{\Phi}$is the numerical values multiplied by 100. The relation satisfies the equation(1) shown in Fig. 6. As mentioned above, it is clear that determined physical quantity is valid for each figure drawn by the interpolate method.

Next, the degrees of judging to man face for A_1, A_3, A_5, A_7, A_9 and A_{11}, and those of judging to girl shape for U_1, U_3, U_5, U_7, U_9 and U_{11} are calculated by the scaling of sensation for the sequence of continuous figures A_1 to A_{15} and U_1 to U_{15}.

First, the geometrical mean value of evaluation values of A_1 is calculated for each subject and the geometrical mean value of these values is obtained for 20 subjects. Let this geometrical mean values for A_1 be correspond to 1 in the degree of man face and that value for A_{15} to 0. And the degrees of man face for A_3, A_5, A_7, A_9 and A_{11} are calculated by the geometrical mean values of 20 subjects. Similarly, the degrees of girl shape are obtained. Now, standing GMA_i for the geometrical mean value of 20 subjects' geometrical mean values that are calculated by the evaluation values for A_i and GMU_i for U_i, the degree of man for A_i, m_i and of girl shape for U_i, g_i are obtained by following equation.

$$\left.\begin{aligned} m_i &= \frac{GMA_i - GMA_{15}}{GMA_1 - GMA_{15}} \\ g_i &= \frac{GMU_i - GMU_{15}}{GMU_1 - GMU_{15}} \end{aligned}\right\} \qquad (4)$$

In the sequence of continuous figures A_1 to U_1, as the degree of man for A_1 is 1 and the degree of girl for U_1 is 1, let 1 at the degree of man correspond to 1 at the degree of judging to man face and 1 at the degree of girl correspond to 0 at the degree of judging to man face. So, the degree of judging to man face is ranged from 0 to 1. Also, in the case of 0 at the degree of man and girl, the degree of judging to man face is regarded as 0.5. The degree of judging to man face 0 means that the figure is the most similar to girl shape and

0.5 means the most ambiguous figure. The relationship among the degree of judging to man face, the degree of man and the degree of girl is shown in Fig. 7. The upper limit J_{iu} and lower limit J_{il} of the degree of judging to man face for the sequence of continuous figures Ai to U is given by

$$\left. \begin{aligned} J_{iu} &= \frac{m_i + 1}{2} \\ J_{il} &= \frac{-g_i + 1}{2} \end{aligned} \right\} \quad (5)$$

Table 5 Distributed interval for degree of judging to man face

sequence	distributed interval for degree of judging to man face
A_1~U_1	0~1
A_3~U_3	0.07~0.96
A_5~U_5	0.13~0.87
A_7~U_7	0.23~0.78
A_9~U_9	0.29~0.72
A_{11}~U_{11}	0.37~0.64

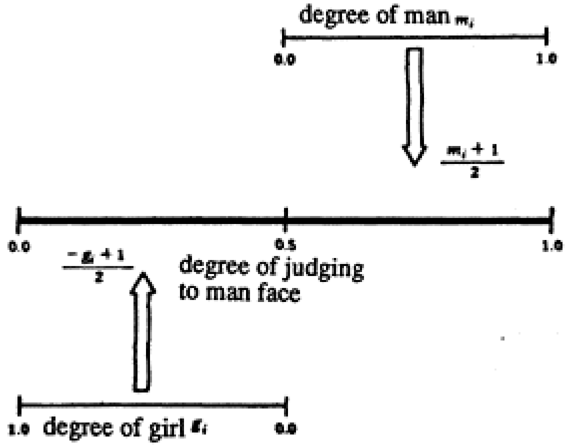

Fig. 7 Relation of degree of judging to man face, degree of man and degree of girl

The degree of judging to man face is distributed in the narrower interval as the detail of figures is lost. For example, the interval in which the degrees of judging to man face distribute is calculated as follows. For A_9 to U_9, the degree of man and girl are calculated 0.44, 0.42 by equation(3) respectively. The interval of the degree of judging to man face is calculated (−0.42+1)/2 to (0.44+1)/2, that is, 0.29 to 0.79.

Table 5 shows the calculated values of the upper and lower limit of the degree of judging to man face for each detail of the sequence of figures.

On the basis of mentioned above, the degree of judging to man face is calculated by the data of each subjects. The data in the case of the change from man to girl and that of back are considered separately. The degrees of judging to man face are calculated by dividing the interval of distribution for degree of judging to man face by eight. For example, if man face is judged 8 times when figure H in the sequence 11 is seen from man face A to girl shape U, the degree of judging to man face becomes

$$0.37 + (0.64 - 0.37) \times \frac{8}{8} = 0.64$$

For each subject, the degrees of judging to man face for each figure in the sequence of figures of 1, 3, 5, 7, 9 and 11 are calculated. The frequency distribution for the degree of judging to man face were shown in Fig. 8 to Fig. 11 by solid lines for 43 subjects. However, the frequency distribution in Fig. 8 to Fig. 10 is obtained by observing from man face A to girl shape U and that in Fig.11 is from U to A;

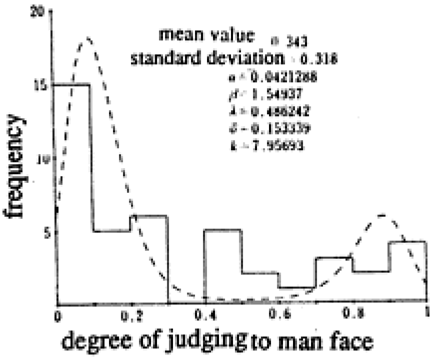

Fig. 8 Frequency distribution for degree of judging to man face and its estimated curve (N_3)

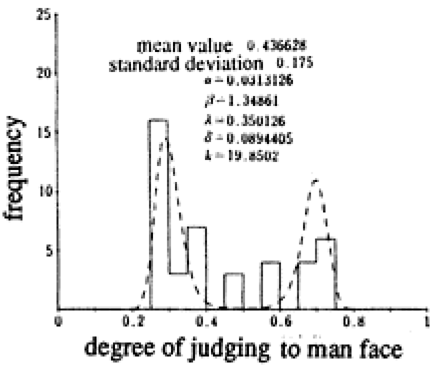

Fig. 9 Frequency distribution for degree of judging to man face and its estimated curve (N_9)

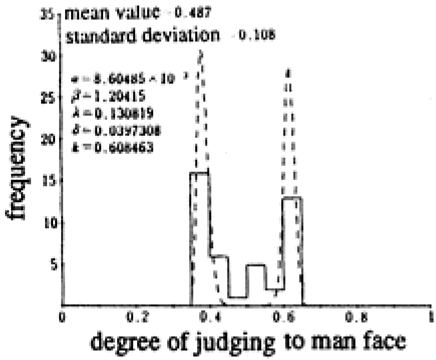

Fig. 10 Frequency distribution for degree of judging to man face and its estimated curve (N_{11})

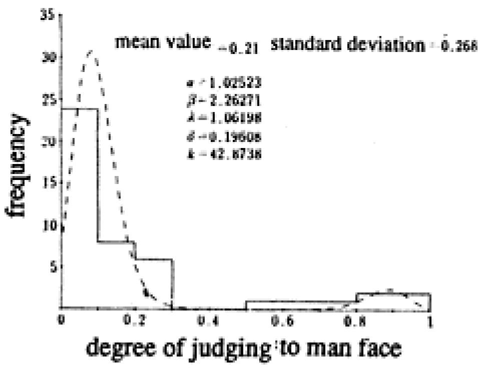

Fig. 11 Frequency distribution for degree of judging to man face and its estimated curve (N_3, in the case of seeing from girl shape to man face)

DISCUSSION

Applying Stochastic cusp catastrophe model to frequency distribution for the number of judging to man face shown in Fig.2, Fig.3 and frequency distribution for degree of judging to man face in Fig. 8, Fig. 9, Fig. 10 and Fig. 11, he bistable bistable perception for man/girl figure is investigated. The stochastic catastrophe model induces probabilistic concepts to the deterministic catastrophe model and is capable of dealing with discontinuous phenomena involving randomness. In this model, the following cusp probability density function is essential

$$f(x) = k \cdot \exp\left[\left\{\alpha(x-\lambda) + \frac{\beta}{2}(x-\lambda)^2 - \frac{1}{4}(x-\lambda)^4\right\}/\delta\right] \tag{6}$$

where, x: random state variable, α: asymmetric parameter, β: bifurcation parameter, λ: scale parameter, δ: dispersion parameter.

The constant k is chosen so that f(x) satisfies the condition of probability density function. The parameters α, β are of special importance and correspond to normal factor and splitting factor of catastrophe model, respectively. In this paper, the evaluation ratio corresponds to the random state variable x. If the value of the following D is negative, the p.d.f. f(x) has bimodality. This corresponds to the bifurcation set, and it is probable that x changes discontinuously. The p.d.f. f(x) has unimodality, if the value of D is more than 0. Based on the frequency distribution for the number judging to man face and the frequency distribution for degree of judging to man face, the broken curves in Fig. 2, Fig. 3, Fig. 8, Fig. 9, Fig. 10 and Fig. 11 are estimated by means of the method of moment. In this method, the parameters of (6) are estimated as follows. The sample moments of the same number with the parameters estimated are taken up. The equations obtained by equalizing the sample moments and the population moments are solved with the parameters.

The broken curve shown in Fig. 3 is f(x) and the parameters in equation(6) are estimated from the frequency distribution for the number of judging to man face. These parameters is reduced that α=0.0145, β=1.3333, λ=0.0542 and δ=0.080. Figure M is the ambiguous figures that are located at the center of Fig.1. As estimated curve shows bimodality, the perception characteristic of figure M is catastrophic. It has been clarified that in the case of looking at the man face figure, the frequency of high degree of judging to man face and girl shape is high, and intermediate degree of judging to man face, that is, the degree where man face and girl shape have a fifty-fifty of perception is low according to the bimodality of estimated curve for frequency distribution for number of judging to man face. This fact explains that ambiguous figure M is not judged as ambiguous one, but as man face or girl shape, that is, the catastrophe phenomenon in the case of looking at ambiguous figure occurs.

Table 6 shows the parameters of cusp probability density functions from figure I to R and D values. The D value of figure M is negative. If the D value is negative, the estimated curve of frequency distribution for the number of judging to man face has bimodality. The D values of ambiguous figures K, L, N, O and P etc. are negative and these estimated curves have bimodality. In short, D is equivalent to a discrimination by which is judged whether

Table 6 Parameters of cusp probability density function

figure	α	β	λ	δ	D
I	−12.5122	6.77473	−2.39178	0.235222	2982.5
J	−3.38028	3.64196	−1.51127	0.20754	115.3

K	−0.82347	2.32341	−0.84701	0.29062	−31.9
L	0.03727	1.51555	−0.31196	0.138047	−13.9
M	0.01455	1.33326	0.05418	0.079837	−9.5
N	−0.83322	1.40611	0.33464	0.06627	−10.9
O	0.10521	1.64483	0.57353	0.12494	−17.5
P	0.89099	2.43745	1.0735	0.174094	−36.5
Q	3.86455	4.05766	1.6301	0.271665	136.0
R	29.2542	11.7036	2.87776	0.820685	16694.0

the estimated curve for frequency distribution for number of judging to man face has bimodality or not. Subsequently, broken curves shown in Fig. 8 to Fig. 11 represent f(x) estimated the parameters of equation(6) by moment method from frequency distribution for degree of judging to man face. In the case of Fig. 8 (figure N of series 3), as the degree of judging to man face distributes from 0.07 to 0.76 as shown Table 1, most detail figure in the series from A_1 to U_1 is almost resembles. Figure N_3 is sometimes perceived as man face and sometimes as girl shape. Perception is different by individuals. In other words, as there is sometimes in the perception for this figure, the experimental data can not be applied to deterministic catastrophe model. The discontinuous change with randomness is explained from the bimodality of cusp steady probability density function of state variable (in this paper, degree of judging to man face). The state in which probability density function has bimodality means that control factors are in bifurcation set and state changes discontinuously. As estimated curve for degree of judging to man face shown in Fig. 8 has bimodality, it is clear that the bistable perception in the case of looking at ambiguous man/girl figure is catastrophic phenomenon. The estimated curve of frequency shown in Fig. 9 (figure N of series 9) and Fig. 10 (figure N of series 11) have bimodality, but the distributed interval of degree of judging to man face becomes narrow and two modes of estimated curve close to 0.5 value in which the degree of judging can not be determined to man face or girl shape. This result shows that the change of perception does not occur as the detail of figure is lost. The discontinuous change between upper and lower attractor does not occur as the value of factor on the axis of β is close to zero.

In short, the detail of figure has the function as splitting factor, however the intervals of frequency distributions in series 9 and 11 are made narrow as distributed interval for degree of judging to man face becomes narrow. Fig. 11 (figure N of series 3) is the figure which is seen in the order from girl shape to man face, but the catastrophe theory in this case is also explained from the bimodality of probability density function. Fig. 8 and Fig. 11 are same figure N3 and show that the number of girl shape perception is more numerous in the case of seeing in the order from girl shape to man face. As mentioned above, the bistable perception for ambiguous man/girl figure is analyzed by stochastic catastrophe model considering the randomness which is inherent in this phenomenon. Therefore, stochastic catastrophe model is useful in the case of analyzing discontinuous phenomenon with randomness.

CONCLUSIONS

1) The figures changed smoothly from man face to girl shape, that is, the physical quantity of continuous stimulus are drawn.

2) As a result of scaling of sensation for three sequences of A_1 to U_1, A_1 to A_{15} and U_1 to U_{15}, it is clarified that the relation of logarithm of physical quantity and logarithm of psychological quantity is linear.

3) In this experiment, variation in the occurrence of changes in perception is not influenced by localized vibration or the size of figure.

4) Stochastic cusp catastrophe models are applied to the frequency distribution for the degree of judging to man face for the each of sequences and figures obtained by the experiment. After all, it becomes clear that such bistable perception phenomenon can be explained by a cusp catastrophe manifold in which normal factor is the change of figure from man face to girl shape and splitting factor the detail of figure.

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PRESSURE SENSITIVITY OF THE HEAD

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A pressure of .95 kg/cm^2 was applied to 48 locations on the head of 30 subjects. There was no difference between the left and right side of the head but the temple area is the most sensitive to pressure. Females are more sensitive than males. Pressure applied on coarse hair gave less discomfort than that applied on medium or fine hair.

INTRODUCTION

Head injuries, which may occur in a variety of occupational and recreational settings, are reduced or avoided by the use of protective headgear or helmets. The helmets can protect vs. the sun, vs. noise (Paakkonen et al., 1991), vs. high velocity impact (bullets), vs. low velocity impact (sports, industrial accidents), etc. However, if the helmet is uncomfortable, then the person is under additional stress and may even not wear the helmet (thus eliminating the protection).

One of the comfort factors is the sensitivity of the head to pressure at different parts of the head.

Helmet research

Rather than comfort, most helmet research focuses on human impact tolerance; Freivalds, Johnson and McEntire (1990) have 105 references. Hickling (1986a) and Fenney (1986) discuss head protection at work. Hickling (1986b) emphasizes the need for different helmet designs for different tasks and occupations. Proctor and Rowland (1986) gave weight, thermal buildup and comfort as problems of helmet design. Rowland (1987) showed that helmets give better impact protection than turbans.

Abeysekera and Shahnavaz (1988) reported on some of the factors making industrial safety helmets unpopular in tropical developing countries. Recommendations included reducing the helmet weight, improving ventilation, better fit (sizing) and a harness material which adsorbed sweat. Gilcrest, Mills, and Khan (1988) reported the part of the head for helmet wearing primarily was of two shapes (nearly spherical and “watermelon shaped”); they suggested the need for a better range of sizes to fit these shapes.

We were unable to find any studies concerning the head’s sensitivity to pressure (as from a strap or webbing).

Pressure

Human determination of pressure is complex. The Vater-Pacinian corpuscle produces an impulse which is sent to the central neurons (Chaffee and Greisheimer, 1974). The central neurons then pass the impulse to the thalamus. If the pressure is severe, the thalamus produces an immediate response. If the pressure sensation is not severe, the signal is sent on to the cerebrum for comparison. The cerebrum then sends out a signal with a response to the pressure.

METHOD

Measuring device

A spring device was constructed in the Industrial Engineering shops; see Fig. 1. It applied a constant pressure of .95 kg/cm^2 to the head. Because it was a spring it did not depend upon gravity; thus the head could be held in a normal position and pressure measured on the side as well as the top. A pilot project with three different pressures (.72, .95 and 1.19 kg/cm2) determined that .95 kg/cm^2 was an acceptable pressure.

Subjects

The 30 subjects (21 males; 9 females) were students in a senior industrial engineering class; they volunteered and received extra credit.

Procedure

The pressure was applied at a head location for 10 s and then removed. The subject then evaluated the pressure sensation on a 1–9 scale with 1=very light, 3=light, 5= acceptable, 7=heavy and 9=very heavy.

There were 48 locations tested; see Fig. 2.

The subject’s hair was judged for thickness (fine, medium and coarse) and style (straight, curly). Then a ski cap with 48 holes was placed on the subject’s head. The cap was centered on the nose and ears to standardize locations. Then the pressure was applied and the sensation votes obtained. A total of 56 measurements were taken on each subject; the first 8 measurements provided the subject a frame of reference but the subject did not know the first 8 measurements were for practice.

RESULTS

For ease of understanding the 1–9 scale was transformed to a 0–100 scale using the equation:

New score=(score−1)*(100/8)

The first test was for symmetry. The 24 locations on the left side of the head were compared vs. the 24 on the right side using paired t tests. Only one pair was significantly different. This 1 in 24 result was considered a chance effect and the data then was combined into 24 locations.

The mean vote was 62.1 with a standard deviation of 6.0.

An ANOVA showed males (mean vote=60.5) were less sensitive to pressure than females (mean 65.8). A higher vote means more sensitivity to pressure.

Those with coarse hair (mean=59.6) were significantly less sensitive than those with medium (mean=62.3) and fine hair (mean=63.1). The difference between the 62.3 and 63.1 was not statistically significant.

Because only 2 of the 30 subjects had curly hair, straight vs. curly hair was not analyzed.

The effect of location was significant. Figure 2 shows the deviation from the mean vote of 62.1 with contour lines at −5, 0, 5, 10, and 15. In general, the back and top of the head are less sensitive to pressure; the area around the temple is most sensitive to pressure.

DISCUSSION

The experiment demonstrates that the same pressure produces more discomfort in certain parts of the head than others. The temple is the worst location to apply pressure.

Hopefully helmet manufacturers can use this information in the design of helmet suspension systems.

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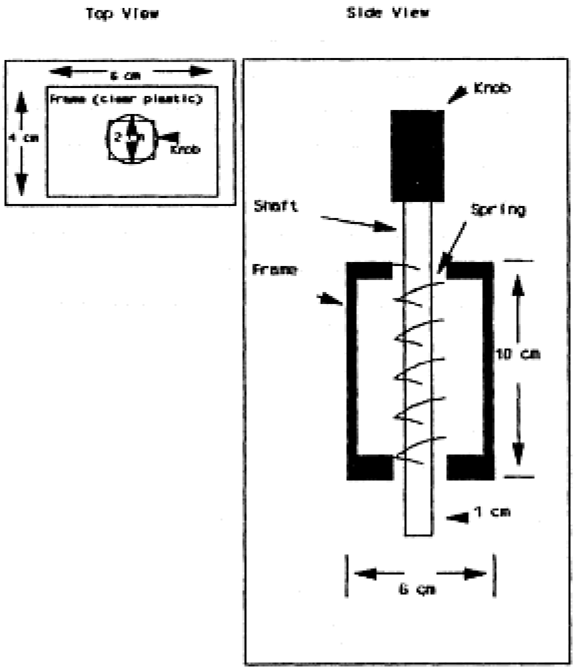

Figure 1. The spring device permitted a consistent pressure to be applied to any portion of the head.

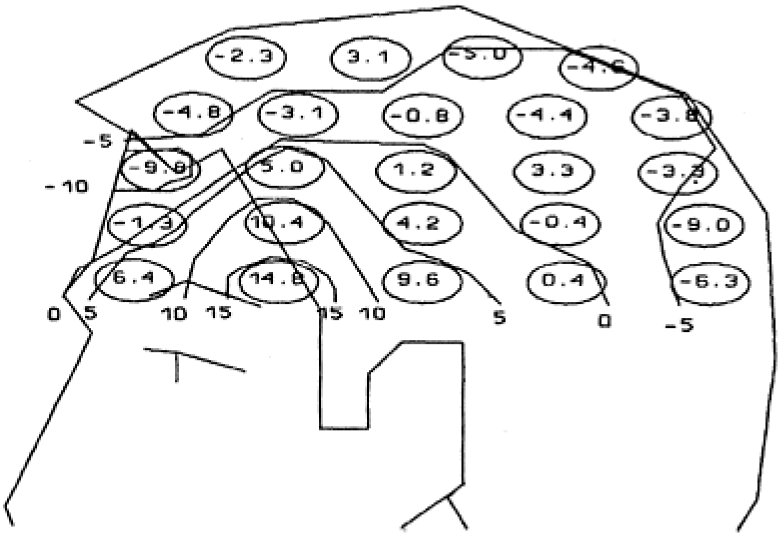

Figure 2. Sensitivity contour map (n=30 subjects) showing the deviations in votes from the mean of 62.1. Only 24 of the 48 locations are shown. Since there was no significant difference between the left and right side, the values are for both sides combined. The temple area is the most sensitive to pressure.

EFFORT PERCEPTION AS AN ERGONOMIC TOOL

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Ten young normal males of mean age of 22.2 years, mean height 175.3 cm and mean weight of 71.4 kg performed 20%, 40%, 60%, 80% and 100% of their maximal voluntary contraction in pinch hand grip and stoop lift. The data acquired in randomized order were statistically analyzed. The pinch, grip and lift activities were significantly different from each other ($p<0.01$). The peak and average strengths generated were highly correlated ($r=.9$; $p<0.01$) but significantly different ($p<0.01$). There was a consistant perception bias overestimating efforts above 40% and under-estimating efforts below it.

INTRODUCTION

Overexertion injuries in contemporary industrial society is a common place (NIOSH 1981, Statistics Canada 1988). Statistics Canada (1988) reported that 48% of all WCB compensated cases were due to overexertion. Therefore, a reduction in overexertion may result in injury control. Such a strategy, however, is a three-stage implementation process. First, determination of the critical level of exertion beyond which overexertion may occur. Second, development of an effective and reliable method of determination of the level of effort. The ease with which the latter can be accomplished will determine the success of the implementation strategy. Thirdly and finally, incorporation of thus generated standards in job design. The current study addresses the second stage of the stated strategy, developing an affective and reliable methodology for determination of level of exertion which is also simple to administer for wider industrial application.

Psychophysical ratings have been widely used in design of manual materials handling jobs (Snook 1978, Ayoub et al 1978, Mital 1983, Asfour et al 1983, and others). Such applications have been based on the finding that the psychophysical ratings were highly correlated with physiological stresses as measured by heart rate or oxygen uptake (Borg 1962, Gamerale 1972, Johanssen 1986 and others). All these studies were conducted using bicycle ergometer with varying work intensity and/or duration. Such experimental protocol makes the physiological observations clearly more relevant to the methodology. However, injury precipitation invariably involves biomechanical failure. The latter was not a variable in the development of Borg's 1962 methodology. Moreover, Ekblom and Goldbarg (1971) pointed out that the perception of exertion was based not only on a central cardiopulmonary factor, but also on a musculoskeletal local factor. Using autonomic blocking agents they demonstrated that the heart rate was not correlated with perceived exertion. Other workers, such as Pandolf (1972), demonstrated by superimposing environmental stresses, that the heart rate was not a primary factor in determination of perceived exertion.

In light of large majority of occupational injuries resulting due to overexertion and a strong influence of local factors in determination of the level of strain, effort perception suddenly assumes a level of urgency which needs attention. Due to paucity of data in this area and a cross activity comparison a study was launched to study to maximal and graded effort perception in precision, power and gross motor activities.

METHOD

Subjects

Ten young normal males with no history of pain of injury to trunk or upper extremity were recruited for the study. Their age, height and weight are given in Table 1. These subjects were familarized with the experimental protocol and subsequently an informed consent was obtained. These subjects were given a practice session during which any remaining questions regarding the experimental procedures were answered.

Table 1. Anthropometric variables of experimental sample

Parameter	Age years	Weight kg	Height cm
Mean	22.2	71.4	175.3
Standard deviation	2.9	9.9	6.4

Tasks

The subjects were required to perform a maximal isometric pinch, grip and stoop lift with 30° trunk flexion in a random order. Following maximal activities the subjects performed 20%, 40%, 60%, and 80% of their perceived maximal effort in pinching, gripping, and lifting modes in a randomized sequence. Each of the tasks (maximal as well as graded submaximal) were repeated three times. The pinch and grip activities were performed in a seated posture with arm resting on the arm rest. For pinch and grip only the dominant hand was used.

Devices

The lift tests were carried out using a load cell anchored to floor and connected to a handle through an iron chain. The load cell fed to the Force Monitor ST-1 (Prototype Design and Fabrication Company, Ann Arbor, Michigan). The load cell and Force Monitor well calibrated in the range of 0 to 650 kg load in increments of 10 kg. The device was accurate within 2% of the calibration range.

The grip test was performed on a hand dynamometer of ComputAbility Corporation. The hand dynamometer was calibrated by suspending standardized weights through weight hooks in the range of 0 to 40 kg in increments of 5 kg. The device was found to be linear within 1% of the calibration range. The pinch strength were measured through a specially designed pinch grip device. The device consisted of two aluminum rectangular bars measuring 2.5 cm×7.5 cm×.5 cm separated at one end by a metal block glued to the two bars.

On the inside of one of the bars a full bridge thin beam strain gauge (Omega LCL-O2O) was mounted. The pinch meter was calibrated by applying standard weights from 1 to 10 kg in steps of 1 kg. The device was linear within 1% of the calibration range.

While the output of the Force Monitor was directly read from the screen of the device, the outputs of the hand dynamometer and the pinch grip meter were fed to a chart recorder (Omega RD 2000). The gains were adjusted such to give full scale deflection (15 cm) within the calibration range. The data recorded on the chart was converted to force values by multiplying them with calibration factor. The peak and average values were extracted for each of three trials of all activities. Such assembled data were subjected to t-tests, analyses of variance and multiple regression.

RESULTS AND DISCUSSION

The mean peak and average strengths in maximal isometric efforts for pinch, grip and lifts were 80N and 75N, 449N and 427N, and 810N and 735N respectively. These represent a ratio of 1:5 or 6:10 across these activities. Such ratios were also valid for all other graded levels of effort (Figure 1). Thus, these activities produced significantly different strengths values ($p<0.01$). The peak and the average strengths for each of the maximal and graded activities within the activity and the grade of effort were significantly different ($p<0.01$). However, they were highly correlated ($r=.91-.99$; $p<0.01$). Within the activity the decline from the maximal effort to 80% effort was highest in proportion. As the magnitude of the grade of the effort declined so did the proportional difference between the subsequent steps. The magnitude of the strength produced at each of these graded levels within their respective activities were significantly different from each other ($p<0.01$). A comparison of these values with objectively predicted grades based on the maximal voluntary contractions within the activities revealed a significant difference ($p<0.01$) for all grades except 40%. The observed strengths for all activities at 80% and 60% of MVC were lower than the predicted values. On the other hand, the observed strength of the grade of 20% efforts for all activities were higher than those predicted from MVC. AT the 40% grade effort these were coincidental or overlapping with no significant difference (Figure 2). Thus, this 40% phenomenon may have a valueable ergonomic use. The

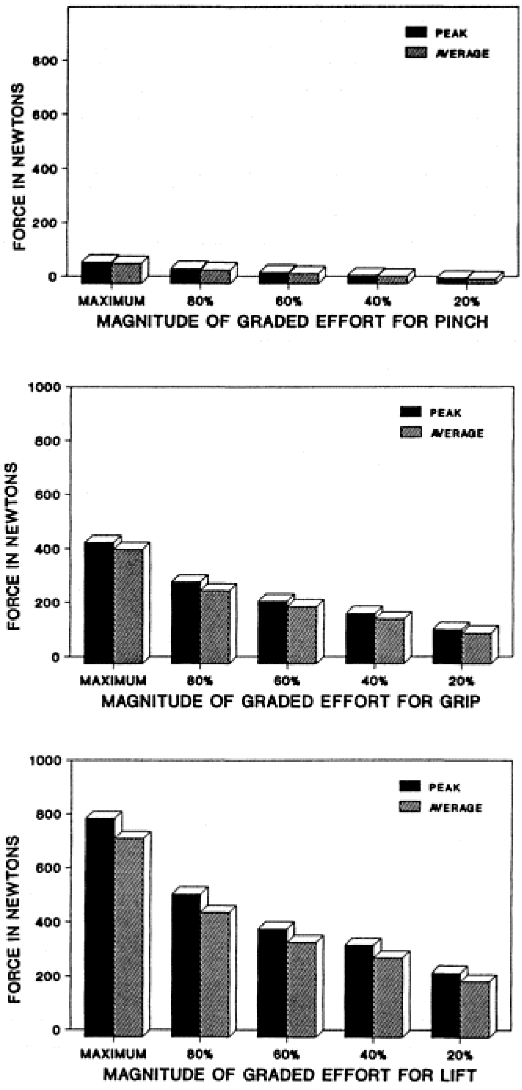

Figure 1. Pinch, Grip and Lift Strengths

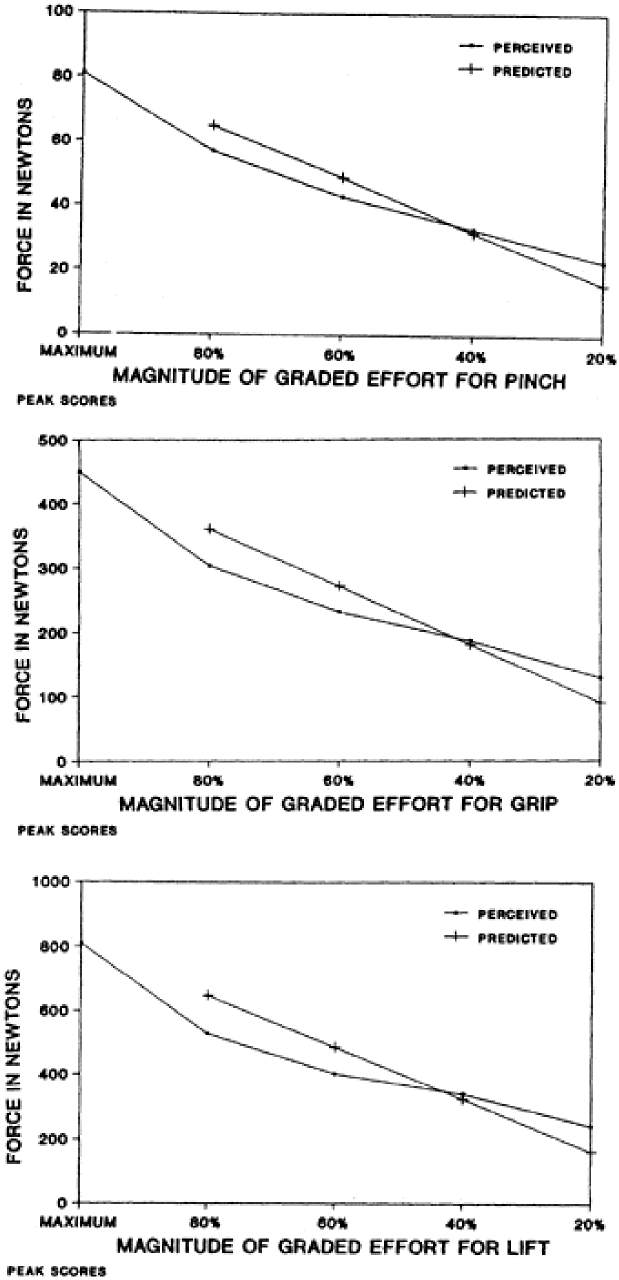

Figure 2. Perceived and predicted strengths for pinch, grip and lift

psychophysical estimation of the 40% effort, therefore, may place one very close to an objectively determined value. Since this phenomenon occurred with a high statistical significance across precision and power grips as well as gross motor effort, it may have the robustness to cut across most physical efforts. Having determined an optimum level of exposure or effort for a given activity to prevent overexertion, one may then express it in terms of percent of MVC. Using this effort perception methodology one can then determine the discrepancy between the optimum for a person or a population and the job requirement. This information can be incorporated in job design/redesign efforts. The described method of testing a population based on perceived effort production at a submaximal level of 40% simplifies the process significantly for easier industrial application, and hence acceptance.

The analyses of variance revealed significant main effects due to activity and perception ($p<0.001$) and a significant interaction between them. All regression equations calculated for submaximal and maximal activities for pinch, grip and lift were highly significant ($p<0.01$). The variances of the predicted variable was explained to a greater extent (up to 72% to 87%) when within activity graded levels were used for prediction of a chosen grade level. Thus, a highly significant regression augmented with a 40% phenomenon may be a useful ergonomic tool.

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PERCEPTION OF LOAD HEAVINESS AND EMG QUANTIFICATION OF MUSCULAR RESPONSES IN MANUAL LIFTING: A PILOT STUDY

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The main objective of this study was to model the relationship between human perception of load heaviness in manual lifting expressed in linguistic terms and the corresponding muscular activity based on the electromyographical recordings. Five male college students participated in the laboratory experiment The results point out that the psychophysical methodology that require the subjects to select maximum acceptable weights of lift may lead to accepting loads that are not perceived by the subjects as comfortable, and, therefore, the lifting limits based on the psychophysical approach may not be an effective tool to prevent the overexertion injury.

INTRODUCTION

Rating of acceptable load (RAL) method is based on the assumption that *workers are able to determine with some accuracy the highest acceptable workload* (Gamberale, 1985). An important factor in studying the RAL's reliability is the subjective evaluation of effort in terms of perceived heaviness of the load lifted, and its relation to objective measurements of muscular activity in terms of electromyographic technique. The subjective perception of load heaviness should be considered when setting guidelines for safe lifting tasks (Karwowski, 1988; Karwowski and Pongpatana, 1991). As an imprecise and vague phenomenon, the subjective perception of load heaviness can be studied using the fuzzy modeling techniques (Karwowski and Ayoub, 1984; Luczak and Gee, 1989). The main objective of this study was to model the relationship between human perception of load heaviness expressed in linguistic terms and corresponding muscular activity based on the electromyographical recordings. In particular, the differences between *"acceptable"* and *"comfortable"* weights of lift were examined.

METHODS

Five healthy males, college students, participated in the laboratory experiment. The subjects were asked to lift compact boxes with weights ranging from 10 lbs (4.5 kg) to 70 lbs (31.75 kg), with increments of 10 pounds, from floor to table height. The order of all boxes for each subject was randomized, and all boxes were identical in their appearance. For safety reasons, the subjects were instructed to pre-weigh each box before lifting. The subjects were asked to lift the box repeatedly with frequency of two lifts per minute (for at least 10 minutes), until they were sure that they could make a decisive judgement about the box heaviness, keeping in mind that the task was to be performed for an eight-hour work day.

Subjects were given a randomly pre-selected box one at a time. After completion of each test, the subjects were given a questionnaire for the box they just lifted. The psychophysical scaling technique was used to quantify subjects judgement of load heaviness. The subjects were asked to mark a 10 cm scale, with values between 0 (no compatibility) and 10 (full compatibility), in order to assess the degree to which the perceived heaviness of the box was compatible with the linguistic descriptors related to load heaviness and load acceptability and comfortability for the 8-hour day (*'comfortable'* and *'acceptable'*). The subjects were also asked to judge the degree of compatibility of the lifted boxes with each of the following nine linguistic categories of load heaviness: 1) very light, 2) light, 3) not light, 4) more-or-less medium, 5) medium, 6) not very heavy, 7) heavy, 8) very heavy and 9) extremely heavy. In addition, two Borg scales (1962,1980) were used to quantify perceived exertion levels in the lower back, upper back, shoulders and for the whole body.

EXPERIMENTAL PROCEDURES

The subjects were paid for their work on an hourly basis. Each subject read and signed an informed consent form prior to the beginning of the project. Age, body weight, anthropometric dimensions and strength characteristics of the subjects are shown in Table 1. The isometric strength measurements (arm, shoulder and back) were made according to the procedures described by Chaffin (1975), while the isokinetic strength tests were done following the procedures outlined by Pytel and Kamon (1981).

The Transcienetics Real Telemetry system was used to record the EMG signals. These EMG signals were processed using the RMS/DC convertor system as described by Yates and Hertel (1990). Bipolar EMG surface electrodes were attached to the skin above the muscle group to be sampled: deltoid (upper arm), trapezius (upper back) and thora-lumbar fascia (lower back). For normalization purposes, the resting EMG and the EMG during of maximum strength measurements of these muscle groups were measured before the experiment. The measurements of resting EMG were done twice, and the results were averaged. For the MVC, three isometric strength tests were utilized, i.e. 1) isometric back, 2) isometric shoulder, and 3) isometric composite strength. Only the EMG values of the strengths that were within 10% of each other were used. There were a total of 20 lifts per box, and EMG of each lift was recorded. Each subject was asked to lift 7 different identical looking boxes with weight range from 10 to 70 pounds in 10 pound increments.

Table 1. Age and physical characteristics of the subjects [N=5].

Variable	Mean	S.D.	Range
Stature	173.0	4.87	164.0–177.0
Body weight [kg]	145.4	13.46	130.0–161.0
Acromial height [cm]	144.6	4.28	137.0–149.0
Knee height [cm]	50.4	1.20	48.0–51.0
Ann length [cm]	86.0	23.24	70.0–132.0
Hip height	102.2	3.32	97.0–107.0
Static back strength [kg]	128.9	68.52	64.0–252.0
Static shoulder strength [kg]	73.2	19.62	48.0–104.0
Static composite strength [kg]	189.6	47.56	135.0–254.0
Dynamic back strength [kg]	114.0	11.76	91.0–124.0
Dynamic shoulder strength [kg]	32.2	5.79	23.0–38.0
Dynamic lift strength [kg]	148.3	42.02	71.0–191.0

RESULTS

The main results of the study are illustrated in Tables 2–5 and Figures 1–2. The results showed that subjectively perceived levels of load heaviness highly correlate with the objectivity quantified muscular responses. At higher levels of MVC there were significant differences in muscular activity as measured by EMG for upper back and shoulder muscles. As shown in Table 4, except for the load range from 30 to 50 lbs, there were significant increases in perceived levels of physical exertion for the whole body as the load lifted increased from 10 to 70 lbs.

Table 2. Pearson correlation coefficients between box's weight and normalized EMG signals (lifting from floor to table; vertical distance of 70 cm).

	Upper back	Lower back	Shoulder
MWL	0.77	0.55	0.87
Static back	0.26	0.43	0.13
Static shoulder	0.48	0.16	0.26
Static composite	0.47	0.25	0.41

Dynamic lift	0.52	0.42	0.69
Dynamic back	0.36	0.48	0.48
Dynamic shoulder	0.58	0.33	0.59

Table 3. EMG as a percent of maximum weight lifted from floor to table height

Upper back			
Weight	Mean	S.D.	Range
10	38.91 a	14.91	18.8–60.0
20	50.10 a	9.30	35.7–60.0
30	72.56 b	11.76	60.0–85.0
40	80.60 b	13.92	60.0–99.3
50	88.10 b	18.77	60.0–110.5
60	90.00 b	18.26	60.0–105.0
70	92.00 b	19.87	60.0–100.0
Lower back			
Weight	Mean	S.D.	Range
10	63.38 a	8.55	51.4–72.8
20	66.76 a	24.06	31.3–94.2
30	67.92 a	22.12	33.3–91.2
40	70.00 a	22.78	31.3–87.8
50	91.14 a	28.74	60.2–137.4
60	84.00 a	11.73	67.1–98.2
70	100.0 a	0	100.0–100.0
Shoulder			
Weight	Mean	S.D.	Range
10	35.67 a	15.68	14.6–55.5
20	45.47 a	20.13	21.4–76.7
30	64.53 b	9.79	53.9–79.8
40	72.75 b c	11.79	58.4–84.5
50	92.46 c d	10.18	80.2–104.2
60	90.39 c d	11.77	71.58–98.8
70	100.0 d	0	100–100

Finally, a comparison of compatibility values for the concept of *"maximum acceptable weight of lift"* with the *"maximum comfortable weight of lift"* showed significant differences at all levels of lifted loads, with the exception of 30 lbs (see Table 5 and Figure 2). At loads lighter than 30 lbs, *"comfortable"* weights were greater than *"acceptable"* weights. However, at load levels higher than 30 lbs, the *"comfortable"* weights were significantly lower than the *"acceptable"* ones. These results indicate that what is perceived as maximum acceptable weight of lift is different than the comfortable weight of lift.

Table 4. Perception of effort exerted by the three muscle groups.

Weight	Shoulder[1]	Upper back[1]	Lower back[1]	Overall[2]
10	0.7 a	0.5 a	0.7 a	7.0 a
20	2.0 b	1.6 b	1.9 b	9.6 b
30	2.5 b c	2.2 b	2.8 c	11.4 c
40	3.4 c d	3.2 c	3.6 c d	12.4 c
50	4.2 d	3.6 c	4.0 d	12.6 c
60	5.4 e	5.0 d	5.4 e	14.2 d
70	6.6 f	5.0 d	6.4 f	16.0 e

[1]Borg (1980): 0–10 scale
[2]Borg (1962): 6–20 scale

Table 5. Comparison of compatibility values for *"maximum comfortable" and "maximum acceptable"* weights lifted.

Weight	Mean difference	T	P
10	−3.04	−4.20	0.0002
20	−1.69	−2.29	0.0293
30	−0.12	−2.26	NS
40	0.93	2.96	0.0061
50	1.62	4.52	0.0001
60	1.07	6.22	0.0001
70	0.82	2.32	0.0360

NS—not significant

CONCLUSIONS

The preliminary results of this study showed that the fuzzy-set-theoretic approach is very useful for modeling human perception of load heaviness. The interpretation of the maximum *'acceptable'* and *'comfortable'* descriptors needs careful explanation as it has direct bearing on the safety of manual lifting activities in industry. The results of this study indicate that the psychophysical methodology that require the subject to select maximum acceptable weights of lift may lead to accepting loads that are not perceived by the subjects as comfortable, and, therefore, the lifting limits based on the psychophysical approach may not be an effective tool to prevent the overexertion injury.

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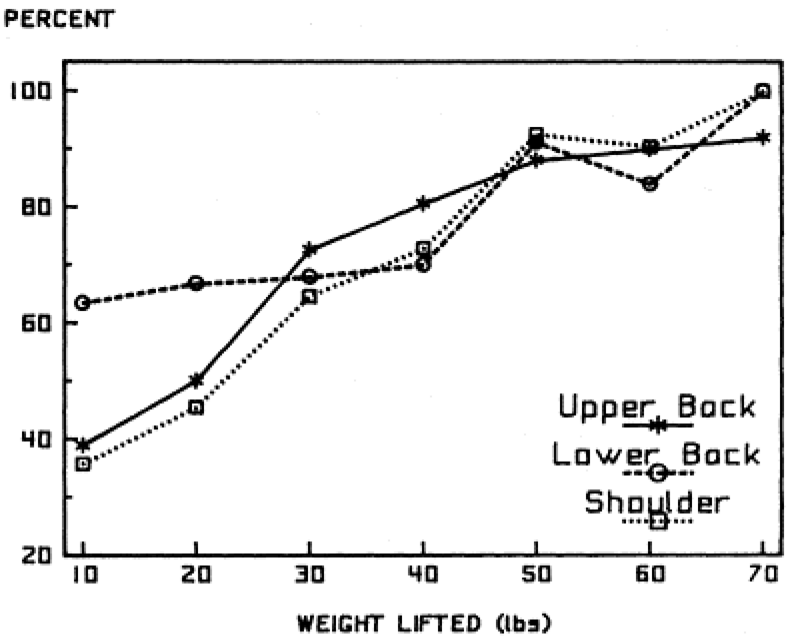

Figure 1. EMG values as percentage of the maximum weight lifted

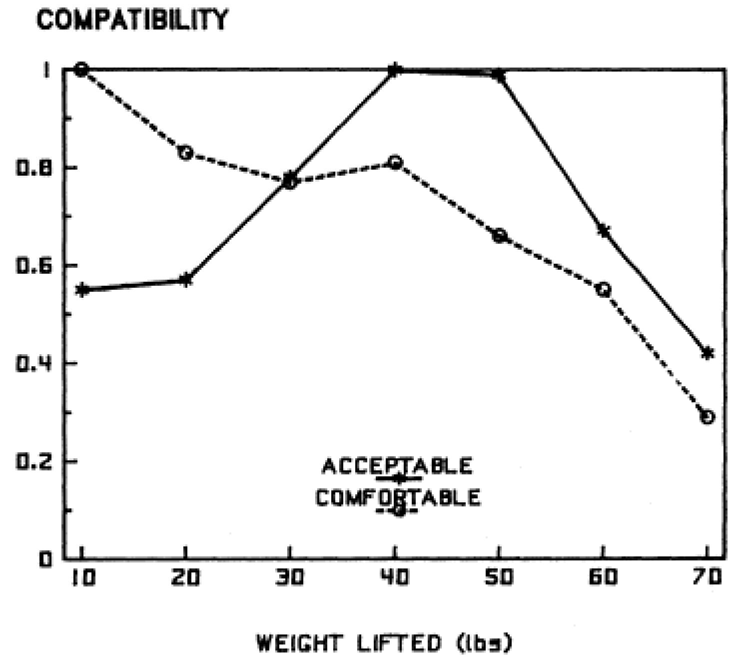

Figure 2. Normalized compatibility values for the maximum *acceptable* and maximum *comfortable* weights of lift

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PERCEPTION OF TROUBLESOME FACTORS FOR THE BACK ASSOCIATED WITH THE WORKPLACE: A STUDY OF AIRCRAFT ASSEMBLERS.

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A questionnaire about the perception of troublesome factors for the back associated with the workplace was answered by 176 assemblers from an aircraft assembly company. The objectives were, on the one hand, to identify which work activities and situations are perceived as being difficult for the back and, on the other hand, to verify the influence of the back health on this perception. Results show that globally, the work situations are judged more severely than the activities. It also appears that back health influences in a marked but complex way the perception of what is difficult for the back.

INTRODUCTION

Absenteeism caused by back pain is an important industrial problem, responsible for substantial medical, compensation and productivity costs. In this respect, prolonged absences (>6 months) are a major challenge as, according to Abenhaim and Suissa (1987), they are responsible for nearly 75% of lost working days, medical costs and compensation payments, although they represent only 7.4% of the officially compensated back pain. For this population, the work environment seems to be an important factor in a successful work reintegration. Vällfors et al (1985) report that 31% of their subjects with chronic low back pain considered their work environment as preventing them from reintegrating into their job, and that with better working conditions, they would have been able to return to their jobs even with their back pain. Furthermore, Berquist-Ullman and Larsson (1977) indicate that 62% of their studied subjects who were low-back pain sufferers experienced one to six recurrent episodes during the following year, and 32% changed jobs because of their back problem.

Up to now, attention has mainly been directed towards the functional and physical limitations of the persons with low back pain (LBP). Questions about functional limitations are most often centered on current activities (participation in sports, going to the theatre, stooping over a sink, making a bed, carying a bag) and on specific actions such as walking, running, sitting for a long period of time (Berquist-Ullman and Larsson, 1977; Vällfors et al, 1985). Furthermore, physical limitations are evaluated through direct measurement of ranges of motion, strength and endurance (Battié et al, 1990; Jørgensen and Nicolaisen, 1987; Mayer et al, 1985). All these questions rarely refer directly to work situations, and the studied subjects suffer or have always sufferred from severe back pain (acute or chronic). On the other hand, psychophysical approaches are widely used, as in studies on postural comfort and handling; however, subjects of these studies are generally free of back pain. Overall, up to now, little interest has been paid to active populations working despite back pain. It would then be pertinent to better understand what is perceived as being difficult in the work.

The objectives of this study are to identify which work activities and situations are perceived as being difficult for the back, and to verify the influence of back health on this perception.

This study was conducted on aircraft assemblers who, as demonstrated by Bigos et al (1986), officially report work accidents more often than other workers in the aircraft manufacturing industry. Their tasks are very variable. The work is done either on a master part within or around which the assembler works, or on a handleable part resting on a work bench. At one extreme, an assembler may have to work on a very large number of different parts during the year (up to 200 parts/year), with a work cycle of about half an hour. At the other extreme, he may work only on one part but with a time cycle lasting up to eleven days.

METHODOLOGY

Population

Two questionnaires were distributed to the assemblers of a Quebec aircraft assembly industry: one on back health and another on the perception of troublesome factors for the back associated with the workplace. The first one was distributed twice at a one-year interval, and the second one only to respondents of the first; 72% (265/366) answered the questionnaire about back health, and 69% (183/265) the one about troublesome factors. For the latter, seven were rejected for being filled out inadequately.

The average age and duration of employment in the industry were 37 and 11 years respectively, including three and a half years in the actual job.

Answers to the back health questionnaire were used to divide the 176 assemblers who answered the second questionnaire into two groups according to the three following modalities:

1. Presence or absence of work limitations caused by a back problem during the week preceding the reception of the questionnaire (Lim: 40 assemblers, Lim0:114). The

question allowed the importance of the disability to be graduated (no limitation, bothered in normal work duties, could not perform normal duties, and had to stay home for at least one day due to the back); for analysis purposes, the Lim group comprises all the assemblers who indicated any work limitation. Twenty-two assemblers did not answer this question.

2. Presence or absence of back pain during the week preceding the reception of the questionnaire (Back: 79, Back0:79). Eighteen assemblers did not answer.

3) Having been compensated or not by the Quebec Workers' Compensation Board for a back problem, but not during the year of the study (Comp: 49, Comp0:124). Ten assemblers receiving compensation were eliminated and three did not answer.

The six sub-groups did not show any significant differences in age and duration of employment.

Questionnaire description and data treatment:

The questionnaire included among others, questions on work situations, activities and tools. For eight activities, the assembler had to indicate whether they were causing him any problems (none, some, enough, many). The five situations had to be judged in terms of back pain contribution (contributes a lot, enough, a little, does not contribute, doesn't know), and the five tools in terms of difficulty for the back (very, enough, a little, not difficult, doesn't know), and if any difficulty was indicated, the reason for it (the position adopted, the efforts needed, both, another reason, doesn't know).

Essentially, the answers to the six sub-groups will be compared, namely their distribution and the odd ratio for each pair. Odd ratios were calculated according to Bernard and Lapointe (1987). Invalid answers (no answer or every choice checked) were kept for the answer distribution but eliminated in the calculation of the odd ratios. The significances were calculated using chi-square.

RESULTS:

As mentioned in the methodology, the assemblers were divided into three sets of paired sub-groups according to three different modalities: presence or absence of a work limitation caused by a back problem, a back pain, a prior compensation for a back problem by the Quebec Workers' Compensation Board. Cross comparison shows that there were as many assemblers with back pain who indicated a work limitation as indicated none; the majority (61%) had never been compensated, just as it was for the Lim assemblers (53%). Inversely, 35% of the Comp assemblers no longer had back pain.

Work activities

Table 1 shows, for eight activities, the percentage of assemblers who considered that the activity was causing them enough or many back problems, and the odd ratios. The higher the odd ratio, the more discriminant the activity.

The two activities most frequently identified by the assemblers as causing problems for the back are "keeping a position for a long period of time" (51%) and "straightening up after being bent over" (40%). Inversely, "turning to pick up something behind" and "changing position often" are rarely identified (11%) as well as "climbing or stepping over" (7%).

Of the twenty-four tested pairs, answers are statistically different at p≤0, 05 for twelve pairs. Overall, the assemblers reporting work limitations answered almost systematically in a different way than those not reporting any limitation, while being compensated or not did not significantly affect the answers. The Back-Back0 pair had an intermediate profile.

The most marked intra-group differences were mainly due to static activities such as "keeping the same position for a long period of time" and "standing for a long period of time" (odd ratios of 7.9 and 5.9). Results also show that activities not normally identified as being difficult by the entire group of assemblers can be very discriminant (e.g.: changing position often, turning to pick up something behind).

Table 1. Percentage of assemblers perceiving that the work activity causes enough or many back problems, and odd ratios.

Activity	% assemb	Δ1 at p≤0, 05	Lim	Odd ratios Back	Comp
Keeping a position for a long period of time	51%	A	7, 9 ***	3, 1 ***	1, 7
Straightening up after being bent over	40%	B	3, 5 ***	2, 4 **	1, 9
Handling bulky parts	32%	BC	2, 1°	1, 1	1, 4
Standing for a long period of time	27%	C	5, 9 ***	2, 9 **	1, 1
Squatting	24%	C	2, 5 *	1, 3	1, 4
Turning to pick up something behind	11%	D	3, 8 **	4, 0 *	3, 9 **
Changing position often	11%	D	4, 0 **	3, 3 *	1, 4
Climbing, stepping over	7%	D	2, 2	0, 7	0, 6
Invalid answers (mean)	3%		1, 1	0, 6	1, 1

1: Results not significantly different (A) have the same letter. ***: p≤0,001 **: p≤0,01 *: p≤0,05°: p≤0, 1

Work situations

The five work situations judged in terms of back pain contribution are shown in Table 2.

Forty percent or more of the assemblers have identified four out of the five situations as contributing enough or greatly to back pain; only "walking a lot" was rarely considered as a contributing factor. It is also worthwhile noting that one worker out of two considered the hardness of the floor as contributing significantly to back pain.

Overall, situations were evaluated more severely than activities. However, contrary to the activites, there are few significant differences between the sub-group answers (three pairs out of fifteen). The only significant differences, all found for the Lim-Lim0 pair, involve the standing position.

Table 2. Percentage of assemblers perceiving that the work situation contributes enough or greatly to back pain, and odd ratios.

Work situation	% assemb	Δ at p≤0, 05	Lim	odd ratios Back	Comp
Having difficulty reaching the working zone	65%	A	1, 9	1, 0	1, 7
Working in a confined space	56%	AB	1, 7	1, 3	1, 3
Working on concrete floor	52%	BC	2, 9 **	1, 7°	0, 7
Working mainly standing	43%	C	3, 8 ***	1, 7	0, 5°
Walking a lot	13%	D	3, 3 ***	2, 2	0, 7
Does not know, or invalid answer (mean)	8%		0, 9	0, 7	1, 7

Legend: see Table 1

Tools

The assemblers were asked whether using the tools contributes to making the work difficult for the back, and if such is the case, the reason why.

Table 3 shows that the alligator squeeze is the worst tool. It is in fact the heaviest (35 pounds) and the bulkiest one. The four other ones were identified as difficult by one assembler out of three.

The sub-groups answered significantly differently six times out of fifteen, with most of the differences occuring for the Lim-Lim0 pair. However, results show that the tool perceived as the most difficult one, the alligator squeeze, doesn't discriminate them, contrarily to those perceived as being easier. This is the case in particular for the rivet gun, identified as being difficult much more often by subjects with limitations than those without (60% Lim vs 18% Lim0).

Regarding the reason why using tools makes the work difficult for the back, the majority of assemblers indicated that it is as much due to the positions as to the efforts. No significant differences were observed between tools, even for the alligator squeeze. The efforts were never identified as being the primary cause of back pain. Having a back problem or not or previous compensation very rarely influenced the answers. Only three pairs out of fifteen showed significant differences, but without any trend in groups or tools.

Table 3. Percentage of assemblers perceiving that using a tool contributes enough or greatly to making the work difficult for the back, and odd ratios.

Tool	% assemb	Δ at p≤0, 05	Lim	Odd ratios Back	Comp
Alligator squeeze	45%	A	1, 9°	1, 1	1, 2
Countersink	37%	AB	4, 4 ***	1, 9	1, 7
Bunking bar	32%	B	4, 0 ***	1, 7	1, 6
Rivet gun	30%	B	7, 0 ***	3, 3 ***	1, 8
Drill	30%	B	2, 3 *	2, 0 *	1, 9 o
Doesn’t know, or invalid answer (mean)	5%		1, 1	0, 9	0, 9

Legend: see Table 1.

DISCUSSION

Work factors perceived as being the most difficult for the back

One of the reasons why we developed a questionnaire rather than an observation procedure was that it seemed difficult to evaluate the work stations adequatly and in a direct way. There were two reasons for this. First, in an initial study on fifty assembly stations, none of the nineteen variables characterizing different aspects of the workstations could predict in an important way any of the sixteen variables describing the posture (Ledoux et al, 1990). Second, postural observation data can not be interpreted independently of their duration, frequency and the type of effort simultaneously applied; the interpretation of observations is therefore very contextual, and the integration of all these elements is difficult. It is worthwhile to note that the assemblers evaluated the situations (consisting of element aggregates) more severely than the activities. For example, they gave more importance to the concrete floor, a factor not extensively considered up to now in studies, than to all the activities on which they were questioned. In fact, questioning about work situations is rarely done as their significance is contextual. For example, it is hard to define in a standardized fashion what a confined space is as it depends on the type of work and its impact on postures. Besides, even if it is easier to ask questions about activities, it is clear that people also answer by refering to the context. For example, the assemblers indicated that it is the positions as much as the efforts that make the use of the alligator squeeze difficult for the back; however, given the weight of this tool, it would seem more plausible that efforts predominate, even if it is recognized that the capacity to apply an effort depends to a large extent on the posture.

Then, used in another context, the answers to questions about tools could have been totally different.

Lastly, the dominant factor among the situations and activities seems to be the "stationary nature" or everything referring to the duration of a position, judged much more severely by the assemblers than changes in position or movements. However, up to now, it seems that duration is an element not given sufficient consideration in studies. But, it goes without saying that it is very difficult to interpret this factor because on the one hand its significance is relative to the posture and effort involved, and on the other hand, it is very hard to as questions about it with precision.

Influence of back health on the perception of troublesome factors

Overall, results show that being compensated in the past has little influence on the perception of what is difficult for the back. This can be explained by the fact that there is an important percentage of assemblers with back pain, as much in the Comp assemblers (57%) as in the Comp0 ones (39%). In contrast, the Back assemblers answered differently from the Back0 ones one time out of three, and those with work limitations, two times out of three. Globally, it seems that reporting a work limitation has an amplification rather than a differentiation effect on what is perceived as being troublesome, when comparing the answers of this sub-group with those of the Back's. Therefore, the following discussion will refer only to the answers for the Lim-Lim0 pair.

First, on the whole, the results show that the Lim assemblers judged the activities and the tools much more severely than the others; however, they judged in a similar manner the situations even if, as previously mentioned, the situations are perceived by the entire group of assemblers as being more troublesome than the activities. Then, a priori, what is most difficult for the back is not necessarily what is the most discriminant. Second, the relative weight given to the factors is not the same. For example, the Lim assemblers estimated that using the rivet gun is as troublesome as using the alligator squeeze, in contrast to the other assemblers for whom the rivet gun causes very few problems, as comparedto the alligator squeeze.

The Lim assemblers clearly appear more sensitive to a prolonged position than to movements. Moreover, the results of the Vällfors and al study (1985) on fifty-nine sub-acute LBP persons, and the Berquist-Ullman and Larsson study (1977) on 217 acute LBP patients, showed that static activities such as bending over a sink, going to the theatre or cinema, and sitting for a long period of time caused more problems than dynamic activities such as walking and carrying a bag. The same tendency is found in Million's study (1982), where chronic LPB people evaluated a factor such as "standing still" more severely on visual analogue scales than "twisting" and "walking". Berquist-Ullman and Larsson (1977) also noticed that subjects with more fixed working positions had longer recurrent episodes. It is known that isometric endurance of the back muscles is lower among chronic LBP persons (Biering-Sørensen, 1984; Jørgensen and Nicolaisen, 1987). Therefore, the duration also seems to be an essential notion for evaluating workstations and activities.

Low back pain workers, “normal” people, and severe low back pain sufferers

In this study, the subjects were active workers, whether or not they had any back pain or work limitation. However, up to now, studies have most often involved people either without any back pain or with severe LBP (acute or chronic); the results obtained with these populations are not necessarily adapted to the intermediate population composed of active workers with back pain. For example, this study shows that factors which normally do not cause any problem can be an important source of difficulty for the worker with back pain. This is the case of the rivet gun, among other; this type of tool, like many others, would have remained unnoticed if the evaluation criteria were based on the answers of subjects not suffering from back pain. Inversely, this study shows that what is normally difficult for people without any back pain is not necessarily more difficult for subjects with back pain. Such is the case for the alligator squeeze, considered as difficult for assemblers with back pain as for those without any back pain. The effects of a back problem on the perception of what is troublesome are hence complex, and inter-individual differences are important. On the other hand, using the results obtained with severe low back pain sufferers is also difficult because the latter are mainly questioned about outside work activities whose significance is not easily transposable to a work context. Consequently, these answers bring information about extreme situations, but not on intermediate ones; on a practical level, they offer little help in defining the zones of difficulty in the work.

CONCLUSION

Overall, this study shows that the context greatly influences the answers, and that work situations are judged more severely than activities. It also demonstrates that back health influences in a marked but complex way the perception of what is difficult for the back. Active workers with back pain appear to be different from subjects without any pain as well as from those whose back pain is severe enough to force them to abandon their regular work. This “grey zone” is not well known.

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APPLICABILITY OF RPE FOR THE EVALUATION OF MUSCULAR FATIGUE

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The Rating of Perceived Exertion scale represents a feasible way of retrieving the subject's own personal rating of the exertion required to perform a physical activity. Generally, experimenters have asked for these evaluations after an activity was performed. The purpose of this paper is to evaluate the applicability of the Rating of Perceived Exertion scale (Borg, 1982) during a physical activity. Thirty subjects were asked to exert a predetermined force upon a hand dynamometer at various wrist positions while EMG readings were recorded. Starting from time zero, subjects were asked to give a rating (6–20) on the amount of exertion every 15 seconds. An ANOVA was performed on the dependent variable RPE and significant main effects were examined using post-hoc analysis. The results showed that both wrist posture and exertion level significantly affected the RPE.

INTRODUCTION

Muscular fatigue affects many areas of our everyday world. Whether in business or sport, understanding muscular fatigue at least partially can give an advantage over a competitor. But, the processes involving fatigue are not fully understood. For instance, highly motivated subjects may maintain an activity that requires a great amount of energy for five minutes, while others will feel and believe that they have to quit after one minute (Kroemer, Kroemer, and Kroemer-Elbert 1986). There are many techniques that can be used to measure the physiological aspects of muscular fatigue, including EMG, heart rate, and oxygen consumption. These techniques allow an insight into the various processes involved in a particular study site (the heart, for example). One place that can't be studied as objectively is the human mind. As the control center for our body, the brain is very much aware of the different stressors affecting the body. With such an amount of information, our brain may not be able to give the objective information of, say, an EMG output, but it can see the whole picture and assess how the body, as a whole, feels. Borg (1962) developed a rating of perceived exertion (RPE) scale to quantify those feelings so that the information could be analyzed.

Initially used as a predictor of heart rate in bicycle ergometer testing, the RPE scale has proven excellent in representing ventilatory minute volume, carbon dioxide production, lactate accumulation, and body temperature. Hence, RPE should be equal to any single physiological variable (Morgan 1975). Overall muscular fatigue has also been measured with the RPE scale (Morgan 1975). However, localized muscular fatigue has only been studied as a function of endurance time, force decrement, and EMG median frequency shift (Rohmert 1960 and Caldwell 1963). The effect of percent maximum voluntary contraction (MVC) and posture have not previously been investigated using subjective ratings. Thus, a study was performed to assess the effect of exertion level and posture on RPE.

METHOD

Subject

Thirty subjects, ranging from 19 to 35 years of age, voluntarily participated in this study. The subjects were selected on the criteria of being right handed, had no history of musculo-skeletal disorders, and possessed the palmaris longus muscle. All subjects gave their informed consent to the procedure described below.

Apparatus

The experiment took place in a private room, containing only the apparatus, the subject, and the experimenters. A postural constraint device was constructed so that a standardized position could be established from subject to subject. A Jamar hand dynamometer was used to measure the grasp strength of the subjects right hand at various combinations of wrist posture and exertion level. A mirror was placed in front of the hand dynamometer so that the subject could read the dial and maintain a prescribed bandwidth of plus or minus ten percent.

Procedure

Prior to the experimental trials, each subject’s s standing elbow height (NASA 1972) was measured to set the apparatus height. Also, the subject’s maximum range of motion in flexion and extension of the wrist was measured. Based upon his or her range of motion, the maximum grasp strength in the right hand with the wrist in each of five postures: full extension, half extension, neutral, half flexion, and full flexion was measured to obtain the MVC in each posture. Each subject was asked to perform 15 trials over the course of

15 days. Each experiment consisted of a combination of a percentage of the MVC (40%, 60%, and 80%) and one of the five previously mentioned wrist postures.

For each experiment, the subject was asked to keep the hand dynamometer within the plus or minus 10% bandwidth of the set force until fatigue, where fatigue is defined as the voluntary cessation by the subject or the inability to maintain the force necessary to stay within the bandwidth. During the experiment, the subject was asked to rate the exertion level and the overall feeling of the arm according to Borg's (1985) RPE scale (see table 1). This rating was taken every 15 seconds after the subject began the experiment trial and upon fatigue (as previously defined).

Experimental Design

The effects of the independent variables wrist posture (P) and exertion level (L) on the dependent variable of RPE were analyzed using an analysis of variance. Since both males and females were in this study, gender is an independent variable with two levels. The resultant design was a 5 (wrist posture)×3(exertion level)×2 (gender) mixed factor model with blocking on the subjects nested within gender.

RESULTS

An ANOVA was performed for the dependent variable RPE. The results, which are summarized in table 2, indicate that wrist posture and exertion level both significantly affect the RPE. Post-hoc analysis of the independent variable wrist posture using the Tukey test showed that the half extension wrist posture was significantly different from the full extension, full flexion, and half flexion postures and that the neutral posture was not significantly different from any other posture. The results of the test are summarized in table 3.

A second post-hoc analysis was performed, but this time on the independent variable exertion level. All three levels were found to be significantly different from one another. The results of this test are summarized in table 4.

CONCLUSIONS

The results of the exertion level post hoc analysis were as we expected. Forty percent of MVC was expected to be different from the other % MVC's in the way it affected the RPE. Since it was a smaller load, the RPE was expected to start out smaller than the 60% or 80% and gradually build until fatigue. The 80% of MVC was expected to start out fairly high in the RPE scale (15–19) and the 60% of MVC was somewhere in the middle.

The results of the wrist posture were somewhat unexpected. Since each posture was normalized, we expected to see that, for example, 60% of MVC in the half extension posture would be similar to a 60% of MVC in the half flexion posture or any other posture. This was not the case. The half extension posture was similar to the neutral posture in all cases and the neutral posture was similar to the full extension, full flexion, and half flexion in all cases. The mean of the half extension wrist posture was 16.50 and the lowest mean for the other group was 15.80, which is a difference of 0.70. The minimum significant difference value was 0.58, therefore the half extension was only 0.12 from being not significant. Perhaps if the test was performed again under an improved protocol, the half extension would not be significant.

Tables

Table 1. Borg's 1985 RPE scale

Number	Verbal Anchor
6	No exertion
7	
8	Extremely light
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

Table 2. Analysis of variance summary table

Source	d.o.f.	Sum of squares	F value	P
G	1	61.27	0.77	0.39
S(G)	28	2222.46	–	–
P	4	214.36	4.59	0.0018
P×G	4	19.17	0.41	0.80
P×S(G)	111	1297.25	–	–
L	2	981.04	34.19	0.0001
L×G	2	3.84	0.13	0.88
L×S(G)	56	803.46	–	–

Table 3. Tukey test for dependent variable RPE using the independent variable of wrist posture.

Grouping		Mean	Wrist posture
	A	16.6	Half extension
B	A	16.3	Neutral
B		15.9	Full extension
B		15.8	Full flexion
B		15.8	Half flexion

Table 4. Tukey test for the dependent variable RPE using the independent variable exertion level.

Grouping		Mean	Exertion level
A		17.2	80% of MVC
	B	16.3	60% of MVC
C		15.6	40% of MVC

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THE RELIABILITY OF PALPATION SKILLS IN THE THERAPEUTIC PROFESSIONS

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This study investigated factors influencing the reliability of palpation. Twenty physical therapists participated in an intra-and inter-rater investigation. Four body points differing in form and depth were palpated and marked with invisible ink. The distances between marks made on the same structure were measured. Deeper and less defined structures were associated with more error, especially between raters ($p<.05$). There is a systematic error associated with palpation.

INTRODUCTION

Palpation is the process of examining or exploring the body by means of touch. It is a fundamental skill that has been practised by medical practitioners for a long time. Palpation is a standard component of a clinical examination, and provides important information about tissue temperature, texture, resilience and joint motion. This information is then used in the formulation of a diagnosis and treatment plan (Lewit, 1985; Lee, 1991; Grieve, 1981; Hoppenfield, 1976). The results of palpation testing are accepted as providing accurate and objective information (Grieve, 1981; Lee, 1989). However, studies on the reliability of palpation generally reveal poor agreement between raters (Potter and Rothstein, 1985; Matyas and Bach, 1985; Herzog et al, 1989; Carmichael, 1987; Keating et al, 1990; Mootz et al, 1989). In spite of this, there remains a clinical belief in the reliability and significance of clinical tests (Twomey, 1985). For example, whilst acknowledging the anatomical, biomechanical, and radiological evidence that largely precludes movement in the sacroiliac joint, Lee (1989) writes “sacroiliac joint mobility…is best judged by accurate, objective, clinical evaluation.” The problem is that manual therapy has advanced to a position of having a large and complex clinical theory in advance of a sound scientific and verifiable base (Matyas and Bach, 1985). It is also evident that research which questions clinical theory is often not well received.

Matyas and Bach (1985) reported their results from a well controlled objective study aimed at addressing the reliability of intervertebral motion testing. They used a force platform and a biomechanical algorithm to measure the specific application of force obtained at various predetermined clinical measures of resistence to motion. The results indicated poor reliability between therapists and between days. The mean inter-therapist correlation was r= 0.22. In addition a systematic bias was found between therapists. Some therapists were consistently light in their palpation technique whilst others consistently used more force (Matyas and Bach 1985). This excellent work generated a shrill response from manual therapists (Stoelwinder et al 1986), who argued that; 1) the experimental method interfered with the palpation technique, and 2) Matyas and Bach were not qualified to judge the manual techniques because they did not have a background in manual therapy.

Empirical models have obvious flaws. However, it is also true that strict scientific experimental models also have problems, and it is necessary to distinguish between statistical significance and clinical significance. The problem is, to determine where the clinical significance level is, and what measurement error is therefore acceptable. It is also useful to know what factors influence the error.

Characteristics of the therapist will influence accuracy, reliability and also validity. The level of anatomical knowledge is obviously fundamental. The therapist must know where to palpate in order to locate a specific structure. Experience of the therapist may (Evans, 1986), or may not (Harvey and Byfield, 1991; Mior et al, 1990; Herzog et al, 1989) influence their perceptual sensitivity to joint motion.

Evans (1986) reported that experience improved the sensitivity to motion of palpation. He used a mechanical device designed to simulate palpation and found that manipulative therapists detected resistance to motion earlier in the range than untrained subjects. However, the criteria for “untrained” is not reported. In addition, mechanical problems with the palpation simulator were reported. The methodological flaws limit the strength of the conclusion that experienced therapists are more accurate in their perception.

Harvey and Byfield (1991), also used a mechanical model to evaluate spinal motion palpation. They reported no difference in the skill levels of chiropractors and chiropractic interns. These findings appear to generalise to the clinical situation (Herzog et al, 1989; Mior, 1990).

Carmichael (1987) used both student and graduate examiners in a reliability study on sacroiliac dysfunction. He reported a variable level of competance between all examiners, so instituted a three month training period prior to data collection. This training period was designed to standardise and improve skill level. This may have paid off in improving the reliability, which he reported as 85% and 89% agreement between intra- and inter-rater respectively. However, once agreement by chance was factored out using Cohens Kappa statistic, agreement was significantly reduced.

Poor reliability of clinical tests was also reported by Potter and Rothstein (1985). However, they noted that reliability was greater, if the outcome of the test was based on the patients response. Specifically, the patient was required to report whether they experienced pain during the test. This point serves to emphasise the fact that palpation findings are not the objective tests they are believed to be. The lack of inter-rater reliability indicates they are essentially tests of the therapists subjectivity.

Individual perception of palpation influences the judgement of the structure or motion being assessed. However, the individual technique of palpation will also influence reliability between raters. The amount of pressure exerted by therapists during palpation differs systematically between raters (Matyas and Bach, 1985). This difference will alter what is felt by the therapist, in regards to tissue resilience and joint motion. The amount of force will also influence what is felt by the patient, whether it be light touch, pressure or pain. It is necessary to systematically examine the impact of these factors so that a model to predict the reliability of clinical tests can be formulated.

The purpose of this study was twofold, 1) to investigate whether the physical characteristics of a structure influence the reliability of location by palpation, and 2) whether the reliability differs between and within raters.

METHOD

Subjects for both experiments (intra-rater and interrater) were graduate physical therapists (PTs), and students in the final year of a physical therapy programme. A total of 20 physical therapists participated in both experiments. The age range was 24 to 41 years. All subjects were randomly assigned as “therapists” or “subjects”. The role of the therapist was to palpate and identify specific anatomical structures on the subjects.

The four points outlined below were selected for identification. All of these points are frequently palpated during standard clinical practice. The rationale for selecting each point is also presented.

The anterior border of the lateral ligament of the knee

This point is representative of ligament, and is frequently palpated during clinical examinations of the knee (Hoppenfield, 1976). It is also representative of a superficial and fairly well defined line.

Posterior superior iliac spine (PSIS)

This point was selected because it is representative of a superficial bony structure. It is also a frequently used landmark for spinal and pelvic girdle assessments (Lee, 1989; Grieve, 1981). This point is often used as a landmark against which to determine individual spinal levels.

Spinous process of L4

This point is also a superficial bony structure, but it is smaller in size than the PSIS. In addition, identification of the L4 spinous process is a secondary level of palpation i.e. the specific identification is made, based on a more easily identified primary reference point. In this case the primary landmark is usually the PSIS or the iliac crest. The PSIS is generally at the S2 spinal level. Given this “definitive” level, the palpator counts the bony prominences in a proximal direction, until L4 is reached.

Transverse process of L4

This point was selected to represent a deeply placed, fairly small bony structure. The transverse process is also a secondary point of palpation.

Each therapist palpated two subjects in both experiments. In the intra-rater experiment, therapists were instructed to palpate each of the four structures and mark each structure with a dot, employing a pen which used invisible ink. The instruments used for writing and illuminating the marks were similar to those used by Burton (1990). After five minutes, therapists were insructed to palpate the same four points and again identify them with a dot. The therapists were allowed to use free palpation techniques. The five minute time interval between tests limited the visual cue that would have resulted from the presence of cutaneous erythema. This erythema sometimes persists for a few minutes after deep palpation. It was also necessary to ensure that no trace of the mark was visible. The palpation area was checked after each test, and prior to the following test to ensure that no visible cues were present.

Once the palpation and marking was completed, the invisible marks were identified with a special ultra-violet light (Blak-Ray UVL 21, Ultraviolet Products Inc. San Gabriel, California). The distance between marks was then measured with a flexible ruler.

The same procedure was basically followed for the inter-rater tests. However, subject position for palpation of specific points was standardised. The lateral ligament of the knee was palpated with the subject seated. The knee was flexed at 90° and the hip was in lateral rotation. All other points were palpated with the subject in prone lying. The time between tests and method of measurement was the same as for the first experiment.

The data was subjected to a repeated measures MANOVA, using the SPSSPC statistical package. Post hoc comparisons were computed using univariate t-tests.

RESULTS

The descriptive data for intra- and inter-rater tests is presented in Tables 1 and 2. Comparison of the data for both tests reveals a similar pattern for most locations, though the raw values are greater for inter-rater distances. The KNEE is the most reliably palpated both within and between testers. In contrast, the TPL4 which is the deepest structure demonstrates the most variation of palpation.

Table 1. Descriptive statistics of distances between consecutive tests for intra-rater experiment (n=20)

Location	Mean Distance (mm)	Standard Deviation	Minimum mm	Maximum mm
Lat. lig knee	7.85	5.93	0.00	18
PSIS	8.00	5.06	0.00	17
SPL4	11.90	7.27	0.00	25
TPL4	14.30	11.24	0.00	37

Table 2. Descriptive statistics of distances between consecutive tests for inter-rater experiment (n=20)

Location	Mean Distance (mm)	Standard Deviation	Minimum mm	Maximum mm
Lat. lig knee	11.95	3.73	7.00	19
PSIS	20.40	13.16	7.00	48
SPL4	16.00	8.47	8.00	35
TPL4	24.50	11.84	0.00	43

Table 3. Results of post-hoc t-tests between intra- and inter-rater distances for each location

Location	Intra-rater Mean (mm)	Inter-rater Mean (mm)	Significance Level
KNEE	7.85	11.95	0.008
PSIS	8.00	20.40	0.001
SPL4	11.90	16.00	0.160
TPL4	14.30	24.50	0.023

The repeated measures MANOVA revealed significant effects ($p<.05$) between locations and between intra-and inter-rater groups. Post-hoc univariate analysis on the intra-rater locations revealed significant differences between, KNEE and SPL4. In addition, PSIS differed significantly from SPL4 and TPL4. The same post-hoc analyses were run on the inter-rater tests and significant differences were revealed between KNEE and all other locations, and between SPL4 and TPL4. Finally, comparison between intra- and inter-rater measures, revealed significant differences for all locations except SPL4. An alpha level of $p < 0.05$ was accepted as significant on all tests. Table 3 summarises the results of the post hoc analyses.

DISCUSSION

The results of this study confirm the findings by other authors that there is a statistically significant lack of reliability with palpatory findings. The results also indicate there is variability in reliability which is related to form and depth. Finally, the lower levels of inter-rater reliability was expected and confirms the soundness of the methodology.

The KNEE was associated with least error. This indicates that the line of the ligament was fairly easy to distinguish from the underlying tissue. In most cases the ligament was palpated over the joint line rather than at its bony origins. The fact that it is a quite distinct line and is superficial adds to the lower rate of error.

The PSIS was associated with low intra- but high inter-rater error. This is probably explained by the fact that the although the PSIS is superficial, it is sometimes an indistinct bone and is frequently assymetrical. Each therapist obviously used their own individual reference point for identification.

The error associated with SPL4 tended to be due to error in the identification of the correct spinal level. There was very little discrepancy in horizontal distances. This is in contrast to TPL4 in which there were considerable discrepancies in the identification marks in all directions. This indicates an error in the spinal level identified, and also in the location of the relatively small deeply placed bony process. The results indicate statistical significance, but do they also indicate clinical significance? Clinical significance relates primarily to the interpretation of the results of palpation.

The PSIS is often palpated in order to determine pelvic symmetry. It is a reliable measure for one rater but not between raters. The error in location of the bony prominences of the pelvis probably contributes to the low reliability of clinical motion tests of the sacroiliac joint. However, the lack of proven specificity of the clinical tests must also play a major role.

The identification of the spinous process was subject to an error of one spinal level. This was true both within and between raters. In clinical practice this error could be reduced if the patient with a painful back participated in the localization of the problematic level. Whether this range of error is clinically significant depends on the specificity of treatment. The error is insignificant for general treatment, but not for treatment aimed at a specific spinal level.

The highest level of error was associated with identification of the transverse process. The relative position of the transverse process is tested, in order to guide treatment, which is very specific. The nature of the error in the location of the transverse process questions the validity of the test and any treatment based on the results of positional tests. It is possible that motion testing may decrease the error but the results of other studies do not support this argument.

CONCLUSION

The lack of reliability and lack of proven validity of palpation as a measurement on which to base treatment is cause for concern. This study provides more evidence of the error associated with palpation. Moreover, it shows that there is a systematic error associated with depth and form. The poor reliability of many clinical tests may be due to a fundamental error in the localisation by palpation of specific structures.

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STRENGTH

Re-evaluation of the Caldwell Regimen: The Effect of Instruction on Handgrip Strength in Men and Women

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This study evaluated the effect of instruction on handgrip strength in males and females and re-evaluated the Caldwell Regimen for measuring grip strength. Three sets of handgrip instructions were used to evaluate 18 men and 17 women, ranging in age from 18 to 31 years. The results showed, unlike previous measurements on finger pinch strength, that subjects were able to maintain the ±10% bandwidth and that different instructions for force generation resulted in varying maximal grip force. Therefore, instructions used should be precise, consistent, reported along with the results, and reflect the intended use of the data.

INTRODUCTION

Purposes of grip strength testing

Grip strength testing is used for many purposes: screening workers for placement in jobs requiring upper extremity strength, monitoring rehabilitative progress, and determining when an injured worker can resume his duties. Work and leisure activities require various durations of force exertion. For example, catching an object requires a quick grip, while carrying a suitcase requires a sustained grip. The majority of life activities require sustained sub-maximal exertion, thus, grip strength testing which requires sustained effort (rather than sudden maximal exertion) may be more appropriate for both pre-placement and rehabilitative testing.

The Caldwell Regimen

Muscle strength measurement is influenced by instruction (Berg, et al., 1988; Caldwell, et al., 1974; Kroemer and Howard, 1970), therefore, to achieve consistent results from testing, specific procedures must be identified and adhered to during testing. The Caldwell Regimen (Caldwell, et al., 1974) for muscle strength testing requires that a sustained exertion be performed in the following manner: the subject increases force to maximum in approximately one second, maintains the exertion for four seconds, and decreases force over the sixth (final) second. The strength score is calculated as the mean of three averaged seconds, during which a ±10% bandwidth must be maintained. The Caldwell Regimen was recently re-evaluated for use during pinch strength measurements (Berg, et al. 1988). It was shown that subjects were unable to maintain the recommended ±10% bandwidth and that peak strength differed according to duration of effort.

Study objectives

The present study's primary objective was to compare maximal forces generated using three different methods of instruction: (a) peak force, maintained (instruction one)—a sudden maximal voluntary contraction (MVC) sustained for the remainder of the test period, (b) peak force only (instruction two)—a sudden maximal contraction ("peak") followed by immediate release of the grip, and (c) built-up force maintained (instruction three)—gradual increase to maximal exertion over one to two seconds, followed by a sustained MVC bringing total time for build-up and sustained force to 6 seconds (Caldwell Regimen).

Additional objectives were to: 1) compare the number of subjects who were able to maintain the force exertion within ±10% of the average versus those who needed a ±15% bandwidth; 2) compare average forces obtained during two and three second intervals of sustained contraction; and 3) determine the effect of instruction on the time required to reach peak contraction and to initiate sustained force for two and three seconds.

METHOD

Subject characteristics

The subjects were 18 men and 17 women aged 18 to 31, with no test related physical impairments. All subjects except two were right handed. The dominant hand was used in all testing. Each subject was briefed using a prepared script. Subjects completed three trials of each instruction type.

Subject positioning

Subjects were positioned with feet flat on the floor, back straight and supported by a backrest, shoulder adducted and neutrally rotated, elbow at 90 degrees, and forearm supported in a neutral position (The American Society of Hand Therapists standard position, Fess and Moran, 1981). Subjects were permitted to select a comfortable wrist position. The isometric handgrip gauge was set so that the third metacarpalphalangeal joint was at 150 degrees and the third proximal interphalangeal joint was at 110 degrees (Mundale, 1970). Wrist positions were measured and recorded for each subject using a goniometer. All subjects selected a wrist angle that was between 0 and 30 degrees dorsiflexion. A minimum of three minutes rest between each trial was provided and more time was given, if needed. Although a decrease in effort can be observed after a short period of maximal contraction (deVries, 1966; Milner-Brown, et al., 1986), Moudgil and Karpovich (1969) found that a true maximal isometric contraction could last up to 8.6 seconds. If the subject lifted his arm (elbow) from the table, the trial was terminated and a minimum of three minutes rest was allowed before the next trial.

Experimental configuration

Grip force measurements were collected using a specially designed isometric handgrip gauge (Ramos and Knapik, 1980) (Figure 1). The gauge was fabricated according to Mundale's design (1970). Force applied on the grip pieces wastransferred to a BLH Electronics C2M1 tension/compression transducer, which has an accuracy of 0.5% and a range of zero to 225 kg. A Hewlett-Packard 900–3000 micro-computer with a 9153 disk drive were used to process and display information received from the handgrip ergometer via an amplifier (Graphtec Linearcorder WR3101). Subjects were permitted toview the computer screen during training and testing. The same investigator performed all measurements in a controlled laboratory environment.

The instructions to the subject were as follows:

> Instruction One (sudden maximal contraction, maintained): At the sound of the beep, the examiner will say, "ready, squeeze", at that time, you will immediately exert your maximal effort, (without jerk), and maintain that effort for the rest of the testing period. It is important to exert a maximal force which can be held constant over the rest of the testing period.
>
> Instruction Two (sudden maximal contraction): At the sound of the beep, you will grip the gauge as hard as you can, exerting your maximal effort (without jerk). When you feel you have reached your maximal effort, you can relax.
>
> Instruction Three (built-up force, maintained): At the sound of the beep, you will slowly build up to your maximal effort (without jerk) and maintain that effort for the rest of the testing period. The slow build-up to your maximal effort should take one to two seconds. To help you do this, the examiner will count aloud "one thousand one, one thousand two". At the word "two" you should be at your maximal effort. You should maintain that effort for the rest of the testing period. It is important to exert a maximal force which can be held constant over the rest of the testing period.

RESULTS

Data Analysis

BMDP Statistical Software (Berkeley, California) was used to perform a two way analysis of variance. During each rest period, the data from the trial were analyzed for peak force, number of seconds to peak force from the start of the effort, average force during a two second (2s) interval surrounding the peak force, and mean force during a three second (3s) period surrounding the peak force. Data were also assessed for whether the ±10% and ±15% bandwidth were maintained for the two and three second periods.

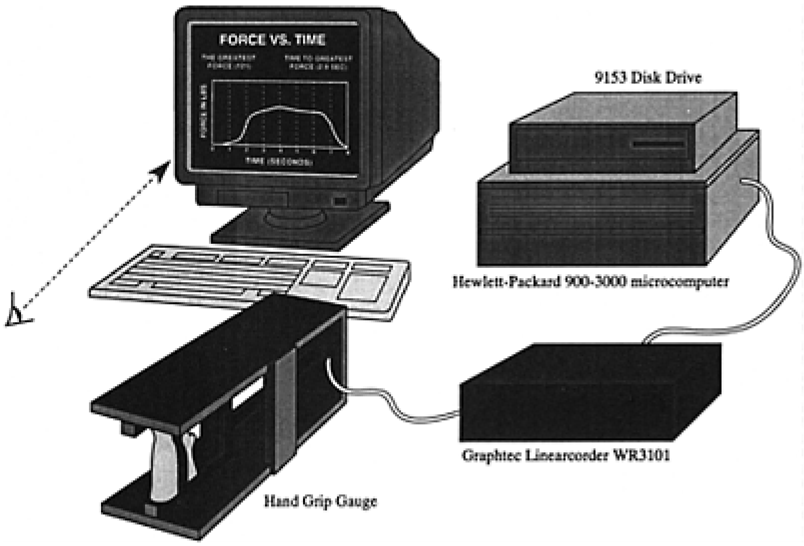

Figure 1. Experimental Configuration

Effect of instruction type

The effect of instruction type on force for men and women combined can be seen in Table 1. Instruction type had a statistically significant effect on peak force and time of peak force occurrence, but did not significantly effect mean force values for the 2s interval or the 3s interval. Time to peak grip strength was greater for instruction one than for instructions two and instruction three showed a greater time than either instructions one or two.

Table 1. Effect of instruction on measures of performance

Instruction Type	Peak Force (lbs)	Mean Force (lbs)		Time to Peak Force (seconds)
		2s	3s	
One	84.6 ± 25.8	82.3	81.3	2.98 ± 1.62**
Two	90.4 ± 23.8*	N/A	N/A	2.25 ± 1.18
Three	83.8 ± 24.8	81.6	80.8	3.77 ± 1.27***

*significantly different from One and Three (p< 0.01)
**significantly different from Two (p< 0.01)
*** significantly different from One and Two (p< 0.01)

As shown in Table 2, men had a greater maximum peak grip strength than did women for all instructions. The men also had a greater average force than women during both the two second (98.5 vs 64.3 pounds) and three second (97.5 vs 63.5 pounds) periods ($p<0.01$).

Table 2. Gender differences for peak force.

Instruction Number	One	Two	Three
Male	101.7 ± 21.3*	106.4 ± 18.1**	100.4 ± 20.2**
Female	66.4 ± 15.9	72.8 ± 15.0	66.1 ± 15.1

*significantly different from the Female Value ($p< 0.001$)
**significantly different from the Female Value ($p< 0.01$)

A 10% and 15% bandwidth was maintained for a majority of the trials (Table 3).

Table 3. Percent of trials meeting 10% and 15% bandwidth during two second and three second periods.

	Length of period	
Bandwidth	2s	3s
Within ±10%	98.0%	94.4%
Within ±15%	98.6%	96.7%

CONCLUSIONS

The results demonstrate that maximal grip force values are affected by the instruction presented to the subject and that subjects did follow the instructions given for testing handgrip strength. However, if an averaged value of 2s or 3s (with a 10% bandwidth criteria) is to be used as a measure of handgrip strength, subjects can select either a sudden or gradual method of building to peak force without significantly affecting the resulting force.

In an earlier study, Mathiowetz, et al. (1985) found a peak force that was 10% to 15% higher for men than that of the men measured in the present study. The differences between the results from the two studies, shown in Table 4 may be due to the subject population, the apparatus used, instructions provided, and the type of motion used during testing (isometric for the present study versus isoinertial for Mathiowetz's work). The differences may also be due to the subject population; however, without a description of the procedures this is difficult to determine the discrepancy in results between the two studies demonstrates the importance of using standardized procedures. Standardization would allow for easier comparison of studies and improved reliability within studies.

Table 4. Comparison of strengths (lbs.) exerted by subjects in this study to the study by Mathiowetz, et al. (1985).

Present Study (Peak Force, Instruction Two)		Mathiowetz et al.	
Males		20–24 yrs.	121.0
18–24 yrs.	106.4	25–29 yrs.	120.8
Females			
18–30 yrs.	72.8	20–24 yrs.	70.4
		25–29 yrs.	74.5
		30–34 yrs.	78.7

Strength measurements which are averaged over time and standardized measurements of strength may be more closely related to actual work and leisure demands and therefore may be more useful for work station design, worker selection and placement, and determination of readiness to return to activities after injury. Practical information can be gained from taking strength measurements which are averaged over time, such as the present study where data were averaged over 2s and 3s. This practical aspect may be realized by comparing strength measurements to strength needed for work or leisure. However, more research is needed on the practical implications of strength measurements which are selected by duration of effort. It may, however, be more convenient to use a peak strength measurement during rehabilitation, since a portable apparatus may be used.

Although subjects had difficulty attaining the bandwidth requirement and the 3s average during pinch grip strength testing (Berg, et al., 1988), subjects easily attained these requirements for handgrip strength. Therefore this study reiterates the validity of the Caldwell Regimen for grip strength testing.

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PSYCHOPHYSICAL TESTS, ISOMETRIC AND DYNAMIC MUSCLE FORCE MEASUREMENTS AS DETERMINANTS OF AIRCRAFT LOADERS' FUNCTIONAL CAPACITY

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INTRODUCTION

Back injuries and back pain at work are related to a variety of risk factors (Troup, 1984). The increase of the musculoskeletal complaints has proven to be connected with the frequent occupational activity of load transportation in exceptionally narrow spaces as are the aircraft compartments (Stålhammar et al. 1986, Jørgensen et al. 1987, Luttmann et al. 1988). All these studies demonstrated that the proportion of aircraft loaders with spinal diseases was highest. Therefore, the measurement of trunk strength has been of considerable interest due to back injury affliction and secondary consequences.

Testing of maximal isometric lifting strength has been recommended as a screening tool for the prevention of back injuries (Chaffin et al. 1978; Keyserling et al. 1980). Several authors (Kroemer, 1970, Caldwell et al., 1974, Chaffin, 1975, Pytel and Kamon, 1981, Kumar et al. 1991) have pointed out that the posture must be standardized for the assessment of human strength, as it influences the strength exertion capability of workers. However, the isometric test is a static test in one body position whereas muscle contraction in manual materials handling is dynamic. Muscle performance is dependent on joint function, the dynamics of motion, and posture, thus suggesting dynamic testing methods.

Griffin et al. (1984) demonstrated the repeatability of a quick and simple psychophysical assessment of acceptable weights for dynamic lifting: the Rating of Acceptable Load (RAL). This method has been used for differentiating the task and load characteristics in lifting (Stålhammar et al. 1989 a, b). When assessing a given work task and a given individual's capacity to tackle it the screening methods must be developed keeping in mind both the job demands and biological factors. In this study the aim was to use isometric and isokinetic lift strength and psychophysical tests—the Rating of Acceptable Load (RAL)—for assessing the aircraft loaders work capacity at work site.

METHOD

The subjects were 103 male aircraft loaders. Their ages were 18–43 years, heights 160–193 cm, weights 59–122 kg. In the Standard RAL-test (RAL_{St}) a subject assessed the load of a box (30x30x30 cm) with handles which he individually felt to be acceptable for lifting between a table (height 72 cm) and the floor at 5-min intervals for an 8-hour working day. The Work Simulated RAL-test (RAL_W) was administered for the simulation of luggage handling (12 pieces min^{-1}) in an aircraft compartment for a habitual 14 hour shift. At this test the researcher changed the weights into the luggage at a subject's bidding until the subject felt that it was an acceptable weight for lifting in a restricted space of the compartment. The mock-up of the compartment was built in a testing room. In this test the contents of the luggage was invisible to the subjects. A random selection of unlabelled bags of lead shot weighing between 0.5–2.5 kg was used in both tests.

A test procedure for arm flexor strength evaluation was developed for simulating the work inside the compartment: maximal isometric flexion strength was measured in a kneeling posture with straight back and flexed forearm (90°) as well as the acceptable holding force corresponding about 10 s luggage carrying. The isokinetic lifting force was measured during lifting movement from floor to the standing upright with raised arms. The speed was 1 ms^{-1}.

RESULTS

The results of the psychophysical tests, isometric and isokinetic strength measurements are given in table 1, and the correlations between variables in table 2.

Table 1. Mean, SD and the range of individual characteristics of aircraft loaders, isometric arm flexor strength (IMF), isokinetic lift strength (IKL), rating of acceptable holding force (RAH), rating of acceptable loads for the box with handles (RAL_{St}) and the luggage (RAL_W).

	N	Mean	SD	Range	
Age (a)	103	24.7	4.5	18	43
Height (cm)	103	179.6	6.0	160	193
Weight (kg)	103	81.4	12.7	59	122
IMF (N)	103	448	99	151	711
IKL (N)	103	1087	259	602	1682
RAH (N)	103	150	54	43	333
RAL_{St} (kg)	103	20.9	10.9	4	64

RAL_W (kg)	103	14.9	4.7	8	36

The means of RAL_{St} and RAL_W tests were 21±11 kg and 15±5 kg, respectively. RAL_{St} correlated better with the kinetic lifting strength and RAL_W with the isometric strength, although generally the correlations between psychophysical and strength tests were rather weak. The mean acceptable luggage weight and holding force were about the same as the average luggage weight in European flights, about 15 kg.

Table 2. Pearson's correlation coefficients between the variables of table 1. Statistical significance is shown by asterisks:—$p>0.05$, * $p<0.05$, ** $p\leq0.01$, *** $p<0.001$.

	Height	Weight	IMF	IKL	RAH	RAL_{St}
Weight	0.489***					
IMF	0.196*	0.595***				
IKL	0.228*	0.429***	0.588***			
RAH	0.091–	0.450***	0.506***	0.296**		
RAL_{St}	0.211*	0.230*	0.157–	0.208*	0.336***	
RAL_W	0.151–	0.291**	0.212*	0.156–	0.514***	0.617***

CONCLUSIONS

Because manual materials handling is dynamic work, an objective assessment of functional capacity must be based on dynamic functional measures rather than on static. The results of this study—especially the acceptable luggage weight and holding force—were highly related to the physical demands of the job: the average luggage weight in European flights is about 15 kg! The loaders assessed their acceptable holding force about one third of the maximum thus leaving a wide safety margin. The firefighters did the same tests in standing position but their acceptable force was 50 % of maximum reflecting some overestimation of their capacity (Baxter et al. 1986). The mean peak isokinetic lift strength was high, above 1 kN, and even the weakest of our subjects could lift about 600 N. This shows that the loaders would not have difficulties in their daily work if they only could work in unrestricted postures. The isometric holding strength in the kneeling posture describes better than the isokinetic lifting strength the subjects' capacity to lift inside the compartment. The normal loading work includes heavy lifts involving muscle forces probably exceeding the capacity of at least the weakest loaders. Those who have normal or higher strength levels in respect to the job demands are able to better stand the stress on the spine due to the awkward postures in restricted work spaces. Strength capabilities might have an important role in employee selection to prevent back injuries. The tests must have task relevant, both static and dynamic features.

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THE EFFECT OF FOREARM ORIENTATION ON WRIST-TURNING STRENGTH

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A study was performed to determine the effect of forearm orientation on peak wrist-turning torque. Five male and five female manual workers generated torques on a cylindrical handle with the right hand, while standing comfortably, with the forearm in three different orientations—neutral, pronated and supinated. The pronated orientation proved to be the strongest, but did not depend on the type of turn; wrist-extension turn was 18% stronger than wrist-flexion turn; and females were only half as strong as males, Forearm orientation has different effects on different types of hand-arm strength

INTRODUCTION

There are many occasions in industry, especially in maintenance and assembly activities, where muscular strength for gripping and turning is still important, and where the arm is used in different orientations. This type of exertion is common where either space limitations precludes the use of tools, or there are no tools for a particular task, or the use of tools could damage equipment (e.g. measuring fluid pressure in the oil and gas extraction industry; Imrhan and Farahmand, 1991). Available ergonomic data on the effect of arm orientation on gripping and turning is lacking. Thus there are no objective guidelines for arm or tool orientation, or for the method of exerting wrist-turning torques to minimize musculoskeletal strain. This study was a preliminary one designed as a first step to fill this gap in knowledge.

METHODS

Subjects

Ten adults (5 male and 5 female) served as subjects. All were volunteers and were unpaid for this study. All males were manual workers and all females were homemakers. Males were between the ages of 33 yr and 43 yr (mean=35.0 yr), and females between 28 yr and 40 yr (mean=31.4 yr). Subjects were chosen on the basis of their availability. They were 10 of the 20 subjects who had participated in a previous strength testing experiment (Imrhan and Jenkins, 1990), and so had some experience in strength testing with the present apparatus.

Objectives

The specific objectives of this study were:

1. To measure and compare the magnitudes of maximum voluntary contraction (MVC) peak torques for wrist-turning exertions in both the extension and flexion directions, for three different forearm orientations—pronated, supinated, and mid-pronated/supinated (neutral).
2. To compare male and female torques for each arm orientation.
3. To compare the torques with other measures of hand strength (handgrip and pinches) and Anthropometry.

Apparatus and experimental design

The following instruments were used for measuring the three types of strength:

1. Torque a Snap-on-Tools torque meter with a range of 150 in-lb. and increments of 2.5 in-lb. This was the same instrument used in Imrhan and Jenkins (1990).
2. Handgrip—a Lafayette handgrip dynamometer with a range of 100 kg and increments of 1 kg.
3. Pinch—a Best Price pinch gauge with a range of 60 lb. and increments of 2 lb.

A custom designed aluminum cylindrical handle of diameter 2 1/4 in (63 mm) and length 5 1/2 in (140 cm) was fitted to the shaft of the torque meter. Grasping and turning this handle generated a torque whose peak could be easily read by a moving- pointer fixed-scale display on the torque meter. The torque meter was clamped and held in a stable position, at about shoulder height, with a vice on a steel upright bolted to a wall. This arrangement permitted easy reorientation of the torque meter, and enabled the human subject to g grasp the cylinder while standing upright comfortably with the forearm in any of the three orientations. The confounding effects of different body postures were therefore eliminated.

Anthropometric variables were measured with the aid of a Pfister anthropological kit, using standard methods (NASA, 1978).

Procedure

For the torque measurements, subjects stood in front of the clamped torque meter, with the right arm extended, gripped the attached cylindrical handle and applied an MVC turn with the wrist. Only a slight contortion of the upper body was allowed for body balance and comfort. Greater contortions would have added the effects of upper body musculature and body weight to the wrist-turning torque. The left arm was held free at the side of the body.

To facilitate achieving the pronated and supinated forearm positions, the cylindrical handle (axis) was oriented horizontally; and for the neutral forearm position the handle was vertical.

Each subject performed 6 different wrist-turning contractions—a flexion and an extension type contraction with the forearm in 3 different orientations. The different trials were randomized. Before final measurements, each subject performed a few trial contractions to familiarize himself/herself with the apparatus and tests. Since experienced subjects were used, as mentioned earlier, the final data were assumed to be uncontaminated by learning effects.

For each sex, a 3×2×5 fully crossed factorial design was used to gather the data and analyze the results.

Data Analysis methods

Data were analyzed with the Statistical Analysis System (SAS) on an IBM 4381 mainframe computer. The data was assumed to come from a normally distributed parent population, and group means were compared by Analysis of Variance (ANOVA) followed by Duncan's Multiple Range test, where necessary. All tests were performed at the 5% level of significance. The male and female data were analyzed separately, since their large difference in torque magnitude (males were twice as strong as females) implied that they constituted two distinct subpopulations. A within subjects design was used for the data in each sex (Hays, 1987) so that the variability within subjects could be separated from the variability due to the other factors.

RESULTS AND DISCUSSION

Table 1 describes the size and hand strength characteristics of the 10 subjects. A comparison of height and body weight data with those from the U.S. Public Health Service (1965) indicated that, on the average, the females in this study were slightly taller but slightly lighter, and the males were significantly taller (181.5 cm vs. 173 cm) and heavier (85.4 kg vs 75 kg).

The weakest and strongest individual torques were 3.7 Nm and 9.3 Nm for females, and 7.5 Nm and 17.5 Nm for males, a ratio of 1:2.4. The weakest individual torques for both sexes were for flexion turns with the forearm in the neutral position. The strongest individual torques for both sexes occurred for extension, in two different forearm orientations—pronation and supination.

Table 1. Summary of anthropometric and simple hand strength measurements

	Female (n=5)		Male (n=5)	
Measurement	Mean	Standard Deviation	Mean	Standard Deviation
Age (Yr)	31.4	2.9	35.0	1.6
Stature (cm)	164.5	5.7	181.5	5.2
Body weight (kg)	60.0	4.5	85.4	9.9
Outer hand breadth (cm)	7.9	0.3	9.8	0.3
Handgrip (kg)	34.0	4.3	64.0	5.9
Lateral pinch (kg)	7.5	1.0	12.5	1.0
Chuck pinch (kg)	8.2	0.7	11.3	1.2
Pulp 2 pinch (kg)	6.7	1.7	9.9	2.0

The strongest mean torques (n=5) were 7.1 Nm for females and 14.9 Nm for males; and both were for extension type wrist motion (Table 2). For males it occurred with the forearm pronated, and for females it occurred with both the pronated and supinated forearm. The weakest mean torques (n=5) were 5.6 Nm for females and 11.1 Nm for males. They were all for the flexion wrist motion, but for females it was for the neutral forearm position, and for males it was for the supinated position.

ANOVA indicated that both forearm orientation and type of contraction had a significant effect on torque, for both females and males (Table 3). However there was no interaction effect between these two variables.

Duncan's Multiple Range test on the effects of arm orientation confirmed that for females, the neutral and supinated forearm mean strengths were not significantly different (6.4 and 6.1 Nm) but that both were significantly weaker than the pronated forearm strength (6.9 Nm); and for males, the pronated forearm strength (13.9 Nm) was stronger than the supinated one (12.6 Nm) but neither was different from the neutral one (12.9 Nm).

That the pronated forearm was able to generate the most powerful torques is an important finding in this study. The strength of the arm in different forearm orientations has been determined for other types of contraction—elbow flexion and elbow extension (Provins and Salter, 1955) and handgrip (Terrell and Purswell, 1976)—but the results were different. Provins and Salter (1955) found that, for elbow flexion, the supinated forearm was stronger than the neutral or pronated forearm; and that, for extension, the differences were small; and Terrell and Purswell (1976) found that the supinated forearm was the strongest for gripping, and the pronated forearm the weakest. The handgrip results of Terrell and Purswell is relevant to this study since MVC wrist-turning requires gripping a handle.

These comparisons provide further empirical evidence the specificity of muscular contraction; and that it could be misleading to draw generalizations based on limited studies of human strength characteristics.

ANOVA also indicated that extension motions generated stronger wrist-turning torques than flexion motions, by a ratio of 1.18:1 The extension-flexion ratio was practically the same for females and males (1.17:1 for females and 1.19:1 for males). This is consistent with the data of Asmussen and Heebol-Nielson (1961) which showed that extension torques were about 25% greater than flexion torques (for simple extension and flexion, not wrist turning).

The lack of significant interaction between type of wrist motion and forearm orientation indicates that the extension-flexion difference did not depend on forearm orientation. This relationship is not so clear from an examination of the magnitude of the differences in mean torques. For example, for females the extension-flexion ratio

Table 2. Mean wrist-turning MVC torque (Nm) for different forearm orientations and different directions of turn

	Female (n=5)		Male (n=5)	
	Turn Direction		Turn Direction	
	Flexion	Extension	Flexion	Extension
Forearm Orientation				
Pronated	6.6 (0.6)	7.1 (0.7)	13.0 (1.9)	14.9 (1.1)
Neutral	5.6 (0.7)	6.5 (0.7)	11.9 (1.5)	13.8 (0.9)
Supinated	5.7 (0.6)	7.1 (0.8)	11.1 (1.1)	14.0 (1.7)

The number in parentheses represents the standard error of the mean, and each mean was computed from 5 observations.

Table 3. Summary results of ANOVA for the effects of test variables on wrist-turning torque

	Female			Male		
	d.f.	F-ratio	p-value	d.f.	F-ratio	p-value
Variable						
**	4	56.3	0.0001	4	20.9	0.0003
O	2	13.9	0.003	2	10.8	0.119
C	1	25.0	0.008	1	37.6	0.027
O*C	2	2.0	0.202	2	1.7	0.722

*S=Subjects; O=forearm orientation; C=type of contraction (or direction of wrist motion); and O*C=interaction between O and C.

was 1.08, 1.16 and 1.25 for the pronated, neutral and supinated forearm, respectively; and for males, it was 1.15, 1.16 and 1.26, respectively. The supinated forearm seems to display a greater difference in extension-flexion strength than the other two orientations. However, the lack of significance was most likely due to the large variation among the individual values.

Correlation analysis was performed with the male and female data combined. There was fairly strong correlation between the 6 different wrist-turning strengths and 3 of the 4 simple hand strengths (pulp 2 excepted). Pearson product moment correlation coefficients

(r) ranged from 0.58–0.97 (p=0.08–0.0001), with 16 of the 18 p-values below 0.05. The lateral pinch seems to be more strongly correlated than either handgrip or chuck pinch. Body weight, stature and hand breadth were all positively and strongly correlated with the wrist turning strengths (r's ranged from 0.66–0.97; and p-values from 0.04–0.0001), Correlation coefficients for sex were negative, of course, and ranged from −0.79 to −0.91 (p-values=0.01–0.0004).

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CONCLUSIONS

The strength of the hand for turning depends not only on the direction of turn but also on the orientation of the forearm. Extension turns are stronger than flexion turns and the pronated forearm is stronger, but extension-flexion difference is not affected by forearm orientation. Differences in the mechanical advantage of these muscles and degree of stretching they wee subjected to when grasping objects seems to be the underlying biomechanical mechanisms. The effect of forearm orientation on the arm for wrist-turning is not the same as for other types of arm strength. Generalizations about the relative strength of the hand in various forearm orientations should therefore be task specific.

THE EFFECT OF DEVIATED WRIST POSTURE ON PINCH STRENGTH FOR FEMALES

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An experiment was performed to determine the effect of wrist posture on seven different pinch styles for fifteen females. Peak pinch strength measurements were recorded with the wrist in five postures. Results indicated that pinch strengths were significantly reduced ($p<0.001$) in the deviated wrist posture. Trends in pinch strength reduction of up to 37% were observed. These results emphasize the importance of considering wrist posture as one important factor in the design of industrial guidelines for acceptable operations involving pinch forces.

INTRODUCTION

Ordinary movements of the upper extremities such as reaching, gripping and twisting combined with chronic repetition in a forceful and awkward manner without rest or sufficient recovery time, are the main activities associated with the onset of cumulative trauma disorders (CTD). One of the major forms of CTD is carpal tunnel syndrome (CTS). CTS is generally attributed to compression of the median nerve within the wrist as it passes through the carpal canal (Armstrong and Chaffin, 1979). In many industries and workplaces, the hand is called upon to grasp and apply muscular power to manipulate objects. As a result of these actions, finger tendons inside the wrist become swollen and pressure is applied to the median nerve which can cause pain, numbness, and tingling in the hands; all of which are symptoms of CTS.

Fernandez et al. (1989) researched the effects of CTS on hand anthropometry, strength, and range-of-motion for a sample diagnosed with CTS and a matched control group. Results indicated that grip strength, tip pinch strength and range-of-motion of the wrist were significantly different between groups.

Imrhan and Loo (1989) conducted a study on the empirical relationships between different pinch styles across three age groups (children, adults, elderly), all of which could be classified as a student sample population. Analysis of three main types of pinch styles indicated that lateral and chuck pinch strength were significantly greater than the pulp pinches. Imrhan et al. (1989) also identified that pulp pinch strength decreased from the index and middle finger (pulp-2, 3) down to the ring and little finger (pulp-4, 5), and that all of these quantitative relationships were consistent regardless of age group and gender.

Imrhan (1991) performed another study which examined the effects of different wrist postures on maximum voluntary (MVC) pinch strength. Peak MVC forces of 30 male adults were measured for lateral, chuck, pulp-2 and pulp-3 pinches, each in five wrist positions—neutral, radial deviation, ulnar deviation, dorsiflexion and palmar flexion. The results showed that all the deviated wrist postures degraded pinch strength, with palmar flexion having the greatest effect and radial deviation the least. Pinch strength degradation ranged from 14% to 43%, depending on wrist position and type of pinch. The lateral pinch was less affected than the others.

Mathiowetz et al. (1985) established clinical norms on four tests of hand strength for a more diverse socioeconomic and occupational sample population. The tests included grip strength and tip, lateral and chuck pinch strengths. In this study the age of the adult sample ranged from 20 to 75+ years, therefore subjects were stratified into 12 age groups for both sexes. Whereas a high correlation was observed between grip strength and age, a low to moderate correlation between pinch strength and age was observed.

Differences in testing equipment, protocol and sample population probably influenced the pinch strength values for all of the above cited research, however the empirical relationships between the different pinch styles remain fairly stable and consistent.

Most of the previous research on pinch strength was performed with the wrist in the neutral posture, and subsequently guidelines are currently based on pinch strength in the neutral posture. However, through observation, individuals who utilize the pinch grip in the workplace, often do so with their wrists in deviated postures. Marley (1990) confirmed the hypothesis that deviated wrist posture had a significant effect on grip strength. Drawing a parallel from grip strength to pinch strength, Fernandez et al. (1991) conducted an experiment to document the effect of deviated wrist posture on pinch strength for males. Results from that study indicated that pinch strengths for males were significantly reduced ($p < 0.001$) in the deviated wrist posture, with a reduction up to 34%.

Due to the continued lack of normative data for pinch strength in deviated wrist postures for a female sample population, the objectives of this study were to determine the effect of deviated wrist postures on female pinch strength for various pinch styles and document the changes in pinch strength at deviated wrist postures.

METHOD

Subjects

Fifteen female university students volunteered to be subjects for this study. The subjects were first interviewed to make sure they had not overexerted their hands and/or wrists in the last two days and had no history of hand or wrist injuries. Next, Phalen’s test was administered to complete subject screening for symptoms of CTS. If the subject felt any cramping, pain, numbness or tingling sensations, the test was considered positive (Graham, 1983).

Apparatus

The equipment used in this study included a Jamar hydraulic handgrip dynamometer, ENG pinch strength gauge, Jamar goniometer and anthropometric instruments (Sieber Hegner & Co., Inc.).

Procedure

Standard anthropometric measurements of the subject’s dominant hand and wrist were collected. These measurements included: hand length (wrist crease to the distal end of the third finger), breadth at metacarpal, breadth at thumb, thickness at metacarpal, circumference at wrist, breadth at wrist and thickness at wrist. Range-of-motion of the wrist, in terms of maximum flexion and extension in the transverse plane, was also recorded with the use of a goniometer. For pinch strength, three most common pinch strength measurement procedures were used. Imrhan and Loo (1989) describe the pinch strength procedures as follows:

1. Pulp pinch—taken for each finger, separately in opposition to the thumb. The lips of the pinch gauge were squeezed by the thumb and the specified fingers.
2. Chuck pinch—the pinch gauge was squeezed with the thumb on the lower lip with the index and middle fingers on the upper lip.
3. Lateral pinch (or key pinch)—the pinch gauge was squeezed with the pulp of the thumb on the lower lip and the lateral aspect of the index finger on the upper lip.

According to the Caldwell Regimen, each subject was asked to slowly build up to her maximum exertion force and then sustain that force for four seconds (these were all maximum voluntary contractions). Adequate rest was afforded between combinations, and two or more trials were administered to limit variance to 10%. Protocol for the pulp pinch mandated that the subject exert her maximal force on the pinch gauge with the remaining fingers extended. The fingers utilized in each variation of the pulp pinch are as follows: index (pulp-2), middle (pulp-3), ring (pulp-4) and little (pulp-5) finger as each opposes the thumb. The other pinch protocols, namely index pulp pinch (tip), chuck pinch and lateral pinch, mandated that the remaining fingers be flexed during the pinch motion. The handgrip strength measurement was collected with the wrist in the neutral posture, while the pinch strength measurements were collected with the wrist in the neutral posture (N), 1/2 of maximum extension (1/2 ME), 1/2 of maximum flexion (1/2 MF), maximum extension (ME) and maximum flexion (MF). All of these strength tests were administered while the subject sat upright in a chair with her feet resting on the floor. A mid-pronated/supinated arm position was maintained while the elbow was abducted and held at 90 degrees flexion.

Experimental design

A complete randomized block design with subjects as blocks was utilized for this study. The data analysis for this experiment was performed using the SAS statistical package on the IBM 3081 mainframe computer.

RESULTS

The descriptive statistics for the fifteen female subjects are provided in Table 1. Hand grip strength for the current study was compared to Rodgers (1986) and range of motion of the wrist was compared to Bonebrake et al. (1990). No significant differences in these variables were revealed for the similar student populations.

Table 1. Subjects Descriptive Statistics (n=15).

Measure	Mean (STD)
Age (years)	21.5 (2.8)
Hand length (mm)	172.0 (9.2)
Breadth at metacarpal (mm)	76.1 (5.6)
Breadth at thumb (mm)	89.7 (6.0)
Thickness at metacarpal (mm)	27.7 (3.1)
Circumference at wrist (mm)	150.3 (7.0)
Breadth at wrist (mm)	51.1 (4.4)
Thickness at wrist (mm)	38.0 (5.4)
Maximum flexion (degrees)	86.7 (7.3)
Maximum extension (degrees)	69.6 (14.7)
Handgrip strength (kg)	24.1 (4.1)

Table 2 presents the summary data of pinch strength for seven different pinch styles in five different wrist postures. Figures 1 to 7 graphically present the peak pinch strength values for each of the seven pinch styles. Univariate analysis was performed on the data and the results indicated that the data was normally distributed. ANOVA was next performed for all of the pinch styles with wrist posture and wrist style as factors. Results indicated that wrist posture factor was significant ($p < 0.001$) and consistent for all the pinch styles except for pulp-3, 4 and 5. For the four pinch styles that were significant, Duncan's multiple range tests were subsequently performed at alpha level=0.05. Results from this test for the posture factor revealed that as the wrist angle increased from the neutral posture to maximum extension or maximum flexion, the pinch strength significantly decreased.

The results of ANOVA with pinch style as a factor revealed that pinch style factor was significant ($p<0.001$) and consistent for all wrist postures. This corresponds with the findings of Imrhan et al. (1989). The interactions were found to be significant ($p<0.05$) for the pulp-3, 4 and 5 pinches. The existence of the interactions may be attributed to low usage and non-training of the digit 3, 4, and 5 fingers.

Table 2. Summary of Peak Pinch Strengths in Kilograms for Females, Mean (STD).

Pinch Style	Neutral	1/2 ME	1/2 MF	ME	MF
Pulp-2	4.21 (0.68)	4.01 (0.77)	3.57 (0.62)	3.29 (0.66)	2.79 (0.63)
Pulp-3	3.97 (1.16)	3.83 (0.89)	3.46 (1.01)	3.29 (0.77)	3.00 (1.13)
Pulp-4	2.70 (0.82)	2.43 (0.69)	2.25 (0.66)	2.25 (0.46)	2.17 (0.52)
Pulp-5	1.85 (0.43)	1.73 (0.42)	1.65 (0.42)	1.63 (0.43)	1.54 (0.35)
Tip	4.78 (0.65)	4.74 (0.54)	4.42 (0.51)	3.77 (1.02)	3.67 (0.70)
Lateral	6.39 (0.65)	6.09 (0.82)	5.83 (1.12)	5.69 (1.01)	4.97 (0.93)
Chuck	6.35 (1.11)	6.27 (1.19)	5.32 (0.97)	4.97 (0.79)	3.99 (0.92)

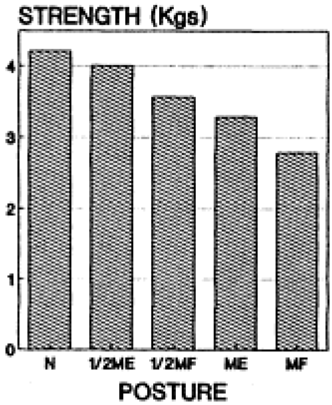

Figure 1. Pulp-2 pinch strength.

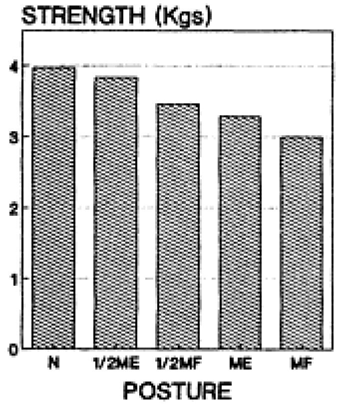

Figure 2. Pulp-3 pinch strength.

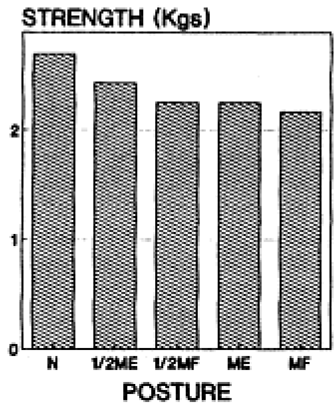

Figure 3. Pulp-4 pinch strength.

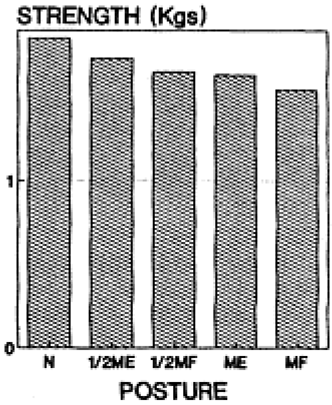

Figure 4. Pulp-5 pinch strength.

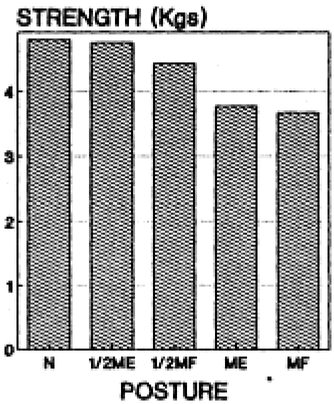

Figure 5. Tip pinch strength.

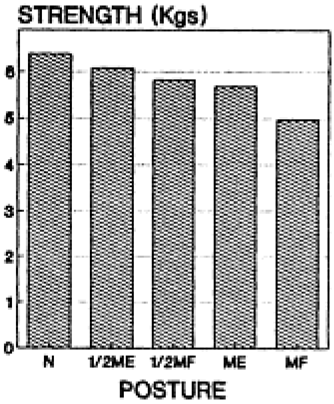

Figure 6. Lateral pinch strength.

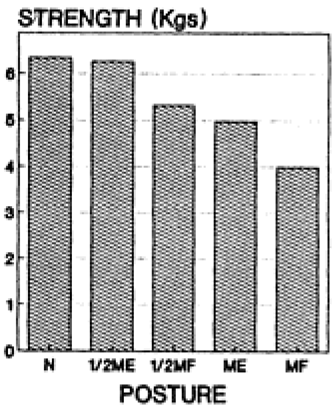

Figure 7. Chuck pinch strength.

Results from the current study were then compared to results from previous studies using a t-test statistic. Table 3 depicts the summary of comparisons. Differences in pinch strength between the current study and Mathiowetz et al. (1985) could be attributed to differences in the pinch gauges used and the sample populations tested. While the current study and Imrhan et al. (1989) both utilized a student population and screened for debilitating hand injuries, differences between these two studies may be attributed to the strength testing equipment.

Table 4 shows a summary of the percentage decreases in pinch strength at deviated wrist postures as compared to the neutral posture. The percentage decreases were 1% to 10% for 1/2 ME, 8% to 17% for 1/2 MF, 11% to 22% for ME and 20% to 37% for MF. The smallest decrease was in the 1/2 ME posture, and the largest decrease was in the MF posture. This closely agrees with the findings of Fernandez et al. 1991. For all of the pinch styles, wrist flexion caused the largest decrease in pinch strength compared to the other wrist postures.

Table 3. Comparison of Female Pinch Strength with Different Studies. (wrist in the neutral posture) (Mean (STD))

Pinch Style	Current (n=15)	Mathiowetz et al. (1985) (n=26)	Imrhan et al. (1989) (n=30)
Pulp-2	4.21 (0.68)	–	4.7 (0.17)*
Tip	4.78 (0.65)	5.03 (0.95)	–
Lateral	6.39 (0.65)	7.98 (0.91)*	6.5 (0.17)
Chuck	6.35 (1.11)	7.80 (1.04)*	7.0 (0.23)*

* represents significant difference from current study (alpha=0.05)

Table 4. Percent Decreases in Pinch Strength in Deviated Wrist Postures (compared to neutral posture).

Pinch Style	1/2 ME	1/2 MF	ME	MF
	(%)	(%)	(%)	(%)
Pulp-2	5	15	22	33
Pulp-3	4	13	17	24
Pulp-4	10	17	17	20
Pulp-5	6	11	12	17
Tip	1	8	21	23
Lateral	5	9	11	22
Chuck	1	16	22	37
average	5	13	17	25

Female hand strengths as a percentage of males were also calculated from the male values found in Fernandez et al. (1991). The current study revealed that female pinch strength as a percentage of males ranged from 60% to 91%, with an average pinch strength of 75% of males. Female handgrip strength as a percentage of male handgrip strength was slightly lower then 52%. These both correspond to the findings of Roebuck, Kroemer and Thompson (1975), and Chaffin and Andersson (1991), respectively.

DISCUSSION

Hand intensive operations such as hand sewing, working plastics and insulation, and fine dexterity work such as precision gripping small tools or probes, or holding small parts in lieu of a holding fixture, often incorporate deviated wrist postures with excessive pinch forces over extended time durations. Results from the current study reveal that operations which demand deviated wrist postures, can also expect a correlated significant reduction in pinch force. Strength related literature often suggests certain percentages of maximum strength to be "safe", therefore for females working at deviated wrist postures these "safe" pinch strengths may be reduced by up to 37%. With this in mind, the risk of CTD could differ for a particular pinch style and deviated wrist posture. These results and the superior strength values documented for composite pinch styles (lateral and chuck) should be considered by designers of hand tools and workstations.

CONCLUSIONS

The results of this experiment reveal that as the wrist posture deviated from neutral to flexion or extension, pinch strength decreased by up to 37%. Flexed wrist posture also revealed a larger decrease in pinch strength as compared to extension of similar magnitude. Pinch strength guidelines for both males and females need to be modified in order to possibly decrease the risk of CTD in the upper extremities.

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THE EFFECTS OF WRIST POSITION/GLOVE TYPE ON PEAK LATERAL PINCH FORCE

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Industries experience high incidence rates of cumulative trauma disorders including tendinitis, tenosynovitis, and carpal tunnel syndrome which may be largely attributable to repetitive high forces in awkward wrist positions. Thus, a study was performed to examine the impact of gloves and wrist position on physical activities when maximal voluntary power "lateral pinch" forces were applied under isometric conditions. Gloves are widely used in industries for protection against cuts, abrasions, and dermatitis—the leading industrial skin disease. The effects of wrist position, gender, dominant/non-dominant hand, and glove type on the dependent measure of lateral pinch force were measured. A B&L® pinch gauge was used to monitor applied peak forces. Six glove types were used: bare hand, thermal, knit, reinforced knit, a layered combination of thermal and knit, and a layered combination of thermal and reinforced knit. The five wrist positions employed were: 65° extension, 45° extension; neutral, 45° flexion, and 65° flexion. Twelve (six males, six females) voluntary subjects (20–25 years of age) were selected. The subjects were instructed to build up to a maximum voluntary contraction according to the Caldwell regimen. Each subject held the MVC level for three seconds. An ANOVA was conducted using peak lateral pinch force exertion as the dependent variable and glove type, wrist position, hand, and gender as the independent variables. Significant effects were determined to be wrist position and gender. Post-hoc analyses were performed. The study confirms strength decrement associated with awkward wrist postures when peak lateral pinch forces are applied, as is the case in

industry. Extreme wrist postures should therefore be avoided under such conditions.

INTRODUCTION

Cumulative trauma disorders (CTD's) such as carpal tunnel syndrome and tenosynovitis frequently occur in industry when the wrist is repeatedly positioned in awkward postures (Tanaka and McGlothlin, 1989). Forceful hand movements and deviated posture of the wrist joint have been suggested as risk factors (Birkbeck and Beer, 1975; Armstrong, Fine, Goldstein, Lifshitz, and Silverstein, 1987). Flexion at the wrist reduces the carpal tunnel size and the tension applied to the flexor tendons during wrist flexion considerably elevates pressure in the carpal tunnel (Smith, Sonstegard, and Anderson, 1977). This phenomenon is applicable to extension, flexion, radial or ulnar deviation of the wrist (Tanaka and McGlothlin, 1989). If the wrist has not rested before resumption of the task, or if the hand movement is continued despite discomfort or pain, the tendons will eventually swell and create pressure on the median nerve causing further pain and numbness (Drury, Begbie, Ulate, and Deeb, 1985). Despite their frequent occurrence, CTD's remain somewhat obscure in terms of the combination of factors that are responsible for their development. A reasonable hypothesis is that a tool and/or task design that requires less pinch force effort and a neutral wrist position will be less likely to induce CTD's. This study was conducted to determine peak lateral pinch force magnitude differences for six glove types in five wrist postures for both hands. Male and female subjects of the same age group were selected since age was not found to be a significant factor in similar work at the University of Nebraska (Hallbeck and McMullin, 1991a; Hallbeck and McMullin, 1991b; McMullin and Hallbeck, 1991).

REVIEW OF THE LITERATURE

Wrist Position

The neutral wrist position has been shown to allow the highest pinch force exertion (Anderson, 1965; Kraft and Detels, 1972). Pinch strength in wrist extension (up to 30 degrees) has not been found to differ significantly from that in a neutral posture (Anderson, 1965; Kraft and Detels, 1972). Flexion of 15°, however, significantly reduced pinch strength (Kraft and Detels, 1972). This concurs with the power grasp strength data where any wrist deviation from neutral decreases the external force, with flexion causing a larger decrement than extension (Anderson, 1965; McMullin and Hallbeck, 1991; Kraft and Detels, 1972; Pryce, 1980; Putz-Anderson, 1988; Terrell and Purswell, 1976).

Hand

The non-dominant hand has been found to exert less pinch force than the dominant hand and this decrement can be as severe as 30% (Anderson, 1965). On average, the non-dominant hand can exert 91–94% as much pinch force as the dominant hand (Anderson, 1965; Kellor, Frost, Silberberg, Iverson, and Cummings, 1971), 94% (Hallbeck and McMullin, 1991), 95% (Swanson and Goran-Hagert, 1987), and 97.5% (Mathiowetz et al., 1985a).

Glove Type

The only literature found on the effect of gloves on pinch strength was a study by Hallbeck and McMullin (1991a; 1991b). They reported that the peak pinch force generated was not effected by the use of gloves. This contradicts the power grasp strength findings of Cochran, Albin, Bishu, and Riley (1986), Sudhakar, Schoenmarklin, Lavender, and Marras (1988), and McMullin and Hallbeck (1991).

Gender

Human skeletal muscle can generate approximately 3–4 kg of force per square centimeter of cross-sectioned muscle. However, males contain a greater amount of muscle area than females, thus enabling males to generate a greater amount of force (McArdle and Katch, 1986). The pinch strength that females can exert has been reported as 50% (McArdle et al., 1986), 60–63% (Kellor et al., 1971), 65% (Swanson et al., 1987), 67% (Grandjean, 1982; Mathiowetz et al., 1971), 70% (Berg, Clay, Fathallah, and Higginbotham, 1988), 74% (An, Chao, and Askew, 1983), and 78% (Hallbeck and McMullin, 1991) that of males.

Summary

The following findings are expected based upon a review of the literature of lateral pinch force exertion:

1) As the wrist posture deviates from neutral, strength decreases with a larger decrement in flexion than extension.
2) The non-dominant hand will be in the range of 91–98% as strong as the non-dominant hand.
3) If the glove type effect proves to be significant, the bare-handed condition will allow the greatest strength with a strength decrement as more glove interference is encountered.
4) Female strength is expected to be 50–78% that of male strength.

METHOD

Subjects

Twelve subjects (six females and six males) voluntarily participated in the study. The subjects' age ranged between 20–25 years. All subjects indicated that they were in good health, had no joint afflictions, and experienced no previous wrist injuries.

Apparatus

A B&L® pinch gauge was used to test peak lateral pinch force. The B&L® has the highest accuracy of all commercially available pinch gauges at ±1% (Mathiowetz, Weber, Volland, and Kashman, 1984). Three glove types were used: a 100% cotton inspection glove (thermal protection), a Polar Bear® Plus (Spectra® Knit glove), and a Polar Bear® Supreme (three-strand steel reinforced knit glove). A goniometer was employed to measure wrist position.

Procedure

Pinch force has been shown to differ among arm, elbow, and wrist positions (Mathiowetz, Rennells, and Donahoe, 1985b; Woody and Mathiowetz, 1988); thus a standardized body posture was employed (standing with a relaxed adducted shoulder and a 90° elbow angle) for all trials. The sequence of trials between subjects was randomized. After putting on the gloves and placing their wrist in the appropriate position, the subjects were instructed to build up to their maximum voluntary contraction (MVC) using the Caldwell regimen (1974) as modified for pinch (Berg et al., 1988). Following this regimen, each subject held the MVC (lateral pinch exertion) for 4 seconds. The peak MVC exerted was recorded. This procedure was repeated with a different glove-wrist position combination with the opposite hand. The subject alternated between hands until all combinations were completed on both hands. Strength has been shown to vary ±10% from one day to the other; thus, all exertions were performed in one session. Since more than 2 minutes of set-up time elapsed between trials, no additional time was allotted for fatigue recovery unless so desired by the subject.

Experimental Design

This study evaluated the effects of glove type, wrist position, hand, and gender on peak lateral pinch force exertion. Glove type had six levels: bare hand, thermal, knit, reinforced knit, a combination of thermal and knit, and a combination of thermal and reinforced knit. The wrist position variable parallels the positions described by Putz-Anderson (1988): neutral, 45° extension, 45° flexion, and 65° flexion, in addition to 65° extension. The order of gloves within the experiment was randomized for each subject as was wrist position. Subjects were nested within gender and served as the block. The two levels within the hand variable referred to dominant or non-dominant. The resultant design was a 6 (glove) by 5 (wrist position) by 2 (hand) by 2 (gender) mixed factor model.

RESULTS

An ANOVA was conducted using peak lateral pinch force exertion as the dependent variable and glove type, wrist position, hand, and gender as the independent variables. The ANOVA is summarized in Table 1. Significant effects were found to be wrist position (p=.0001) and gender (p=.045). Post-hoc tests were conducted on the significant main effects of wrist position (Table 2) and gender (Table 3).

Table 1.

ANOVA Summary Table for Peak Lateral Pinch Strength

SOURCE	DF	Sum of Squares	F-Value	P
Gender (G)	1	2501.33	5.24	.0450
Subject (S)	10	4771.56	–	–
Glove (GL)	5	50.99	1.82	.1252
GLxS(G)	50	279.67	–	–
GxGL	5	72.59	2.60	.0366
Wrist Position (WP)	4	1167.33	17.82	.0001
S(G)xWP	40	654.94	–	–
GxWP	4	87.90	1.34	.2712
GLxWP	20	96.44	1.07	.3870
S(G)xGLxWP	200	903.83	–	–
GxGLxWP	20	71.56	.79	.7219
Hand (H)	1	28.01	2.17	.1719
HxS(G)	10	129.35	–	–
HxG	1	4.36	.34	.5746
HxGL	5	5.43	.41	.8402
HxS(G)xGL	50	132.65	–	–
HxGxGL	5	11.71	.88	.4996
HxWP	4	1.20	.06	.99
HxS(G)xWP	40	202.54	–	–
HxGxWP	4	15.71	.78	.55
HxGLxWP	20	37.59	.88	.6179
HxS(G)xGLxWP	200	429.21	–	–
HxGxGLxWP	20	36.74	.86	.6429
Total, Corrected	719	11692.66		

Table 2

Post-Hoc (Tukey) Test for Wrist Position

Grouping	Mean Pinch (Kg)	Wrist Position	Percentage of Neutral
	8.2	Neutral	100.0%
	7.6	45° Extension	93.3%
	7.2	45° Flexion	88.8%
	7.0	65° Extension	85.7%
	6.4	65° Flexion	79.0%

Table 3

Post-hoc Analysis of Lateral Pinch by Gender

Grouping	Gender	Mean Pinch (Kg)	Percentage of Male
[redacted]	Male	8.1	100%
[redacted]	Female	6.4	79%

Table 4

Comparison of Mean Lateral Pinch Force (Kg) for Bare-Handed Males and Females in the Neutral Position

	Male Hand		Female Hand	
Author	Dominant	Non-Dominant	Dominant	Non-Dominant
Swanson et al., 1987	7.5	7.1	4.9	4.7
An et al., 1986	11.1	–	7.7	–
Mathiowetz et al., 1985a	11.1	10.7	7.3	6.9
Mathiowetz et al., 1985b	–	–	7.7	7.2
Kamal et al., 1992	9.1	9.0	7.5	7.1

DISCUSSION

Based upon a review of the literature, significant main effects were expected to be wrist position, hand, glove type, and gender. Only wrist position and gender were found to be significant in this study.

Wrist Position

As the wrist position deviated from neutral, the lateral pinch strength was expected to decrease, with a larger decrement in flexion than extension. This effect was found to be the case in this study as shown in Table 2. The percentage of neutral force exertion that these positions allowed is comparable to that reported by Hallbeck and McMullin (1991).

Gender

Females tested in this study were 79% as strong as the males. Since females were expected to be 50–78% as strong as the males on average, the females in this study had higher lateral pinch forces while the males had lower lateral pinch forces than was expected compared to the levels of exertion measured by An et al. (1983) and Mathiowetz et al. (1985a).

Glove Type

The findings in this study correspond with the results of Hallbeck and McMullin (1991a; 1991b), who found no glove effect for three-jaw chuck pinch.

Hand

The non-dominant hand was found to be 97% as strong as the dominant hand and was not a significant effect. This compared well with 96% reported by Mathiowetz et al. (1985a) and 95% by Swanson et al. (1987) for lateral pinch exertion.

CONCLUSION

The results of this study demonstrates that non-neutral wrist postures severely inhibit peak lateral pinch force exertion. A reasonable assumption is that a tool and/or task design that requires less lateral pinch muscle effort will be less likely to contribute to cumulative trauma disorders. Thus, wherever possible, extreme wrist postures should be avoided.

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THE EFFECT OF ARM POSITION ON PINCH STRENGTH MEASUREMENTS: A PILOT STUDY

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High pinch forces in awkward arm and hand positions are commonly required in industry. A study was performed to quantify the effect of arm position at the shoulder on the static three-jaw chuck pinch force. Three-jaw chuck pinch strength measurements were taken at eight different arm positions ranging from 90 degree flexion to 45 degree extension and 0 through 180 degree abduction. Ten males and ten females between the ages of 20 and 24 voluntarily participated in the experiment. Using the Caldwell Regimen standardized procedure, the subjects were informed to perform a maximum voluntary contraction. The peak static three-jaw chuck pinch data was obtained using a B&L® pinch gauge. An analysis of variance was performed and indicated that a significant difference in pinch strength does exist between genders and a slight significant difference exists between arm positions but no interaction effects were present. A Tukey's comparison test verified that only two of the arm positions differed significantly suggesting that the arm positions evaluated do not greatly influence maximal static pinch strength measurements.

INTRODUCTION

The importance of proper f functioning of the arm and hand in combination with the rest of the body should not be neglected. The arm and hand are a very useful mechanism of the human body. They are a means of grasping, carrying, and expressing various movements, and a means of applying force. Therefore, studies evaluating arm and hand strengths are becoming more popular in determining their effectiveness in the work place.

Some of the previous studies conducted include the examination of the effect of forearm position (Woody and Mathiowetz, 1988) and elbow position (Mathiowetz et al., 1985) on pinch and grip strength. It was found that forearm position significantly effected key pinch strength, and measurements were higher when the forearm was in the neutral position than when fully pronated. In addition, elbow position clearly affected grip and key pinch strength in the right hand of subjects. Mathiowetz et al. (1985) supported a 90 degree flexion of the elbow over full extension.

Kraft and Detels (1972) studied the functional position of the wrist on the strength of pinch and grasp and the time required to complete standardized tasks. This study found that no significant differences existed with regard to pinch and grip strength in neutral, 15 degree, and 30 degree extension of the wrist.

A majority of the studies to date evaluate the effects of elbow, forearm, wrist, and body position on pinch strength. No one has conducted a study involving a 180 degree included elbow angle at different arm/shoulder positions. In many current working environments, it is necessary for the worker to extend their arm and perform a task that involves pinching. In such an environment, it is important to understand the relationship between the position of the arm and the strength of the pinching task. The purpose of this study is to determine the effect of arm position, with elbow at an 180 degree included angle, on the three-jaw chuck pinch strength.

METHOD

Subjects

Twenty subjects (10 males and 10 females) voluntarily participated in this study. Their ages ranged from 21 to 24 years old and all were right-handed. They were verbally informed of the test's purpose and procedure, and the possible negative effects (e.g., muscle strain, discomfort and fatigue).

Equipment

A B&L® Pinch Gauge with a maximum of 14 kilograms was used for measuring the three-jaw chuck pinch strength and was read to the nearest 0.25 kilogram.

Procedure

Subjects were evaluated at different times and locations. The subjects were tested in groups ranging from one to five and each subject completed the experiment during the testing period, which lasted approximately one hour. The subjects were instructed to stand erect with feet together, fix the arm at a 180 degree included elbow angle, keep the hand pronated, and extend the wrist to its maximum point. This position was demonstrated.

Each subject was required to perform a maximum voluntary contraction (MVC) using a three-jaw chuck pinch in eight different arm positions which were predetermined and standardized for all subjects. Figure 1 shows the spatial arrangement and description of each arm position. The subjects performed a MVC at each position in numeric order, one through eight, then repeated this sequence for a total of three trials in each position. The strength testing procedure was based on the Caldwell Regimen (Caldwell et al., 1974). A subject was asked to build up to a maximum exertion in one second and maintain this effort for four seconds. The measurement was read and recorded. In between each MVC, the subject rested for at least two minutes to reduce the influence of fatigue.

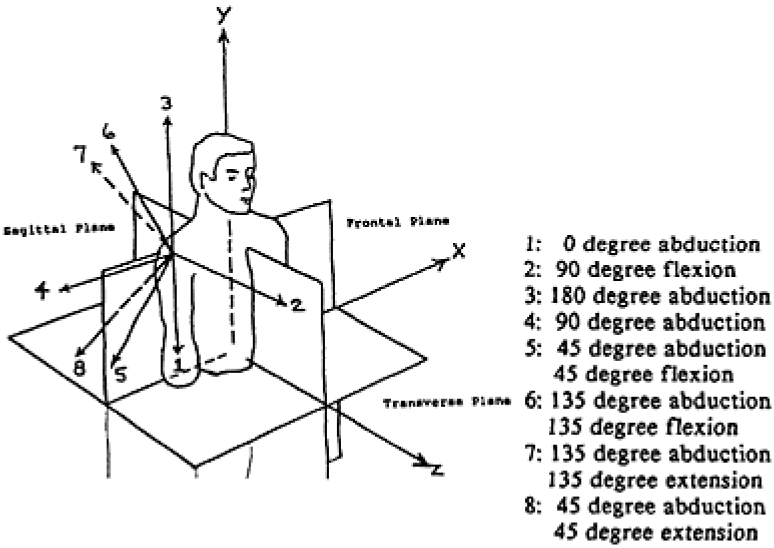

Figure 1. Spatial Arrangement of Arm Positions

RESULTS

The three trials at each arm position were averaged for each subject. The data was entered in SAS and an analysis of variance (ANOVA) was performed with MVC as the dependent variable using the independent variables of gender and position. The resultant design was a 2 (gender) X 8 (arm position) mixed factor model with 10 subjects nested within each gender as the blocking factor. The ANOVA results are summarized in Table 1.

Table 1. ANOVA Summary Table

SOURCE	df	SUM OF SQUARES	F-VALUE	P
Gender	1	116.76	9.57	0.0063*
Subjects (Gender)	18	219.50	–	–
Position	7	2.82	2.19	0.0394*
Gender*Position	7	0.99	0.77	0.6099

Position* Subject (Gender)	126	23.15	–	–
* significance at the 0.05 level				

Since no interaction effects were concluded and there was a significant difference between genders and between positions, a Tukey's comparison test was performed to examine the nature of the differences for the significant main effects (Table 2 and Table 3). In Table 2, the minimum significance difference is exceeded between male and female averaged MVC measurements. The only significant difference observed in Table 3 exists between position 3, 180 degree abduction, and position 8, 45 degree abduction and 45 degree extension, with a mean difference of 0.4200. Since the minimum required difference is 0.4179, the difference is not substantial.

Table 2. Tukey's Post Hoc Analysis of Gender

GENDER	GROUPING	MEAN (kg)
Male	|	9.70
Female	|	7.99

Table 3. Tukey's Post Hoc Analysis of Arm Position

ARM POSITION	GROUPING	MEAN (kg)
180 degree abduction	|	9.05
90 degree flexion	| |	8.94
135 degree abduction 135 degree flexion	| |	8.92
0 degree abduction	| |	8.91
135 degree abduction 135 degree extension	| |	8.83
90 degree abduction	| |	8.82
45 degree abduction 45 degree flexion	| |	8.66
45 degree abduction 45 degree extension	| |	8.63

CONCLUSIONS

The statistical analysis of the data indicates that arm position is not very signif icant in effecting an individual's MVC. The only suggestion is to avoid placing a pinch task in the area of 45 degree extension with 90 degree or less abduction since this resulted in the lowest mean strength value. This research study is difficult to correlate to previous studies. The research and literature are limited and involve other position considerations such as elbow and wrist. Only the three-jaw chuck pinch was analyzed, and the results may be different for other types of pinch.

It is recommended that further research be conducted involving a combination of the wrist, elbow and arm positions and various types of pinch. In particular, an analysis of an actual work station in an industrial situation should be considered. The results obtained from an actual arrangement would be more applicable.

Several factors should be mentioned that possibly influenced the subjects' performance. The subjects were tested at different times of the day and in different environments such as a classroom or an individual's homes. Since the subjects were tested in groups, subjects were spectators and noise and conversation were permitted at a minimum level. Competition and goal setting were discouraged, but the research conductors were not fully in control over a subject's behavior. It is strongly suggested that testing occur in a more controlled and standard environment.

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WRIST FATIGUE IN PRONATION AND SUPINATION FOR DYNAMIC FLEXION AND EXTENSION: A PILOT STUDY

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Cumulative trauma disorders (CTDs) encompass a wide range of musculoskeletal disorders and are the results of repeated microtrauma. High repetition, insufficient rest, awkward posture and high force are some of the risk factors which contribute to the development of CTD in the wrist. Previous research by Bishu, Manjunath, and Hallbeck (1990) and Sheeley, Hallbeck, and Bishu (1991) strove to relate endurance in a dynamic task to load and pace. These studies were done in a standardized body and arm posture with the hand either pronated (Bishu et al., 1990) or supinated (Sheeley et al., 1991). Since it is known that the mechanical advantage of the muscles varies with posture, this pilot study was performed to assess the effect of full pronation and full supination on endurance time. Four male subjects between 20 and 25 years of age participated in this study. Each subject his wrist between full wrist flexion to full wrist extension and back until fatigue. This task was performed at two paces (20 and 60 cycles per minute) for each of three loads (4, 6, and 10 lbs), using both the dominant and non-dominant hands, with the hand supinated and pronated. A non-parametric analysis of variance procedure was employed to determine that load, pace, and forearm position (pronation or supination) were the significant main effects upon endurance time.

INTRODUCTION

Many industries today have very high incidence rates for cumulative trauma disorders (CTD). Several factors are known to contribute to the onset of CTDs including the application of high prehension forces. A reasonable inference is that a tool and/or task design that requires less muscular effort will be less likely to lead to the development of a CTD.

Wrist, arm, and whole-body posture affect the magnitude of force exerted. The angles at which the extrinsic digital flexors approach the digits change with wrist position (Brand, 1985; Bunnell, 1944). When the angle at which muscles act during maximal voluntary exertion differs, the capacity to generate force varies (Brand, 1985; Bunnell, 1944; Hazelton, Smidt, Flatt, and Stephens, 1975). The capacity of the musculotendinous units to generate force is dependent in part upon the effective functional length (Hazelton et al., 1975). Many muscles act as flexors and extensors of the hand and wrist. All these muscles, except the extensor carpi ulnaris (ECU), which cross the wrist move with the radius as it moves around the ulna into pronation or supination (Brand, 1985). The ECU is an effective wrist extensor only in supination and may not be an extensor at all when the forearm is pronated (Brand, 1985). Studies by Mathiowetz, Rennells, and Donahoe (1985b) and Woody and Mathiowetz (1988) have demonstrated that elbow and forearm postures significantly affect pinch and grasp exertion levels and these, in turn, may affect the endurance time.

The findings of studies by Jorgensen, Riley, Cochran, and Bishu (1989) and Hallbeck, Stonecipher, Cochran, Riley, and Bishu (1990) indicated that the direction of power grasp force relative to the hand also appears have a significant effect on the magnitude of the force exerted. The force for an isoinertial task with the hand pronated depends on the intrinsic and extrinsic extensors, while in supination the major force is borne by the intrinsic and extrinsic flexors. When predicting maximal force generation based upon the tension fraction (Brand, 1985) or the physiological cross-sectional area (Chao, An, Cooney, and Linscheid, 1989) the flexor group would be expected to be stronger than the extensor group. Thus, it is expected that a given weight with the hand supinated will represent a smaller percentage of the maximal exertion than when the hand is pronated and this may increase resistance to fatigue (endurance time) in supination as compared to pronation.

Anderson (1965) reported that the dominant hand can be up to 30% stronger than the non-dominant hand. Results from separate studies on grip strength show that on the average the non-dominant hand has about 85–95% of the strength of the dominant hand (Anderson, 1965; Kellor, Frost, Silberberg, Iverson, and Cummings, 1971; Mathiowetz, Kashman, Volland, Weber, Dowe, and Rogers, 1985a). Therefore, one would expect the endurance time of the non-dominant hand to be significantly less than that of the dominant hand.

In a study by Sheeley et al. (1991) increase in pace was found to lead to a significant increase in the rate of fatigue in supination. Sheeley et al. (1991) and Bishu et al. (1990) also found that increased load significantly decreased endurance time in supination and pronation, respectively.

In summary, based upon past research, it is expected that load, pace, hand, and forearm/hand posture will significantly affect endurance time. Therefore, a pilot study was performed to investigate these main effects.

METHOD

Subjects

Four male subjects between 20 and 25 years of age volunteered for this study. All subjects stated that they had never been diagnosed with any form of CTD, had broken bones nor had surgery in either hand or wrist.

Apparatus

Three chrome barbells weighing 4, 6, and 10 pounds (lbs) were constructed from identical barbells by milling material from the interior of the 10 lb barbell for the 4 and 6 lb barbells. The identical barbell appearance helped reduce the motivational and perceptual effects of barbell size. The two paces at which the flexion/extension cycle were performed were established using an electric metronome.

Procedure

After informed consent was obtained, each subject had his grip strength measured for each hand using a (Jamar) hand dynamometer. This static exertion, following the Caldwell et al. (1972) regimen, was termed his maximum voluntary contraction (MVC). Then anthropometric data was recorded for extended arm length, forearm length, and hand length for both arms.

For experimental data collection, subjects had the arm to be tested resting on a level surface. The hand was fully supinated or pronated, there was a 90 degree included elbow angle, and the shoulder was relaxed in an adducted position. The subject was then given one of the three weights (randomly assigned) and instructed to fully flex and extend their wrist at one of the two task paces (randomly assigned). The subject was asked to continue the wrist motion of full flexion to full extension and back until they reached fatigue. Fatigue level was defined to be the point when the subject could no longer lift the weight or maintain the established pace, whichever came first. The time to fatigue was measured with a stopwatch and began with the first cycle and ended when fatigue was reached.

Each subject then performed the same protocol for the left arm, with a new randomly assigned weight and pace. After both arms had been fatigued and data collected, the subject was dismissed until the following day. This was repeated ten more times for each subject, until both supination and pronation were tested with three weights and two paces on each arm for every subject.

Experimental Design

The independent variables of forearm/hand posture (supination or pronation), load (4, 6, and 10 lbs), hand (dominant or non-dominant), pace (20 and 60 cycles per minute) were assessed for their effect upon the dependent variable time to fatigue. The resultant was a 2 (Posture)×2 (Pace)×3 (Load)×2 (Hand)×4 (Subject) design with blocking on subjects.

RESULTS

A non-parametric analysis of variance (ANOVA) was performed for the dependent variable of time to fatigue using SAS. The significant main effects were forearm/hand posture ($p=0.04$), pace ($p=0.0038$), and load ($p=0.0001$). The mean time to fatigue with a supinated hand was 608.6 seconds, significantly higher that the mean time to fatigue for pronation which was 254.5 seconds. Slower pace (20 cycles per minute) yielded a mean time to fatigue of 678.3 seconds, significantly higher that the faster pace (60 cycles per minute) which had a mean time to fatigue of 184.8 seconds. The 4 lb load had a significantly longer mean time to fatigue (929.6 seconds) than both the 6 lb (257.7 seconds) and the 10 lb (107.4 seconds) loads. The 6 and 10 lb loads were not significantly different from one another in mean time to fatigue.

CONCLUSIONS

It was expected that hand, load, pace, and forearm/hand posture would significantly affect the mean time to fatigue (endurance time). However, the mean time to fatigue did not appear to differ significantly between the dominant and non-dominant hand.

The load was found to significantly impact the endurance time with the 4 lb barbell differing from the 6 and 10 lb barbells which were not significantly different. This agrees closely with the findings of Sheeley et al. (1991).

The pace significantly affected endurance time with the slower pace (20 cycles per minute) yielding about a 3.7-fold increase in endurance time over the faster pace (60 cycles per minute). This finding may indicate that there is an absolute number of cycles to fatigue. This preliminary theory is currently being investigated more fully.

The final factor, forearm/hand posture, surpassed the expectation that a dynamic flexion/extension task would have a longer time to fatigue in supination than pronation. The mean endurance time of supination was (significantly) 2.4 times longer than in pronation. The difference in mean time to fatigue between supination and pronation may be due to several factors. These factors may include the direction of the primary isoinertial resistive force, the relatively superior flexor capability over the extensors, the angle at which the muscles work in full pronation and supination, and the loss of the ECU as an extensor in full pronation.

The findings of this pilot study lead to the recommendations that to maximize endurance time in a dynamic flexion/extension task the loads should be kept small (4 lbs or less), the pace should be slower (20 cycles per minute or less), and the hand should be supinated rather than pronated.

Although the basic findings of this study indicate that supination is superior to pronation, it is still necessary to perform additional studies in this area. Future studies will expand on this pilot study to include both genders, several age categories, and numerous forearm/hand and wrist postures.

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CUMULATIVE TRAUMA DISORDERS

COMPARATIVE RISK OF REPETITIVE STRAIN INJURIES BY SEX AND OCCUPATION

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Analysis of workers' compensation claims for repetitive strain injuries (RSIs) from 1984 to 1989, indicates that female workers in processing, machining or fabricating occupations have 9 times the number of RSI claims with 11 times the number of days off work as the average worker in Ontario. Males in the same occupations, however, had only twice the Ontario rates for RSIs. Female clerical workers also had relatively higher risks than their male counterparts, but RSI rates in clerical occupations were lower than the average for all occupations.

INTRODUCTION

The specific types of repetitive strain injuries (RSIs) included in the current analysis are "diseases" diagnosed as synovitis, tenosynovitis, tendonitis, epicondylitis, bursitis, ganglion, carpal tunnel syndrome, vibration white finger disease, or other diseases of the synovium, tendon, bursa, arteries and nerves. The option of including accidental motion-related "injury" claims with the same diagnoses as those listed above is discussed separately in Krammer (1992).

Risk factors for repetitive strain in women have received particular attention in the literature. For example, carpal tunnel syndrome was noted to be more common in women in several studies as reported by Armstrong and Chaffin (1979). More frequent RSIs in women, however, have usually not been related to the size of the male and female workforce, so that comparisons are difficult to make.

Processing, machining and fabricating occupations evaluated here are found primarily in the manufacturing industry. The manufacturing industry and several occupations which would be included here, were identified as having the highest rates of motion-related wrist disorders in the United States (Jensen et al., 1983).

METHODS

Statistical tabulations were obtained from the Ontario Workers' Compensation Board for disease RSI claims settled between 1984 and 1989 inclusive. Data on 11,439 settled claims and 769,664 days off work were used to calculate annual incidence and severity rates relative to the employed labour force as estimated by Statistics Canada (see Table 1). Rates are not corrected for incomplete compensation insurance coverage or under-reporting of claims. Rates, particularly for clerical and other occupations, may therefore be understated.

Occupations were defined according to a Canadian standard (Occupational Classification Manual). Processing, machining and fabricating occupations were aggregated and defined as manufacturing occupations, after differences in RSI rates between these groups were found to be minor. The term fabricating includes product fabricating, assembling and repairing occupations. Clerical occupations include office machine operators, typists and secretaries, tellers and cashiers, as well as bookkeepers, librarians, store clerks, inventory clerks and other related occupations.

Table 1. Ontario labour force estimates (000's), 1984–1989

Occupation	Male	Female	Both Sexes
Manufacturing	555 (23%)	152 (7.5%)	707 (15%)
Clerical	168 (6.5%)	625 (30%)	793 (17%)
All occupations	2,574 (100%)	2,032 (100%)	4,606 (100%)

RESULTS

The majority of RSI disease claims (57%) and days off work for these (60%) occurred in a minority of fifteen percent of the workforce. These workers were employed in "manufacturing" occupations involving processing, machining and fabricating. Similarly, most of the wage-loss RSIs and work days lost in female workers (60%) are attributed to only 7.5% of the female workforce employed in the same occupations.

Table 2. Annual incidence rates of repetitive strain injuries in Ontario 1984–1989 (claims/1000 workers)

Occupation	Male	Female	F/M	Both Sexes
Manufacturing	0.97	3.59	3.7	1.53
Clerical	0.07	0.12	1.9	0.11
All occupations	0.38	0.46	1.2	0.41

Table 3. Annual severity rates of repetitive strain injuries in Ontario 1984–1989 (work days lost/1000 workers)

Occupation	Male	Female	F/M	Both Sexes
Manufacturing	52	317	6.1	109
Clerical	2.5	8.7	3.4	7
All occupations	19	39	2.1	28

For every ten thousand workers in Ontario there were about four RSI disease claims with 280 working days of disability. Other rates were expressed relative to this average (Tables 4 and 5) or relative to each other (Tables 2 and 3).

Female workers have about 9 times the number of RSI claims and about 11 times the number of days off work as the average Ontario worker. Men in these occupations, on the other hand, were only twice as likely to be absent from work with twice the time off work with RSIs compared to that of the average Ontario male worker.

Estimated rates of RSIs are much lower than average in clerical occupations, but lower risk is not necessarily inferred (see Discussion).

Table 4. Relative incidence rates of repetitive strain injuries, 1984–1989, (1.0=Ontario average).

Occupation	Male	Female	Both Sexes
Manufacturing	2.3	8.7	3.7
Clerical	0.2	0.3	0.3
All occupations	0.9	1.1	1.0

Table 5. Relative severity rates of repetitive strain, 1984–1989, (1.0=Ontario average).

Occupation	Male	Female	Both Sexes
Manufacturing	1.9	11.4	3.9
Clerical	0.1	0.3	0.3
All occupations	0.7	1.4	1.0

Relative to male workers, Ontario RSI rates in females were only insignificantly higher by 22% but absences from work were twice as long. In manufacturing occupations, however, female incidence and severity rates were respectively 3.7 and 6 times higher than for males (see Tables 2 and 3). Differences between male and female clerical workers are somewhat less, at: twice the incidence and three times the severity of RSIs in male workers.

DISCUSSION AND CONCLUSIONS

The risk estimates presented here can provide no insight as to why RSI rates differ between groups of workers of different occupation and sex. They can be used to help identify highrisk groups of workers for further study, and to test or generate hypotheses.

Many factors can influence rates. For example, repetitive strains in men may be recorded as overexertion "injuries" somewhat more often than repetitive strain "diseases" simply because male tasks may more often involve exertion and, conversely, less often involve highly repetitive tasks. If this is the case, the excess rate in females relative to males may be overestimated. The analysis could be repeated, however, using an expanded definition of RSIs which adds accidental RSIs and possibly even sprains and strains attributed to repetitive motion (Krammer, 1992).

Claim reporting rates for clerical workers, and even for all workers combined may be somewhat underestimated relative to those in manufacturing. In the manufacturing industry, a relatively greater proportion of workers are likely to be covered by compensation insurance. Comparable risk of RSIs in clerical workers could conceivably be up to two- or even three-fold higher than calculated. The proportion of clerical workers covered by compensation insurance could not be estimated, but there is no reason to assume that less than one fifth of these workers would be covered. Therefore an increased risk of RSIs in clerical occupations is not supported. Nevertheless, females in these occupations risk comparatively more frequent RSIs with more time off work than males.

A ninefold higher rate of repetitive strain "diseases" in females employed in manufacturing occupations, and an eleven-fold increase in the duration of absence from work are not likely to be wholly explained by limitations of the data sources. Although the number of RSIs expected for a worker is about the same for either sex, females spend twice as much time off work. The higher comparative rates of non-accidental RSIs observed in women could be attributed alternatively to personal risk factors unique to females, to differences in the type of work done by women even when working in similar occupations, or to a combination of these and other factors.

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The Spectrum of Upper Extremity Disorders Associated with Hazardous Work Tasks

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INTRODUCTION

In 1989, investigators observed and videotaped workers performing various tasks at a pork processing facility plus photocopied and reviewed OSHA logs and medical records. One aspect of this project involved review of the videotape to semi-quantitatively estimate ergonomic exposures and classify the exposures as “hazardous” or “safe” according to their perceived potential to cause or materially contribute to the development of musculoskeletal morbidity. Subsequent to this exposure assessment and assignment, the spectrum and number of musculoskeletal disorders was determined by review of OSHA logs and company medical records. This paper presents analysis of the spectrum and number of upper extremity disorders associated with “hazardous” versus “safe” job categories and compares the current findings to other such studies in the literature.

METHODS

Each exposure assessment included a description of work elements using “Therbligs” or MTM. For the upper extremity, exposure factors included force, posture, static exertion, frequency, and localized mechanical compression. The presence of vibration and cold temperature were noted for their presence or absence. The details of the exposure assessment methodology has been previously described (Moore and Garg 1991).

Employee medical records were the primary source of morbidity data. All entries on the OSHA 200 log had corresponding medical record entries. With rare exception, the medical record entries used to determine the location and type of disorder were documented by a physician that held office hours at the facility part-time. Specific hand and wrist disorders included carpal tunnel syndrome, stenosing tenosynovitis of the finger (trigger finger), stenosing tenosynovitis of the thumb (trigger thumb), or stenosing tenosynovitis of the first dorsal compartment (DeQuervain's). The diagnosis of carpal tunnel syndrome was generally confirmed electrodiagnostically. Often, the physician recorded the presence of symptoms, usually pain, but failed to render an explicit diagnosis or impression. These were recorded as hand/wrist pain and, in accordance with the physician's documentation, assumed to represent strain-related disorders. Medial and lateral epicondylitis were classified as elbow disorders and included in the analysis since the extrinsic muscles of the hand originate at the epicondyles.

RESULTS

It was possible to estimate distal upper extremity exposure for 32 job categories. Of these 32, 14 were believed to pose risk for developing distal upper extremity disorders and were called "hazardous." The other 18 were considered "safe." At least one elbow or hand/wrist disorder was noted among 15 job categories. This occurred among 13 of the 14 "hazardous" job categories and among 2 of the 18 "safe" job categories. No elbow or hand/wrist morbidity was observed for one of the "hazardous" job categories and the remaining 16 "safe" job categories.

The observed elbow and hand/wrist morbidity is summarized in Table 1. Of the 102 total conditions, 22 (22%) were localized to the elbow and 80 (78%) were localized to the hand/wrist (including carpal tunnel syndrome). The 21 cases of carpal tunnel syndrome accounted for 21% of the total distal upper extremity morbidity (ratio=4.9) and 26% of the hand/wrist morbidity (ratio=3.8). It is noted that each "hazardous" job category associated with carpal tunnel syndrome has an equal or greater number of elbow and/or hand/wrist disorders.

Table 1. Number of cases of elbow or hand/wrist disorders and carpal tunnel syndrome in a pork processing plant.

Job Category	Elbow	Hand-Wrist	CTS	Total
Belly Pump Loader	0	1	0	1
Wizard Knife Operator	4	9	1	14
Comber	0	2	0	2
Smokehouse Operator	2	3	0	5
December/Bacon Press	1	6	0	7
Scaler/Grader	7	19	5	31
Tucker	1	2	0	3

Loader/Hanger	0	5	0	5
Sausage Hanger/Stuffer	3	5	5	13
Bagger/Scaler/Packer	0	5	3	8
Peeler	0	1	0	1
Tree Loader	0	1	0	1
Snipper/Feeder/Scaler	4	0	4	8
Control Operator[a]	0	0	2	2
Loader/Slicer Operator[b]	0	0	1	1
Total	22	59	21	102

[a] One of the "safe" job categories. The two cases of CTS represent bilateral CTS in one worker.
[b] One of the "safe" job categories. One worker had unilateral CTS.

The 59 cases of non-CTS hand/wrist disorders include 41 cases of hand/wrist pain, 12 cases of stenosing tenosynovitis of the fingers, 3 cases of stenosing tenosynovitis of the thumb, and 3 cases of DeQuervain's tenosynovitis. Table 2 presents the specific types of disorders and their associated number of cases for the 7 job categories associated with carpal tunnel syndrome. Five of these categories were considered "hazardous" and accounted for over 73% of the total observed morbidity. The two "safe" job categories accounted for 3% of the total morbidity.

Table 2. The location, type, and number of specific disorders among job categories associated with CTS.

Job Category	Right Side	Left Side
Wizard Knife Operator	Lateral epicondylitis-2 Medial epicondylitis-1 Trigger finger-9 CTS-1	Medial epicondylitis-1
Scaler/Grader/Downgrader	Lateral epicondylitis-5 Hand/wrist pain-7 Trigger finger-3 CTS-2	Lateral epicondylitis-2 Hand/wrist pain-6 Trigger thumb-2 DeQuervain's-1 CTS-3
Hanger/Stuffer	Lateral epicondylitis-2 Hand/wrist pain-2 DeQuervain's-1 CTS-4	Lateral epicondylitis-1 Hand/wrist pain-4 CTS-1
Bagger/Scaler/Packer	Hand/wrist pain-1 CTS-2	Hand. wrist pain-4 CTS-1
Snipper/Feeder/Scaler	Lateral epicondylitis-1 CTS-2	Lateral epicondylitis-3 CTS-2
Control Operatora	CTS-1	CTS-1
Loader/Slicer Operatora	CTS-1	

[a] "Safe" job categories.

The data in Table 2 suggest a clear pattern of morbidity among "hazardous" versus "safe" job categories. "Hazardous" jobs are associated with a variety of manifestations of strain on the distal upper extremity. Carpal tunnel syndrome is but one of these manifestations and is generally not the most common one. This contrasts sharply with the morbidity observed among the "safe" job categories, where carpal tunnel syndrome was the only reported disorder and was limited to one worker in each category.

DISCUSSION

Review of the literature revealed a number of other studies that have also examined the occurrence of a variety of upper extremity disorders, including carpal tunnel syndrome, within the workplace. As with the current investigation, these studies allow one to examine the context within which carpal tunnel syndrome has been observed to be associated with work, with special regard to co-morbid conditions, especially disorders of the muscle-tendon unit.

Hymovich and Lindholm (1966) published their observations of 62 injuries among 47 workers in a plant that manufactured small electrical components. The total population was 960; the observation period was 6 years. The observed injuries were considered to primarily be sprains of the forearm muscles, with or without tenosynovitis. There were five cases of DeQuervain's tenosynovitis, but no reported cases of carpal tunnel syndrome.

Ferguson (1971) studied 77 women that were absent from work at least once during a 21-month period with upper limb disorders that were attributed to repetitive actions associated with process work in an electric factory. The recorded diagnoses and opinions on work-relatedness were those of the private attending physicians. Table 3 summarizes the findings. The presented data does not allow one to identify which of the nerve cases were carpal tunnel syndrome, but it is clear that the number of muscle-tendon unit disorders is greater than the number of "nerve" disorders (ratio=5.4).

Table 3. Number and type of upper extremity disorders associated with process work in an electrical factory.

Job Category	Muscle Disorders[a]	Nerve Disoiders[b]
Cable Forming	24	3
Wiring	21	6
Coil Winding	10	2
Other	4	0
Total	59	11

[a] "Muscle" includes muscle strain, myalgia, myositis, fibrositis, and muscle pain.
[b]"Nerve" includes cervical spondylosis, carpal tunnel syndrome, and indefinite disorders, such as neuritis. Of the 11 nerve disorders, there were 3 CTS, 3 were cervical spondylosis, and 5 were indefinite.

Kuorinka and Koskinen (1979) published a study of the prevalence of neck and upper extremity disorders among employees performing manual operations in a scissor manufacturing process. Of 115 workers at risk, clinical and exposure-related data were complete for 93. The point prevalence of muscle-tendon disorders was 17 (18.3%). The disorders were mainly on the extensor aspect of the forearm and wrist. They reported no cases of carpal tunnel syndrome.

Luopajarvi et al. (1979) performed a study similar to Kuorinka and Koskinen, except they compared the prevalence of neck and upper extremity disorders among packers in a food production factory (bread) versus retail sales shop assistants. The morbidity data was obtained by interview and physical examination administered by a physical therapist. Table 4 summarizes the prevalence of the distal upper extremity disorders. Again, it is clear that carpal tunnel syndrome was relatively uncommon compared to muscle-tendon disorders (ratio=25.8). The authors noted that carpal tunnel syndrome was more often associated with flexor tenosynovitis.

Table 4. Number and prevalence of upper extremity morbidity among packers vs. shop assistants.

Job Category	Muscle-Tendon Disorders	CTS
Packers	85	4
Shop Assistants	18	0
Total	103	4

Armstrong and Langolf (1982) published a summary of “compensable” upper extremity disorders occurring in an athletic product factory in the years 1976 and 1977. Table 5 summarizes their observations. It is noted that carpal tunnel syndrome did not occur when there were few or no tendon-related disorders and that carpal tunnel syndrome tended to occur when there were relatively more tendon-related disorders. The ratio of muscle-tendon disorders to carpal tunnel syndrome was 7.7.

Table 5. Number and type of “compensable” upper extremity disorders in an athletic product factory.

Job Category	Muscle-Tendon Disorders	CTS
QC	0	0
Stamping	10	2
Packing	2	0
First Cure	5	0
Edge Dip	3	0
Second Cure	10	1
Third Cure	3	0
Buff and Dip	3	0
Assembly	33	6
Total	69	9

Armstrong et al. (1982) published a similar upper extremity morbidity summary referent a poultry processing plant. The recorded disorders, summarized in Table 6, occurred during an 8-month period. Point-in-time injuries were excluded. “Nerve” disorders include specific recorded diagnoses, such as carpal tunnel syndrome, and disorders associated with numbness. “Tendon” disorders include entities related to the tendons or tendon sheaths. “Non-specific” disorders include soreness, aching, swelling, or knots. Again, it is noted that “nerve” disorders are relatively uncommon, approximately 7%, compared to the other conditions (ratio=15.0).

Table 6. Upper extremity symptoms and disorders associated with a poultry processing plant.

Job Category	Non-Specific	Tendon	Nerve
Trimming	6	1	0
Boning	8	1	1
Thigh Skinning	9	1	0
Turkey Parts	1	0	0
Pan Roast	1	0	1
Curing	1	0	0
Cook Roll	0	1	0
Sanitation	1	0	0
Total	27	3	2

Viikari-Juntura (1983) reported the point prevalence of upper extremity disorders occurring among slaughterhouse workers. A screening evaluation, including interview and physical examination, was administered by a physiotherapist. Each subject also completed a pain drawing. Each subject underwent an additional clinical evaluation by the physician to confirm the screening diagnosis or resolve controversies. The clinical examination detected five cases of muscle-tendon disorders in four workers and one case of carpal tunnel syndrome. This case of carpal tunnel syndrome, plus one additional subject with only nocturnal paresthesias but no clinical signs, both had volar ganglia at the wrist. When inquiring about symptoms that occurred in the previous 12 months, almost 60% of workers reported arm or hand symptoms. In addition, there had been 18 cases of tenosynovitis or peritendinitis and four cases of epicondylitis diagnosed by a physician in the preceding 12 months. Again, the number of muscle-tendon disorders exceeds the number of cases of carpal tunnel syndrome (ratio=5.0).

Barbara Silverstein’s doctoral dissertation was published in 1985, followed by a pair of related publications (Silverstein 1985; Silverstein et al. 1987; Armstrong et al. 1987). This work was a cross-sectional study of upper extremity disorders that occurred among 574 active workers in six industries. There were four exposure categories, defined as combinations of high force (HIF) or low force (LOF) with high repetitiveness (HIR) or low repetitiveness (LOR). Table 7 presents the summary data for hand or wrist tendinitis and carpal tunnel syndrome based on interview and physical examination. The total number of cases of muscle-tendon disorders exceeds the total number of cases of carpal tunnel syndrome (ratio=2.1). Within the HIF.HIR exposure category, this ratio is also 2.1. Within the LOF.LOR category, the ratio was 1.0. The 14 cases of carpal tunnel syndrome were associated with 10 jobs. Of these 10 jobs, 5 were associated with hand or wrist tendinitis. All 5 were in the HIF.HIR category. The 5 jobs associated only with carpal tunnel syndrome were from the following categories: LOF.LOR-1, LOF.HIR-2, and HIF.HIR-2.

Table 7. Number of cases of hand or wrist tendinitis and CTS according to categories of force and repetitiveness.

Job Category	Tendon Disorders[a]	Carpal Tunnel Syndrome[a]
HIF.HIR	17	8
LOF.HIR	5	3
HIF.LOR	6	2
LOF.LOR	1	1
Total	29	14

[a] Classification based on interview and physical examination.

In a different context, Amadio and Russotti (1990) noted a similar pattern of morbidity among 40 cases seen at Mayo Clinic's Music Clinic. They noted 15 cases related to the muscle-tendon unit, compared to 5 with carpal tunnel syndrome (ratio= 3.0). Exposures in the performing arts are often associated with the presence of the same generic risk factors used to characterize "hazardous" exposures in the occupational setting.

CONCLUSION

The historical epidemiological data, as well as the data from the reported study, suggest that disorders of the muscle-tendon unit are much more common than carpal tunnel syndrome among jobs believed to pose risk for upper extremity disorders. In addition, it is observed that jobs believed to be associated with cases of "work-related" carpal tunnel syndrome are almost always associated an even greater number of cases of muscle-tendon unit disorders. By contrast, carpal tunnel syndrome associated with the two "safe" job categories lacked such "co-morbidity."

These findings suggest that a "co-morbidity" criterion might be useful in verifying upper extremity exposure assessment methodoligies. In particular, jobs believed to be "hazardous" are likely to be associated with several manifestations of strain of the muscle-tendon units in the distal upper extremity, with carpal tunnel syndrome being but one such manifestation and generally not being the most common one. By contrast, jobs believed to be "safe" may have none to few reported manifestations of musculoskeletal strain. When carpal tunnel syndrome is the only manifestation recorded, it may not be causally related to the employment activities. It is recognized that the standard of practice among physicians in the community may affect the spectrum of diagnoses reported, especially regarding carpal tunnel syndrome.

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TOWARD A KNOWLEDGE BASED SYSTEM OF CUMULATIVE TRAUMA DISORDERS FOR OFFICE WORK

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Cumulative trauma disorders account for 51% of reported occupational illnesses in U.S. work places. Thus there is a need for something which helps workers alleviate the risks and problems associated with cumulative trauma disorders. The knowledge base is written so it is easy for workers to understand and implement the recommendations provided, and alleviate or avoid cumulative trauma disorders, saving themselves pain and injury and their employers' money.

INTRODUCTION

Cumulative trauma disorders (CTDs) include both "injuries to the soft tissue of the body, due to repetitive movements of forceful exertion" (Schoenmaklin & Marras, 1990) and musculoskeletal disorders resulting from long periods of time spent working in "twisted or bent postures" with minimal worker movement or adjustment of the position (Rodahl, 1989). These illnesses cost U.S. industry as much as $27 billion annually (Mallory and Bradford, 1989).

Cumulative trauma disorders can be reduced by changing the workplace. This can be accomplished through the ergonomic design of the workplace with attention to the physiological aspects of work.

The purpose of this research was to develop a knowledge based system for reduction of cumulative trauma disorders. This paper will concentrate on two problems, carpal tunnel syndrome and back pain (due to twisted or bent postures) and give an overview of solutions to carpal tunnel syndrome (CTS).

Background: Carpal tunnel syndrome

Normally CTS patients, according to Bernard (1979), are 30 to 60 years old. The problem of compression or entrapment has been caused by individual anatomy, trauma to the wrist, or infection. Other causes of CTS include cuts, a lower supply of blood to the wrist, hormone changes, rheumatoid arthritis, and some medications (Waikar et al., 1990). Hobbies also cause CTS. Some people who sew experience CTS, in addition to some who play the piano (Mallory & Bradford, 1989), perform yard work such as clipping and leaf raking, or participate in a number of activities which can traumatize the wrist.

Increasing the pace of work may have a dual effect on CTDs as increasing the workpace tends to increase the number of repeated motions and to increase the muscular activity (Arndt, 1987).

Thus CTDs can be caused by constant repetitive motions which do not give the body adequate time to recover from the stress.

Symptoms of carpal tunnel syndrome include numbness, tingling, and burning feelings in the fingers; pain, dry or shiny palms, and clumsiness (Konz & Mital, 1990).

Groneman (1985) developed a chart of symptoms to watch for in workers performing jobs with high risks of CTS. For example, if a person tends to drop small objects, or has problems grasping large objects, Groneman suggests the condition “indicates a loss of muscle control and progression of disease process in CTS.”

CTDs can be prevented, but prevention requires a genuine commitment from management. Hymovich & Lindholm (1966) recommend four steps toward preventing these injuries: analyze hand motion, provide proper instruction and supervision, use spring suspension or counter-weighing tools, and rotate workers among jobs.

There are several medical methods used to treat CTS. Patients can be treated by putting ice packs on the hands and wrists, using anti-inflammatory drugs, splinting the wrist, and administering pressure on the median nerve (Mallory & Bradford, 1989). Surgical treatment of CTS often entails the same procedures, but many researchers disagree on the therapy after surgery.

Improvements were demonstrated due to a rehabilitation program. Improvements were seen in grip strength, tip pinch strength, radial deviation and flexion, and ulnar deviation. Patients reported a 15% reduction in the pain and distress (PAD) score, in which patients subjectively rate the amount of pain and discomfort they are experiencing (Fernandez and Marley, 1990).

Background; Back pain

“Failure to apply ergonomics results in unnecessary operator fatigue” (Stewart, 1980). The physical problems workers experience are due to the fact that, in the search to be comfortable, workers “will adopt postures which improve matters in the short term but cause increased fatigue and strain in the long term” (Stewart, 1980). Stewart also pointed out that it was “difficult for the user to modify the workplace or work method to overcome problems,” and that it is the responsibility of the employer to make the changes.

The introduction of computers in the workplace in the late 1970s and through the 1980s changed the way people work and how their work affected their bodies. A study of 384 employees, 88% female, aged 21–30, in the insurance industry (Springer 1980) examined the effects of bringing computers into the workplace. Of the people studied, 62% of the workers using the terminals experienced some discomfort. Of those experiencing discomfort, 74% had discomfort in the back.

Rossignal et al. (1987) studied 1545 subjects in 38 work sites in Massachusetts which provided valuable insight into the effects of VDTs on musculoskeletal discomfort. Of the subjects, 85% were women at work sites with 50 or more workers each. For those people using the VDT more than seven hours per day, they determined an increased occurrence of musculoskeletal conditions.

With 60 million VDTs in the U.S. by 1990 (Rossignal et al., 1987), this study illustrates the need to carefully plan the workstations and jobs of people using VDTs each day.

A study in Japan evaluated 5097 VDT workers in 23 different types of business (Yamamoto, 1987). The Yamamoto study also asked the workers which environmental factors disrupted their VDT work. Chair height was listed as a problem by 62%, desk height by 56%, and the keyboard height by 49%.

RULES FOR KNOWLEDGE BASED SYSTEM FOR CTS

The actions listed here (Figure 1) progress from simple steps to redesign of the work station or radical medical treatment if earlier steps do not work or the problem is too severe for a prior step to positive affect. Some steps may be taken sequentially, but depending on the situation, the severity of the pain, and the length of time the pain has been experienced, selected steps may be taken simultaneously.

Diagnostic Tests

Phalen's wrist-flexion (Kemp 1980) The seated patient's elbows should be propped on a table. The elbows should be bent at a 90° angle, and the wrists should be allowed to "drop" for 30 to 60 seconds. If the patient experiences burning, tingling or numbness, the test is positive (likely to have CTS).

Tinel's sign The patient should be tapped on the wrist crease (where it bends) with a percussion hammer. If the patient's hand tingles, the test is positive.

Forced Wrist-Flexion (Kemp 1980) The patient's elbows should be propped on a table, as in Phalen's test, but one wrist, then the other, should be held in flexion for 20 to 30 seconds. If the patient experiences burning, tingling, or numbness in the affected hand, the test is positive.

Vibrometry Vibrometry tests for CTS by measuring the patient's sensitivity to vibration. The patient's index finger is tested for sensitivity. Carpal tunnel syndrome is likely to exist if the vibration perception threshold is higher than for non-CTS patients (Lundborg et al., 1986).

Neurometry A neurometer is used to test people with sensory impairment (Katims et al., 1986). This diagnosis is accomplished by finding "abnormalities of conduction in motor fibers of the median nerve in the carpal canal" (Bleecker 1986).

Exercises

Prevention Exercises can improve flexibility or strength. For flexibility, the wrist should be bent upward and downward slowly, and rotated in circles. A fist should be made, and

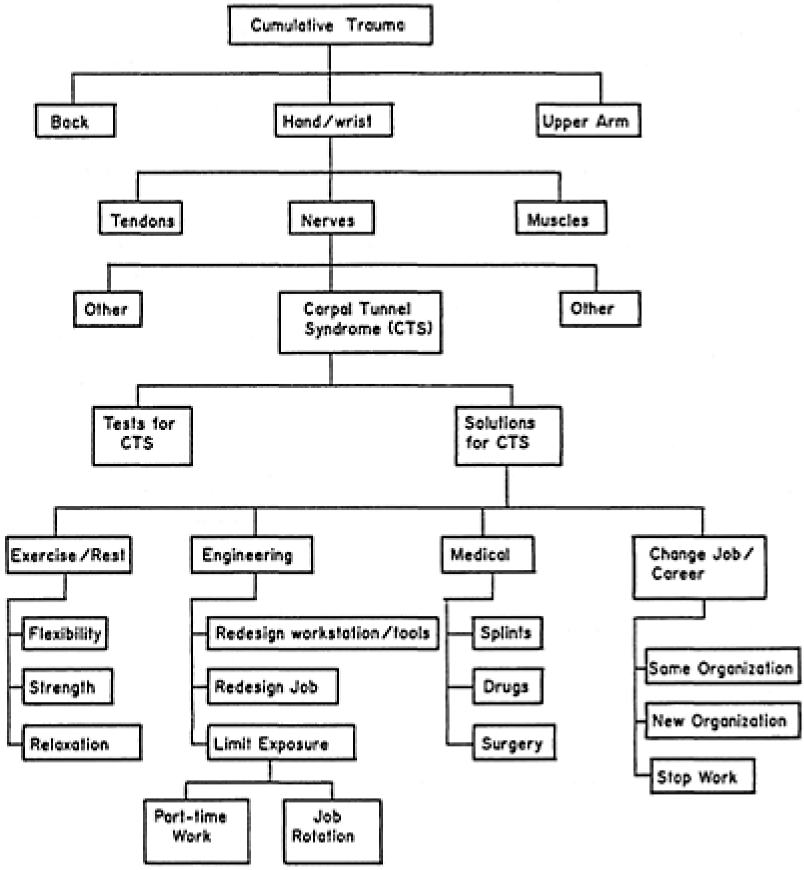

Figure 1. Knowledge based system for carpal tunnel syndrome

the fingers should be extended slowly. The thumb should be bent, extended, and reached toward the little finger (Falkenburg, 1987). In addition, to temporarily relieve symptoms, the fingers may be actively moved, and the hand shaken or rubbed (Groneman 1985). In another exercise, the fingers should be slowly spread, then squeezed together (Begnoche, 1991). These exercises should be performed every one to two hours.

Hand strength can be improved by using a putty ring. Make a ring of putty, such as that with which children play, and place it around the fingers and thumb. The thumb should be placed on a table and the fingers should be slowly stretched away from the thumb. This exercise should be performed five to ten times per hand (Tramposh 1989). The putty provides resistance and helps strengthen the muscles in the hand.

Relaxation Sore muscles often are tense, and this can add to injuries to the body such as pinched nerves. Thus when people learn to relax while at work, the pain often is lessened or eliminated (Brown & Mitchell, 1986).

The patient should lean back into a chair and close the eyes, take three deep breaths and let the body go "floppy." Allow the mind to relax and not think about work.

The procedure should be repeated four or five times, until the patient is able to quickly relax. If the patient is unable to relax, he/she should try to relax using an electronic device, the Fresh Muscles Trainer.

Engineering

Adjustable equipment When multiple people use the same workstation, the equipment needs to be adjustable. In addition, workers need to be able to change their work station settings through the day to adjust for various postural needs. Adjustable equipment allows them to avoid confined postures, which lead to cumulative trauma disorders. (The accompanying videotape provides more detailed information about VDT work stations).

Job enlargement The job can be enlarged so workers do not perform the same function all day, each day. For example, if the subject normally uses a keyboard, add phone answering, filing, and copying to the job description. Another method is to limit the amount of VDT work to 4 hours per day (MacKay, 1989).

Job rotation Implement job rotation by having the workers "share" their jobs, to avoid making too many of the same repetitive motions. A daily or weekly schedule helps workers avoid performing the same repetitive tasks each day. This schedule can be adapted to two hour periods during the same day. For example, the worker keys for two hours, files for two hours, takes a lunch break, answers the telephone for two hours, then copies documents during the last two hours of the shift. Rotation within days is better than rotation between days.

Change jobs or careers When all the worker's options for redesigning the job or work station have been exhausted, and problems are still experienced, the worker should change to a job which will not have a detrimental effect on the worker's health. This may be elsewhere in the same organization or even in a different organization. It may be necessary to shift occupations.

Medical treatment

When CTS has been diagnosed or a high risk of developing CTS exists, it is important for the patient to obtain medical assistance. This assistance can prevent further problems or alleviate the current problem.

Splints (Barrer, 1991) Splints are used to keep the wrist from bending at dangerous angles and to keep the wearer from performing too many repetitions per minute, once a patient begins to experience symptoms of CTS. They can be individually fitted for greater comfort.

Splints with medication (Kemp, 1980) Splints can be used in conjunction with medication to relieve the symptoms of CTS. Temporary relief can be obtained by injecting hydrocortisone into the carpal tunnel. More permanent relief (in some instances) can be gained by phenylbutazone.

Surgery Surgery is used only as a last resort, when other methods to relieve the carpal tunnel symptoms have failed, or the muscles of the wrist and hand begin to atrophy.

Surgery requires a 2 to 3 day hospital stay. Patients are placed under local anesthesia. During the operation, the surgeon removes or reconstructs the pressure source in the carpal tunnel. After surgery, a canvas or plaster splint is applied to the wrist for 7 to 14 days (Duncan et al., 1987) to immobilize the suture. The hand should be totally immobilized for 24 to 48 hours after the operation.

After the operation the patient should begin slow, simple exercises by making a fist and slowly releasing the fingers. After the cast is removed, the patient can begin exercises but should avoid lifting heavy objects for 2 to 3 months after the operation. When the patient does become more active, it is important to wear a sling while working or playing. This process requires patience, because it takes as long as a year for normal feeling and use of the hand to return after carpal tunnel release surgery (Duncan et al., 1987).

While it takes up to a year for complete recovery, some people in jobs with low muscular activities will need only a week or so to recover before returning to work. However, workers in highly manual jobs or those with high repetition may require from two to three months until they are sufficiently recovered to return to work (Schenck, 1989). Some workers may require four to six months of recuperation before they become “tolerant of work” (Begnoche, 1991). Once a worker has successfully been treated for CTS, it is important to redesign the job and/or redesign the tools so the condition does not return.

CONCLUSION

Many of the cumulative trauma disorders can be alleviated or prevented by using the correct equipment and procedures. The knowledge based system is designed to be used by a worker or supervisor to reduce cumulative trauma disorders via such physical aspects as work station design, rest breaks, and exercise. Psychological job design aspects (such as relaxation techniques, job content, and changing worker and management attitudes towards work expectations and stress to be more realistic) also are included in the knowledge base.

The knowledge base will help workers and supervisors diagnose problems and provide the necessary steps to reduce the problems, including medical treatment and physical therapy where needed.

An accompanying videotape is part of the knowledge base, and is used to teach VDT workers how to adjust the work station for maximum individual comfort and how to reduce problems with glare and musculoskeletal discomfort. These objectives are achieved by explaining good worker posture and by describing work station design.

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PREVENTION OF REPETITITVE STRAIN INJURY IN PORK SLAUGHTERHOUSES

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Ergonomic work analysis not only involves the identification and evaluation of risk factors, but also has the objective of understanding the work activity. We have applied this approach following a request for a study involving the abdominal and thoracic evisceration stations in two pork slaughterhouses. The analysis of the postural activity, the operating methods and the comments of several workers revealed the different components of the work that affect the musculoskeletal load on the upper limbs. In their activity, the workers use individual or collective means to control the load.

1. INTRODUCTION

Trying to find the means for preventing musculosketal disorders in the upper limbs raises the broader question about the occupational problems encountered in the sectors involved. In fact, to correct risk factors (excessive forces, constraining postures, too much repetitivity, vibration, cold), the cause must be more precisely determined. This can only be achieved through a detailed analysis of the work activity and of the sociotechnical functioning of the sector involved.

The analysis of the worker's activity is the basis for understanding occupational problems. The work activity corresponds to the involvement of working person's physiological and psychological functions (Daniellou, 1988). It refers to observable manifestations (movements, postures, displacement, communication, actions) as well as their underlying processes. The goal of activity analysis is therefore to describe and explain, or at least understand, the worker's observable activity in relation to the risks present. Its purpose is to provide correction indicators that allow changes to be made to eliminate, or at least reduce, the risk factors present.

This process is carried out with the social partners who are members of the Health and Safety Committee within the company. They receive training and help interpret the data collected by the ergonomists as well as contribute to the development of corrective measures that they are subsequently responsible for implementing.

The study was carried out in two pork slaughterhouses located in Quebec. The production rate is 420 pigs/hour in slaughterhouse A, and 480 pigs/hour in slaughterhouse B, for the same number of employees (80). The workstations studied (abdominal evisceration and thoracic evisceration workstations) were chosen by the Health and Safety Committee and are ones with a high risk of musculoskeletal disorders in the upper limbs.

In the abdominal evisceration task, the worker removes the viscera from a carcass suspended vertically from an aerial conveyor and places them behind him on a tray on the inspection table. The thoracic evisceration task consists of removing the lungs and separating the liver which 10 also placed on a tray on the inspection table. Each tray advances with the carcass at the speed of the production line. The viscera and the liver are controlled in this way by inspectors from Agriculture Canada. When disease is detected, the carcass is marked and taken from the production line to a location where the animal will be inspected and contaminated parts removed.

In this article we will mainly study the work activity from the standpoint identifying risk factors.

2. METHOD

The population of workers is those likely to be assigned to the evisceration workstations at the time of the study, namely 4 regular workers and 5 replacements. The study involved the following steps: circulating a pain questionnaire, identifying musculoskeletal hazards, analyzing the work activity, and describing the sociotechnical functioning of the companies and the sector.

Data on pain was collected using an adaptation of the Silverstein questionnaire (1984).

Risks were identified by applying evaluation criteria described by Armstrong (1982).

The work activity was filmed for 20 minutes at different times of the day (beginning of the day, before mealtime, after mealtime, and at the end of the day) on different days of the week (Monday, Wednesday and Thursday).

The analysis of the work activity was based on systematic observations and worker verbalizations. The systematically-collected observables relate to work activities, postures, the length of the operating cycle, the time between two cycles, the cutting time, the knife-sharpening time, and the cleaning time.

From the worker verbalizations, which are based on the visualization of their activity recorded on video film, it is possible to identify the activities and how they proceed, as well as obtain explanations about them.

3. RESULTS AND DISCUSSION

The sites of pain described by the workers at the two workstations are mainly located in the upper limb handling the product (Figures 1 and 2).

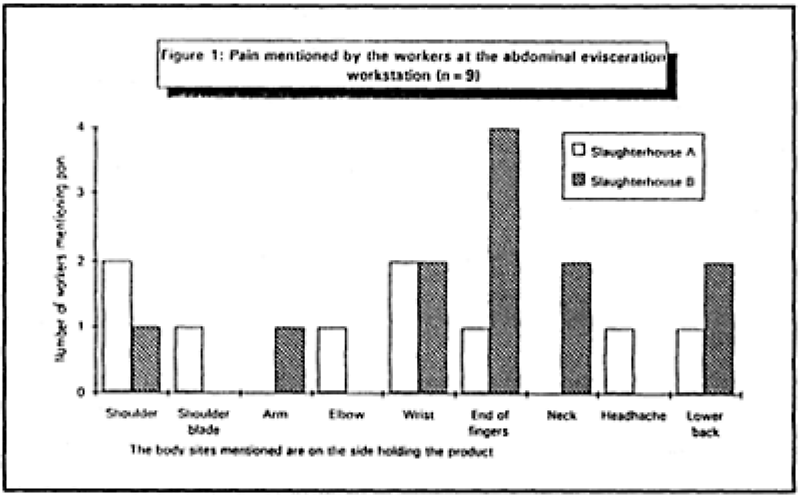

Figure 1: Pain mentioned by the workers at the abdominal evisceration workstation (n=9)

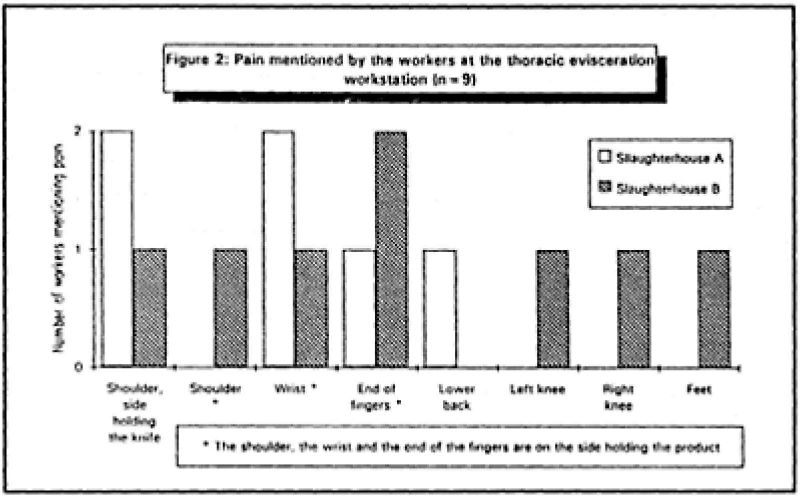

Figure 2: Pain mentioned by the workers at the thoracic evisceration workstation (n=9)

3.1 Risk factors

During abdominal evisceration, the amount of force exerted depends on the weight of the viscera that the worker must place on the inspection table behind him. The weight measured for 18 pork viscera varied from 12 pounds to 25 pounds, depending on whether the animal had finished digestion or not. For sows, the weight varied from 28 pounds to 56 pounds.

During thoracic evisceration, the force exerted is mainly due to attached lungs, with the average force measured over 8 cycles varying from 10 pounds to 14 pounds. There were force peaks of 29 pounds. We noted that 1 out of 3 pigs to 1 out of 5 pigs had attached lungs (the result of pneumonia).

At slaughterhouse A, the abdominal-evisceration cycle averaged 5.80 seconds, with 6.60 seconds for thoracic evisceration. At slaughterhouse B, the operating cycle was 5.95 seconds for abdominal evisceration, and 5.50 seconds for thoracic evisceration. Consequently, they are highly repetititive tasks.

The postural constraints at the two workstations involve the shoulder of the upper limb holding the knife. It is bent at 90 degress with abduction and internal rotation. The force necessary for cutting is not considered by the workers to be constraining.

The forces exerted on the upper limbs handling the organs are greater than the 10-pound limit and have a time cycle under 30 seconds, according to the reference criteria proposed by Armstrong (1982). These results agree with the site of the pain felt by the workers.

The postural constraints for the upper limb holding the knife seem to affect the workers to a lesser extent. The force by the arm handling the organs seems to be an important contributing factor in the risk of musculoskeletal disorders. We will analyze in greater detail the work activity involving the application of force at the abdominal evisceration workstation.

3.2 The activity involving the exertion of force at the abdominal evisceration workstation

Force is exerted to remove the viscera from the carcass and place them on the trays on the inspection table. This force varies with the weight and the size of the viscera as well as with the quality of the abdominal and thoracic opening. Various conditions may also affect the effort to be exerted during the handling of viscera.

Problems relating to changing the slaughterhouse supply system

The reason for a greater weight and size of the viscera is that the slaughtered pigs have not finished digestion. For two years a new slaughterhouse-supply system has in operation. With this system, there is a reduction in the time between the moment when the pig leaves the piggery and when it is slaughtered. The pigs come from producers nearer the slaughterhouses. They are not selected by the producer in advance, but chosen from among a group of pigs, which explains why they could have eaten. Therefore, due to the reduced time between the moment that the pigs leave the pig producer's premises and their arrival on the production line, the pigs have not finished digestion.

This problem between the slaughterhouse and its sources of supply is not the only one. It demonstrates the importance of developing what Duraffourg (1990) calls the notion of meat production sequence (from pig breeding to meat sales). In fact, in this case (but there are others as well), one notes the effect that the different product processing steps can have on each other. While this effect is well known in relation to productivity, it has been less extensively studied in relation to health and safety.

The effect of workstation layout

The force exerted during abdominal evisceration is related to the removal and carrying of viscera to the inspection table. By comparing work methods in the two slaughterhouses, the constraints that increase the effort can be better identified.

In slaughterhouses A and B, the evisceration workstations are located at the beginning of the inspection table. At this location, the trays on which the organs will be placed rise after having been cleaned with hot water. Because the production line moves to the right in slaughterhouse A, the organs are handled by the left arm, and the worker's natural movement is to place the viscera on the left side, namely at the end of the inspection table at the point where the trays rise. The workers are ready to place the viscera on the tray before it has risen, and have to wait, supporting the load until the tray is horizontal. Furthermore, since the work zone is limited (4 feet), the workers stand at the beginning of their working zone in order to have room to deal with incidents that increase the time of the operating cycle. in this way, the worker creates reserve time. One finds the same time-regulation strategy for the activity that was demonstrated by Teiger and Laville (1972) in the electronics industry. It seems that this strategy is characteristic of tasks with major time constraints.

Since the production line moves towards the left in slaughterhouse B, the workers do not have to wait for the tray. However, in this slaughterhouse, the inspection table is higher, which increases the constraints for the effort in two ways:

–First, the viscera have to be lifted so that they can be placed on the inspection table;
–Second, because the table is high, the viscera have to be grasped from above and the rectum rolled around the wrist to prevent it from hanging and catching on the fixed part of the table when the viscera are put down. In slaughterhouse A, where the table is lower, there is greater variation in the way the viscera are grasped. It can be assumed that this variation in the grasping method allows the workers' individual differences at the physical as well as at the psychological level to be taken into account, since some workers do not like to put their entire hand in the viscera.

The influence of the collective work activity

In slaughterhouse B there is also the problem regarding the quality of the work performed at the workstation upstream from the opening of the thoracic and abdominal cavity. It is opened using a small circular saw, whereas at the following workstation, the abdominal opening is made with a knife. To avoid piercing the viscera, the worker does not adequately raise the saw, which results in the diaphragm not always being completely cut if the subsequent workstation does not do it with the knife. The opening is therefore narrower, which means that the abdominal evisceration worker must lift the viscera even higher to remove them from the carcass.

This case demonstrates an aspect of the interdependence between workstations which affects the work load. The workers' verbalizations reveal a collective regulation of the work load, which is carried out in both directions between the upstream and downstream workstations in the production line. When the upstream worker is having more difficulty, he can leave out part of his task, which will then be done by the downstream worker. Also, under normal conditions, the upstream worker will do the work in such a way as not to overload the downstream worker.

The collective regulation of the work load requires that the workers have a good understanding of the effect of their activity on the work load of their coworkers upstream. This is not always the case, as was shown in the interviews with the workers, because on-the-job training does not always take this aspect into account. When there is conflict between workers, they can refer to the official task description and to arbitration by the foreman.

Individual influence

There are also individual regulations that allow the worker to exert less force. When the thorax is narrower, more lifting and pulling of the viscera are required to remove them, particularly when the stomach is full. To make it easier, workers adopt different strategies. Some put their hands in both sides of the opening at the beginning of the cycle to remove the viscera before detaching them. This also allows abscesses or adherences to be diagnosed. Others, after having detached part of the viscera when removing them, use their knife hand to push the stomach outside.

These methods of regulation that allow a reduction in the effort by the upper limb handling the viscera include negative aspects, particularly when they are not taken into account by the work organizers. In the case studied, a guard welded to the knife increases the risk of the worker catching it inside the carcass and of cutting himself.

CONCLUSION

Analysis of the work activity has given us a better understanding of the conditions affecting the force exerted. Besides the well-known problems of workstation layout that are involved in correcting musculoskeletal risk factors, we will refer to two aspects that are not extensively studied, the meat production sequence approach, and the collective and individual regulation of the work load.

The meat production sequence approach seems necessary because of the interdependence between the different steps from pork production to product marketing. This approach, seen as important from a quality and productivity standpoint, is also important from the perspective of the conditions under which the work is carried out. In the case studied, for example, the producer’s management aspects and the type of supply affect the conditions of work performance at the workstations studied. Duraffourg (1990) mentions different cases that demonstrats that influences can be found between the different steps in the sequence. The difficulty in correcting problems depends on the organizational method and the possibility of negotiation between the different industries making up the meat production sequence.

It also appears important to identify the collective and individual methods used by the workers to regulate the work load. Taking these regulation methods into account at the organizational level allows their negative effects to be avoided. It would also contribute to a better control of the risk factors. These regulation methods are in fact developed by the workers according to their skills and characteristics, and are not always known or taken into account by the work organizers. The same is true at the collective work level. Prevention of musculoskeletal problems cannot alway be achieved by simply eliminating the risk factor. Most often, it can only be accomplished by adopting different measures at different levels, including: workstation layout, tool design, work organization, and training, which all contribute to risk reduction and control.

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THE ANALYSIS OF REPETITIVE TASKS
A SIMPLIFIED APPROACH

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The last decade has seen the birth of cumulative trauma disorders (CTD) as a major source of disability for workers. Many of the injuries are attributed to repetitive tasks. Occupational ergonomics seeks to address the problem by a process of problem identification, task analysis, and ergonomic redesign. Liberty Mutual has developed a repetitive task analysis worksheet to help analyze jobs and evaluate the risk factors present. The completed worksheet reveals the worst aspects of the tasks and helps to focus preventive efforts on the parts of the job that are most likely to influence the development of a CTD.

INTRODUCTION

Cumulative trauma disorders (CTDs), also called repetitive strain injuries, repetitive motion injuries, cervicobrachial syndrome and a host of other names, are a collection of various syndromes which affect the nerves, muscles, and tendons and which are believed to be caused by repetitive motion. (Louis, 1990) Typical CTDs include carpal tunnel syndrome, tendinitis, tenosynovitis, epichondylitis, vibration white finger, trigger finger, and thoracic outlet syndrome. There are many other syndromes that are also categorized as CTDs. (Parniapour, 1990) Virtually all syndromes associated with repetitive motion can have non-occupationally related causes as well.

The trend in disability associated with cumulative trauma disorders of the upper extremities has advanced steadily over the last decade. By 1987, CTDs comprised about 60% of all reportable cases of occupational illness within manufacturing industries. (Nelson, 1991) Although comprising a relatively small proportion of overall Workers' Compensation claims for American business, for specific occupations and tasks, the incidence of CTDs can be the predominant cause of lost time. For some industries, e.g. automobile manufacturing, newspaper publishing, and meat packing, CTD's have become a collective bargaining issue because of their impact on the health and welfare of a substantial proportion of the work force. (BNA, 1991)

Business, labor, and government are trying to work together to control the CTD problem. Landmark agreements have been reached between companies, unions, and OSHA to provide a framework for identifying, analyzing, and redesigning tasks to remove or mitigate CTD risk factors. (BNA, 1991) The process of identification, analysis and task redesign is the principal focus of occupational ergonomics.

The purpose of this paper is to discuss a particular task analysis procedure, the procedure used by the Loss Prevention Department of Liberty Mutual Insurance Company. The main purpose of task analysis is to identify risk factors. The risk factors linked to the development of CTD include repeated motions, static postures or awkward postures assumed during these motions (type of movement), muscular exertion, mechanical stresses, cold, vibration, and some aspects of work organization that contribute to psychosocial stress. (Parnaipour, 1990; Rohmert, 1973)

A number of task analysis methods currently exist and some of these methods involve the use of computer software. (Keyserling, 1986) Most methods are based in relatively standardized and traditional industrial engineering techniques for time-and-motion study. (Armstrong, 1986) Liberty Mutual determined that using traditional industrial engineering methods analysis was difficult to teach to our own ergonomics consultants, very time consuming, difficult to explain to non-engineers, and often confusing to our clients. We endeavored to develop an approach that would alleviate these difficulties but be sufficiently rigorous for decision making.

Liberty Mutual is currently conducting psychophysical research on human capabilities for performing repetitive tasks. (Snook, 1990) Our analysis method was also designed to be integrated with the results of this research and provide additional data for future epidemiological study.

TASK ANALYSIS PROCEDURE

Task analysis begins with interviewing the supervisor and preferably the workers also about prior complaints about the task, the content of the task and work organizational factors. Types of information that can be important include:

- Description of the task
- Whether any recent changes have been made in the task
- The number of parts or cycles per day
- Frequency and duration of breaks
- The number of Workers' Compensation claims during a specified time frame
- The locus of complaints, e.g. wrist, elbow, shoulder, etc.
- Whether wage compensation is by piece rate (incentive)
- Whether the task is machine paced
- Whether there is a work rotation system
- Whether the task is performed throughout the day
- The number of hours in the shift
- Tool and equipment maintenance schedules

After getting basic information about the task, the next step is to observe the work to establish the sequence of discrete task steps. Traditionally, a time-and-motion analysis would require breaking the task down into fundamental elements or “Therbligs” as shown in Table 1.

Table 1

Work Elements or “Therbligs” suggested by Gilbreth (1924) and Modified by Barnes (1972)

Search	Reach
Select	Grasp
Move	Inspect
Position	Hold
Use	Idle
Plan	Rest
Avoidable Delay	Unavoidable Delay

Distinguishing between the work elements and itemizing them for both the left and right hand proves to be a complex and often arbitrary process. Furthermore, using these terms does not appear to provide much benefit to the analysis. Consequently, we use simple descriptions of the major task steps. Not only does this approach eliminate unnecessary confusion for our consultants, it is also much easier to explain to our clients.

Establishing the sequence of steps can be done through direct observation. Determining the work content of each of those steps is often quite difficult to do through direct observation. Many repetitive tasks are performed with a wide variety of rapid hand and arm movements and recording those movements is made much easier by the use of videotape. Through slow-motion review, every motion can be examined for the presence of postural and exertion risk factors. Videotaping the task is recommended for the “layman” although experienced ergonomics researchers have been successful using direct observational techniques. (Stetson, 1991)

A form should be prepared in advance to assist in recording relevant information. We have found that the form shown in Figure 1 serves the purpose nicely. After filling in the header, the task steps are listed in the left-hand column. The number of times a significant postural deviation from neutral occurs is recorded for each task step as are the type of hand grip used (if applicable) and the forcefulness of exertion (if applicable).

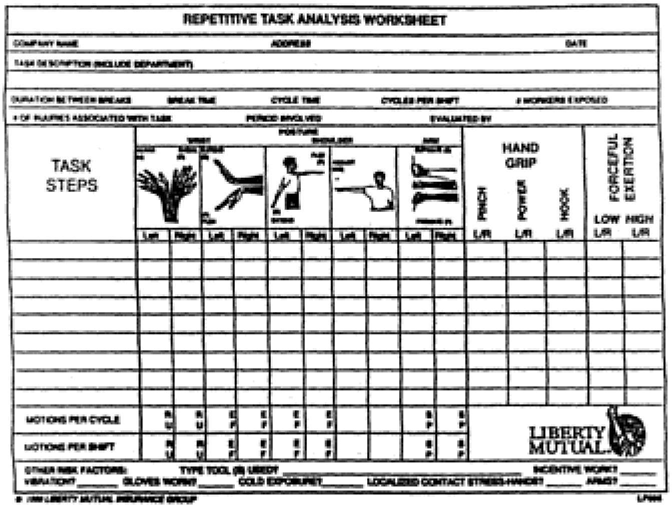

Figure 1

Repetitive Task Analysis Worksheet

The degree to which the task is broken into steps is dependent on the task being analyzed, the type of information being sought, and the need for the client to be able to readily understand the analysis. If one is simply curious about the number of times a given posture is adopted during a task, the number of steps used is relatively unimportant. Describing the task in a few steps will make the task easy to understand and will have the effect of a large number of entries per step thereby losing some important details for evaluation. Using many steps can make the analysis difficult to explain and will have the effect of a few number of entries per step but greater detail for evaluation. To draw some useful conclusions for redesigning the task, one needs to know which portion of the task involves the most motions, has motions that seem to be related to musculoskeletal complaints, requires forceful exertion (especially with other risk factors present), etc. Therefore, a balance is sought between detail and simplicity.

Several postural deviations have been identified as putting workers at greatest risk of injury. (LaDou, 1990) These are:

- Ulnar deviation
- Ulnar deviation with supination
- Palmar flexion
- Ulnar deviation with palmar flexion
- Extension
- Extension with pronation
- Arm flexion with pronation
- Radial deviation, dorsiflexion and pronation

The worksheet separately categorizes the deviations from neutral for the wrist, elbow, and shoulder. Individually itemizing the above listed combinations and all other potentially harmful combinations would make the worksheet unwieldy and confusing.

We do not use goniometers in the field to measure range of motion. Whether a movement is significant enough to be recorded on the form is a matter of judgement for the ergonomics consultant based upon general guidelines.

The type of grip used is a concern because of evidence suggesting association between forceful pinching, particularly in combination with wrist flexion and extension, and carpal tunnel syndrome as well as an association between forceful thumb exertions and DeQuervain's disease. (Armstrong, 1982)

Forceful exertion is recorded for each job step because of the apparent association with carpal tunnel syndrome and tendinitis. (Silverstein, 1987; Armstrong, 1987) Since we lack the instrumentation in the field required to measure force exerted, the decision on whether the exertion is high force, low force, or "not applicable" is determined by qualitative assessment based on two indicators: the appearance of the wrist and forearm and the judgement of the worker. We look for the change of definition and shape that is seen when people clench their fists forcefully. We also ask the worker whether they consider the exertion to be high or low force.

The experience of videotaping tasks has taught us some guidelines that can be helpful to those unfamiliar with this technique:

- Plan the camera angle to show motions of both hands simultaneously.
- Make sure that as much of the body as possible is continually visible so that no steps are missed.
- Because stop action and slow motion often reduces picture clarity, be sure there is enough light.
- Pay special attention to the focusing of your subject because you will need to look closely at arms and hands to determine exertion.
- To be able to judge variations in the task, tape three or four cycles.

After the task steps have been examined and the motions entered, the individual motions in each column are summed to give the number of motions per cycle. Motions per shift are the product of cycles per shift and motions per cycle. Cycles per shift are generally determined through production records. Cycle time, listed in the header of the form, is determined by timing the cycle from the videotape.

The process of examining the content of task steps should be done for several cycles of the task. If more than one person does the same task, it can be helpful to tape several cycles of other's techniques.

Other salient risk factors are noted on the form at the bottom. These include:

- the type of tool(s) used,
- the presence of vibration,
- whether gloves are worn,
- whether the hands are cold,
- local contact stress on the arms and hands, and
- whether wage compensation is on an incentive plan (piece work).

Unfortunate, but true, is the fact that hand tools are often chosen exclusively on the basis of their cost and that the people purchasing the tools don't have to experience the difficulty of using them. The type, shape, weight, sharpness, vibration characteristics, handle characteristics and so forth can contribute to biomechanical stress. (Chaffin, 1984)

The presence of vibration is recorded but the magnitude of the exposure is not evaluated. Vibration white finger (Reynaud's syndrome) and carpal tunnel syndrome are linked to vibrating hand tools. (Behrens, 1982; ANSI, 1986) Industrial hygienists evaluate the exposure.

The use of gloves is noted because gloves interfere with tactile sensitivity and affect hand-to-tool coupling. The ill-fitting gloves usually found in industry require the exertion of more force to get the same grip. Gloves are also occasionally used to dampen vibration and it has been found that some materials tend to amplify vibration. (Hampel, 1990)

Although gloves can be a problem, so too are cold hands. When hands are cold, there is a loss of tactile sensitivity and manipulative ability. (Dusek, 1957) There is also some evidence that cold may directly produce tendinitis. (Georgitis, 1978)

Contact stress is noted. Mechanical stress on the arms and hands is a direct insult to tendons, nerves and other soft tissues. Local contact stress can come from the sharp edge of a work bench, an edge on a machine, a chair arm, a tool or the workpiece. Using the hand for pounding is also a source of contact stress. Connections have been drawn to carpal tunnel syndrome and paraesthesia in the hands. (Tichauer, 1966; Kendall, 1960)

If compensation for doing the task is by piece rate (incentive work) it is noted on the form. Some people on piece rate work through their allotted breaks and sometimes through a portion of the lunch period. It is important to ask about this. There is also evidence to suggest that piece work produces additional tension in the muscles of the arms. (Arndt, 1987)

INTERPRETING THE ANALYSIS

A caveat is in order before beginning discussion of data interpretation. There are scant experimental data on which to base a decision of whether the task being analyzed is a problem or not. We do not have a good data base from which to determine whether a task is acceptable or unacceptable from the point of view of frequency, forcefulness, or posture. In short, we can't answer the questions: how fast is too fast and how much force is too much.

We do have some epidemiological data on specific tasks and types of exertion but the data cannot be applied universally. For example, estimates of a "high" work rate range from 5,000 exertions (Tichauer, 1966) to 12,000 exertions (Hammer, 1934). Because of the relatively infrequent nature of the occupational illnesses, the wide variety of syndromes, the large variety of risk factors which are neither independent nor mutually exclusive, and the relatively short time frame in which this problem has been examined by researchers, we are not able to be predictive about the potential for a task to evoke CTDs or to define the transition from a "good" to a "bad" task. We must also bear in mind that not all CTDs are work related.

An analysis is completed as a step in the process toward task redesign. Implicit in the analysis is the need for redesign. There is little point in conducting the analysis without a management decision to improve the task or at least investigate the feasibility of improving the task.

The purpose of the analysis is to give a starting point for prioritizing interventions. The most important part of the analysis form is the middle section where postural changes for the task steps are quantified, forceful exertions are noted, and the total number of motions per shift are summed. These are the primary risk factors and this section should be examined for interrelationships and patterns.

Analyses of several cycles should be compared for significant differences. Similarly, analyses of others doing the same job should be compared when possible. Occasionally we find the same task being done using substantially different techniques. One technique can have fewer and different motions than another and consequently be a preferred method.

The main concern is repetition and the analysis gives the number of motions per shift for each postural deviation. Owing to the above considerations, we have no established upper limit for frequency of repetition. As a rule of thumb, though, anything over 12,000 exertions (or motions) per shift should be carefully considered for change.

We often find that one or two categories of postural deviation comprise the majority of the motions in a cycle or task. Concentrating on the steps where these motions predominate, particularly when in conjunction with forceful exertion, can substantially reduce musculoskeletal stress. This is especially true if a pinch grip is also involved.

Often task analyses are conducted as a result of employee complaints of pain or numbness in a specific part of the shoulder, arm, or hand or when making a particular motion. Identifying the steps of the task where the joint is moved most often or where the pain-inducing motion occurs most frequently can be a guide to focused solutions.

It is not unusual to find tasks that are predominantly right or left arm intensive. When this appears in the analysis, consideration should be given to redesigning the task to spread the job demands to both arms. This can effectively reduce the frequency of an arm motion by as much as fifty percent.

After we are satisfied with our evaluation of the primary risk factors, we review the other risk factors at the bottom of the form. If any risk factors have been noted regarding the type of tool, vibration, gloves, cold, or contact stress, there is an opportunity for redesign through providing improved tools, equipment, and environment or through eliminating the risk factor(s).

Lastly, we should review the frequency and duration of breaks. We prefer to see the duration between breaks for highly repetitive tasks to be less than one hour. (Kogi, 1982; Rohmert, 1973)

SUMMARY

Disability associated with cumulative trauma disorders is a major safety and health issue. The incidence of claims is rising and both the public and private sector are working to curtail the trend. Redesigning repetitive tasks to prevent CTDs is the most permanent and cost-effective solution to the problem. To provide a basis for task redesign, tasks must be analyzed for risk factors including forceful and repeated exertions, postural deviations, contact stress, vibration, and cold.

The risk factors are identified and evaluated using a modified industrial engineering methodology.

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MRI of the Carpal Tunnel. Implications for Carpal Tunnel Syndrome

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The prevalence of work related cumulative disorders such as Carpal Tunnel Syndrome (CTS) warrant great concern. Within the carpal tunnel, the exact mechanism and location of the mechanical insult to the median nerve are still in dispute. This study used Magnetic Resonance Imaging (MRI) of the carpal tunnel to investigate the effects of posture and gripping on the geometry of the carpal tunnel contents. The wrist was splinted and MRI scanned in flexed (20° and 45°), straight, and extended (20°) postures in loaded and relaxed conditions. The radius of curvature was found to be non-constant and to reach minimum value near the distal end of the carpal tunnel with increased flexion. Median nerve loading was greatest in the 45° flexion case when loaded.

INTRODUCTION

Forearm and wrist disorders, such as carpal tunnel syndrome (CTS), are a significant health concern in many industries. CTS is found in numerous industries, in fact, the list of occupations varies from aircraft assembly to fruit packing to musicians to upholsterers (Bleecker, 1986). The health concerns and financial burden of CTS promote research into the causal factors of CTS, which at this point have been described with many conflicting opinions.

Compression of the median nerve is the net cause of carpal tunnel syndrome, yet very few studies have attempted to quantify the compressive force on the nerve itself. The relationships between wrist postures and/or movement and the internal loading of structures require clearer definitions than are presently available. One study which did look at these relationships found the pressure on the median nerve to be greater with wrist flexion and increased flexion caused increased pressure (Smith et al., 1977). These investigators also found that the pressure increased with tendon tension, ie. with a ten pound load on flexors digitorum profundus (FDP) 2, 3, the pressure was greater than with a five pound load. These increases appeared negligible with the wrist in extension but increased with flexion angle. The findings of Smith et al. (1977) make sense when one considers “Phalen’s test”, a clinical test used to elicit the symptoms of CTS. In this test, the patient acutely flexes the wrists and the test is considered positive if within a minute the symptoms are replicated (Phalen, 1966). To elicit CTS symptoms more quickly, the test is modified so that flexion and pinching the index and thumb are performed simultaneously.

A model of median nerve compression due to wrist posture would be a valuable tool to assess the possibility of inducing CTS due to wrist position and external load, if it accurately reflected the human system. The wrist has been modelled as a circular pulley (Armstrong and Chaffin, 1979) with the tendons acting as a rope around the pulley. This oversimplification of the anatomy provided estimates of the loading on the median nerve as it traversed the carpal tunnel. Analytically described anatomy, that is, measured or calculated radii of curvature for the tendons and median nerve as opposed to Armstrong and Chaffin’s idealized circular wrist pulley are a much needed step in wrist modelling, and would locate the point where the median nerve would receive the greatest mechanical insult. If anatomical data is acquired in both loaded and passive conditions, the effects of tendon tension towards compression of the median nerve may then be quantitatively assessed as well as the effect of gripping on the contents of the carpal tunnel.

METHOD

Four wrist positions were used in loaded and unloaded conditions. The positions used were straight, extended 20°, flexed 20°, and flexed 45°. The postures were maintained using PVC splints at each of the four angles. The subject’s hand was taped to the splint to minimize both movement and wrist postures not in the sagittal plane. Force was applied to a fluid filled rubber tube pressure transducer in a three finger pinch grip at a nominal level (approximately 10 N), maintained via visual feedback from the transducer.

The MR scanning procedure which has been found to give good resolution and contrast as well as minimizing the acquisition time is known as “gradient echo”. This represents a combination of T1 and T2 weighting, or T weighting. Contiguous four millimetre axial slices were acquired from approximately 2 cm proximal to the distal wrist crease to approximately 2 cm distal to the hook of the hamate. This procedure resulted in twenty to twenty-five cross-sectional slices for digitizing. Scans in coronal and transverse planes were collected for posture measurements as the splints allow only approximate positions.

Locally developed software was used to manually digitize each tendon from the MR scans. Each tendon was digitized three times per slice then averaged to reduce random error introduced by digitization. The resulting tendon paths were then low pass spatially filtered. The digitized coordinates were then transformed into an anatomical reference system defined by bony landmarks on the scans, the origin of the anatomical system being the most prominent portion of the hook of the hamate. The z-axis conformed to the progression of the MR slices which were cross-sections of the hand and forearm. The x-axis was defined as the component of the vector from the hook of the hamate to the tubercle of the trapezium that was perpendicular to the z-axis. The tendon centroids from each slice formed a trajectory which was differentiated digitally to allow calculation of it's instantaneous radius of curvature.

The instantaneous radius of curvature was then used to calculate the compressive force caused by the tendon on the structures of the wrist. The tendons wrapping around wrist structures can be likened to a belt around a pulley (Armstrong and Chaffin, 1979). Neglecting the minimal friction in typical synovial contacts, the calculation of compressive force simplifies to:

$$F_L = F_T / \rho \qquad (1)$$

where,

F_L is the normal force per unit length,
F_T is the tendon tension and,
ρ is the radius of curvature.

Based on the previous models of the internal muscular forces from a tip to tip pinch, the FDP tendon tension was estimated to be 10.4 N after dividing the total pinch force of 10 N equally between the second and third fingers (An et al., 1985).

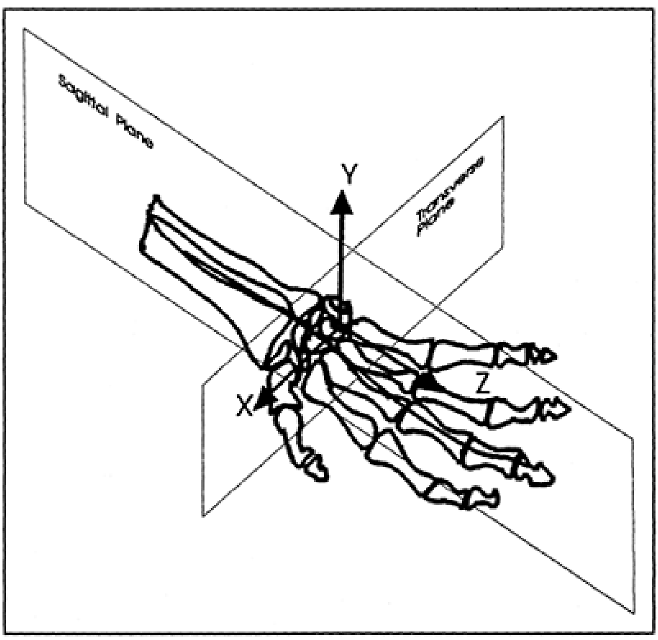

Figure 1. A schematic of the anatomical reference system with origin on the hook of the hamate.

Included are the planes of interest: the sagittal and transverse planes.

RESULTS

The radii of curvature calculated ranged from thousands of millimetres to less than nine millimetres at a minimum. This indicates that the tendon trajectories were virtually straight at the endpoints of the range examined (ie. in the forearm and hand) becoming increasingly curved near the centre of the region. In flexion the FDP tendons had smaller radii of curvature than the FDS tendons. Increased flexion of 45° produced the smallest values of ρ (8.6 mm in FDP 3, loaded condition, while the straight wrist position produced the largest (58 mm in FDS 3, unloaded; 57.6 mm in FDP 3, loaded). The point of minimum radius of curvature appears to be dependent on wrist posture (Table 1). The location of the minimum radius of curvature moved closer to the distal end of the carpal tunnel (zero corresponds to the hook of the hamate, distal being positive) with increasing wrist flexion. It should be noted that the radius of curvature is a scalar, thus the values for ρ in Table 1 imply no direction, however, in flexion the curvature is around the flexor retinaculum, while in the straight and extension postures the tendons curve about the carpal bones. To aid in the interpretation of the data, the start of the carpal tunnel, ie. the pisiform bone, is near the −25 mm mark.

Table 1. Minimum radii of curvature and the location of the minimum radii of curvature for loaded (L) and unloaded (U) conditions. A negative location indicates a position proximal to the hook of the hamate.

		FDP3		FDS3	
Posture	L/U	Min. ρ (mm)	Location of min. ρ (mm)	Min. ρ (mm)	Location of min. ρ (mm)
Flexion (45°)	L	8.6	0	11.9	−6
	U	11.4	−6	18.2	−2
Flexion (20°)	L	14.8	−6	31.1	−7.5
	U	15.1	−9	20.2	9
Straight	L	57.6	−28	24.4	−28
	U	40.0	−12	58	−20
Extension (20°)	L	26.3	−12	26.5	−12
	U	26.6	−8	13.5	−10

The 6.2 mm difference in radius of curvature between the increased flexion and functional flexion postures, translated into a near doubling of the compressive force per unit length (Fig. 2). The data in Fig. 2 have been plotted such that positive values indicate forces toward the median nerve (palmar side) and negative values indicate forces toward the carpal bones (dorsal side). The compressive force in flexion is supported by structures

on the palmar side of the wrist, particularly the flexor retinaculum and possibly the median nerve which lies just deep to the ligament. In extension, the tendons are supported by the carpal bones. In the case shown, the forces in the neutral position were toward the carpal bones.

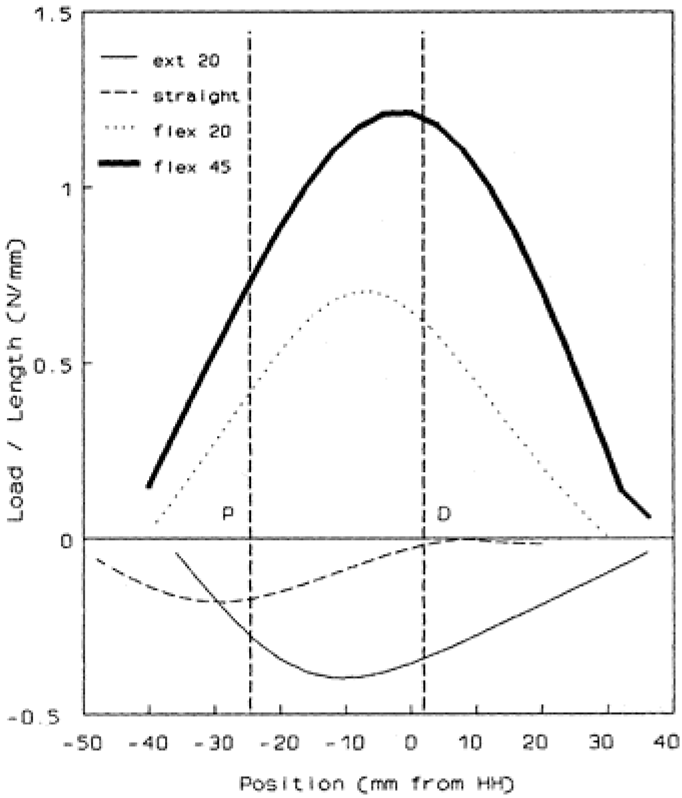

Figure 2: Compressive forces on wrist structures due to FDP 3 loading of 10.4 N. Negative forces indicate compression towards the carpal bones, positive towards the flexor retinaculum. The proximal (P) and distal (D) ends of the carpal tunnel are indicated.

DISCUSSION

The data seen in Table 1 indicates that a single radius of curvature can not explain the tendon paths at all wrist angles. Describing the wrist as a perfectly circular belt-pulley model greatly oversimplifies the tendon paths through the carpal tunnel. The radius of curvature values for a 95th percentile male were 12.0 mm and 18.1 mm for the profundus tendons and 14.4 mm and 20.5 mm for the superficialis tendons in extension and flexion, respectively. The values for a fifth percentile female wrist were three to four millimetres less in each case (Armstrong and Chaffin, 1978, 1979). Our digitized tendon data indicates that the radius of curvature of the extrinsic finger flexors (as demonstrated by FDS 3 and FDP 3) is affected by the posture of the wrist. For comparison, the subject whose data is presented had a wrist thickness of 41.5 mm which is slightly below 44.8 mm of the 95th percentile male model used by Armstrong and Chaffin (1978). However, some values of ρ are smaller than the 5th percentile female from the same study. The magnitudes of the radii of curvature used by Armstrong and Chaffin (1978, 1979) provided estimates, however, a constant radius can not be assumed due the posture effects shown here.

The main implication of a tendon adopting a non-constant radius of curvature is that greater forces may be transmitted to adjacent structures where the tendon curves more sharply. Most importantly, the location for the minimum radius of curvature may have greater loading on the median nerve associated with it. The radius of curvature appears to be smaller close to the distal end of the tunnel while in a more flexed posture. The position within the carpal tunnel where the greatest mechanical insult to the median nerve occurs is a topic of great concern and discussion. Nerve conduction deficits in the carpal tunnel have been associated with its distal portion (Luchetti et al., 1990; Kimura, 1979). It could be argued that this is the most important finding in terms of locating the site of injury as latencies are caused by nerve compression and/or lesions. This neurological finding gives very strong evidence for the distal carpal tunnel as the anatomical location in which CTS occurs yet does not provide insight for the etiology of CTS. The compelling neurophysiological evidence is somewhat clouded by an histological study which found the greatest changes in synovium and tissues to occur in the proximal carpal tunnel (Armstrong et al., 1984). Possibly due to the abundance of literature and *in vivo* nature of recording, pressures within the carpal tunnel (Tanzer, 1959; Gelberman et al., 1981; Thurston and Krause, 1988; Szabo and Chidgey, 1989) are often discussed to the exclusion of pressures recorded on median nerve itself. Smith et al. (1977), in a well controlled study with cadavers, excised the median nerve and replaced it with a pressure transducer and found that loading the tendons created peak pressures in the mid to distal carpal tunnel. Unloaded trials found pressures to be greatest in the proximal region. This is consistent with our data as we found a strong effect of tendon tension in a similar flexed posture to that used by Smith et al. (1977).

Tendon loading, in addition to wrist posture, also appears to play a role in the radius of curvature of tendons (Table 1). In the 45° flexion posture, loading decreased the radius of curvature. This is an important finding as it has been documented that tendon loading increased carpal canal pressures (Thurston and Krause, 1988) and increased pressure on the median nerve (Smith et al., 1977). A decrease in radius of curvature with tendon loading would vastly compound the situation, increasing the median nerve loading in a multiplicative manner. From Equation 1, increased grip force increases the normal force (F_L) in two ways, by a decreased radius of curvature and increased axial tension. Our pinch was of low intensity, approximately 5% to 10% of maximum force, to prevent fatigue during data acquisition. Realistic pinch forces of a greater percentage of maximum, up to 95 N, (An et al., 1985) would create correspondingly higher normal loads on the wrist structures.

The peak compressive forces of the loaded tendon on anatomical structures in the carpal tunnel were much greater in flexion. The increased flexion angle (approx. 45°) shows a peak compressive force of almost twice that of the lesser flexion angle which were both much greater than either the straight or extended postures. It should be mentioned again that the radius of curvature measure is a scalar, thus the compressive force caused by extension is created against the carpal bones, while in flexion, the tendons wrap around the transverse carpal ligament. Also, it should be noted that the median nerve is typically closest to the ligament, thus in extension the loading is away from the median nerve and in flexion the median nerve bears much of the compressive force.

O'Driscoll et al. (1990), found that wrist extension was the preferred wrist posture during maximal grip. This may be partially explained by the arguments presented thus far. Given that muscle length is most likely the largest component of choosing the extended posture, compression of the median nerve in flexion may inhibit muscle activity, hence muscle force. This argument gains strength when one is reminded that the median nerve supplies many intrinsic hand muscles, especially those of the thenar group.

These data indicate that postural effects on median nerve compression are quantifiable and possibly greater than previously believed. Increased flexion angles must certainly be avoided especially when strong grips are involved. As seen, over 10% of the FDP tendon tension can be inflicted on the supporting structures of the wrist, thus the total force supported by the median nerve due to all tendons is likely overwhelming in certain positions and individuals.

CONCLUSIONS

A constant radius of curvature does not adequately model the path of the tendons through the carpal tunnel. In all postures a definite minimum was evident. This minimum radius of curvature approached the distal end of the carpal tunnel as the flexion angle increased. Wrist posture has a large effect on the radius of curvature of tendons through the carpal tunnel and thus the loads created by the tendons on adjacent structures are dependent on wrist angle. As the flexion angle increased from an angle of 20°, a near-doubling in compressive force from loaded tendons on the median nerve was found. This finding supports the neurological data which indicates that nerve injury occurs in the distal portion of the tunnel and suggests loading of the median nerve by tendons is a viable injury mechanism for carpal tunnel syndrome.

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ANATOMY AND CONGRUENCE OF THE ARTICULAR SURFACES OF THE THUMB CARPOMETACARPAL JOINT

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INTRODUCTION

The thumb carpometacarpal joint (CMC) is commonly afflicted with osteoarthrosis (OA), which is predominant in the female population over 45 (Kelsey, 1982). A common hypothesis attributes the development of this disease to the saddle-shaped anatomy of the articular surfaces of the CMC joint. Many investigators have analyzed the shape of these surfaces as related to the function of the joint and its multiple degrees of freedom. MacConaill (1946) has given a remarkable description relating joint displacement to articular surface topography; he explained that the saddle configuration is the most efficient for providing conjunct rotation during circumduction of the thumb. Napier (1955) also addressed joint anatomy and congruence, and the stabilizing role of capsular ligaments. He discussed opposition of the thumb and the 'direct' and 'indirect' pathways along which this motion occurs. Kuczynski (1974, 1975) provided similar descriptions of this joint and stated that flexion of the CMC joint is accompanied by an obligatory medial rotation of the first metacarpal. Smith and Kuczynski (1978) classified the various shapes of the trapezium as sellar, triangular, ovoid and semi-cylindrical. They noted that some of these CMC articular surface shapes predispose to, or accompany OA changes. North and Rutledge (1983) also found that the trapezium tended to be flatter in joints with early OA changes, and that CMC joints from female subjects had shallower surfaces than those from male subjects. They suggested that the saddle-shaped surfaces progressively transformed into a semi-cylindrical configuration with degenerative changes. Pieron (1973) and Kapanji (1981) gave detailed reviews on the biomechanics of the thumb. Thomas (1977) and Koebke (1983) further attribute the incongruence of the joint to the rotation of the first metacarpal on the trapezial surface during opposition. They attribute cartilage degeneration on the dorso-radial and volar-ulnar aspects of the trapezium to the high concentration of stresses on these diametrically opposed regions. Thus, these investigators hypothesized that these lesions are the first stage in the development of OA in this joint.

This paper describes a method for accurately quantifying the anatomy of the articular surfaces of the thumb carpometacarpal joint, using close-range stereophotogrammetry (SPG). Principles of differential geometry are applied to the study of surface curvatures and congruence, and comparisons are made between joints from female and male subjects. The role of congruence as it relates to articular cartilage contact stresses is also described.

METHOD

Eight female (aged 54 to 71, avg. 64) and five male (aged 61 to 80, avg. 70) fresh frozen human cadaver joints were used in this study. Each joint was thawed at room temperature, and carefully dissected to separate the trapezium and first metacarpal bones. The articular surfaces of each joint were quantified using SPG developed by Ateshian and co-workers (1991).

Stereophotogrammetry Method

In this method, the articular surface is placed inside the workspace of a ceramic calibration frame fitted with sixteen optical targets whose three-dimensional coordinates are precisely known (±6 µm). A grid pattern consisting of a dense mesh of square cells is optically projected on the articular surfaces from a 35 mm slide placed within a high-intensity strobe light. The intersections of these grid lines provide a set of recognizable object points (nodes) on the otherwise uniformly smooth articular surface. A pair of photographs (a stereogram) of the calibration frame and articular surface are taken from two convergent directions using 20 cm×25 cm (8 in×10 in) large format cameras. The two-dimensional coordinates of the calibration targets and articular surface nodes are subsequently digitized from each photograph, using a X-Y digitizer with a rated accuracy of 20 µm. From the knowledge of the photographic and three-dimensional coordinates of the calibration targets, the camera interior and exterior parameters are evaluated using the collinearity condition (Ghosh, 1979). Given the camera parameters for both photographs, the three-dimensional coordinates of the surface nodes are subsequently reconstructed using a geometric space intersection technique. Using a calibrated flat plate, the accuracy of this procedure was found to be within 25 µm along each of the three spatial coordinate directions, at a 95% confidence level.

Geometric Modeling

The digital data from each articular surface was fitted with the equation of a parametric biquintic spline of the form

$$x(u, w)=\Sigma_i \Sigma_j a_{ij} u^i w^j \quad i, j=0 \text{ to } 5 \qquad (1)$$

where x is the position vector of a point on the surface whose parametric coordinates are u and w ($0 \le u \le 1$, $0 \le w \le 1$). The three components of vectors aij represent the coefficients of the spline for each coordinate direction, and are obtained from the least-squares surface-fitting technique. Given this analytical representation of each articular surface, various surface differential properties can be evaluated at any point of coordinates (u, w), and graphically displayed (Beck et al., 1986; Ateshian et al., 1992). Specifically, the principal curvatures κ_{min} and κ_{max} were calculated at all the surface nodes, and curvature maps were subsequently generated from these data. From these principal curvatures, the Gaussian curvature $K=\kappa_{min}\kappa_{max}$ and the rms curvature $\kappa_{rms}=[(\kappa^2_{min}+\kappa^2_{max})/2]^{1/2}$ were also evaluated and displayed. Finally, the principal directions of curvature were also obtained using a numerical integration scheme (Ateshian et al., 1992). These quantities provide a precise description of the differential geometry of the articular surfaces of the thumb CMC joint. Global values of these parameters for each surface were defined and obtained by calculating the mean and standard deviations of the nodal values of κ_{min}, κ_{max}, and κ_{rms} over each surface.

Joint Congruence

The congruence of a joint in a certain contacting position is an intrinsic geometric property which depends on the principal curvatures and directions of curvature of its opposing articular surfaces at the point of contact It is possible to represent the contact of two arbitrary surfaces with an equivalent system where a new surface, representing the difference in the profiles of the two original surfaces, comes into contact with a plane (Figure 1). The congruence of the joint is then defined by the principal curvatures $(\kappa^c_{min}, \kappa^c_{max})$ of this equivalent surface at the point of initial contact with the plane. Calculation of these relative curvatures may be found in standard textbooks as Lur’e (1964). An overall congruence index at a contact point can also be defined as the rms value of the equivalent principal curvatures, denoted by κ^c_{rms}. In this study, the absence of experimental contact area data precluded the determination of joint congruence indices at precise contacting positions. However, as a first step toward more detailed analyses, a characteristic measure of congruence of CMC joints from female and male subjects was evaluated using global values of the principal curvatures of the opposing trapezial and metacarpal articular surfaces (Ateshian et al., 1992).

RESULTS

The quality of the surface-fits was estimated from a parameter e which is a measure of the mean distance from the experimental nodal points to the biquintic spline surface for all surface nodes. For the trapezium, the mean value and standard deviation of e over all specimens was 66.6±17.1 µm, while for the metacarpal it was 65.5±16.4 µm.

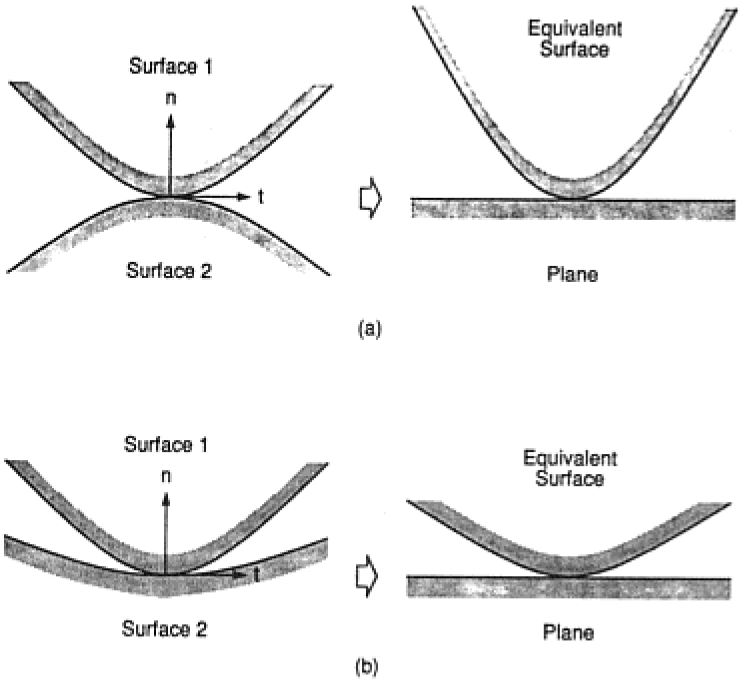

Figure 1: Two surfaces coming into contact may be represented by an equivalent system, where surface 2 is subtracted from itself and from surface 1. This will result into an equivalent surface coming into contact with a plane. This "subtraction" is operated along the coordinate direction n only, where n represents the normal to the surfaces at the point of initial contact. The principal curvatures of the equivalent surface at that point are called relative principal curvatures, and they represent a direct measure of the congruence of the two original surfaces in that position. For example, the surfaces displayed in (a) are less congruent than those in (b). This comparison is unambiguous because it

is made relative to a fixed reference planar surface.

Figure 2 shows lines of curvature for a typical trapezio-metacarpal pair. On the trapezium, lines of minimum curvature were found to be almost perfectly aligned with the radio-ulnar anatomic direction, while lines of maximum curvature followed the dorso-volar direction. On the metacarpal, the opposite scheme occurred in the central aspect of the surface, i.e., minimum and maximum curvature lines were aligned with the dorso-volar and radio-ulnar directions, respectively. Gaussian curvature maps are shown in Figure 3, where negative values indicate a sellar shape and positive values indicate an ovoidal shape. Thus, it was observed that the trapezium is generally sellar over most of its surface, with narrow ovoid regions sometimes appearing around the periphery where the surface curls away. However, in four female trapezial specimens, ovoid regions extended in the form of dorso-volar bands on the ulnar and/or radial aspect of the joint The metacarpal was found to be sellar along a central band which extends from the radial to the ulnar aspect of the joint surface, and spans slightly more than half the width of the surface along the dorso-volar direction. The dorsal and volar aspects of the metacarpal are ovoid in shape, with the dorsal ovoid region being made up of one or sometimes two prominences, and the volar ovoid region having always one prominence.

RMS curvature maps provide a graphical display of the topographical variation of κ_{rms} over the entire articular surfaces. In this analysis, we refer to the terms “most curved” and “least curved” to represent regions of high and low κ_{rms}, respectively. On the trapezium, the least curved region occurs in a broad diagonal band which spans the surface from the dorso-radial region to the volar aspect of the surface. The most curved regions are the ulnar and dorso-ulnar regions. On the metacarpal, the most curved regions are the dorsal and volar prominences, followed by the ulnar aspect of the joint

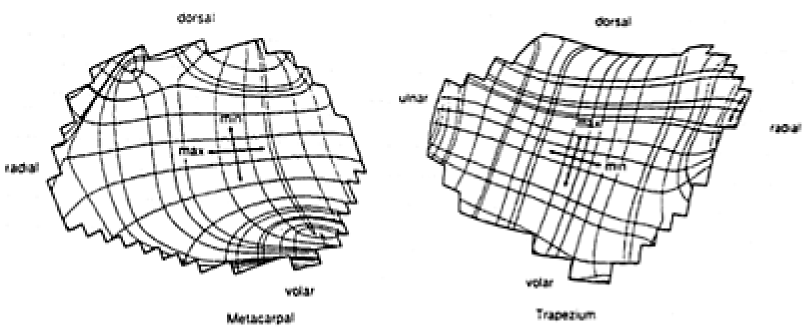

Figure 2: Display of principal directions of curvature for a typical trapezium-metacarpal pair. Directions of maximum and minimum principal curvature for the metacarpal are opposite to those of the the trapezium.

surface. The least curved region corresponds to a crescent-shaped band on the radial side of the surface.

Table 1 displays averages of the articular surface area, and global values of κ_{min}, κ_{max} and κ_{rms} over all specimens for male and female trapezial and metacarpal surfaces (denoted with an overbar). In this group of specimens, the surface area of the metacarpal was statistically greater than that of the trapezium for females only. As expected, female joint surfaces were statistically smaller than male joints. As seen from Table 1, for both trapezial and metacarpal surfaces, the global curvature values were significantly different between female and male specimens. However, most of these differences disappeared when the curvature values were normalized with the reciprocal square root of the corresponding articular surface area (Table 2, normalized quantities have a superscripted asterisk). This normalization was performed to eliminate the effects of size so as to look only at the shape of the joints. Nevertheless, statistical differences in $\bar{\kappa}^*_{min}$ and $\bar{\kappa}^*_{max}$ persisted between female and male trapezial surfaces, indicating fundamental differences in the anatomic shape of the trapezium between the sexes. From the ratio $\bar{\kappa}_{max}/\bar{\kappa}_{min}$, it can be seen that all surfaces are more convex in the direction of maximum curvature than they are concave in the direction of minimum curvature, though this effect is significantly less pronounced in male trapeziums.

As a consequence of the differences in size and shape, the congruence indices also differed between male and female joints. Table 3 displays the average values of the congruence indices $\bar{\kappa}^c_{min}$, $\bar{\kappa}^c_{max}$, and $\bar{\kappa}^c_{rms}$ over all specimens. Since none of the indices are equal to zero, it follows, as expected, that the CMC joint is not perfectly congruent; thus the two opposing saddle surfaces *do not constitute a positive-negative image of one another*. Since all three congruence indices are statistically smaller for male joints than for female joints, male joints are more congruent. Furthermore, by looking at the predominant direction of $\bar{\kappa}^c_{min}$, eleven of thirteen specimens were found to be more congruent in the radio-ulnar plane than the dorso-volar plane.

DISCUSSION

The results from the curvature analysis of the thumb CMC joint quantitatively confirm previous findings in the clinical literature. For example, Kuczynski (1974) had noted that the trapezial surface was more curved on the ulnar side but became progressively flatter in the radial direction. He also found that the dorso-ulnar region of the metacarpal was more concave than the volar-radial region. He observed that the ridge of the trapezium and the groove of the metacarpal had the same general direction, and this observation is consistent with the above results on the principal directions of curvature. Napier (1955) had also noted that the thumb CMC joint was more congruent in the radio-ulnar direction than the dorso-volar direction.

Our study also provides new insight into the anatomy of the CMC joints in relation to gender. Significant differences were found between the thumb CMC joints from male and female subjects for this sample of older specimens. In brief, we found that the trapezial surface has a different shape (i.e.,

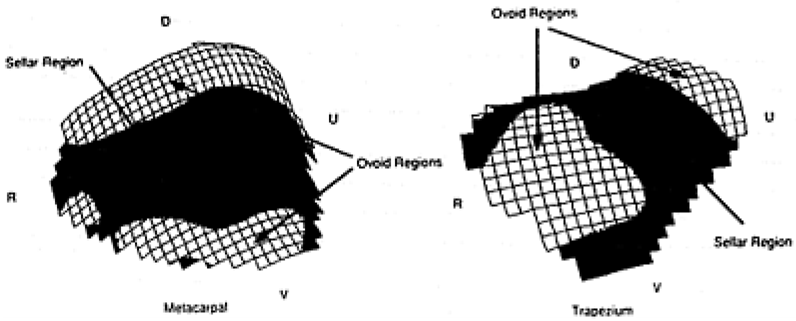

Figure 3: Gaussian curvature maps of the metacarpal indicate that it is sellar along a middle radio-ulnar band, where K<0. (Key: D=dorsal, V=volar, U=ulnar, R=radial.) The trapezium is sellar over its entire surface in most specimens. Some female specimens, as shown here, exhibit ovoid patches on the ulnar and radial regions.

curvature characteristics) in male and female CMC joints, even when the effects of size are eliminated. No such differences were found for the metacarpal surface. These results are based on measures of surface averages of the principal curvatures and on comparisons of the various curvature maps.

Joint Congruence and the Biphasic Nature of Cartilage

When cartilage is subjected to loads, its response varies as a function of time. Under compression, this time-dependence is largely due to the flow of interstitial fluid through the porous-permable collagen-proteoglycan solid extracellular matrix. The motion of the fluid is resisted by a diffusive drag which is controlled by the pore size of the porous solid matrix which, in turn, is controlled by the organization of the collagen meshwork and proteoglycan molecular organization. In order to model the response of cartilage from basic thermodynamic and continuum mechanics principles, it is essential to account for both the collagen-proteoglycan solid phase and the interstitial fluid phase of the tissue. The biphasic theory for hydrated soft tissues has been used successfully to model the compressive flow-dependent creep and stress-relaxation behaviors of articular cartilage (Armstrong and Mow, 1982; Athanasiou et al., 1991; Mow et al., 1980,1990; Spilker et al., 1990; Brown et al., 1986). In this theory, the total stress σ^T in cartilage is separated into two parts:

$$\sigma^T=\sigma^s+\sigma^f \qquad (2)$$

where σ^s is the stress acting on the solid phase and σ^f is the stress acting on the fluid phase. In the tissue, these stresses depend on the interstitial fluid pressure p and interstitial fluid velocity through the porous-permeable solid phase of the tissue. To illustrate how the tissue might function, consider a 1-D analysis of the tissue in compression. In this simple problem, the total stress acting on the tissue is simply equal to

$$\sigma^T = -p + H_A\varepsilon \quad (3)$$

where H_A is called the aggregate modulus (i.e., the one-dimensional compressive modulus) and represents a measure of the compressive stiffness of the solid matrix of cartilage, and ε is the compressive strain in the solid matrix. The aggregate modulus can be measured at equilibrium when there is no fluid flow, i.e., when the frictional drag force of fluid flow is zero, and the pressure is zero. In the theory, the fluid stress σ^f is directly proportional to the fluid pressure p in the tissue, and is given by $\sigma^f = -\phi^f p$ where the proportionality constant ϕ^f is simply the tissue porosity (i.e., volume of water/total volume), which is approximately 75% in CMC cartilage. The solid stress consists of the remaining pressure component, $(1-\phi^f)p$, as well as all deformational effects due to the strain ε, i.e., $\sigma^s = -(1-\phi^f)p + H_A\varepsilon$. Thus, the fluid and solid stresses satisfy both of the equations above.

If the tissue is immersed in a fluid under hydrostatic pressure a special form of the 1-D problem—then by virtue of incompressibility there will be no deformation of the solid matrix, i.e., ε=0. Under this circumstance, the fluid stress is $\sigma^f = -\phi^f p$ and the solid stress $\sigma^s = -(1-\phi^f)p$. In other words, under hydrostatic loading, approximately 75% of the total stress is supported by the fluid phase and 25% by the solid phase. This situation applies for highly congruent joints, and typically during the first few seconds after load application when there is likely to be a thin layer of synovial joint fluid between the articulating surfaces.

In another extreme case, if the tissue pressure p is zero (i.e., no interstitial fluid flow), then ($\sigma^f=0$ and $\sigma^s=H_A\varepsilon$. Under this circumstance, all of the applied stress must be supported now by the collagen-proteoglycan solid matix. This case applies when cartilage is allowed to creep to equilibrium when the movement of interstitial fluid inside the tissue has completely stopped. Typically this occurs after a period of several hundreds or thousands of seconds of continuous loading. Therefore, the aggregate modulus H_A (which is an intrinsic material property of cartilage) governs the amount of strain in the tissue for a given applied stress; This situation occurs in very incongruent joints where the interstitial fluid may flow unimpeded from the highly stressed contact region or when joint loading is maintained for long periods of time.

The speed of fluid flow, w, relative to the solid matrix in any direction, x, is given by $w = -(k/\phi^f)(\partial p/\partial x)$ where $\partial p/\partial x$ is the pressure gradient A pressure gradient may exist in all three spatial directions and it is highly sensitive to the geometry of the articular surfaces and the stresses acting in the region of contact In an incongruent joint, the pressure gradient along a tangential direction to the surfaces will be high because the contact region will be small and the pressure will decrease rapidly from its peak value at the center of the contact region to a zero value at its periphery, causing a high fluid velocity in that direction. Conversely, in a congruent joint, the pressure gradient will be small and the resulting fluid velocity will be small in that direction. Under these circumstances, there will be a delay in the transmission of the load from the fluid phase to the solid phase as compared to an incongruent joint, thus sparing the collagen matrix from a major portion of the total applied stress.

Using the relative principal curvatures as quantitative indices of congruence, it was determined that male CMC joints are significantly more congruent than female joints as a result of the different shape of the trapezial surfaces in the two sexes, as well as the difference in joint size. Consequently, contact stresses in the solid phase of cartilage in female CMC joints will be greater than in male joints under similar joint loading conditions. Thus, during similar activities of daily living which involve similar hand pinch or grasp load levels, female thumb CMC joints may experience higher stresses than male joints. These higher stresses may predispose females to degenerative disease of the thumb CMC joint

CONCLUSION

While the above results do not provide a definitive answer to the highly complex phenomenon of gender-related predisposition to CMC joint OA, they do establish a new plausible pathway which can be further investigated in future studies. We caution that our curvature calculations were based on measurements made on a pool of aged and diseased specimens which may not represent those of younger and healthier specimens. Furthermore, the results of this study cannot answer the question as to whether gender-related shape differences lead to increased OA in the female population, or whether prevalence of OA in females lead to shape differences, i.e., which came first? To further investigate the various hypotheses on OA, it would be necessary to understand how the shape of the surfaces changes with age and disease. Data from young healthy specimens could provide controls with which older and diseased specimens may be compared. If strong correlations are found between articular surface curvature and predisposition to OA, it will be clinically useful to investigate methods of measuring salient curvature characteristics from ordinary biplanar radiographs.

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Table 1: Mean curvature characteristics of CMC joint articular surfaces (average and standard deviation over all specimens)

Trapezium	n	Area (cm^2)	$\bar{k}_{min}$(m^{-1})	$\bar{k}_{max}$(m^{-1})	$\bar{k}_{rms}$(m^{-1})	$\bar{k}_{max}/\bar{k}_{min}$
Female	8	1.05 (0.21)	−61 (22)	190 (36)	165 (32)	−3.7 (2.3)
Male	5	1.63 (0.18)	−87 (17)	114 (19)	118 (6)	−1.4 (0.5)
Total	13	1.27 (0.35)	−71 (24)	161 (48)	147 (34)	−2.8 (2.1)
Female vs Male		$p \leq 0.01$	$p \leq 0.05$	$p \leq 0.01$	$p \leq 0.01$	$p \leq 0.01$
Metacarpal	n	Area (cm^2)	$\bar{k}_{min}$(m^{-1})	$\bar{k}_{max}$(m^{-1})	$\bar{k}_{rms}$(m^{-1})	$\bar{k}_{max}/\bar{k}_{min}$
Female	8	1.22 (0.36)	−49 (10)	175 (25)	154 (20)	−3.8 (1.3)
Male	5	1.74 (0.21)	−37 (11)	131 (17)	116 (8)	−3.9 (1.5)
Total	13	1.42 (0.40)	−44 (12)	158 (31)	140 (25)	−3.8 (1.3)
Female vs Male		$p \leq 0.05$	$p \leq 0.05$	$p \leq 0.01$	$p \leq 0.01$	NS
NS=Not Significant						

Table 2: Normalized mean curvature characteristics of CMC joint articular surfaces (average and standard deviation over all specimens)

Trapezium	$\bar{k}_{min}^*$	$\bar{k}_{max}^*$	$\bar{k}_{rms}^*$
Female	−0.62 (0.21)	1.93 (0.36)	1.69 (0.35)
Male	−1.12 (0.25)	1.45 (0.21)	1.50 (0.09)
Total	-0.81 (0.33)	1.75 (0.38)	1.62 (0.29)
Female vs Male	$p \leq 0.01$	$p < 0.05$	NS
Metacarpal	$\bar{k}_{min}^*$	$\bar{k}_{max}^*$	$\bar{k}_{rms}^*$
Female	−0.53 (0.11)	1.90 (0.27)	1.68 (0.21)
Male	−0.49 (0.14)	1.74 (0.29)	1.53 (0.17)
Total	−0.52 (0.12)	1.84 (0.28)	1.62 (0.20)
Female vs Male	NS	NS	NS

Table 3: Congruence Indices (Relative Principal Curvatures)

	k^e_{min} (m^{-1})	k^e_{max} (m^{-1})	k^e_{rms} (m^{-1})
Female	109.5 (36.0)	145.3 (36.2)	129.3 (33.3)
Male	43.9 (28.3)	77.1 (25.8)	63.5 (24.7)
Total	84.2 (46.1)	119.1 (46.7)	104.0 (44.3)
Female vs Male	$p \leq 0.01$	$p \leq 0.01$	$p \leq 0.01$

FORCES IN THE HAND-ARM SYSTEM STUDIES INTO THE PROBLEMS OF LEFT-HANDEDNESS

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Due to changes in pedagogics, there are more left-handed persons, uninfluenced by environmental factors, today than there used to be. In the Western civilizations, the number of left-handed persons amounts already to about 10 to 25 % of the total population and is even likely to increase. Thus it is important to gather ergonomic fundamental data of this group of people, too.

Up to now, only few approaches to ergonomic product and work design have been made taking left-handers into consideration. For this reason, tests were carried out at the Fraunhofer-Institute for Industrial Engineering to compensate these deficits.

Left-handedness has effects on the individual work strain. If workplaces, machines, tools, devices etc. are designed inadequately for left-handers, the strain on the worker increases, a fact which has consequences for the occupational safety. Since even right-handed people, due to outward circumstances, are compelled to use their left hand, we also included the left hand-arm system of right-handers in our studies.

TASK

An important ergonomic factor in work design is the maximum static operational force of the human hand-arm system. On the basis of these values the maximum reasonable work load for heavy force activities can be determined.

<u>In our studies we concentrated on the following topics:</u>

1. Are the values of people’s static operational force as documented in literature and in the standard specifications—they have been established without special regard to handedness—equally valid

a) for both, right- and left-handed persons?

b) for both extremities, that is the left and the right hand-arm system of each of the two groups?

2. In case differences in strength between left and right arm are observed: Do they depend on the position of the force application point and/or on the direction of the applied force?

DEFINITION

Although tests to measure man's physical strength have been carried out for many years now, inaccuracies regarding the definition and the procedures still exist. Therefore the definition of the term "maximum static operational force" by Schmidke (1981) is stated here.

The maximum static operational force is the force which is measured outside the body. It can be applied by deliberately making the greatest efforts to contract intensively all groups of muscles involved for about 2–6 seconds, and then can be, body and extremities being fixed towards a certain direction and a force application point set in a space position relative to the body, be transferred from the body to a control element outside, if there is sufficient counterforce.

This definition served as the basis for our studies.

PROCEDURE

To answer the above mentioned questions, we chose the procedure described in fig. 1.

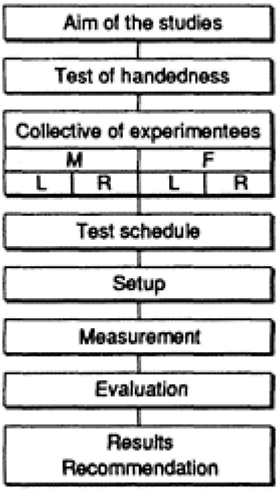

Fig. 1 Procedure "maximum force measurement"

After determining the aim of our studies a collective of experimentees was assembled, that is four groups of experimentees, each of them consisting of 20 students at the age of

20–30 years. Since the aspect of the sex should also be taken into account to clear the topic in question, four different groups of experimentees were needed altogether:

Female and male left-handers as well as female and male right-handers. The difficulty was to find out the transition point between left- and right-handedness, which cannot be as clearly defined as it may seem at first sight. In principle, a distinction has to be made between hand preference, that is whether a person prefers to use his or her left hand, and hand performance, which denotes the greater efficiency of one hand. These two different aspects of handedness have to be considered separately, as there is only a slight correlation between them. The distribution of hand preference looks like a "J" and is illustrated in fig. 2. Accordingly, there are relatively few markedly lateralized left-handers, many not markedly left- or right-handers and a very large number of right-handers.

As can also be gathered from the illustration, hand performance shows a normal distribution in favour of the right side. This means that there are rather few persons being the most efficient when using their left hand-arm system. Many people are similarly efficient with both, left and right hand-arm system; frequently, however, the right side shows a greater efficiency than the left side. Nevertheless, a clear superiority of the right is rarely to be found.

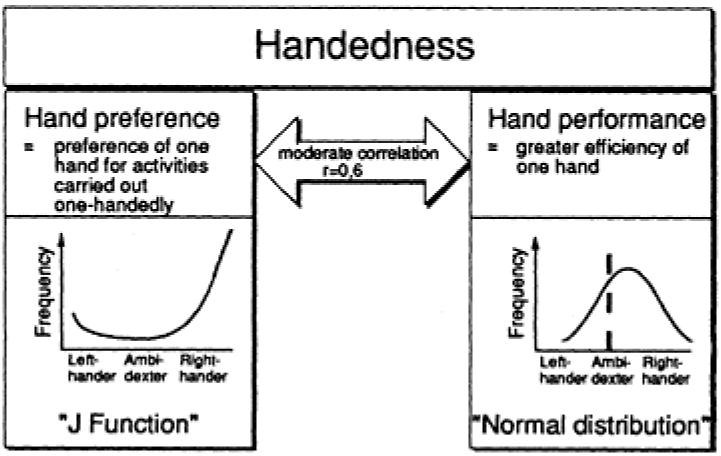

Fig. 2 Hand preference and hand performance

AIM OF MEASUREMENTS

Contrary to the tests of man's static operational forces carried out in the past, the tests in question didn't aim at imitating as close as possible the conditions of reality. The point was rather to work out most exactly the differences between left and right arm concerning the maximum static operational force. The measurements were effected with the test persons being in a fixed sitting position, because it is essential for comparative measurements to take place actually under the same conditions.

This fixation by means of a belt provided an unchangeable position of the experimentees and consequently a maximum of reproducibility. By doing so, a probable influence of the weight on the measurements could be excluded.

In the course of the tests, four respective directions of force were measured in four different positions as shown in fig. 3. When choosing the space position of the force application points as well as when determining the force directions, importance was attached to achieving as great a practice orientation as possible. Without doubt, vertical and horizontal tensile and compressive forces are the forces which are applied by workers the most frequently. As a result, the majority of the occurring force application points are in a range of the arm working distance of 75 to 100 %

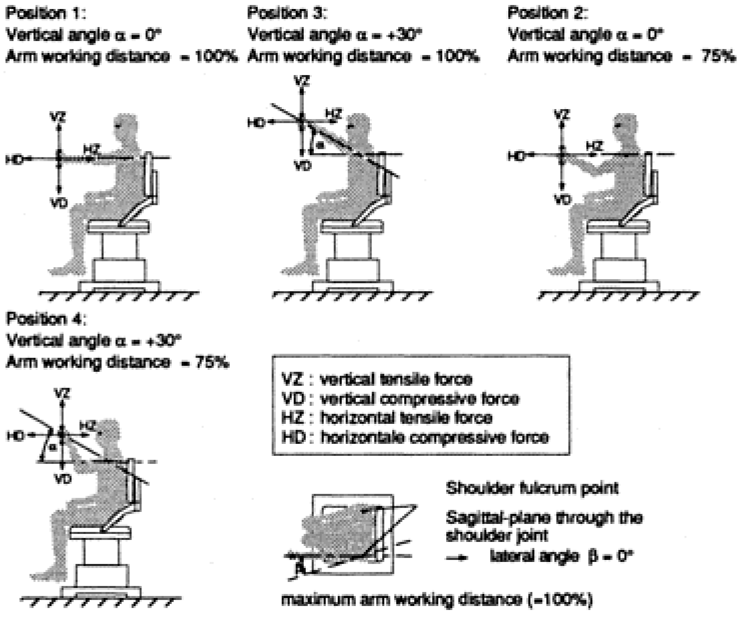

Fig. 3 Space positions of the application of force

A vertical arranged plastic handle, 15 cm long and with a diameter of 32 mm was used as interface between experimentee and measuring instrument. The test procedure itself was carried out according to a randomized test plan, each test consisting of two successive test runs. The measured data were collected by a force measuring system and, after being transformed correspondingly, processed by a computer.

TEST PERFORMANCE

Fig. 4 shows a recorded force development progress: On the whole, one sub-test took 5 seconds, but only the last 2 seconds were used to determine the maximum force. The result of each sub-test was checked regarding its validity. Things such as continuity of the force development progress in the measuring window and the size of possibly arising spurious forces were the criterion applied.

EVALUATION

The effected measurements were statistically evaluated by the programme packet SPSS.

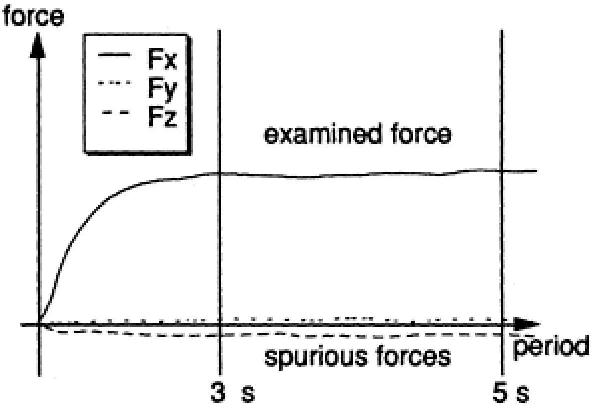

Fig. 4 Example of a “successful” test

ABSOLUTE VALUES

No measurements of maximum static operational forces made under directly comparable circumstances are documented in literature. The studies by Hunsicker (1955) who measured the forces in question of left and right arm in a group of 55 male experimentees, seem to be the most suitable ones for direct comparison. The results of his studies compared to our results can be seen in fig. 5.

	literature[1] left / right	RH, male[2] left / right	LH, male[2] left / right
VZ	182,8 / 191,7	60,9 / 70,2	87,8 / 83,3
VD	156,1 / 182,8	93,1 / 89,4	113,6 / 114,9
HZ	521,7 / 539,5	520,1 / 591,4	771,6 / 758,5
HD	561,8 / 615,4	477,2 / 529,6	497,3 / 550,9

1: mean value of 55 test persons
2: mean value of 5 test persons

Space position of the application point of force
Vertical angle α = 0°, arm working distance R = 100%
All results are in Newton [N]

Fig. 5 Comparison of the maximum position forces of both male test person groups with bibliographical data

The clear differences in the case of the vertical forces are remarkable. A possible cause for this appears to be, first of all, the strong dependence of the vertical forces on the spurious forces.

Because of the design of the force-receiver and the computer-aided measurements of the present study spurious forces could immediately be recognized and, to a large extent, eliminated by repeatedly carrying out such tests, whereas this was probably not equally possible in 1955. If we concentrate on the horizontal forces we notice that in Hunsicker's studies the maximum compressive forces are distinctively stronger than the corresponding tensile forces. This is not quite what was expected, and it is also in complete opposition to the results achieved by the present studies.

The reason for this discrepancy lies mainly in the lacking possiblity of body support. As far as horizontal tensile forces are concerned, only an adequately effected positioning of the upper part of the body enables the maximum static operational forces to develop to the full.

If we consider the horizontal compressive forces in Hunsicker's studies as normal—only these can actually be compared with those of the present studies—both groups of male experimentees have to be characterized as rather weak.

However, our studies didn't aim at determining the absolute maximum forces, but rather at comparing left and right side of left- and right-handed persons. On the basis of these studies, the measured values can be denoted reliable.

RELATIVE VALUES

Figure 6 represents the differences in strength of left and right hand-arm system, each time related to the dominant hand. Both right-handed experimentee groups showed a distinct superiority in strength of the dominant hand-arm system which is even more evident with male than with female right-handers.

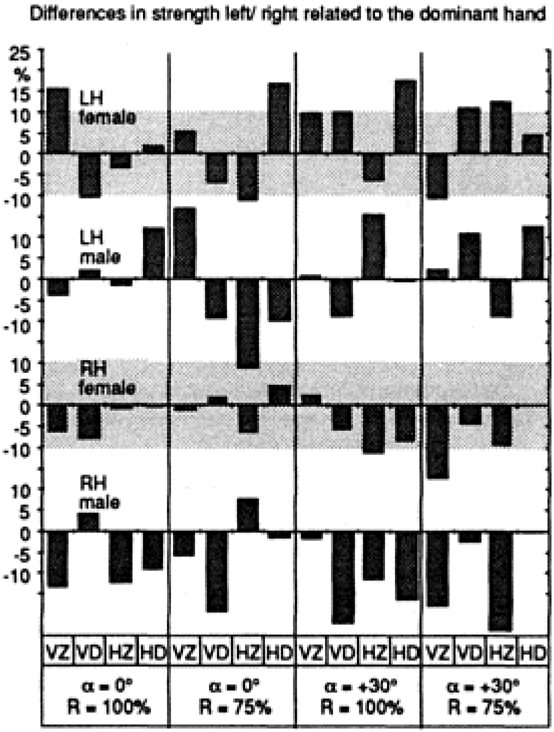

Fig. 6 Differences in strength

The application of the T-Tests led to significant results according to the one per cent probability of error. The fact that left-handed persons are not more efficient with their dominant hand-arm system than with their subdominant one, is quite surprising.

On the contrary, left-handed experimentees even achieved slightly stronger maximum static operational forces when using their right hand-arm system. However, these differences could not be proved on a statistically expressive level. The generally almost identical forces in the right and left hand arm system of left-handers are a clear sign that the right-oriented environment compels even strongly lateralized left-handers to train the forces of their subdominant right hand-arm system continuously.

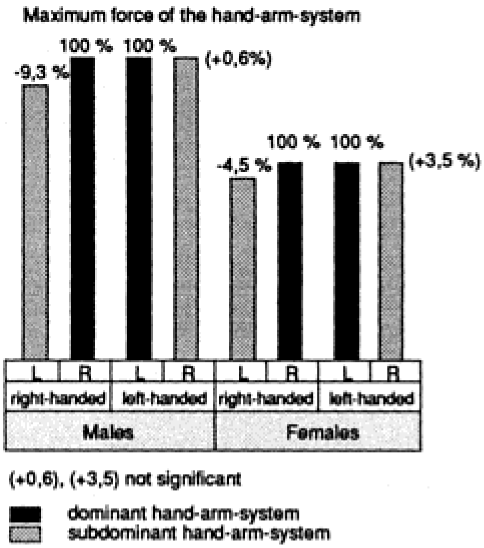

Fig. 7 Survey of the results in maximum force determination

RESULTS

All test results are summed up and represented in fig. 7. The most important and in this form quite astonishing result of the present studies was that a highly significant inferiority in strength of the subdominant hand-arm system could be observed in both groups of right-handed experimentees. In the case of female right-handers this inferiority amounted to 4.5 %, for male right-handers it even amounted to 9.3 %.

Contrary to this, the maximum static operational forces hardly differed between left and right hand-arm system. On the whole, female left-handers showed a slight superiority of their subdominant right arm of plus 3.5 %; however, this difference could just as little be proved to be significant as in the case of male left-handers who achieved practically the same maximum static operational force in both arms.

Consequently, our questions can be answered as follows:

1. The values for the maximum static force according to the standard specifications are fully valid, at least for left-handers of both sexes.

2. The ascertained inferiority of the subdominant hand-arm system of right-handed persons requires an appropriate modification of the values mentioned.

3. No dependence of the observed differences in strength between left and right hand-arm system on the position of the force application point and/or the direction of the applied forces may be noticed.

RECOMMENDATION

In order to exclude reliably an overexertion in strength, regardless of the handedness of a worker, the values specified in literature should be cut down by 10% for males and by 5% for females. Also a notice should be added, saying that the maxmum static operational force for activities which are to be performed by the left hand should be set at a 5 to 10% lower level. This would make sure that an overexertion of less universally usable right-handers concerning their usability for heavy force workplaces is avoided.

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AN EMG-ASSISTED BIOMECHANICAL MODEL OF THE WRIST JOINT

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A 3-D biomechanical model of the wrist joint was developed that estimated the compression and shear forces on the wrist joint during isokinetic exertions. This model was data-assisted by electromyographic (EMG) signals collected via fine wires from the forearm flexor and extensor muscles. Absolute compression on the wrist joint reached a peak of 500 N, which appears to be anatomically feasible. This model shows it is possible to quantitatively estimate the loadings on the wrist joint during dynamic exertions.

INTRODUCTION

In order to understand the impact of repetitive and forceful hand/wrist exertions on risk of cumulative trauma disorders (CTDs), one needs to look at the physical stress on the internal structures of the wrist joint, such as the tendons, ligaments, and bones. A 3-D biomechanical model of the wrist joint is one way to investigate the stresses on these anatomical structures.

Using Newtonian mechanics, a 3-D biomechanical model of the wrist was developed that estimated the compression and shear forces on the wrist joint during isokinetic exertions. This model did not optimize muscle forces or reaction forces on the wrist joint. Rather, the model was data-assisted in that wrist loads were calculated from estimates of forearm muscle force, as measured by EMG.

MODEL

The biomechanical structure of this 3-D wrist model consisted of a transverse plane cutting through the wrist and force vectors representing seven major tendons passing the wrist, as shown in figure 1. These tendons transmit force exerted by extrinsic muscles in the forearm to the hand and fingers for grip or pinch force and torque generation about the wrist. The seven muscles consisted of the following:

Flexor tendons	
Flexor carpi radialis	FCR
Flexor digitorum superficialis	FDS
Flexor digitorum profundus	FDP
Flexor carpi ulnaris	FCU

Extensor tendons	
Extensor carpi radialis	ECR
Extensor digitorum	ED
Extensor carpi ulnaris	ECU

The approach in this model of analyzing loads across a transverse plane is similar to Schultz and Andersson's (1981) work in assessing loads across a transverse plane in the lumbar region.

The method of estimating loads based on EMG data, rather than using optimization to solve statically indeterminate problems, was patterned after the pioneering work of Marras and Sommerich (1991a and 199 lb). This model of the wrist was data-driven by EMG signals collected from the respective muscles via fine wire electrodes. The EMG signals were normalized, modulated for velocity artifacts and length-strength relationship, and converted into force for each respective muscle.

The flow of data and analysis within the model proceeded as follows. First, EMG signals from the seven major extrinsic muscles were normalized with respect to maximum EMG values, and then they were modulated for velocity artifacts and the length-strength relationship and physiologic cross-sectional area (PCSA) for each muscle. Each muscle's force was calculated by multiplying normalized EMG by a factor called a gain. Muscle force for FDS and FDP was partitioned into a component that produced pinch or power grip force and a component that generated wrist flexor torque. The gain for all muscles, which was the force relative to PCSA, was set at a minimum threshold and incremented upward until external work of a full extension to flexion wrist movement predicted by the model exceeded measured external work. Once predicted external work surpassed measured work, then compression and shear forces on the wrist joint were calculated. In addition, a squared correlation was computed to assess how well predicted torque matched measured torque throughout a full extension to flexion wrist movement.

The outputs of this model were fourfold:

1. Gains for each muscle (N/cm^2).

2. Prediction of external torque calculated by the biomechanical model. Muscle force was estimated from EMG.
3. Statistical comparison of predicted external torque with measured torque.
4. Loadings on the wrist joint (compression and shear forces).

METHOD

Before data collection, fine wire EMG electrodes were inserted into the seven muscle bellies by a licensed physician. The total diameter of these fine wires, including metal and insulation, was approximately 0.003 inches in diameter. Fine wires were chosen over surface electrodes because the resulting signal from fine wires is from a much smaller, more local area of muscle than from surface.

As shown in figure 2, an isokinetic Cybex dynamometer was used to control angular velocity of the wrist and also to measure external torque and wrist position. Two subjects gripped a custom-built handle, outfitted for pinch and power grips, while they exerted constant flexion torque at constant velocities. In each trial, the wrist started at an extension posture greater than 60 degrees and ended at a full flexion angle greater than 60 degrees. The experimental design consisted of two angular velocities (30 and 45 deg/sec), two torque levels (four and eight N-m), and two grip orientations (power and pinch). Based on an industrial surveillance study on wrist motion in hand-intensive repetitive jobs, 30 and 45 deg/sec were the mean flexion/extension velocities that were measured in jobs of low and high risk of CTDs, respectively (Marras and Schoenmarklin, 1991). Power or pinch force was not controlled while the subject exerted constant external torque throughout the full range of movement.

There were three repetitions within each of the experimental conditions, resulting in a total of 24 trials (2 velocities×2 torque levels×2 grips×3 repetitions).

RESULTS

The results from this study are as follows:

1. Final gains ranged from 20 to 60 N/cm^2 of muscle area. These values are consistent with the reported gains in the literature.

2. Torque predicted under pinch conditions agreed with external torque better than power grips. The mean squared correlation values for pinch and power trials were 0.654 and 0.413, respectively. Low correlations for power grip trials might have been due to less than optimal partitioning of FDS and FDP force into grip force and torque generating components.

3. Absolute compression on the wrist joint reached a peak of 500 N, which appears to be anatomically feasible. The wrist is capable of withstanding substantial compressive forces because of its tightly-fitting multifaceted bones and taut ligaments.

4. Compression normalized to external torque was approximately 50 to 60 N per N-m of external torque. Compression normalized to external torque did not reveal a velocity or torque effect over the ranges tested.

5. In the radial/ulnar and flexion/extension planes, shear forces normalized to external torque were about 10 and 5 N per N-m of torque, respectively.

CONCLUSIONS

This model shows that it is possible to quantitatively estimate the loadings on the wrist joint during dynamic exertions. This model was validated by comparing the predicted external torque with actual external torque. The predicted external torque matched the actual external torque well, as evinced by the squared correlation values. The estimates of muscle gain and compression and shear all agree with reported values in the literature.

In the future, this model could be used to explain in part why wrist motions associated with high risk of CTDs are injurious to workers. Quantitative measurement of the forces within the wrist and carpal tunnel would aid researchers and clinicians in understanding the etiology of CTDs. In addition, this model enhances our general understanding of the kinetic and kinematic aspects of the wrist.

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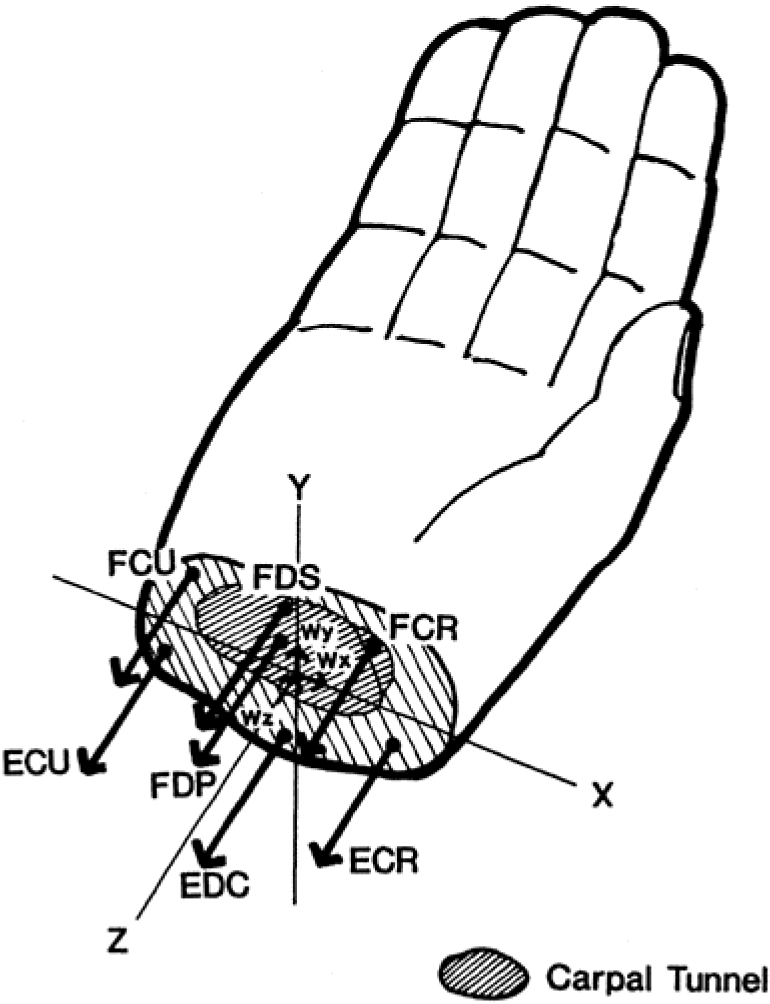

Figure 1. Transverse plane cutting through the wrist joint and force vectors representing seven major tendons passing through the wrist joint.

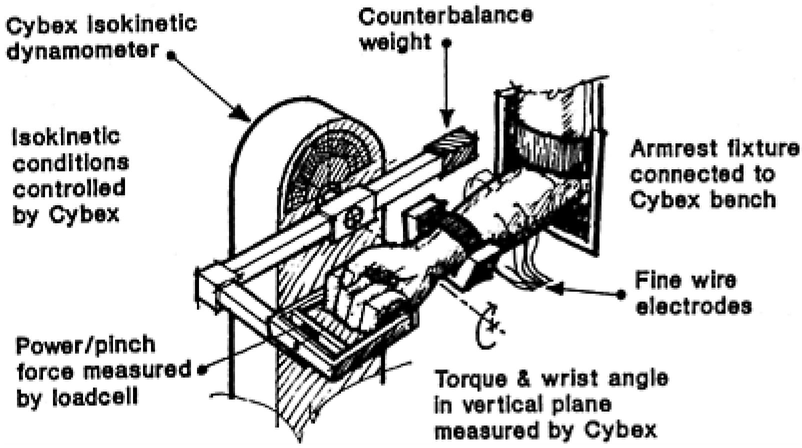

Figure 2. Experimental setup used to control wrist movement and collect EMG data.

Prediction Models of Grip Strength at Varying Wrist Positions

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Two laboratory experiments were conducted to examine the effect of various wrist positions on grip strength for females. Results of ANOVA showed that wrist flexion had a significant effect on grip strength. As wrist flexion angle increased grip strength decreased significantly. A set of 4 regression models were developed to predicted grip strength as a function of wrist flexion angle and various anthropometric and physiological measures which could be used in industrial situations.

INTRODUCTION

Cumulative trauma disorders (CTD) have become a matter of urgent ergonomic concern in the 1980s and 1990s. They represent nearly half of occupational illness reported in the annual Bureau of Labor Statistics survey (OSHA, 1990). One of the major forms of CTD is carpal tunnel syndrome (CTS) (Putz-Anderson, 1988). CTS is a disorder caused by injuries of the median nerve within the wrist due to compression (Kroemer, 1989). The impact of CTS upon business and industry is becoming clear as monetary costs rise. The average cost associated with a CTS case has been reported to be approximately $3,500, while for the more severe cases, compensation and disability claims may range from $30,000 to $60,000 (Hiltz, 1985). Recently, Fernandez, Marley, and Young (1990) reported that the average costs associated with CTS cases in a Midwestern manufacturing facility ranged from $15,000 to $18,000. There are many possible causes of CTS. The risks may be related to occupation or due to non-occupational activities. Among the occupational risk factors are repetitiveness, forceful exertion, static muscle load, awkward body posture, mechanical stress, vibration, and cold temperature (Putz-Anderson, 1988).

Fernandez, et al., (1989) studied the effects of CTS on various anthropometric, physiological, and psychological measures for a sample diagnosed with CTS and a matched control group. Results of this study indicated that the values of grip strength and range of motion of the wrist were significantly lower in the CTS group than in the control group.

In many hand-intensive industrial tasks, it is difficult to keep the wrist in the neutral position while grasping an objects or hand tool. Thus, the effect of deviated wrist position should be considered in grip strength guidelines for hand-intensive industrial tasks. Recently, two experimental studies which, in part, examined the effect of wrist position on grip strength of females (Marley, 1990; Kim, 1991). This paper presents those specific results of these studies and a set of prediction models of grip strength at varying wrist postures is developed utilizing the data from the two studies.

METHODS AND PROCEDURES

Subjects

Twelve female subjects participated in the Experiment One (Marley, 1990), whereas fifteen female subjects participated in the Experiment Two (Kim, 1991). Thus, a total of twenty-seven subjects from the student population (non-industrial workers) at Wichita State University participated in both experiments. Subjects were screened so as not to allow participation of any individual who had a history of CTD of the upper extremities, particularly involving the hands and wrists. This screening was conducted during a selection interview. Phalen’s test was administered to further confirm the acceptability of each subjects.

Apparatus

1. Anthropometric Kit—anthropometric measures were assessed with the Siber Hegner & Co., Inc., anthropometric kit.

2. Hand Dynamometer—an adjustable hand grip dynamometer (Japan Medical Instrument Research Lab, Inc.) was used for measurement of grip strength.

3. Goniometer—a standard mechanical goniometer (Lafayette Instrument Inc.) was used to measure the range of motion and to indicate angles of wrist during experimentation.

Procedures

1. Anthropometric Measures and Range of Motion—standard anthropometric measures of the subject's dominant hand and wrist were taken. These measurements included standing height, weight and six dimensions of the hand wrist. These hand wrist measures were hand length (measured from wrist crease to distal end of third finger), circumference of wrist, thickness of wrist, width of wrist, hand breadth at metacarpals, and thickness of metacarpal. Maximum wrist flexion in the transverse plane and ulnar deviation in the sagittal plane were also measured. The body landmarks for these measures were the axis from the lateral epicondyle to the distal end of the third metacarpal rotating about the palpable groove between the lunate and capitate.

2. Grip Strength—maximum voluntary contraction (MVC) for grip strength was measured using the hand grip dynamometer. Subjects were required to stand with their elbow flexed at 90 degree of angle and the arm adducted. Subjects gradually increased exertion and the maximum effort was maintained for approximately two seconds. This was repeated twice and the highest value was recorded. If the values from two trial were not within ±5% each other, another trial was taken. Between each trial subjects were allowed to take at least three minutes of break so that they could recover from the onset of fatigue. No more than two trials were completed per day. This was primarily due to other concurrent experimental procedures.

Experimental design

A randomized block design model was applied for both Experiment One and Two with subjects as blocks. In Experiment One (Marley, 1990), grip strength was measured at 9 different wrist positions which were the combinations of 3 flexion angles (neutral, 1/3, and 2/3 of maximum flexion) and 3 ulnar deviation (neutral, 1/3, and 2/3 of maximum ulnar deviation). Experiment Two (Kim, 1991) measured grip strength at 4 different angles of flexion which were neutral (0 degree), 10, 20, and 30 degree from the neutral position of the wrist. The order of trial for subjects was randomized in both experiments.

RESULTS AND DISCUSSIONS

Analysis of data

Analysis of variance (ANOVA) models were used to analyze data collected in the two experiments. Data analysis was performed using the SAS statistical package (SAS, 1985) on the IBM 3081 mainframe system and are summarized in Table 1 and 2.

Table 1. ANOVA Summary for Experiment One (Marley, 1990).

Source	SS	df	MS	F	Pr>F
Subject	3456.27	11	314.21	53.55	0.0001*
Flexion	1036.74	2	518.05	88.29	0.0001*
Ulnar dev.	27.68	2	13.84	2.36	0.0998
Flexion*Ulnar	49.99	4	12.49	2.13	0.0826
ERROR	586.78	100	5.87		
TOTAL	5337.47	119			

*denotes the factor is significant

Table 2. ANOVA Summary for Experiment Two (Kim, 1990).

Source	SS	df	MS	F	Pr>F
Subject	453.23	14	32.37	18.50	0.0001*
Flexion	1545.31	3	515.10	294.35	0.0001*
ERROR	73.50	42	1.75		
TOTAL	2072.05	59			

*denotes the factor is significant

The ANOVA for the Experiment One revealed that wrist flexion had a significant effect on the grip strength. However, both ulnar deviation and interaction between flexion and ulnar deviation did not have significant effects on grip strength. The ANOVA from the Experiment Two also showed that flexion had a significant effect on grip strength. Thus, wrist flexion had a significant effect on grip strength in both experiments. As angle of wrist flexion increased, grip strength decreased significantly.

Prediction of grip strength

Since the two experiments were conducted at same laboratory with similar experimental procedures and subject populations, an attempt to combine the data from these two experiments was made to develop prediction models for grip strength. The result of t-tests between two subject groups showed that there were no significant differences ($p<0.05$) between the two groups in terms of their anthropometric and physiological measures. Hence the data from the two experiments were combined to develop a set of prediction models. Table 3 presents the descriptive statistics of the combined subjects. These grip strength data were then compared with grip strength from a previously published research (Mathiowetz et al., 1985). The results of the t-test showed that there was no significant difference ($p< 0.05$) in grip strength between the two studies.

Table 3. Descriptive Statistics of Subjects.

Variables	N	Mean	STD	Range
Age (years)	27	24.8	5.2	19–36
Height (mm)	27	1627.3	52.5	1550–1753

Weight (kg)	27	59.4	8.7	50–81.6
Grip strength (kg) at neutral angle	27	30.1	4.6	22–40

An objective of this study was to develop predictive equations for grip strength based upon wrist flexion angle and other parameters. Stepwise multiple regression and R-square selection procedures were used to determine salient equations using various parameters which were angle of wrist flexion, six hand measurements, age, height, and weight of the subject. Also grip strength at neutral position of wrist and wrist ratio (wrist thickness over wrist width) were used as additional independent variables in the model. First, diagnostic tests such as normality checking were performed to assure that there were no major departures from the assumptions of multiple linear regression models (Neter, Wasserman, and Kutner, 1985). Also, other types of regression models were considered in the selection of model. However, a multiple linear regression model appeared to be the best model in the present study. The results from the residual analysis also confirmed the appropriateness of the multiple linear model.

The general criteria for appropriateness and efficiency of these models were: 1) detection of outlier by residual analysis; 2) analysis of multicollinearity and variance inflation factor (VIF); 3) evaluation of F ratio and R^2; 5) evaluation of Mallow's C(p) criterion to check the bias of a model. When the improvement between models (i.e. R^2 or C(p)) was not significant or small, the model with independent variables which were easy to access or measure was selected. The models were selected to have practicality without significant sacrifice of prediction efficiency. A set of 4 regressional prediction equations are presented in Table 4 with corresponding R^2 and Mallow's C(p).

These models yielded acceptable accuracy in the prediction of grip strength as a function of wrist flexion angle and various anthropometric and physiological parameters. The independent variables in the models appeared to be reasonably easy to measure in many industries without utilization of sophisticated knowledge and expensive equipment. Any of these 4 models can easily be used, however, equations 1 and 3 are preferred since they require the least number of independent variables.

Table 4. Regression Equations for Grip Strength.

Regression Equation		R^2	C(p)
1. GS_{FA}	$=13.163+0.169*WT-0.299*FA+0.920*NGS-30.492*WRT$	0.834	5.27
2. GS_{FA}	$=8.044+0.154*WT-0.302*FA-0.852*NGS+0.133*MB-33.650*WRT$	0.837	6.07
3. GS_{FA}	$=-2.776+0.211*WT-0.298*FA+0.925NGS-0.645*WTH+0.306*WW$	0.836	7.33
4. GSFA	$=-11.093+0.117*AGE+0.152*WT-0.299*FA+0.904*NGS-0.470*WTH+0.354*WW$	0.841	6.99

Where, GS_{FA}=Grip Strength (kg) at the particular flex. angle
WT=Weight (kg)
FA=Wrist flexion angle (degree)
NGS=Grip strength at neutral wrist position (kg)
WRT=Wrist ratio (wrist thickness over wrist width)
AGE=Age of subject (years)
WTH=Wrist thickness (mm)
WW=Wrist width (mm)
MB=Hand breadth at metacarpal (mm).

CONCLUSIONS

The results of this study showed that wrist flexion has a significant effect on grip strength. As angle of wrist flexion increased, grip strength decreased significantly. Thus, the finding from this study concluded that grip strength guidelines in hand-intensve tasks should be adjusted accordingly as wrist is flexed from the neutral positions to reduce the risk of CTD in many hand-intensive industries. The proposed regression models in the prediction of grip strength can be applied with acceptable accuracy and practicality in many industrial tasks to evaluate the grip strength limits of workers when deviation of wrist cannot be eliminated from the tasks.

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VALIDATION OF GRIP FORCE MEASURED BY FORCE SENSITIVE RESISTORS THROUGH COMPARISON WITH PREDICTION FROM EMGS

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INTRODUCTION

Cumulative trauma disorders (CTDs) will continue to be a topic of great concern until the number of injuries is significantly reduced. NIOSH has developed a plan entitled Proposed National Strategies for the Prevention of Leading Work-Related Diseases and Injuries, Musculoskeletal Injuries which states that the first of four steps to reduce injuries is: "Identifying accurately the biomechanical hazard" (NOISH publication No 89–129, 1986).

The need to accurately measure the grip force needed to perform a job stems from the work done by many researchers including Silverstein et al. (1987) who found that high repetitiveness and high grip force together were the most significant factors in CTDs of the wrist. The ability to document the amount of grip force a given job requires is important not only for classifying dangerous jobs but also in judging the effectiveness of interventions. Methods for estimating static grip force include various strain gauge dynamometers, pressure sensors, and predicting grip force from the amplitude of concurrent RMS-EMG of the muscles used in gripping.

Armstrong et al. (1979) made use of the relationship between force and EMG to estimate grip force. In this method the subject grips at known force levels, as measured by a dynamometer, and EMGs of the muscles used to grip are collected concurrently. Then the EMG and concurrent grip force are regressed together using the least squares method. Armstrong et al. recommend that these calibration curves are made for each subject on each day of testing. Armstrong et al. (1979) concluded that a linear relationship existed between grip force and wrist/finger flexor muscle RMS-EMG amplitude after testing over one hundred subjects.

The relationship between force and EMG depends on many factors including: state of training of the subject, the amount of cocontraction, the muscle tested, the duration and the type of contraction and the percent of maximal contraction (Chaffin and Anderrson, 1984; Basmajian and De Luca, 1985). Ohtsuki (1981) reported a linear relationship between flexor digitorum profundus and flexor digitorum superficialis EMGs and the force produced by those muscles in a static hook grip. Smith (1991) found a linear relationship between extrinsic finger flexor RMS-EMG and static power grip force.

Another method of predicting grip force requires using small, thin force sensors. The EXOS, Inc. (Burlington, MA) GripMaster™ measures dynamic grip force using up to 5 resistive ink sensors, made by Interlink Electronics, while simultaneously measuring the amount of wrist flexion/extension and wrist abduction/adduction. Resistance decreases with increasing force in a logarithmic fashion. Each sensor must be calibrated since every sensor has a unique response pattern. During testing each sensor must be carefully placed and taped onto the subject's finger so that it is located between the material being held and a bony surface on the hand.

The main purpose of this study was to test the validity of the GripMaster™s grip force measurements as compared to the method recommended by Armstrong et al. (1979) using a repeated measures analysis of variance on the concurrent grip forces. The extent of the need to calibrate EMG measures each day was also tested using a repeated measures ANOVA to test for differences between dynamometer grip force, GripMaster™ grip force and EMG predicted grip force using the first day as calibration data for the second day.

METHODS

Subjects

Twelve healthy, non-weight-trained adult women were recruited for this study and all subjects gave their informed consent. Subjects had no past or current wrist injuries. The subjects had the following characteristics: mean age of 27.2 years (SD=5.8), mean height of 170.0 cm (SD=4.4), mean mass of 65.5 Kgs (SD=12.0), and mean power grip of 264.5 Newtons (SD=51.6).

Protocol

Each subject's arm was prepared for EMG data collection using methods recommended by Basmajian and De Luca (1985). Indelible ink was used to mark the location of the markers on the first day. There were two minutes of rest between each trial and data were collected on the two separate days spaced three to seven days apart.

All three methods of predicting grip force were collected concurrently during each trial. A static three finger hook grip using digits 2, 3, and 4 (Index, Middle, and Ring) was used during each trial. The first two trials tested the subject's maximum hook grip strength. Next the subject performed four trials at 15%, 30%, 45% and 60% of maximal voluntary contraction (MVC), presented in one of four fixed orders which were repeated on the second day of testing. Dynamic concurrent visual feedback from a voltmeter measuring the output from the dynamometer helped the subject maintain very steady grip forces. Trials lasted 6 seconds, during the first 3 seconds the subjects adjusted their grip to match preset levels based on their maximal grip. The dynamometer was set to collect and average over the last 3 seconds, and over the last 2 seconds both RMS-EMG and GripMaster™ data were collected and later averaged. Trials were considered successful if the average dynamometer grip force was within 4.4 newtons of the peak dynamometer grip force. The first 2 and last 2 trials at each percentage of MVC, for each subject on each day were averaged for all three measurement systems (referred to as the 1st and 2nd data points). This yielded 8 grip force predictions for each measurement system on each day for each subject.

Electromyography

One pair of silver-silver chloride bipolar reusable electrodes was attached parallel to the long axis of the forearm 3.5 centimeters apart on the volar surface of the shaved and scrubbed right forearm. The electrodes were placed one third of the total distance of the forearm length from the wrist of each subject (Ohtsuki, 1981). These electrodes were located over the flexor digitorum profundus and flexor digitorum superficialis, in an area where these muscles were not covered by the carpal flexor muscles (Pansky, 1984).

The raw EMG signal was processed using the root mean square (RMS) method and the input impedance was 10^9 ohms. Skin resistance was reduced to less than 100 Kohms. The common mode rejection ratio was 120 dB.

RMS-EMG data were sampled at 100 Hz for two seconds, then the 200 data points for each trial were averaged. The resting level was subtracted and then each trial was converted to a percentage of the average of the 60% MVC trials (referred to as scaled RMS-EMG). Calibration curves were made from the first data points and second data points on the first and second day and both first day points. This yielded 5 calibration equations for each subject, 2 within each of the two days and one using the first day to predict the second day. Figure 1 contains the calibration curve and equation to predict the grip force for the 2nd data points on the first day for a typical subject. The correlation coefficients were usually larger than 0.90 with a range from 0.69 to 1.00

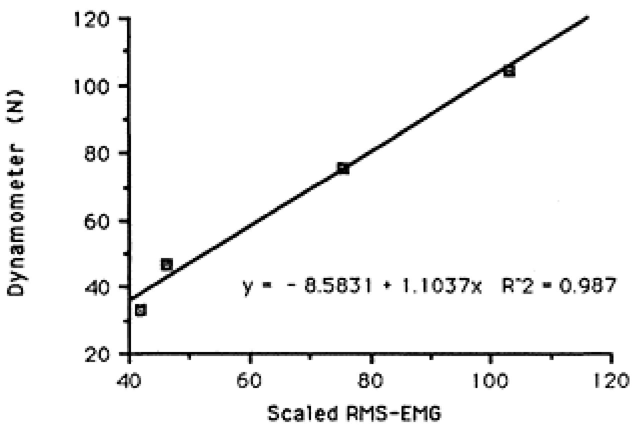

Figure 1. Typical subject's EMG calibration curve to predict the grip force for the second pair of trials. Scaled RMS-EMG is a percentage relative to 60% of MVC.

Jackson Evaluation System

The Jackson Evaluation System (referred to as dynamometer, Lafayette Instrument Company, Lafayette, Indiana) was used to measure static grip force. The dynamometer had a resolution of 4.45 Newtons.

The subjects sat in a comfortable chair with their arms resting on a table in a position that had the elbow in a 90 degree angle. The subjects gripped the dynamometer with their right hand so that they could use a hook grip on the dynamometer handle.

GripMaster™ Grip Force

Three GripMaster™ force sensors were applied ink-side up to the dynamometer handle with Johnson and Johnson athletic tape so that one was under the middle phalange of each of the three fingers used for the hook grip. The force sensors each have a factory resolution of approximately one Newton and an approximate range of 1 to 130 Newtons. The hook grip force was the sum of the force from the three sensors. The sampling rate was 50 Hz for both calibration and grip force data sampling.

Known weights were used to calibrate the GripMaster™ force sensors after each subject. Calibration masses of 1, 3, 5 and 7 kilograms were carefully placed on each sensor for 3 trials. Each trial lasted 3 seconds and an average over the last 2 seconds was taken. A basket suspended from a small, square, flat, hard plastic peg of the exact shape of the sensor held the calibration weights. Each sensor was placed between the peg and a small flat wooden arm. Raw analog to digital units from a 12-bit A to D board (referred to as A to D units) for each sensor for 3 trials at each of the 4 different weights were averaged.

The averaged raw A to D units at each force level were regressed with the concurrent force level using a logarithmic fit for each sensor after each use. Twenty sensors were used during this experiment, each one was identified by a letter. Figure 2 shows the calibration curves for the 2 uses of sensor J. Sensors became less responsive with increasing use until each was subjectively deemed to be dead. Sensors lasted for an average of 3.6 uses with a standard deviation of 1.64 uses. The correlation coefficients for each calibration curve for each use of each sensor were all quite strong with an average R squared of 0.99 and standard deviation of 0.01

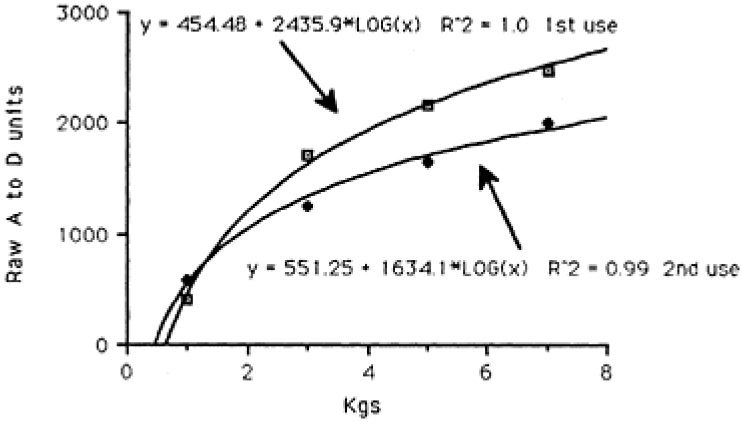

Figure 2. Calibration curves and equations for sensor J

Statistical analysis

A repeated measures ANOVA was used to test for significant differences in means over days, in scaled RMS-EMG predicted grip force, GripMaster™ grip force, and dynamometer grip force measures at each percentage of maximal grip force. A repeated measures ANOVA was also used to test for significant differences between the concurrent grip force data measured by the three methods when the scaled RMS-EMG data from the first day was used to calibrate and thus predict the grip force for the scaled RMS-EMG data from day 2.

RESULTS

Predicting grip force using within day calibration for EMG

The results from the within day EMG calibration are presented in Table 1. The condition factor, which represented the different levels of grip force, was the only significantly different main effect. None of the first order interaction terms were significantly different. No other interaction terms were included; this accounts for the discrepancy between the sum of the degrees of freedom listed and the total at the bottom of the table. The same is true for the sums of squares.

Table 1. Repeated measures analysis of variance for grip force.

SOURCE	DF	MS	F
COND (A)	3	150333.00	73.19**
DAY (B)	1	701.71	0.24

METHOD (C)	2	3692.90	0.73
TRIAL (D)	1	116.54	0.13
SUBJ (E)	11	19336.00	
A×E	33	2094.90	
B×E	11	2940.60	
C×E	22	5081.10	
D×E	11	874.79	
A×B	3	541.44	1.19
A×B×E	33	453.30	
A×C	6	162.27	0.18
A×C×E	66	892.74	
A×D	3	183.78	0.72
A×D×E	33	255.81	
B×C	2	0.85	0.00
B×C×E	22	3412.30	
B×D	1	340.31	1.15
B×D×E	11	296.08	
C×D	2	127.12	0.28
C×D×E	22	451.09	
Total	575		

**p<0.01

Grip force using the 1st day to calibrate the 2nd day for EMG

Table 2 contains the results of using the first day as the calibration data in predicting the grip on the second day for the EMG method of grip force prediction. Only the main and first order effects are presented. The condition factor was the only significantly different main effect. None of the second order interaction terms were significantly different.

Table 2 Analysis of variance using day 1 to predict for EMG.

SOURCE	DF	MS	F
COND (A)	3	72311.00	50.28**
METHOD (B)	2	2591.70	0.39
TRIAL (C)	1	298.10	0.98
SUBJ (D)	11	9197.80	
A×D	33	1438.30	
B×D	22	6647.6	
C×D	11	303.26	
A×B	6	267.33	0.28
A×B×D	66	953.85	
A×C	3	128.73	1.24
A×C×D	33	103.58	
B×C	2	55.55	0.29
B×C×D	22	193.31	

TOTAL	287		

**p<0.01

DISCUSSION

The most important use of this laboratory study of static grip force will be in selecting the best method for measuring grip force in the field. Since the GripMaster™ and the EMG method were not significantly different from each other or the dynamometer, the next important issue is ease of use in the field. Both methods are fairly easy to use in the controlled environment of the laboratory, but there are large differences between them in factory settings.

Both the GripMaster™ and EMG methods can be used in field studies (Smith, 1990; Silverstein et al., 1987; Armstrong et al., 1979). However, the EMG method is easier for several reasons. First, the subject's hands are not encumbered with tape, sensors and wires as the GripMaster™ requires. The EMG electrodes are located on the forearm which leaves the hands with much more mobility.

Both the taped on GripMaster™ sensors and the EMG electrodes can become loose if the subject perspires, but the EMG electrodes have been designed to stay on even during heavy sweating. If the locations for the EMG electrodes have been carefully marked with ink, new electrodes can be placed on the subject and recalibration is not necessary. The ability to collect more EMG data using the previous day's calibration curves or when the electrodes fall off and are replaced is supported by the lack of significant differences between the dynamometer grip force and the GripMaster™ grip force and the predicted EMG grip force using day one to calibrate day two. To keep the GripMaster™ force sensors in place the subject's hands must be fairly clean and dry; this is not always possible in a factory. The EMG method allows the subjects to get their hands wet or greasy.

Another issue is the frailty of the GripMaster™ sensors. The sensors are easily creased or damaged, because they need to be taped to the fingers where the compressive and bending forces are largest. During hectic data collection in a factory, the GripMaster™ computer operator may not notice decreasing force levels due to sensor death, since this is a gradual process. EMG electrodes are fairly rugged and do not normally break during testing. Since the sensors break easily, careful record keeping and calibration is required to make sure data is not lost due to using a sensor which dies before you can calibrate it. In some cases this requires pre and post calibration, which takes 5 minutes per sensor.

A final sensor issue is placement. Some factory jobs require a wide variety of grabs and hand activities. The GripMaster™ force sensors must be carefully repositioned for each new grip. The GripMaster™'s ability to measure individual finger forces is one area where the GripMaster™ is superior to the EMG method of grip force prediction. This is due to fact that the EMG method has no way of predicting individual finger forces since the major flexor muscles' tendon splits to reach the 4 fingers.

In conclusion this experiment found no differences between 2 possible methods of measuring grip force in the field. Ease of use in the field makes the EMG method better than the GripMaster™ for field testing worker grip forces.

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THE INFLUENCE OF HANDLE DIAMETER ON MANUAL EFFORT IN A SIMULATED ASSEMBLY TASK

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The risk of cumulative trauma disorders may be reduced by designing tools to reduce manual effort. This study evaluated the effects of three handle diameters on manual effort. Handles were matched to the user's inside grip diameter, 1.0 cm smaller than grip diameter, and 1.0 cm larger than grip diameter. Applied grip force and surface EMG were monitored. Manual effort was least when the smaller handle was used. The handle matched to the user's grip size also required less effort than the larger handle. For some tasks, handles 1.0 cm smaller than grip diameter may reduce the risk of fatigue and injury.

INTRODUCTION

Workers who routinely handle tools, parts, and materials subject their hands to a variety of mechanical forces. Forceful exertion, especially if repetitive, can cause damage to underlying structures such as tendons, tendon sheaths, and nerves (Armstrong et al., 1987). Data from previous studies have demonstrated a strong association between cumulative trauma disorders (CTDs) such as tendinitis and carpal tunnel syndrome, and forcefulness of manual work (Falck and Aarnio, 1983; Silverstein et al., 1986; Smith et al., 1977; Thompson et al., 1951).

Attempts to identify measures for controlling grip force have focused on various aspects of tool design. Numerous investigators have considered the effect of handle size on manual force exertion (Armstrong et al., 1982; Ayoub and Lo Presti, 1971; Khalil, 1973; Johnson, 1988; Pheasant and O'Neill, 1975; Radwin and Oh, 1991). Nearly all suggest that handle size can significantly influence force exertion in manual work.

A shortcoming of these investigations, however, is few consider the effect of handle size relative to the size of the user's hand. Hand size can vary significantly; in a mixed (50/50) male/female population, grip diameter varies nearly 2 cm between population extremes (Eastman Kodak, 1983).

The findings of several studies suggest that the selection of an "optimum" handle diameter may depend, in part, on the size of the user's hand. For example, several investigators have shown that handgrip strength is greatest at one particular hand span (Bechtol, 1954; Greenberg and Chaffin, 1975). At smaller and larger handle diameters, the joints in the hand and fingers are repositioned such that mechanical advantage is reduced (Petrofsky et al., 1980).

According to Fox (1957), a handgrip where thumb and forefinger overlap is preferred to a wider handle. Others suggest that a handle designed to fit the hand with no overlap of fingers and thumb could have advantages for reducing required grip force. A handle which maximizes surface contact with the skin would permit users to utilize frictional forces to assist in maintaining a grip (Armstrong et al., 1982; Drury, 1980).

The purpose of this study was to evaluate the effect of three cylindrical handle diameters on manual effort in a simulated assembly task. Handle diameters for evaluation were selected based on anthropometric measures of inside grip diameter. The three handles evaluated were (1) a handle diameter matched to the user's inside grip diameter; (2) a handle diameter 1.0 cm smaller than the user's inside grip diameter; and (3) a handle diameter 1.0 cm larger than the user's inside grip diameter. Manual effort was assessed by comparing force exerted on the handle during the task to maximum force generating capacity. Electrical activity (EMG) in the forearm flexor and extensor muscles was also monitored during the task.

METHODS

Subjects

Sixteen right-handed males between the ages of 18 and 30 years were recruited from a temporary employment agency to participate in this experiment. All participants were free of any known musculoskeletal impairments. At the beginning of each test session, informed consent was obtained, and right hand length, breadth and inside grip diameter were measured. The data are summarized in Table 1.

Table 1. Anthropometric characteristics of study participants.

	Age (yrs)	Hand Length (cm)	Hand Breadth (cm)	Grip Diameter (cm)
Mean	22.81	19.72	9.19	5.31
Std. Dev.	3.99	1.08	0.51	0.45

Equipment

A simulated industrial workstation was designed and constructed for this experiment. The workstation consisted of a height-adjustable chair and table positioned in front of a free standing pulley system (Figure 1). The pulley system was constructed using a Baltimore Therapeutic Equipment (BTE) work simulator with rope, pulley and 101.6 cm extension pole attachments (parts 191 and 191B). A spool was attached to the BTE exercise shaft and the extension pole was attached to the exercise head to extend horizontally over the work table The rope assembly was attached to the extension pole and exercise head to permit free movement of the rope over the pulleys and shaft. The test handle was suspended from the rope at the end of the extension rod.

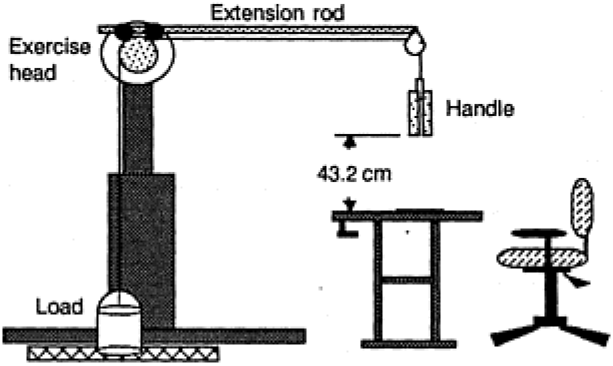

FIGURE 1. Experiment workstation.

The test handle consisted of an aluminum rectangular bar (2.5 cm [length]×1.3 cm [width]×14 cm [height]) instrumented with a strain gage. The configuration used to mount the strain gage is described by Pronk and Niesing (1981). Curved aluminum half-shells (10.5 cm length) were attached to the short sides of the bar with set screws. Handle diameter was adjusted by inserting aluminum shims (0.32 cm width) between the half-shells and the aluminum bar (Figure 2). Three handle sizes were evaluated during the experiment: (1) a handle diameter matched to the participant's inside grip diameter (the "fit" handle); (2) a handle diameter 1.0 cm smaller than the participant's inside grip diameter (the "smaller" handle); and (3) a handle diameter 1.0 cm larger than the participant's inside grip diameter (the "larger" handle). Resistance was varied during the experiment by attaching 1.1 ("light"), 2.3 ("medium"), and 3.4 ("heavy") kg masses to the BTE rope assembly.

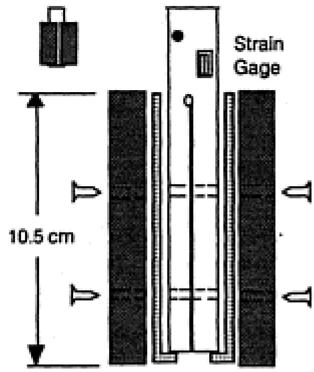

FIGURE 2. Test handle.

Task

Participants were seated in front of the workstation. Chair and table height were adjusted so that the participant's knees were bent at approximately 90 degrees and the feet were flat on the floor. The handle was positioned 43.2 cm above the table, in a sagittal plane with the participant's right shoulder.

Before initiating the work task, isometric strength tests were conducted to determine the participant's maximum grip strength with each handle. Tests were conducted while the participant sat in the same posture used during the experiment; the handle was temporarily lowered to a position 5.1 cm above the table. Strength during maximum voluntary contraction (MVC) of muscles controlling grip was measured using the standard procedures described by Caldwell et al. (1974). Measurements were repeated three times with each handle. One minute of rest was allowed between exertions. The average of the three efforts with each handle was recorded as the maximum grip strength.

During the work task, participants were required to grasp the handle with the right hand and pull it down to a target marked on the worktable. Participants were told to hold this position briefly, then to return the handle to its starting position and release it. This task was repeated once every five seconds for 2.5 minutes. An electronic timer was used to help participants maintain the proper work pace. Participants performed the task using all nine diameter/ resistance combinations, presented in random order. A three minute rest period was provided between experimental trials.

Dependent Variables

Grip compression force and right forearm EMG were monitored during work periods. Grip compression force applied along the length of the handle was measured using the strain gage mounted in the handle. Power and amplification for the strain gage was provided by a Force Monitor© (Prototype Design, Ann Arbor, MI). Right forearm EMG was monitored using surface electrodes positioned over the flexor pollicis longus, flexor digitorum superficialis and extensor digitorum muscles. Three channels of EMG data were collected using the Therapeutics Unlimited (TU) Model 544 Electromyographic

System©. A high-pass filter with a cut-off frequency of 20 Hz was used to remove low frequency noise from the EMG signals. Root mean square (RMS) values were calculated using an 11.75 ms time constant. Strain gage output and processed EMG were sampled at 175 Hz and stored by microcomputer using a 12-bit analog-to-digital converter and LabTech Notebook© data acquisition software.

Research Design

The design for the experiment was a complete within-subject, repeated-measures design (3×3). Multivariate analysis of variance (MANOVA) with univariate repeated-measures tests was used to assess the significance of the main effects (handle diameter and resistance) and interactions. Degrees of freedom were adjusted to correct for violations in the ANOVA assumptions due to the repeated measures (Geisser and Greenhouse, 1958). Dependent variables included: (1) average grip force for each trial; (2) peak grip force for each trial, determined by averaging the peak exertion levels in the thirty task cycles; (3) flexor pollicis longus EMG (average RMS value for each trial); (4) flexor digitorum superficialis EMG (average RMS value for each trial), and (5) extensor digitorum EMG (average RMS value for each trial). Grip force and EMG values were referenced to MVC strength (normalized) to obtain an estimate of effort; these values are expressed as a percent.

RESULTS

Grip strength during MVC is plotted as a function of handle diameter in Figure 3. As reported by others (Petrofsky et al., 1980), grip strength was strongly dependent on handle diameter $F(1, 15)=26.96$, $p<0.0001$. The greatest forces were generated with the smaller handle. Maximum grip strength increased an average of 39% for each 1.0 cm decrease in handle diameter.

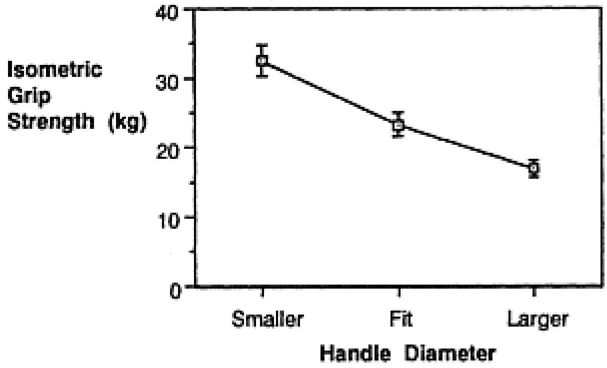

FIGURE 3. Maximum grip strength as a function of diameter.

Peak and average grip forces applied to the handles during the task are plotted in Figure 4. Peak and average grip force varied directly with resistance, $F(1, 15)=57.34$, and $F(1, 15)=105.25$, $p<0.0001$. Handle diameter had no effect on peak or average grip force exertion during the task, $F(1, 15)=0.69$, $p=0.5056$, and $F(1, 15)=1.05$, $p=0.3586$.

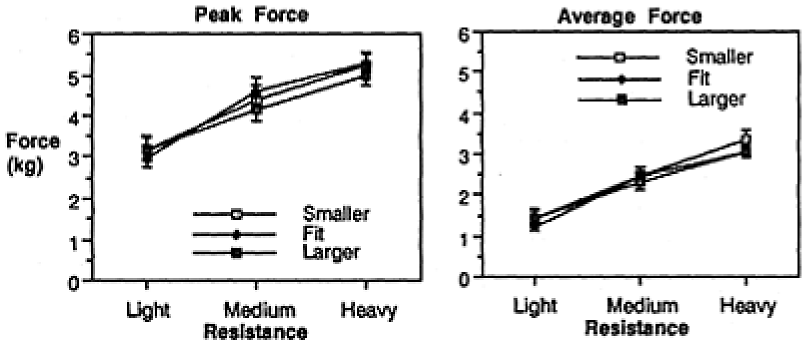

FIGURE 4. Peak and average force as a function of diameter.

Effort can be defined as the percent of maximum force generating capability expended to perform an activity (i.e., actual force exerted/force during MVC). Because capacity for exerting grip force decreased as handle diameter increased, the effort required to use the "fit" and "larger" handles increased, even though absolute force requirements remained constant. Peak and average effort levels for different handle diameters and resistances are plotted in Figures 5a and 5b. Analysis of variance revealed the effect of handle size to be significant for both peak and average effort, $F(1, 15)=9.58$, $p=0.0029$ and $F(1, 15)=9.36$, $p=0.0035$. Increased resistance produced corresponding increases in effort, $F(1, 15)=33.47$ for peak effort, $F(1, 15)=62.47$ for average effort, $p<0.0001$ for both values. No significant interaction between handle size and resistance was observed, $F(1, 15)=1.71$, $p=0.2011$ for peak effort, and $F(1, 15)=2.59$, $p=0.0906$ for average effort.

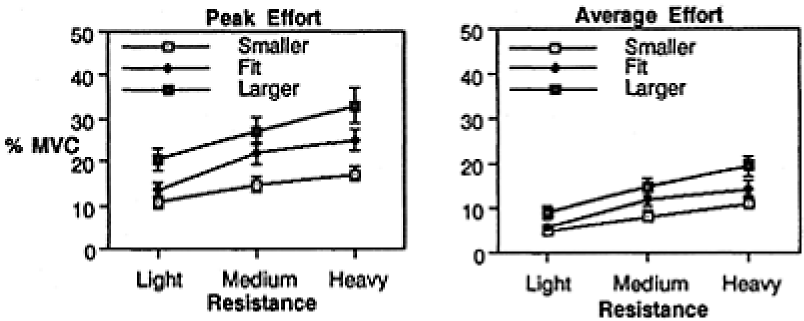

FIGURE 5. Peak and average effort as a function of diameter

Normalized EMG activity in the three forearm muscle groups is plotted in Figures 6a, 6b and 6c. The data indicate muscular effort increased with handle diameter. Analysis of variance revealed the effect of diameter to be significant for all muscle groups, $F(1, 15)=21.39$, $p<0.0001$ for the flexor pollicis longus, $F(1, 15)=4.78$, $p=0.0261$ for the flexor digitorum superficialis and $F(1, 15)=4.56$, $p=0.0348$ for the extensor digitorum. Increased resistance produced strongly significant increases in muscle activity, $F(1, 15)=49.15$ for the flexor pollicis longus, $F(1, 15)=51.21$ for the flexor digitorum superficialis, $F(1, 15)=36.37$ for the extensor digitorum, $p<0.0001$ for all muscle groups.

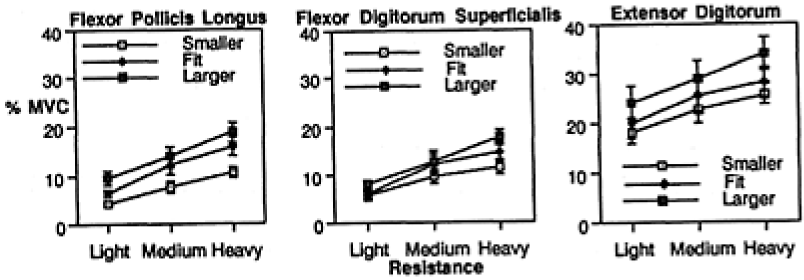

FIGURE 6. Forearm EMG as a function of handle diameter.

CONCLUSIONS

This study demonstrates that even small changes in handle diameter (+/−1.0 cm) can have significant effects on manual effort. The results support Fox’s conclusion (1957) that a handle which allows some overlap between the thumb and forefinger may be better for some applications than a larger handle. Because only three handle sizes were evaluated in this study, it is not known if a handle 1.0 cm smaller than grip diameter actually represents the “optimal” handle size for minimizing manual effort in this task. Additional research is needed to determine if additional decreases in relative handle diameter can further reduce manual effort. There is probably a handle diameter which is “too small”, where grip capacity is decreased due to reduced mechanical advantage. Handles which are significantly smaller than inside grip diameter also concentrate force on the palm of the hand. Sustained or repeated mechanical stress at the base of the palm can result in blood flow obstruction to the fingers and median nerve compression (Tichauer, 1978; Armstrong, 1983).

The results indicate there may be benefit to manufacturing tools with different sized handles to allow users with larger and smaller grips to select handles best suited for their hand size. The difference in inside grip diameter between the 5th and 95th percentiles of a 50/50 male/female population is only 1.9 cm (Eastman Kodak, 1983). Therfore, most users within the population extremes could be accomodated by three to five different handle sizes.

Finally, this study indicates the relationship between handle size and anthropometric dimensions should be an important consideration in future handle evaluations. It is recommended that future investigations consider the effect of relative handle size on grip exertion. Studies involving different tasks, postures and handle orientations are needed to determine if the match between hand and handle has similar effects on manual exertion in other situations.

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An Investigation Into the Effect of Lowforce High Frequency Manual Activities on the Development of Carpal Tunnel Syndrome.

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INTRODUCTION

Cumulative trauma disorders of the upper extremities have reached epidemic proportions in some industries and are a major cause of lost work and worker's compensation (Ferguson, 1984; Gelberman et al., 1988). One common cumulative trauma disorder that has recently received much publicity is carpal tunnel syndrome. Carpal tunnel syndrome is attributed to compression of the median nerve inside the carpal tunnel (Arminio, 1986; Carrage and Hentz, 1988; Hoyt, 1984; Pfeffer, 1988).

Inflammation of the flexor tendons (tendinitis) is the most common cause of compression of the median nerve and is thus a precursor to carpal tunnel syndrome (Ertel and Millender, 1987; Johnson, 1985). The exact cause of tendinitis is unknown at this time although studies of workers in several industries have shown a correlation between the incidence of tendinitis and hand forces, wrist posture, and frequency of hand and finger movements (Armstrong et al., 1987; Barnhart and Rosenstock, 1987).

Presently most research has focused on tendinitis caused by high hand forces and awkward wrist postures (Armstrong et al., 1982; Cannon et al., 1981). However recent evidence indicates that tendinitis can occur in jobs with light hand forces and neutral wrist postures but that require highly repetitive motions such as word processing (Armstrong et al., 1987; Silverstein et al., 1987;, Wieslander et al., 1989).

The exact etiology of damage to the tendons and to the synovium due to low force highly repetitive motion is unknown at this time although many possible mechanisms of injury have been proposed. Some of the more plausible theories are as follows. 1) Micro tearing of the tendons due to excessive strain. 2) Fraying of the tendons due to mechanical wear. 3) Shearing of the synovium due to relative motion between the tendons.

The objective of this project was to study changes to the flexor digitorum tendons and the synovium in the carpal tunnel as they relate to the injury mechanisms discussed above for highly repetitive motions at low hand forces with neutral wrist postures such as would be experienced during word processing.

This objective was accomplished in three separate investigations. First, by quantifying creep of the flexor tendons at loads and frequencies levels experienced during word processing and determining if strain levels were high enough to produce strain-induced tendon damage. Second, the possibility of mechanical wear of the tendons was examined by measuring changes in tendon friction in the carpal tunnel with time. These changes in friction were measured in human cadaver arms under loading conditions that simulated word processing. Third, changes to the tendons and surrounding synovium caused by light load repetitive hand movements were studied in a non-human primate model.

The information obtained from this study will help lay the groundwork and direction for future examination of the etiology of tendon damage caused by word processing. This understanding is necessary so that appropriate changes in work tasks and work place design can be accomplished.

MATERIALS AND METHODS

Creep Test

Sixty eight flexor digitorum tendons (profundus and superficialis) from 17 fresh frozen cadaver hands were utilized for testing. After thawing overnight at room temperature the specimens were prepared for testing by removing the flexor tendons of the middle, index, and ring fingers from the hand and forearm. The bony attachments of the tendons at the fingers were left intact. The tendons were loaded in tension using a MTS Bionix Test System. Load and strain were recorded for each test. Specimens were kept moist with normal saline throughout specimen preparation and testing. All tests were performed at room temperature.

Three loading conditions were investigated: a static load for 30 minutes, a cyclic load at a frequency of 1 Hz (1/2 second load/1/2 second no load) for 100 minutes, and a cyclic load at a frequency of 1/4 HZ (2 seconds load/2 seconds no load) for 100 minutes. Four different load levels, 10, 20, 50, 100 Newtons, were utilized for each loading condition. These load levels were chosen because previous studies by the authors indicated that flexor tendon force during word processing is between 10 and 60 Newtons (Smutz et al., 1992). Seven specimens were tested at each load level for the static test and for the cyclic test at a frequency of 1 Hz and three specimens were tested at each load level for the cyclic test at 1/4 Hz (68 specimens total).

Analysis of variance was used to test for differences in the elastic strain between the three loading conditions (static, 1 Hz cyclic, 1/4 Hz cyclic) at all four load levels (10, 20, 50, 100 Newtons) and to test for differences in elastic strain between the four load levels at all three loading conditions. Analysis of variance was also used to test for differences in creep strain between the three loading conditions at all four load levels and to test for differences in creep strain between the four load levels at all three loading conditions. An α=0.05 was selected as criteria for rejection of the null hypothesis.

Friction Study

Three pair of fresh frozen human cadaver arms were used for the friction study. After thawing overnight at room temperature, the forearms were dissected to isolate the flexor digitorum superficialis tendons of the ring and middle fingers both distal and proximal to the carpal tunnel. The cadaver specimens were then rigidly attached to a test fixture by placing kirschner wires through the radius and ulna. The proximal end of the flexor superficialis tendons of the middle and ring fingers were then attached to pneumatic cylinders using sutures. The distal end of the tendons were attached to coil extension springs again using the sutures. Load cells were placed in series with the pneumatic cylinders and the extension springs to measure tendon force both distally and proximally to the carpal tunnel. Computer controlled solenoid valves were used to operate the pneumatic cylinders.

The tendons were subjected to a cyclic load of 20±1 Newtons, applied to the proximal end of the tendons, at a frequency of 1 Hz. The total test time for each specimen was 6 hours. Tendon force both distal and proximal of the carpal tunnel was recorded for 15 seconds every 30 minutes throughout the test. To help insure that dehydration of the specimens did not occur, saline was infused into the carpal tunnel of one half of the test specimens.

Analysis of variance was used to test for differences in distal and proximal tendon force with time and to test for differences in tendon force between the arms that were infused with saline and those that were not. An $\alpha=0.05$ was selected as criteria for rejection of the null hypothesis.

Animal Study

Two disease free male Macca Mulatta (Rhesus) primates were used for the animal study. Neuromuscular electrical stimulator was used to stimulate the forearm muscles of one arm of each animal. Electrical stimulation permitted control of hand forces as well as the frequency and number of repetitions. Two conditions, simultaneous finger movement (fingers move in unison) and opposing finger movement (fingers move opposite each other) were studied. Opposing finger movement was felt to be a more severe loading condition because it produces relative motion between the tendons. Prior to testing the animal was sedated and secured in a chair specially fabricated for this experiment. The wrist was placed in approximately 30 degrees of flexion by a wrist splint. The other arm was not stimulated but served as a control. Opposing finger movement was achieved by restricting movement of the index and little fingers using velcro straps.

The flexor and extensor digitorum muscles were stimulated at an amplitude just above contraction threshold at a frequency of 3 Hz. Each minute consisted of 45 seconds of muscle stimulation followed by a 15 second rest period. The experimental treatment was conducted for 6 hours per day. The 6 hour per day experimental treatment was performed for 5 days per week for 3 weeks (729,000 cycles).

At the end of the experimental treatment period the animal was sacrificed. At necropsy, tissue blocks containing the entire carpal tunnel region were collected and immersion-fixed in buffered formalin. The tissues were demineralized, embedded in methyl methacrylate, and sectioned. The sections were stained and examined by light microscopy.

A detailed histological evaluation of each of the four wrists was performed. Comparisons were made between the stimulated and control wrists and between the two stimulated wrists. The wrists were evaluated for signs of the infiltration of inflammatory cells, an increase in the number of fibroblasts or capillaries, the presence of fibrosis or edema, or signs of mechanical wear or tearing.

RESULTS

Creep Study

Results of the creep study are shown in Figures 1 through 3. A comparison of the shape of the curves indicates that although elastic strains are similar, creep strain increased faster for the static condition than it did for either cyclic condition and that creep strain was greater for the static condition than it was for either cyclic condition.

No statistically significant differences were found between elastic strains for the three test conditions (static, 1 Hz cyclic, 1/4 Hz cyclic) at any of the four load levels (10, 20, 50, 100 Newtons). Statistically significant differences were found between elastic strains for the four load levels at all three test conditions. Statistically significant differences were found between the creep strain for the static and 1 Hz cyclic tests at 10, 20, and 50 Newtons, for the static and 1/4 Hz cyclic tests at 20, 50 Newtons, and for the 1 Hz and 1/4 Hz cyclic tests at 50 Newtons. Statistically significant differences were found between creep strains for the four load levels at all three test conditions.

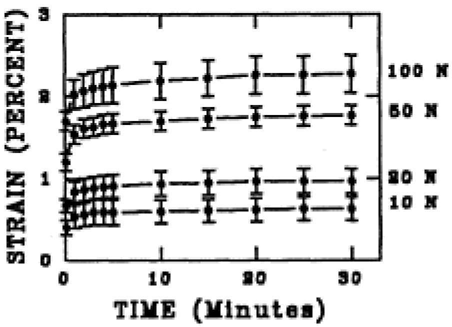

Figure 1

Results of Static Creep Test

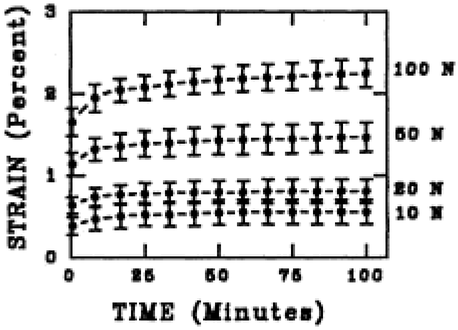

Figure 2

Results of Cyclic Creep Test at 1 Hz

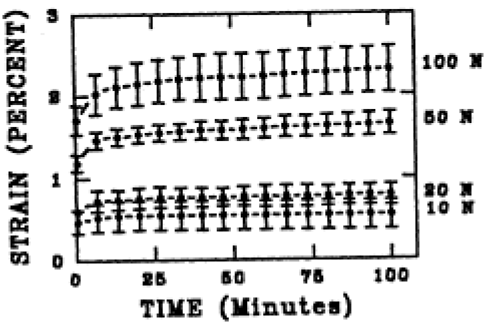

Figure 3

Results of Cyclic Creep Test at 1/4 Hz

Friction Study

Results of the friction study are shown in Figures 4 and 5. Results show that tendon force distal to the carpal tunnel decreases by 10.5±2.4 percent after 6 hours for the arms infused with saline and by 13±4.8 percent after 6 hours for the arm that were not infused with saline while tendon force proximal to the carpal tunnel remained constant. A statistically significant difference was found between the tendon force distal to the carpal tunnel and the tendon force proximal to the carpal tunnel for both the specimens that were infused with saline and the specimens that were not. No statistically significant difference was found between specimens that were infused with saline and the specimens that were not.

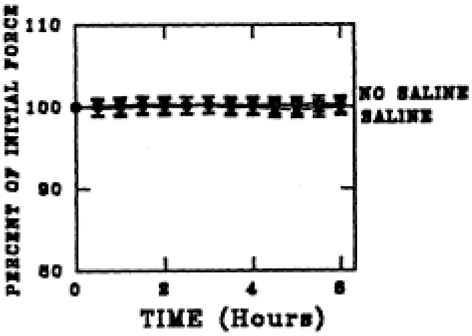

Figure 4

Tendon force proximal to the carpal tunnel.

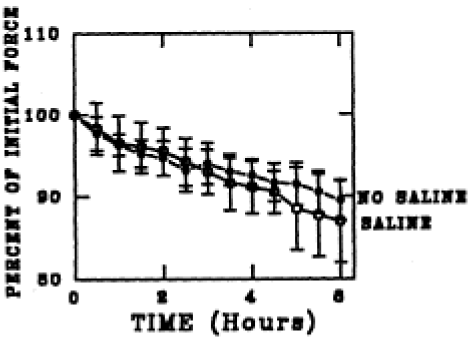

Figure 5

Tendon force distal to the carpal tunnel.

Animal Study

Results of the histological comparison of each wrist showed no distinguishable differences between the stimulated wrist and the control wrist for either animal and no distinguishable differences were seen between the two stimulated wrists for the two different loading conditions (simultaneous vs. opposing finger movement). No evidence of excess infiltration of inflammatory cells was seen. Some macrophages and mast cells were present in the synovial tissue in all the specimens, but there was no apparent difference in number of cells between the two stimulated wrists or between either stimulated wrist and its control. An increase in the number of fibroblasts or capillaries was not seen in any of the specimens. Signs of edema such as increased thickness of any of the tissues were not present in any of the specimens. No signs of mechanical wear or tearing of the tendons was seen in any of the specimens.

DISCUSSION

Results of the creep test suggest that for a flexor tendon force of 60 Newtons, the total strain (elastic plus creep) of the tendon would be approximately 1.8 percent. This is not enough strain to cause permanent damage to the tendon according to the cumulative strain models proposed by Abrahams (1967) and Goldstein (1981). This suggests that a mechanism other than cumulative strain is responsible for tendon damage during high frequency low force activities.

One such possible mechanism of tendon damage that was investigated was fraying of the tendon due to mechanical wear. The results of the friction study showed that tendon friction did increase with time for a low force high repetition loading condition in a cadaver model. Increased tendon friction may result in mechanical wear and abrasion of the tendons. This mechanical wear could result in enough damage to the tendons to cause tendinitis. One explanation for the increased friction is a loss of the synovial fluid from the carpal tunnel during repetitive motion. Synovial fluid is a non-Newtonian, viscoelastic fluid that decreases in viscosity with increases in shear rate (Davis and Palfrey, 1968). As a result, during highly repetitive tendon motions the viscosity of the synovial fluid may decrease sufficiently to allow the synovial fluid to escape from the tendon sheaths.

The results of the in vivo animal experiment indicate that highly repetitive motions encountered over a relatively short period of time have little effect on tissue in and around the carpal tunnel. This would support the theory that the symptoms of tendinitis for high repetition, low force tasks may take months or even years to develop. This would suggest that the duration of the in vivo animal experiment was not long enough for sufficient tendon damage to occur.

CONCLUSIONS

The results of this study suggest that the tendinitis and/or tenosynovitis frequently associated with the performance of highly repetitive low force activities such as keyboard data entry or word processing is not the result of cumulative strain in the finger flexor tendons. This prevents extension of this research to identify work-rest ratios which reduce or eliminate the cumulative strain and indicates that other etiologies of tendinitis/tenosynovitis must be identified.

One explanation of the observed increase in friction (resistance to movement of the flexor tendons within the carpal tunnel) is mechanical wear of the tendon surface. This wear is the result of shear forces between the tendon and the surrounding tissue (synovium or other tissue) as opposed to the actual force in the tendon. This suggests that the control of repetition may be as imaportant as the reduction of tendon force levels in the control of tendinitis/tenosynovitis during the performance of high frequency-low force activities.

The lack of detectable histological indications of inflammation or wear in the tendons of non-human primates, when subjected to 729,000 cycles over three weeks, indicates that the effect of this repetition is independent of the relative movement of tendons within the wrist. It is assumed that the response of primates to these conditions is representative of human response. If so, the results of this study indicate that the development of tendinitis or tenosynovitis by workers within the first few weeks of occupational exposure to these conditions is unlikely unless some level of predisposition or significant non-task factors exist.

Areas of this study that need to be investigated further include the stimulation inflammation and wear of the flexor tendons in the in vivo model and increases in tendon friction seen in the cadaver model. Stimulation of tendon inflammation and wear can be accomplished through additional animal studies that are performed for much longer durations than the present study. Additional cadaver studies are also needed to help understand the increases in friction that were seen. These studies should include the addition of a synthetic synovial fluid into the carpal tunnel during the test to determine how this effects tendon friction. In vivo studies may also be needed to determine the viscosity and production of synovial fluid during highly repetitive tasks.

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ECONOMIC REDESIGN OF AN INSPECTION AND HAND PACKING WORKSTATION

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INTRODUCTION

Musculoskeletal disorders of the upper extremities are rapidly surpassing low back injuries as the most troublesome industrial injury. These injuries are commonly referred to as cumulative trauma or repetitive motion disorders. According to the Bureau of Labor Statistics, their reported frequency increased from 23,000 in 1981 to 146,900 in 1989. While this increase does not mean that the American workplace has become more physically difficult, it may indicate that the American worker has become less tolerant of job induced musculoskeletal aches and pains, and/or workers, unions, and physicians have become more sensitive to the effects of the workplace on the worker. Even where there has not been an epidemic of "diagnosed" disease (carpal tunnel syndrome, tendinitis, etc.) the "prudent" employer is responding to the situation by modifying the workplace to remove the sources of musculoskeletal strain, sprain, and pain.

This paper describes the evaluation and redesign of a combination inspection and hand-packing workstation in which glassware is removed from a suspended conveyor, visually inspected for a variety of defects, and packed into a shipping container. The predominantly female workgroup complains of chronic shoulder/neck/arm pain, as well as occasional acute hand/wrist/elbow pain. The workgroup varies from twelve to twenty persons per shift depending on product flow, with most of the personnel being over forty with five to twenty plus years of experience. Among the older experienced workers, the chronic complaints do not result in medical visits, while among the younger workers they occasionally do. The acute complaints result in medical visits by both groups, but they are proportionally more frequent among the younger workers.

JOB DESCRIPTION

The work task involves an extended reach to access glassware being transported on a basket with four shelves which is suspended from an overhead conveyor, hand manipulation of the glassware while visually inspecting it, placing the inspected glassware into a packing container, and pushing the loaded containers onto another conveyor. Peripheral tasks include getting and placing the packing containers and packing materials, quality control data entry via a touchscreen, placing inspection stickers in the containers, packing materials preparation, and workplace cleanup.

A detailed description of the job's tasks follows:

1. With one hand, make a lateral reach with a fully extended arm, grasp a 5 1b box 62 inches above the floor, lift it 1.5+ inches, and place it in front of her.
2. With the same hand, make a lateral reach with a fully extended arm, grasp a two ounce piece of packing material 30 to 40 inches above the floor, lift it 2 to 12 inches and place it in the box.
3. With the other hand, make a lateral or forward reach which varies from almost fully extended to fully extended with a forward or lateral side bend, grasp a piece of glassware, inspect it, and pack it into the box. The glassware weighs .6 to 5 1bs, and is located on one of the basket shelves suspended from the overhead conveyor. The shelves are 34, 46, or 53 inches above the floor. The actual inspection involves hand manipulation of the glassware with 3 to 8 hand/wrist motions per piece. Glassware which does not pass inspection is placed on a belt conveyor which is under the overhead conveyor. This is done with an extended lateral reach and a side bend. Some glassware is salvageable and an extended reach is used to place it back on the overhead conveyor on the highest shelf which is 60 inches above the floor.

Steps 1 to 3 occur 12 to 48 times per box of glassware depending on the size of the glassware. The glassware arrives on the overhead conveyor at a rate of 8 to 48 pieces per minute. High frequency items are grasped 2 to 3 pieces at a time.

4. When the box is full, the inspector makes a 26 to 30 inch shoulder height forward reach, peels a quality control sticker off a roll of tape, and attaches it to a piece of glassware.
5. The box is then pushed forward onto a conveyor which moves the box out of the area.
6. When a piece of glassware is defective, the defect is entered into a QC system on a touchscreen. This involves reaching forward with a fully extended arm. Screen response inconsistencies coupled with varying screen locations for defect codes often result in static holds of 3 to 5 seconds while entering defect data.
7. Other comments—Inspectors may wear gloves to protect their hands from heat and potential broken glass. In practice, this occurs about 40% of the time. Inspectors may sit or stand, with about half of the inspectors opting for each. At half of the workstations, the inspectors face the oncoming overhead conveyor baskets (they access the conveyor by reaching to do the lift with their left hand as the baskets pass them on their left side). At half the workstations, the conveyor baskets approach the inspectors from behind (they access the conveyor by reaching to the right with their right hand as it passes them on their right side).

METHODOLOGY

The project was initiated at the employer's request in response to the realization that there was an excessive number of musculoskeletal complaints associated with the workgroup. The employer has an active Total Quality Management program which includes worker involvement in all workplace changes. The project was conducted jointly as a team effort by the authors, the plant engineers, the corporate safety engineer, and a group of inspectors representing the four shift workgroups who performed the job.

The project steps included an initial walkthrough to familiarize the consultants with the work, an analysis of the accident/injury data from the workgroup, two workgroup surveys (one on physical complaints and one on glassware location preference), extensive work observation and videotaping, one-on-one interviews between the consultants and essentially all of the inspectors in the four shiftgroups, building a workstation mockup to test redesign ideas, and the use of emg studies to compare the physical stress levels associated with different activities.

ACCIDENT/INJURY DATA ANALYSIS

A comprehensive review of the inspector's accident/injury data was conducted with the significant results presented in tables 1 and 2. Table 1 shows that most of the inspector's injuries are strains and sprains. Further analysis revealed that most of them were due to the handling of either glassware or packing containers (boxes). Table 2 shows that 59% of the inspector's injuries occurred while handling glassware and another 17% occurred while reaching for something (glassware, the box, packing materials, the touchscreen, or the QC stickers). This means that more than three-fourths of their injuries were the result of reaching for, grasping, holding, or manipulating the glassware and its associated packing material/container.

TABLE 1

Type of Injury

Classification	Percent of Injuries
Strain/sprain	60%
Laceration/bruise	22%
Foreign body in eye	6%
Other	12%

TABLE 2

Activity When Injured

Activity	Percent of Injuries
Handling glassware	59.2%
Reaching nos	17.4%
Handling box	10.6%
Walking	8.6%

Other MH	4.2%

Additional analysis was conducted on the glassware which was identified on the injury reports. This analysis revealed an interesting phenomenon. Handling heavy glassware (>2.8 pounds) was identified as being the injury cause in 75% of the cases, medium glassware (1.2 to 2.8 pounds) was the cause in 19% of the cases, and light glassware (<1.2 pounds) was the cause in only 6% of the cases. This becomes more interesting when one considers that heavy glassware is handled at a rate of about 8 pieces/minute, medium glassware at about 16 to 24 pieces/minute, and light glassware at about 32 to 48 pieces/minute.

Since frequency is often the prime culprit in CTDs, and the preceding analysis implied it was a minor contributor, the situation was investigated further. The inspectors (who were unaware of the injury pattern) were surveyed anonymously with a written questionnaire, and this was followed by personal interviews. Their complaints were consistently related to their neck, shoulders, and back, while the previously described injuries were generally (>80%) to the hand/wrist/forearm. The complaints were associated with muscle fatigue from the constant extended reached to locations above the shoulder. The injuries on the other hand were due to some form of overload on the tissues of the hand, wrist, or forearm. The overloads occur as a result of the posture (most glassware is grasped in a flexed wrist posture) and or a slip and regrasp of the glassware. This finding led to a two pronged approach to solving the problem—one aimed at acute injuries caused by the heavy glassware, and one aimed at the chronic muscle fatigue related pain associated with high or extended reaches.

SPECIFIC WORKSTATION PROBLEMS & RECOMMENDED REDESIGNS

Reach considerations—packing materials

The boxes and packing materials are delivered to the packing stations by means of roller conveyors—one above the other. The boxes are on the top conveyor with the top of the box 62 inches above the floor. The conveyor is sloped with a restraining lip at the end to hold the box in place. The box is lifted over the restraining lip and rotated 90 degrees to bring on to the packing platform in the correct position. The 5 pound boxes have a bottom flap that sometimes hangs up on the restraining lip. The reach for the boxes requires an elevated reach behind the plane of the body with full arm extension. The reach is more exaggerated and elevated if the inspector is seated.

An emg study was conducted to determine the comparative difficulty associated with accessing the box and packing materials on the two conveyors. This study showed that 10 to 15 times more muscle activity is required to lift and position the box when it is handled from the top conveyor compared to the bottom conveyor. In contrast, only 10 to 50 % more muscle activity is required to handle the packing materials on the top conveyor.

The plastic packing material placed between each row of glassware in the box is delivered on the lower conveyor. The packing material design causes the material to nest together, and it is often pressed together so that more can be put in a stack. The nesting makes the lightweight material difficult to separate, causes the inspector to exert considerable force with the wrist in a deviated posture, and interrupts the inspector's normal motion pattern.

Proposed Solution—The location of the boxes and plastic packing material will be switched so that the boxes are on the lower conveyor and the packing material above. The boxes will be fed automatically to the packing platform, eliminating the need for the inspector to lift, push, pull, or rotate the box. The upper conveyor will be lowered so that the bottom just clears the empty boxes beneath it. The nesting problem will be controlled by limiting the height of the stacks to 2–3 inches. Compressing the stack will not be allowed.

Packing the glassware

The item to packed is removed from the appropriate shelf on the overhead conveyor as it passes the inspectors workstation. The glassware is packed upside down and must be placed carefully and precisely in the box. For the bottom rows of glassware, the inspector must reach over the edge of the box to place to glassware in the box. The pieces placed in the rows furthest away from the inspector require both an extended forward reach and some forward bending.

When the box is full, the inspector pushes the box forward onto a conveyor that takes it out of the area. Although the packing platform has a roller ball surface, the boxes often get caught at the platform/conveyor interface subjecting the inspector to a sudden jolt which has caused some injuries. Sometimes, the inspectors must wrestle the full box (45 to 65 pounds) onto the conveyor while leaning far forward across the packing platform.

Proposed Solution—A tilt table will be installed and used for a packing platform. The inspectors will be able to control the tilt angle according to their comfort and preference. The tilt will lift the far edge up and move it closer to the inspector. This will reduce both forward reach and forward bending. The tilt will lower the front edge of the box thus making it easier to pack without abducting the upper arms. To further assist the inspectors, lightweight platforms will be provided at the workstations which the shorter inspectors can use to make themselves taller thus reducing the height of the reach they are making. A pneumatic device will be installed to push to full box of glassware off the packing platform onto the conveyor. This will eliminate the jolt as well as the periodic need to wrestle the box.

Quality Control

Defects in the glassware are recorded on a touchscreen monitor located in 28+ inches in front of the inspector about 64 inches above the floor. When a defect is found, the inspector presses the appropriate box on the touchscreen to record the defect. The sensitivity of the screen is poor and unpredictable, often causing the inspector to press the box several times before the entry is accepted. This static elevated and extended reach may be repeated several times a minute if there is a "bad batch" of glassware.

The defective glassware is either discarded to be used as cullet, or is saved and treated to remove the defect. The discarded glassware is place on a floor level conveyor that runs directly below the monorail conveyor. The inspector uses an extended lateral reach and side or forward bend to place the glassware on the conveyor and often has to hold the glassware until there is a clearing between overhead conveyor baskets and no other glassware on the conveyor. The glassware that is salvaged is returned to the overhead conveyor on the highest shelf (60 inches), resulting in another extended elevated reach.

When the last row of glassware is placed in the box, the inspector places a QC sticker on one of the pieces. The stickers are on a roll tape dispenser next to the touchscreen and must be peeled away from the tape backing. This is done with an extended elevated forward reach. Many of the inspectors wear gloves making this task awkward and dif f icult and increasing the time they must maintain the extended elevated reach. This, like the nested packing material, breaks the inspector's normal motion pattern. It also results in rapid extreme reaches to the overhead conveyor to grasp a missed piece of glassware.

Proposed Solution—A keypad, located close to the inspector near waist level, will be used to enter defects. The monitor will be used for verification and information purposes only. The keypad may also be equipped with a voice feedback that tells the inspector what defect has been entered. This saves the inspector time in verifying the entry was accepted, as well as eliminating the reaches and static holds.

A chute will be provided that allows the inspector to discard the defective glassware without waiting for a clearing between baskets and using an extended reach to toss it onto the belt. The belt will be covered to prevent injury to the inspector from flying glass.

The fourth shelf on the basket will be eliminated and salvageable glassware will be placed on the third shelf. This will eliminate the very high reach.

The QC sticker system will be replaced with water soluble ink stamp. The stamp will be mounted close to the inspector where she can easily touch the ware to the stamp while inspecting it.

Work pace—line balancing

The inspectors work pace is determined by the arrival rate of glassware (overhead conveyor basket arrival rate X number of pieces of glassware per basket). This in turn is determined by the preceding work group which loads the basket. The preceding workstation has an intermittent work input which allows them to work extremely fast for fifteen minutes followed by a fifteen minute rest period. This forces the inspectors to follow a similar schedule, and results in their arms working continuously for the work period. This is contrary to reasonable ergonomic practices which state that short work/rest cycles are pref erred to long work/rest cycles.

This "hurry up and wait" work procedure can be at least partly controlled through line balancing. This means the overhead conveyor speed is adjusted to the slowest speed that will meet the overall flow rate in the production system. The line speed is being evaluated and it appears that the work cycle time/piece can be increased from 7.5 seconds/piece to 10 seconds/piece, with the extra time being available to let the arms and shoulders rest.

Job rotation

The glassware varies considerably in weight, is located at three different heights on the overhead conveyor, and is handled at different frequencies. Each location/weight/frequency combination results in a different level of physical stress for the inspectors. In addition, at half the workstations, the glassware on the conveyor comes from in front of the inspector, while at the other half the glassware comes from behind the inspector. The inspectors remain at the same workstations for the entire shift.

Proposed Solution—Rotating the inspectors between workstations reduces the exposure frequency and duration for the affected body part. Each shift work group was encouraged to try rotating within their shift. Initially, all four shifts were against rotation, but after one tried it and found it was less stressful, the others followed. Currently three and one-half shifts are benefiting from job rotation.

Weight of glassware—location control

The accident/injury data analysis previously described indicated that there were two separate injury processes. Heavy glassware on a high shelf was grasped in a flexed wrist posture and caused acute injuries, while light glassware on a high shelf caused muscle fatigue in the shoulders and neck. Since there two or three types of glassware produced at the same time, one must go on the high shelf. The employer wants to avoid the acute injury with its immediate OSHA and Worker's Compensation implications, but at the same time wants to avoid the complaints associated with fatigue. Within the plant, there was considerable disagreement about which glassware should be placed on which shelf under which glassware production combinations.

This was investigated using both an employee survey and an emg evaluation of different conditions. The emg evaluation was conducted by instrumenting people and having them perform various glassware handling tasks. The emg results showed that three to four times as much muscle activity was required to handle glassware on the top shelf compared to the bottom shelf. This confirmed the subjective observation that use of the third shelf on the basket was much more difficult for the inspectors and some form of accommodation was needed.

The emg study was followed by the employee survey in which all inspectors were asked for their opinion and its basis with respect to shelf location for various combinations of glassware. The informal feedback received by the redesign team had indicated there was no glassware location consensus within the workgroup. The survey however, revealed a clear preference for heavy glassware on the lowest shelf, light (and frequent) glassware on the middle shelf, and other on the third shelf. It also identified production combinations which were unacceptable from the standpoint of the physical stress they caused. This information was provided to the production planning supervisor so it could be used as an additional constraint in deciding which glassware combinations to produce.

SUMMARY & CONCLUSIONS

The rapid increase in the number of cumulative trauma disorders reported in American industry should be a warning signal to plant managers, safety and health personnel, and engineers responsible for workplace design. American workers, the medical community, and OSHA have determined that the "aches and pains" traditionally associated with much of the work done in our factories will no longer be tolerated. It is incumbent on those responsible for the workplace to take all reasonable steps to eliminate or control those workplace factors which are contributing to musculoskeletal CTDs.

This paper describes a project undertaken by a manufacturer that has recognized the trend and is addressing the problem. The project was completed by a team consisting of engineers, plant inspectors (the affected work group), and ergonomists. The ergonomists were used to identify the physical problems caused by the workplace, and their source in the workplace. They then worked with the balance of the team to address each cause and find a solution which was acceptable to the affected workers as well as being technically feasible. The physical problems experienced by the inspectors included acute injuries which resulted from handling heavy pieces of glassware in a flexed wrist posture, and muscle fatigue which resulted from frequent extended reaches at or above shoulder level. A number of workplace design factors were identified which contributed to each problem. Each factor was investigated, redesigns were proposed and evaluated, and a change agreed upon. The changes are now in the process of being implemented.

ERGONOMIC GRIP DESIGN FOR A RUBBER FOIL APPLICATION TOOL

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Working with rubber foil application tools (RFAT) means a high workload for the worker. Stress and strain result from unergonomic grip design, uncomfortable body and hand arm postures and from loading environmental factors, especially thermal conditions. An approach is presented to improve the grip design of RFAT. Based on analyses of the work task and tool mechanics 15 alternative grips were developed. They were evaluated by measuring and comparing the maximum voluntary forces.

INTRODUCTION

Rubber foils are used to protect inner surfaces of steel and concrete tanks and pipes in chemical industry, railway tank wagons and especially exhaust fume desulphurization installations for power plants against corrosion. For the application the steel surfaces as well as the foil webs themselves are coated two times each with contact glue. The dimensions of the foil webs are typically 1 by 5 meters. After a defined drying time, the foil webs are attached to the walls. Having adjusted the foil, a defined minimum pressure has to be exerted for a short time to the foil, to guarantee the adhesive strength necessary for liability reasons.

For this task workers use the rubber foil application tool (RFAT). Characterizing parts of the RFAT are the one hand grip and the rolls (figure 1). The required force of 30 N for certain types of rubber foils has to be exerted manually.

In the reported study alternative grip designs are suggested and maximum exertable forces are evaluated to find an appropriate grip design with minimum work load to the worker and maximum force application respectively.

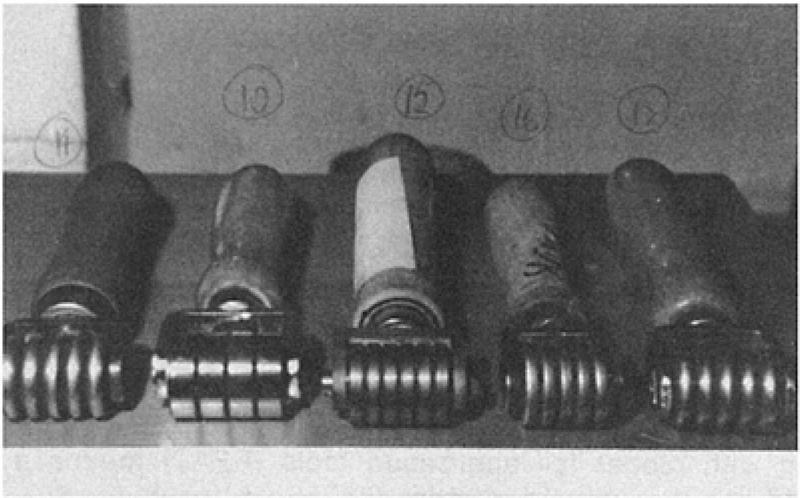

Figure 1: Conventional RFAT.

ON-SITE WORK ANALYSIS (FIELD ANALYSIS)

The first step in this investigation was a detailed analysis of the work on site. Using video recording and a special questionnaire the work tasks were assessed. A special focus was set on:

– occupational behaviour,
– body movements and body postures while working,
– movements of the hand-arm-system and
– environmental conditions.

Furthermore information was recorded on health hazards and workers' suggestions for improvements.

The on-site-analysis showed that working with RFAT is an extremly exhausting work. As an average value RFAT work is carried out for about 6 hours daily. In many cases, for instance rubber-coating in desulphurization plants, work has to be carried out on a scaffold. Since the foil has to be applied in any height above the floor level, standing, sitting, kneelisng or even lying were ob-served as body postures. While coating ceilings even working over head is necessary (figure 2). Thus, postural stress contributes to-gether with repetitive hand-arm movements due to the work task to a considerable amount to the total stress and strain (Chaffin and Andersson, 1988).

In addition, extreme environmental conditions may occur on the site, since heating is often required for good adhesive connection. So in the top of a tank high temperatures (often 30°C and more) can be

Figure 2: Application of rubber foil in an installation for exhaust fume desulphurization.

measured. Asked about personal complaints and indicators of high stress due to force exertion, the workers named

– blisters at the palm and the fingers,
– horny skin at the palm and
– wrist pain.

MECHANICAL ANALYSIS

After the on-site analysis an additional mechanical analysis has been carried out. In order to obtain a certain pressing force F_p at the steel roll of the application tool it is required that the worker applies a certain force F at the grip of the tool. To prevent the application tool from slipping away, an additional supporting force F_s is needed. Forces which are directed parallel to the surface of the foil as well as the weight of the tool can be neglected.

Figure 3 shows a typical way of operating the tool. In this case the wrist is stressed in dorsal direction. It is evident that all forces and the torques have to be in a state of balance.

$$F = F_p + F_s$$

$$F \cdot d + F_s \cdot s = 0 \quad \text{resp.} \quad F_s = F \cdot d/s$$

As F_s has to be exerted by the worker without contributing to the pressure force F_p, the objective is to minimize the supporting force F_s. This can be achieved by minimizing the distance *d* between the steel roll and the centre where the operator's hand force *F* is applied. Another way is to maximize the distance s between the that centre and the line of application of the supporting force F_s.

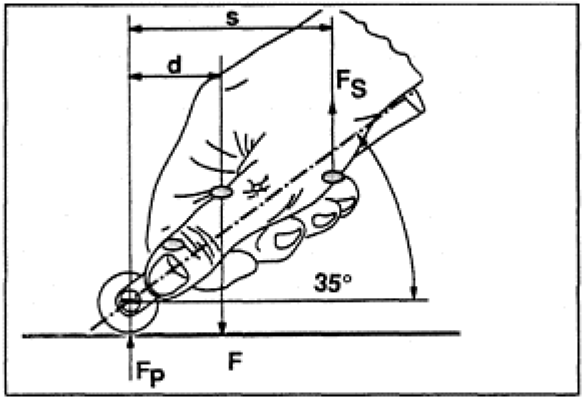

Figure 3: Mechanical analysis.

DEVELOPMENT OF DIFFERENT ALTERNATIVES FOR GRIP DESIGN

Following a systematic procedure (Bullinger and Solf, 1979) 15 alternative forms of grip design were developed (Figure 4). They were classified in one- and two-hand operated tools. Within the class of grips for one-hand operation there were three different types of grips:

–type I: with cross sections causing unidirection gripping by fixing the hand in a defined position at the grip

–type II: with square cross section which allows gripping from two directions

–type III: with circle cross section which allows gripping from multiple directions

The grips also differ in their specific adaption to the human hand. Type I, grip #6 and type III, grip #2 for instance can be called anthropomorphic whereas type II, grip #1 or type III, grip #1 are unspecific. From one point of view it seems to be an advantage to have an anthropomorphic grip to fit better into the human hand. On the other side the anthropometric differences between human hands imply more unspecific designs.

The grips of type IV are characterized by special features like two-hand operation, arm support or supporting wheels to optimize the parameters *d* and *s* which were defined in the mechanical analysis.

LAB EVALUATION

In order to find out the grip design with maximum exertable forces a typical work situation was simulated using a force measuring test rig. The subject has to exert maximum voluntary forces for using the different RFATs with the alternative grip designs at a vertically oriented rubber-coated wooden plate, placed in chest height, where maximum forces are expected (Bandera, Kern and Solf, 1986). The forces acting perpendicular to the plate were measured with an piezoelectric transducer. The amplified signals are AD-converted and input via an RS 232 interface into a μ-VAX II

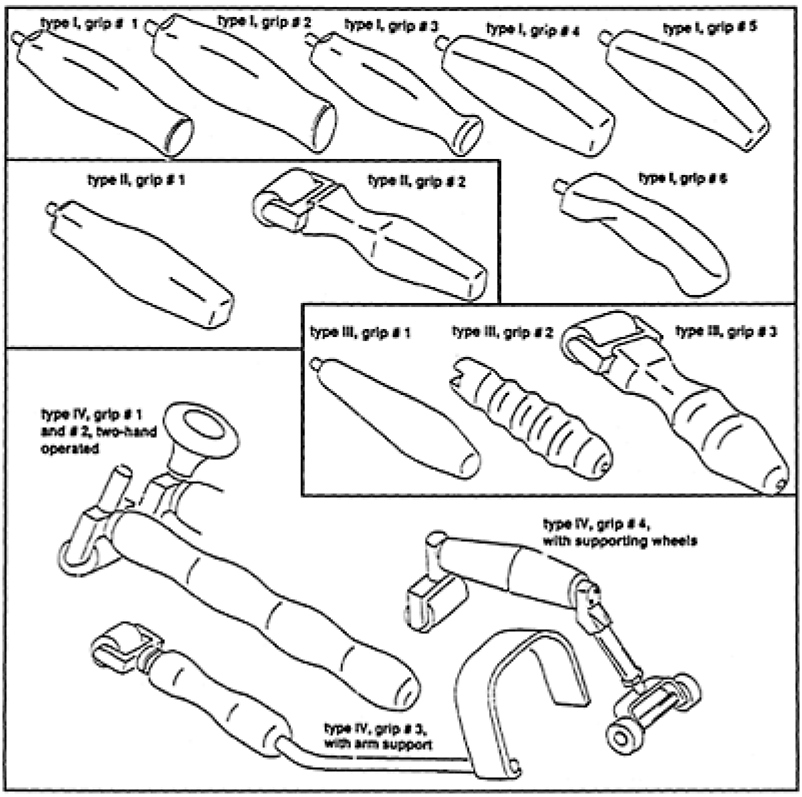

Figure 4: Examples of different grip designs.

computer. An evaluation program calculated an average force value within a defined time window (Figure 5).

For the evaluation five test persons had to work with the different tools. The task was to apply their maximum force during a time of 5 seconds. Although it was possible to find in each of the two classes (type I, II, III; type IV) a grip design with maximum forces, the differences within each class were not significant. As a fact, the average force values in both classes of tools turned out to differ not very much from each other. The highest application forces were reached with tools which were designed for two-hand operation. The values for one-hand operation were in the range of 50 to 70 N, tools

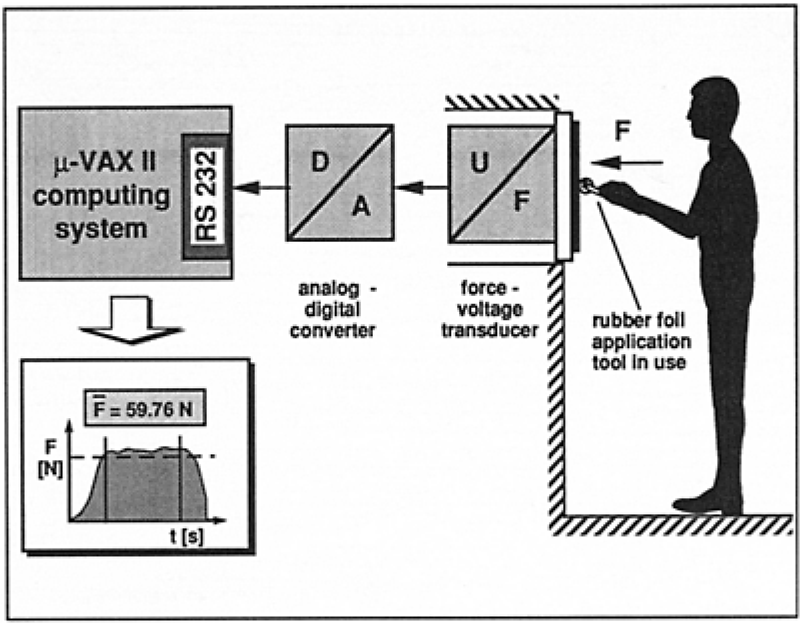

Figure 5: Principle setup of test rig for force measurement.

with special features (type IV, two-hand operation, arm support, etc.) reached values between 85 and 130 N. This means, that grips with special features allow to approximately double the forces.

But these values are maximum force values for short time operation (5 seconds); the values for long term operation (6 to 8 hours a day) can only be 15% of the maximum voluntary forces (Rohmert, 1962). This means, that the maximum values for long term operation vary between

– 7.5 to 10.5 N (types I, II, III) and
– 12.0 to 20.0 N (type IV).

All these values are far below the required force level of 30 N. This means that the work task cannot be fulfilled over a longer period of time.

CONCLUSION

One the one hand workers using RFAT are exposed to a high work load by force exertion. Stress and strain are increased by postural stress and environmental factors. On the other hand human long-term performance is far below the required level to ensure high quality of site rubber-coating with thick foils. Slight improvements can be achieved by measures like a height adjustable platform to reduce stress due to unfavourable postures. Alternative grip designs with special features like two-hand operation, arm support or supporting wheels also may help to improve the situation.

But all measures to improve manually operated RFAT will not result in meeting the technological requirement of high pressure forces. Provided, technological boundary conditions will not change, it is concluded, that the development of powered tools for rubber foil application is necessary. This may be a pneumatic or hydraulic percussive system, that reduces the force to be applied by the worker considerably (see Figure 6).

However it should be taken into account, that with powered systems and impact drives other stress and strain factors may occur like noise, vibration, high weight of the device etc. Thus, besides the required technical developments, further investigations of human factors of the work with powered devices for rubber foil application will be necessary in future.

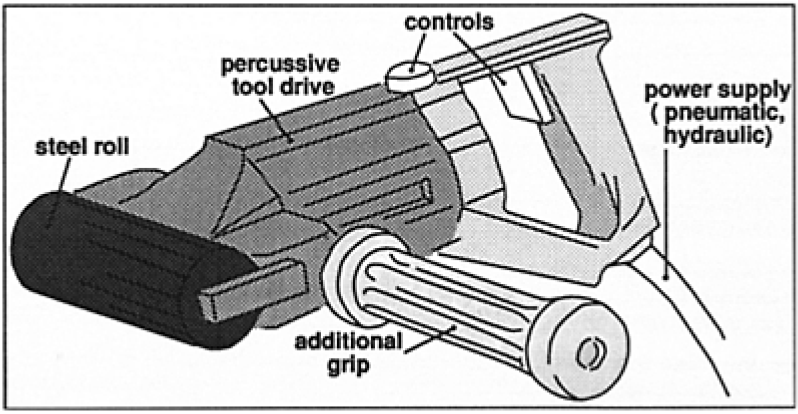

Figure 6: Future powered device for foil application

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MANUAL MATERIALS HANDLING

Biomechanical Simulation of a Lifting Task

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INTRODUCTION

In the area of biomechanics, there is interest in the development of a computer simulation to provide the motion patterns of various joints of a subject performing a task such as sagittal lifting. The hypothesis used to create the simulation model is that the body performs the lift by minimizing a certain cost function. When joints are considered as resources the cost function is used to decide how to distribute the workload to various joints.

With the development of simulation models, it would be possible to provide a basis for performing biomechanical analysis without collecting the displacement-time information of actual human movement for selected tasks. Therefore, the significance of this area of research is the ability to ultimately estimate the kinematics and kinetics of lifting movement under given conditions (Figure 1). An ergonomist specifies the characteristics of the human subject, the workstation, and task variables as appropriate inputs and the model will provide an output describing the kinematics and kinetics of the movement under these conditions. Thus, simulation becomes a valuable contrivance in lifting task analysis and design.

OPTIMAL PRINCIPLES

To accomplish this type of study, generally, there are three tasks to be undertaken. The first task is to generate the possible postures composed by the joints at each time frame during the lift. The second task is to evaluate the kinematics and kinetics of the lift generated by the first task. Within the two-dimensional space defined by the ankle-origin coordinate system, the lifting motion from the starting posture to the ending posture is mathematically described. The major concern in the second task is to ensure that the described movement of each joint is within the range of human capacity and workstation setup. The third task is to use the optimal principles to improve the basic lifting motion.

One should notice that the feasibility and the optimal control of human motion are equally important, though researchers tend to place more weight on the optimal control.

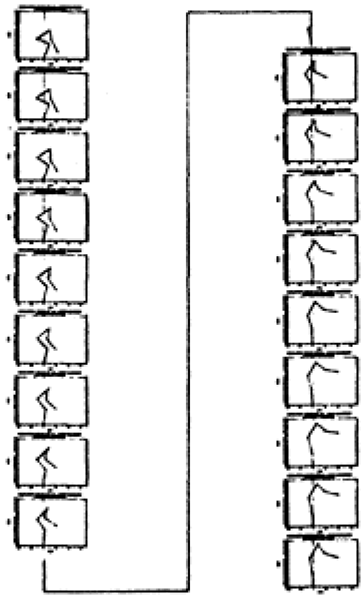

Figure 1. Biomechanical simulation of a sagittal plane lifting.

Optimization principles may be useful in ergonomics to (1) explain the basis of human body movement, (2) design jobs and workstations, and (3) train individuals to achieve optimal motion pattern. It seems natural to assume that certain fundamental principles underlie the movement human body, such as:

1. maximize output (e.g. faster, higher, heavier);
2. minimize fatigue (e.g. less static work);
3. minimize stress (e.g. less load, less speed);
4. minimize strain (e.g. refraining from over-exertion due to load, repetition);
5. minimize impact (e.g. less force);

Many studies based on optimization principles remain in the conceptual phase due to difficulties in (1) standardization and (2) formulation of an adequate objective function. Nevertheless, in biomechanics there are recent promising developments dealing with optimization principles to describe human motion. In the convergence of muscular level, for example, Schultz et al (1982) and Chen (1989) studied an optimization model for the 10 unknown forces acting around the lower back. In the convergence of skeletal level, Lee (1989) and Ayoub et al. (1991, 1990, 1989) studied the optimization of five joints during sagittal lifting. These studies postulate that the body may follow an objective function when performing a specific task. Therefore, an optimization principle is employed to determine which muscles and/or joints are required to accomplish the movement. The general formulation for the optimal control of human body motion can be summarized as follows:

Minimize $f[\theta_l(t), \theta_2(t),\ldots,\theta_n(t)|T, S, B, \Omega]$,
subject to $g_i[\theta_l(t), \theta_2(t),\ldots,\theta_n(t)|T, S, B, \Omega,]$, i=1, 2, 3….

where

$\theta_1(t), \theta_2(t),\ldots,\theta_n(t)$ are the angles of joint 1, 2, …n, at time t.

The inputs to the simulation are T, S, B, and Ω, where T is the total time to perform the task; S is a set of information about the work-station; B is a set of information about the human body, and Ω is a set of information about the task.

The cost function f is usually a function of some biomechanical measurements (joint forces, joint torques, joint work done) based on $\theta_1(t), \theta_2(t),\ldots,\theta_n(t)$, The constraints sets g_i, i=1, 2, 3,…,are based on kinematics and kinetics of the input information T, S,B, and Ω. The critical issue in the simulation of human lifting is to find a realistic cost function f which reflects the way the human body may determine its motion patterns $\theta_1(t), \theta_2(t),\ldots,\theta_n(t)$.

SIMULATION MODELS

Generally in studies of biomechanical simulation, the research can be divided into three phases.

1. Pre-model development analysis: during this phase, data on lifting kinematics and kinetics are collected to identify ranges of motion, angular acceleration and maximum joint strength values at joints of interest.
2. Model development: an optimization model is developed. The objective function f and all the constraints g_i are defined. The data collected from the previous phase are used to (1) provide the basis for building the model, and (2) evaluate the cost function and constraints of the developed model.
3. Model validation phase: various sets of "actual" motion patterns are collected for verification with those predicted by the model. The homogeneity, closeness and trend, between the actual and predicted trajectory of kinematics and kinetics of each joint is justified.

LIFTING SIMULATION MODEL

In recent studies by Lee (1988) and Ayoub, et al., (1991, 1990, 1989), a simulation model was developed for sagittal lifting activities utilizing five joints.

$$\text{Minimize } f = \int_0^T \left[\left(\frac{\tau_1(t)}{M_1(t)}\right)^2 + \left(\frac{\tau_2(t)}{M_2(t)}\right)^2 + \left(\frac{\tau_3(t)}{M_3(t)}\right)^2 + \left(\frac{\tau_4(t)}{M_4(t)}\right)^2 + \left(\frac{\tau_5(t)}{M_5(t)}\right)^2\right] dt$$

where $\tau_1(t)$, $\tau_2(t)$, $\tau_3(t)$, $\tau_4(t)$, and $\tau_5(t)$ are the joint moments at time *t*, and $M_1(t)$, $M_2(t)$, $M_3(t)$, $M_4(t)$, and $M_5(t)$ are the maximal moments of the five joints based on posture at time *t*. This model uses a ratio of $\tau_j(t)$ to $M_j(t)$ to emphasize that the optimization process distributes moments to the joints according to their relative capacities. The "square" of the ratio provides a heavier penalty for any deviants from the optimum.

The above cost function *f* is subject to the following set of constraints g_i: (1) the constraints imposed by the initial and final position, (2) the constraints imposed by the reach envelope, (3) the constraints imposed by the workstation, (4) the constraints of the kinematics (velocities, acceleration, rate of change of acceleration), and (5) the constraints of the kinetics, namely, joint moments (voluntary strength).

SOLUTION METHODS

In effect, the simulation model is required to select a motion pattern which results in a minimal cost function. Three methods, each with specific pros and cons, have been employed to solve these continuous, multi-variable, multi-period, and non-linear optimization problems. Development of different methods (O.R. algorithms) is not the primary goal of this research. However, in the process of finding an efficient way to reach the optimal solution, the following methods provide a better understanding of biomechanical simulation.

Method 1 —Dynamic Programming (Durling 1964)

This method begins with a set of initial motion patterns $\theta_i(t)$, j=1, 2,…n, $0<t\leq T$. By systematically generating variation $\theta_j(t)\pm\epsilon_j$, alternative motion patterns can be evaluated (Figure 2). Improvement of the motion patterns, i.e., smaller value of the cost function, may be found by continuously changing the value of ϵ_j. There are two weaknesses associated with this approach: (1) The final results rely extensively on the initial motion patterns, and (2) The global optimum is not guaranteed.

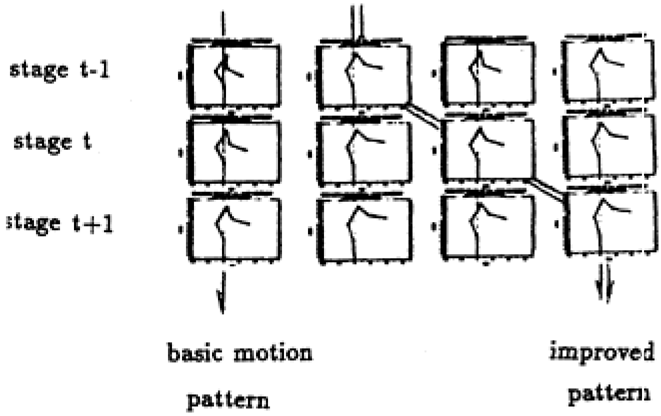

Figure 2. Finding the optimal motion pattern by using Dynamic programming.

Method 2 —Total Enumeration

This method starts by generating a huge family of possible motion patterns (Figure 3), and the feasibility of each pattern with respect to the constraints is evaluated. The final step is to determine the motion pattern with the smallest cost function value among all feasible motion patterns generated. However, the performance of the optimum depends on the size of the family of motion patterns generated at beginning.

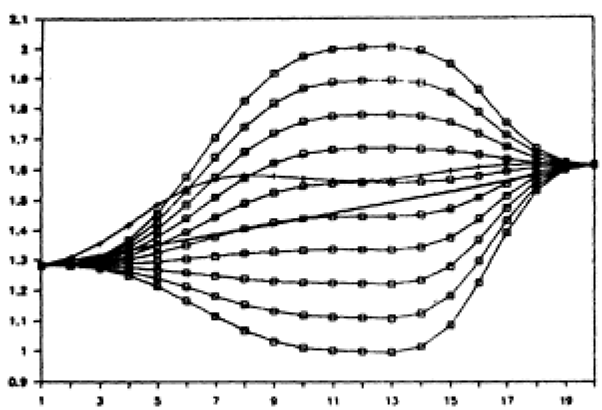

Figure 3. Finding the optimal motion pattern by using total enumeration.

Method 3 —Gradient Descending (Lasdon, 1978)

This method begins by the assumption that $\theta_j(t)$ is a differentiable function, such as a polynomial. Thus, the cost function f and the constraints set g_i become functions of polynomials. If coefficients of the polynomial are found to minimize the cost function f, the optimal motion patterns are found. This method searches the response surface $L(f, g_1, g_2, \ldots)$ constructed by f and the constraints set g_i. The gradient of the response surface $-\nabla L$ is used to determine the direction for minimizing f. Though this method is more mathematically sound, it requires a greater effort for modeling and computation than method 1 and 2.

MODEL APPLICATION

In an attempt to apply the model to a lifting task, a lifting experiment was performed. The task performed was lifting from the floor to knuckle height and from the floor to shoulder height. Five human subjects performed the lifting tasks using two sizes of containers, while being photographed with the Motion Analysis System. To apply the model the following inputs were provided: (1) the initial and final position of the body based on the initial and final location of the load, (2) strength data for the subjects, (3) weight of container, and (4) physical constraints dealing with range of motion, reach envelope, center of mass, acceleration, and the first derivative of the acceleration with respect to body coordination and balance.

When the biomechanical simulation was applied, the predicted joint motion patterns were compared with the actual (human subject) motion patterns. Figures 4–8 show a sample of the results of this application. Based on the results of several applications of the model, one may argue that the human body requires the optimal motion pattern for critical tasks (heavy load, large container), but some satisfying, perhaps “fuzzy” levels (non-optimal motion patterns) are good enough to perform non-critical tasks when the mechanical stress levels are low. Although the above argument is legitimate, it does not decrease the importance of biomechanical simulation.

SUMMARY

With regard to the biomechanical simulation, very few models exist which predict the motion pattern a worker may or should follow in the performance of a task. These simulation models differ from biomechanical models in that biomechanical models require large amount of input information about the displacement-time relationship, while simulation models can generate the displacement-time relationships as an output. Although these simulation models depend on optimization theory and techniques, they do provide a feasible alternative to obtain the knowledge of human motion.

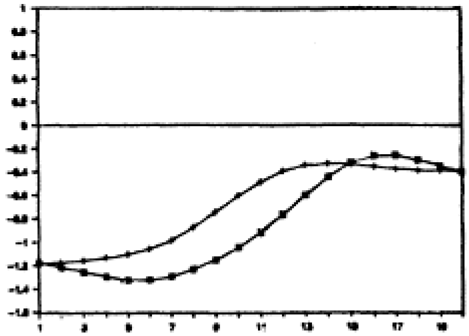

Figure 4. Angular Displacement (Elbow).

+: Actual motion pattern;

□: Predicted motion pattern;

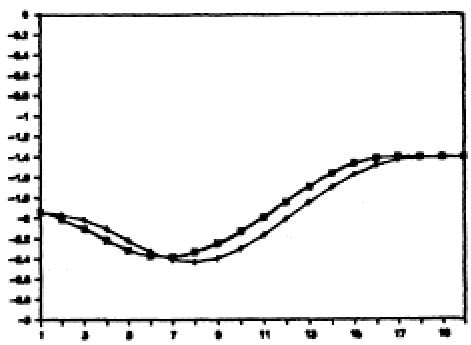

Figure 5. Angular Displacement

+: Actual motion pattern;

□: Predicted motion pattern;

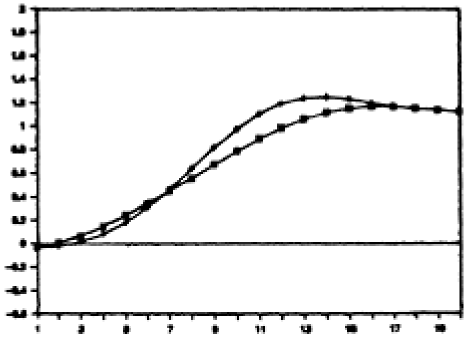

Figure 6. Angular Displacement (Hip).

+: Actual motion pattern;

□: Predicted motion pattern;

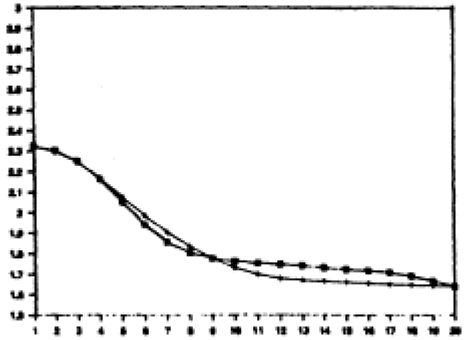

Figure 7. Angular Displacement (Knee).

+: Actual motion pattern;

□: Predicted motion pattern;

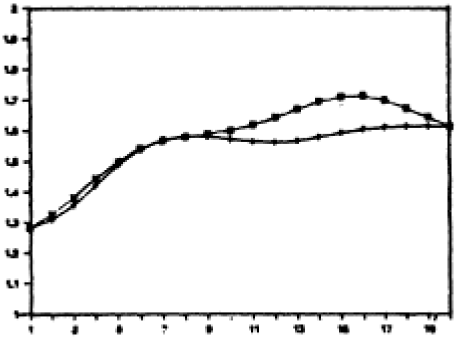

Figure 8. Angular Displacement (Ankle).

+: Actual motion pattern;

□: Predicted motion pattern;

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LUMBOSACRAL COMPRESSION FOR UNI- AND BI-MANUAL ASYMMETRICAL LOAD LIFTING

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INTRODUCTION

Low-back pain, lumbar diseases or termination of the professional activity are frequently the consequence of manual materials handling. In order to identify disadvantageous handling tasks and fulfil the ergonomic aim of deriving work-design criteria, the load on the spine must be quantified for typical manipulation tasks and compared with recommended limit values. In occupational biomechanics, compression on the lowest intervertebral disc of the spine, the lumbosacral joint 'L5-S1', is regarded as an adequate indicator of spinal load and usually determined by computer-simulated modelling (e.g. Ayoub and Mital, 1989; Chaffin and Andersson, 1991). Due to the relatively simple mechanical relationships involved, many studies on spinal load during manual materials handling are confined to sagittally coplanar models (e.g. Chaffin, 1969; Troup et al., 1983). However, many lifting tasks are performed uni-manually. In body twisting or turning activities spinal load is also asymmetrical, even if objects are manipulated bi-manually. Since the mechanical effects differ for each side of the body, three-dimensional analysis is required. The aim of this paper is to introduce and apply a dynamic spatial biomechanical model to asymmetrical load lifting, performed uni- or bi-manually. Tasks with several grasp and release heights are analysed. Age and gender-related limit values for the maximum compression on lumbar discs or vertebrae are recommended for the assessment of lumbar load during manual materials handling. They were derived on the basis of load-bearing capacity data provided by several authors in the literature. Ergonomic recommendations for work design are derived from comparisons between modelling results and individual spinal capacity.

BIOMECHANICAL MODEL 'THE DORTMUNDER'

The present status of 'The Dortmunder' represents a further development of a previous dynamic 3-D model for the quantification of lumbar load during manual materials handling (Jäger, 1987). Several assumptions were made with respect to the skeletal and muscular structures, the role of intra-abdominal pressure in relieving lumbar load (Jäger et al., 1991), as well as to the kinematic and kinetic relationships within the multisegmental model (Jäger and Luttmann, 1992). A brief description of the main features of the model is provided in the following.

Skeletal structure

The skeletal structure of the human model is composed of 30 rigid body segments which are movable at 27 punctiform joints. Linked at the grasping points, 2 supplementary segments and joints are provided to allow consideration of the loads held in the hands. The legs and arms are divided into foot, shank and thigh or upper arm, forearm and hand, respectively, for both sides of the body. Dissecting the trunk enables the simulation of sagittal flexion and extension, lateral bending, torsion and shoulder movements. The trunk was modelled on the basis of 17 segments, i.e. one pelvic, 14 'interdiscal' and 2 shoulder segments. Interdiscal segments are considered superior to the pelvis, which is located between the hip joints and L5–S1. They result from parallel cuts of the torso at the height of the 5 lumbar and 10 lower thoracic intervertebral discs. The uppermost truncal joint considered in the model is the disc T3–T4 which was set at shoulder joint level. Each originating from this joint, the shoulder segments represent the linkage to the arms and a rigid head-neck segment permits head movement.

Muscular structure

The muscular structure in the lumbar region considers bilaterally 4 muscles, i.e., m. erector spinae, m. obliquus externus abdominis, m. obliquus internus abdominis and m. rectus abdominis. The muscles are modelled by 5 'muscle-equivalents' capable of producing tensile forces in the anthropometrically defined directions and distances from the lumbar disc under examination (L1–L2 to L5–S1). At each point in time, the muscle-equivalents counteract, as does to a small extent the intra-abdominal pressure, the moments of force due to gravity and inertia which result from the body and manipulated object. Since equilibrium depends on 5 muscular variables with 3 torque components, mathematical optimization is necessary. Minimization of the sum of all of the muscle forces is used as the optimization criterion when attempting to reduce to a minimum the load-increasing effects of antagonostic muscles.

Intra-abdominal pressure

The supportive effect of intra-abdominal pressure in trunk stabilization was considered in a modified version of a posture and load dependent prediction model provided by Chaffin

(1969). Contrary to Chaffin's model, a supplementary basic intraabdominal pressure is considered which is set so that back muscles are inactive during the counteraction of the moments of force due to the body segments superior to the disc under examination (here L5–S1) if an upright trunk is assumed.

Posture and movement

Body and load motion is simulated on the basis of the postures adopted during the movement. The path of a segment in space, i.e. the trajectories of the centre of gravity and the joints of the segment, comprises rotatory and translatory components.

Posture is specified by the angles of the segments' axes of symmetry relative to an inertial coordinate system. If a segment rotates, these angles change during the movement. Segment rotation is quantified by specifying the segment positions at the beginning and end of the movement. Segment translation results from the superposition of the rotations of the inferior segments. The planes of rotations for different segments are commonly not parallel whereas in sagittal coplanar movements they would be. Consideration of a supplementary position at an arbitrary intermediate moment permits the simulation of further types of motion.

For the quantification of the effects of inertia on the load on the spine, the acceleration of all body and load segments must be considered time-dependently. The assumed time curve for angular acceleration during the rotation of a segment follows a sinus curve, positive for increasing and negative for decreasing velocity (Slote and Stone, 1963). The sinus curve maximum depends mainly on task duration and on the total angle of rotation which is traversed. The time curves for angular velocity and the angle traversed during a rotation can be determined by single or twofold mathematical integration respectively. Finally, the simulated movements are checked visually using 'moving' stick figures on a PC screen.

MODEL APPLICATION

Analysed tasks

In this paper, load lifting is accompanied by the turning of the body and load (figure 1). On the left-hand side, 3 traces of posture sequences during uni-manual lifting are provided in two of which trunk inclination is superposed by turning of the trunk. Loads of up to 10 kg are grasped with the right hand aside the body. Grasp heights of 10 cm, this corresponding to an object with its lower surface on the floor, 50 cm (knee level) or 90 cm (hip joints) are considered. These grasp heights involve differing amounts of trunk inclination and turning. At the end of the movements the object is released frontally at the height of the abdomen (110 cm), guaranteeing an almost upright trunk. Bi-manual lifts of loads to max. 40 kg from 15 cm (corresponding to a higher box located on the floor) to final heights of 50 cm (knees), 100 cm (pelvis) or 150 cm

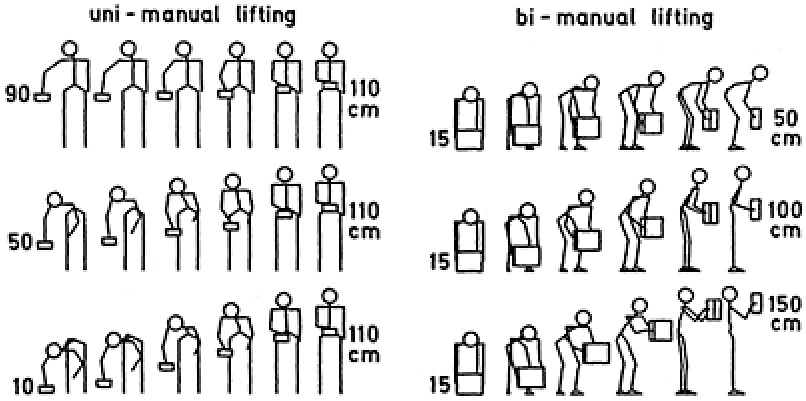

Figure 1. Stick figure sequences illustrating the movements assumed for uni- and bi-manual asymmetrical load lifting. Uni-manual lifting is accompanied here by trunk inclination and turning. Grasp height varies, release height is constant (see left-hand side). Bi-manual lifting is accompanied here by trunk inclination and total body turning. Initial object height is constant, final levels vary (see right-hand side).

(shoulders) are sketched on the right-hand side of figure 1. Trunk inclination is accompanied here by a rotation of the whole body through 90 degrees (viewed from above). For all tasks the body and load are assumed to be at rest initially and finally. Lifting time is assumed as 1, 1.5 or 2 seconds.

Lumbosacral compression for uni-manual trunk-turn lifting

The compressive force on the lumbosacral disc during unimanual lifting, as illustrated in figure 1, was quantified for various grasp heights, task-execution times and object weights (figure 2). Dynamic analyses, i.e. consideration of the effect of inertia during the movements of the body and object, are represented by continuous lines. The results of static analyses are indicated by broken lines. In the upper row of diagrams the object is grasped at 90 cm, in the middle row at 50 cm, and in the lower row of diagrams at 10 cm. The left-hand column of diagrams represents the calculations for an execution time of 2 s, the middle column for 1.5 s and the right-hand column shows results for 1 s.

The 0-kg time curves for lumbosacral compression in each diagram in figure 2 correspond to the effect of body movement. The influence of supplementary 'external' loads held in one hand can be estimated by comparing the curves for 5 or 10 kg

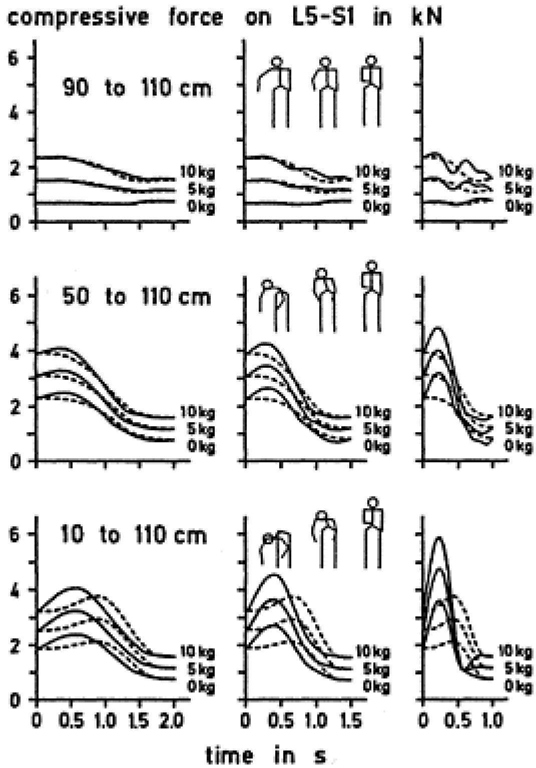

Figure 2. Lumbosacral compression during uni-manual load lifting accompanied by trunk inclination and turning (cf. figure 1). Grasp level varies (90, 50, 10 cm) in contrast to release height (110 cm). Biomechanical analyses are performed for body height and weight of 173 cm and 69 kg respectively. Key:—— dynamic analysis,——static analysis

with the 0-kg curves. Lumbosacral compression increases by about 1 kN for every 5 kg of object weight. An analogous single value for the influence of dynamics is not derivable. The inertial effects of body and load, represented by the differences between the continuous and the broken lines, vary due to postural differences during the movements and to variances in the weight and lever arms of the moved masses.

In the upper left-hand diagram for relatively slow task execution, the 0-kg time curve is almost horizontal due to only arm movement with a constantly upright trunk. Small differences between static and dynamic analyses are observed for moved segments of low mass (upper arm, forearm, hand) and slow movement. With increasing object weight (see curves for 5 and 10 kg), the compression is lower at the end than at the beginning of the movement since the final position of the object is symmetrical whereas it is initially lateral. Greater inertial effects are produced for heavier objects and/or faster task execution (compare corresponding curves in the upper row of diagrams).

A grasp height of 10 or 50 cm results in greater compression on L5–S1 than for 90 cm if the same task duration is assumed (see vertically arranged diagrams). This can be mainly attributed to the steeper trunk inclination which is accompanied by longer body segment and load lever arms to L5–S1. The lower 3 diagrams introduce curves with a pronounced maximum (dynamic and static analyses). This is due to the considerable initial trunk inclination at low grasp heights which leads to the centres of gravity of the body and load reaching their maximum intermediately during the movement and not initially.

Summarizing the results for lumbar load during uni-manual asymmetrical lifting, lumbosacral compression increases with decreasing load grasp height as well as with increasing load weight and working speed. Assuming the conditions specified above, the compression on L5–S1 ranges between 0.7 and 6 kN.

Lumbosacral compression for bi-manual body-turn lifting

The compressive force on the lumbosacral disc during bi-manual lifting, as illustrated in figure 1, was quantified for various load release heights, working speeds and object weights. Figure 3 is organized analogously to figure 2 with the exceptions that the grasp levels are constant while the release heights vary and that the load weight reaches 40 kg due to the bi-manual activities. The results of dynamic analyses are recorded in figure 3, results of static ones are not shown.

A relatively long task duration and short lifting distance are assumed for the analyses in the upper left-hand diagram. The curves are therefore almost horizontal, especially for low object weights. Initial and final lumbosacral compression results in similar values due to nearly unchanged trunk inclination. The curve between these moments depends mainly on the velocity of the rotating body and load. In the case of task execution in 1 s (upper right-hand diagram), maxima occur at the time of highest acceleration and deceleration whereas the minimum in a curve in the middle of the movement results from centrifugal effects which reach their maximum at this moment.

In the 2nd and 3rd rows of diagrams, longer lifting distances occur for a constant grasp and different release heights. Consequently, the movement velocity is higher and the maxima in the curves reach higher values. By contrast, lumbosacral compression is lower at the end of the movement since the trunk is less inclined for greater release heights.

Summarizing the results for lumbar load during bi-manual asymmetrical lifting, lumbosacral compression increases with increasing load release height, object weight and working speed. The compressive force on the L5–S1 disc ranges between 0.5 and 17 kN assuming the conditions in this paper.

DISCUSSION

Lumbar load must be limited with reference to occupational health and ergonomic criteria in order to avoid too great a risk for persons manipulating loads professionally. This is indicated by high rates of complaints, injuries and absenteeism (e.g. Chaffin and Park, 1973; Frymoyer, 1980; Luttmann et al., 1988). The National Institute for Occupational Safety and Health (NIOSH, 1981) has provided recognized and proven practice-oriented guidelines for lifting tasks which are performed 'relatively smoothly', bi-manually and symmetrically to the median sagittal plane. In contrast to these conditions, the tasks analysed in this paper involve body turning and, in part, uni-manual and fast execution. Consequently, the compression limits recommended by NIOSH cannot be applied to the asymmetrical activities here without reservations.

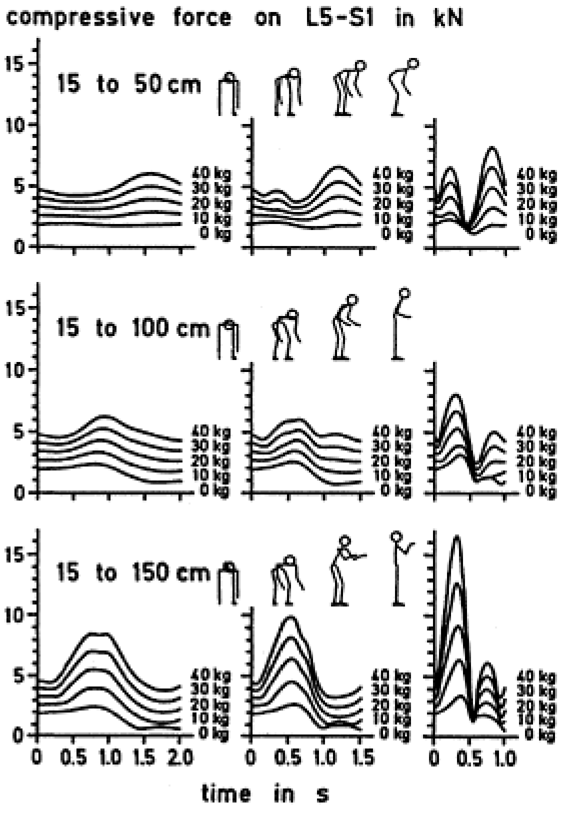

Figure 3. Lumbosacral compression during bi-manual load lifting

accompanied by trunk inclination and total body turning (cf. figure 1). Grasp level is constant (15 cm) in contrast to release height (50, 100, 150 cm). Biomechanical analyses are performed for body height and weight of 175 cm and 75 kg respectively.

The compressive strength of the lumbar spine represents an adequate standard for comparison with the lumbosacral compression during load lifting. Measurements of the maximum load-bearing capacity of spinal segments were performed on autopsy material since strength cannot be determined in vivo. Several investigations into lumbar ultimate compressive strength provided by other authors (e.g. Hansson et al., 1980) were analysed. As a result of the wide range of values (0.7–13 kN), the derived sample was examined to quantify the factors influencing lumbar strength, e.g. donor characteristics and spinal properties (Jäger and Luttmann, 1991). In this study, based on 477 values in total, age and gender were identified as the main factors. A further study provided age and gender-related linear regression models for strength prediction involving an extended sample of 507 specimens (Jäger et al., 1991).

Predictions based on regression functions represent a form of average value and may therefore overestimate the lumbar strength in an individual case. The predicted value should be reduced when deriving load limits for the assessment of materials handling. For example, the regression model value can be lowered by the standard deviation of the respective sample. Table 1 provides recommendations derived on this basis for the maximum lumbar compression during load manipulation, specified for persons of different age and gender.

Comparison of biomechanical analysis data relating to uniand bi-manual asymmetrical load lifting (figures 2 and 3) with recommended limits for lumbar compression during manual materials handling (table 1) demonstrates that lumbar load may exceed the limits in several tasks and/or for specific persons. Lifting from an advantageous height of 90 cm (figure 2) leads to disc compression which is lower than most of the recommended limits. In the case of low grasp levels, however, compression exceeds load limits for both males and females especially if heavy objects (≥10 kg) are lifted in a short time. Assuming the conditions for bi-manual lifting (figure 3), lumbosacral compression exceeds most of the recommended limits for many tasks, even the highest value for males of low age.

The assumptions and limitations of the biomechanical model should be considered when interpreting the lumbosacral load curves. Although the skeletal structure of the human model is simulated by a relatively large number of segments in comparison with other models, the rigidity and cylindrical shape of the segments as well as the punctiform joints and the omission of passive tissue effects within the spine represent simplifications in models which only approximate to reality. Furthermore, the muscular system is described by only a few muscle-equivalents in contrast to the wide variety of muscle structures and innervation. Body and load movements are

Table 1. Recommended limits for lumbar compression during manual materials handling

Age	Female	Male
20 years	4.4 kN	6.0 kN
30 years	3.8 kN	5.0 kN
40 years	3.1 kN	4.0 kN
50 years	2.6 kN	3.0 kN
60 years	2.0 kN	2.1 kN

simulated and may differ from real motion. Lumbar load is quantified and assessed here only in terms of lumbosacral compression. Lateral and sagittal shear at the lumbar discs as well as torques for torsion and sagittal and lateral flexion may provide further information (e.g. Schultz et al., 1979). Finally, disc compression during dynamic load lifting was assessed using static strength data since reliable dynamic strength values derived for real activities are not available to date.

CONCLUSIONS

Lumbar load modelling can be used in the analysis of working conditions and allows consideration of biomechanical criteria in ergonomic work design. Limits for lumbar compression during manual materials handling are recommended in relation to age and gender. Loads should be prepositioned to make grasping possible in erect postures and should be released below shoulder height. Fast task execution should be avoided, especially for long lifting distances and heavy objects.

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COMPRESSION LOADS ON A PHYSICAL THERAPIST'S LUMBAR SPINE DURING SELECTED TREATMENT TASKS

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INTRODUCTION

A prior ergonomic survey of a hospital physical therapy department revealed that patient treatments required physical therapists (PT's) to perform tasks, such as stooping, pushing, lifting and twisting (Fenety and Kumar, 1992), which are considered risk factors for "low back pain (LBP) (Frymoyer et al., 1980). Other risk factors such as constrained postures, hidden tasks and high frequency lifts were identified during the survey.

The positive association between lifting patients and LBP has been demonstrated in nursing (Stubbs et al., 1983a; Harber et al., 1985) where the point prevalence of LBP, 170 per 1000 at risk (Stubbs et a1., 1983a), is higher than for women in other professions (Harber et al., 1985). High lifting frequency also has been identified as a LBP risk factor in nurses (Stubbs et al., 1983b) and in nurses aides (Kumar, 1990). Some PT work postures, such as lifting in kneeling, may contribute to hidden tasks and increase the risk of LBP in PTs (Tichauer, 1978).

Patients, the most common objects lifted by nurses and PTs, represent many difficulties to workers, such as the physical hazards of a bulky load (Anderson and Chaffin, 1984) with long levers (Garg et al., 1991). Additional hazards may be poor patient compliance due to health conditions (Hollis, 1991). A hazard relevant to the profession of physical therapy is the difficulty of estimating the highly variable factor of actual patient contribution in assisted lifts (eg. rising to stand). Furthermore, pre-lift guidelines for minimum standards of patients' strength, balance or cognitive abilities do not exist.

Considering the documented presence of risk factors, and the similarity of nursing and PT patient lifting tasks, PTs should be considered to be at risk of low back injuries. Since it has been shown that the use of proper patient lifting techniques has not reduced spinal stress (Stubbs et al., 1983b), it was considered important to evaluate PT treatment and lifting tasks. Therefore, the purpose of the investigation was to perform static biomechanical analysis of L_5–S_1 compression loads that inpatient PTs incurred during patient treatments.

METHOD

Task analysis

The L_5–S_1 compression loads were calculated using a computerized static planar model based on Chaffin and Andersson's (1984) and Garg and Chaffin's (1975) static models. At the point of load bearing, the model required the input of the joint angles and the load vector. Details of the procedure for obtaining the postural angles is contained elsewhere (Kumar, 1989). For each posture, only L_5–S_1 compression and shear were measured, though the program computed torque. In the analysis, two factors were not measured; patient contribution to assisted lifts and the amount of force applied by the PT in assisting or resisting movements. The computer model allowed the operator to input a range of values for those parameters. For example, patient contribution to the lift ranged from zero (i.e. passive) to lifting 80% of their body weight. In the absence of patient lifting guidelines, the loads were compared to the National Institute of Occupational Health and Safety (NIOSH, 1981) standards for the action limit (AL) (3343 N) and the maximum permissable limit (MPL) (6376 N). Not all NIOSH criteria were met, given the presence of poor couplings and asymmetric activities. The 50th percentile female (height 163 cm, SD 6.4; weight 64.7 Kg, SD 14.7) in the data base was taken to represent the PT. The patient, a 50th percentile male (height 176 cm, SD 7.1; weight 75 Kg, SD 11.7), represented a moderately stringent working condition.

Task simulation

Task performance observations of five PTs were done in the surveyed PT department (Fenety and Kumar, 1992). To confirm whether those observed tasks were representative of average PT postures, similar observations were made on 6 PTs at another multidisciplinary hospital of similar size and caseload mix. Each therapist was observed for a minimum of three hours. Forty PT tasks, regularly performed on neurological or orthopedic inpatients, were analysed in three categories (standing assistance, transfers and raised mat exercises). Seven tasks that were selected to demonstrate the range of compression loads incurred by the inpatient PTs are reported on in this paper. For ethical reasons, patient treatment sessions were not photographed. In the lab, the tasks were simulated by PTs. Before each task was photographed (35 mm), it was observed repeatedly to determine the sequence of load bearing. The center of gravity of the hand, as well as the centers of motion of the ankle, knee, hip, L_5–S_1, shoulder, elbow and wrist joints were digitized from the projected slides.

RESULTS

Standing asistance

Patients began gait training using parallel bars for support. Placing the wheelchair between those bars (Figure 1) created a constraint for the two PTs (A and B) by increasing the load arm. In this task, the PTs shared the weight of the trunk and hips (26 Kg each) and assisted the patient to stand.

The compression load was 2850 N for therapist A (knees bent) and 3200 N for therapist B (straight knee lift). For this moderately frequent task (10–15/PT/day), neither method exceeded the AL and both had similar shear loads (400 N). An increased hazard did occur, however, when a single therapist assisted a patient from sitting to standing. The task required the therapist to face the patient, straddle their feet and lift them with a transfer (waist) belt. With a load of 45 Kg, the compression (6160 N) approached the MPL.

Transfers

Sliding board transfers were commonly used (6 to 10/PT/day) for patients whose leg strength precluded standing, but who could assist with their arms. In this transfer, (Figure 2) the PT approached from behind, placed one knee on the bed and lifted the trunk and hips (52 Kg) over the wheelchair wheel. The L5-S1 compression load of 6800 N exceeded the MPL.

Preparation of patients for bed-to-chair transfers often required that patients be assisted up to a sitting position. Analysis of that task (load 37.5 Kg) showed a compression load (4530 N) that exceeded the AL.

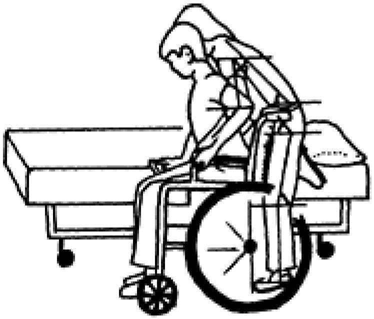

Fig. 1. Two person assist-to-stand constrained by the parallel bars. The lifting styles are: bent knee (A) and straight leg (B). This, and subsequent figures, contain the joint angles with horizontal references.

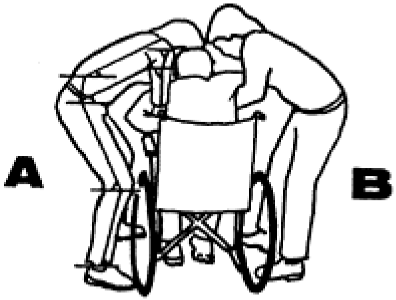

Fig. 2. Sliding board from wheelchair-to-bed.

Raised mat exercises

Use of a raised mat (fixed height of 45 cm) facilitates patient transfers. In order to treat mat patients, PTs were observed to adopt postures such as stooping, kneeling (Figure 3), sitting in trunk rotation or stooping with one knee supported (Figure 4). Treatments that involved passively lifting (Figure 4) or resisting limbs were analyzed for the observed postures.

Compression loads ranged from 672 N for resisted arm exercises (load 7 Kg) to 3200 N for lifting the leg (load 15 Kg) in a stooped posture (Figure 4). In general, tasks that involved pulling had lower compression loads than lifting tasks.

The only mat task that exceeded the AL involved rolling a patient from side lying to supine. Lifting half of the body weight (37.5 Kg) at the initiation of the roll resulted in 5800 N of compression and 510 N of shear at the L_5–S_1 joint. A variety of these raised mat tasks were repeated by a PT from 10 to 25 times per hour. Therapists at each hospital spent four hours per day treating on a raised mat, two hours of which were in a stooped posture.

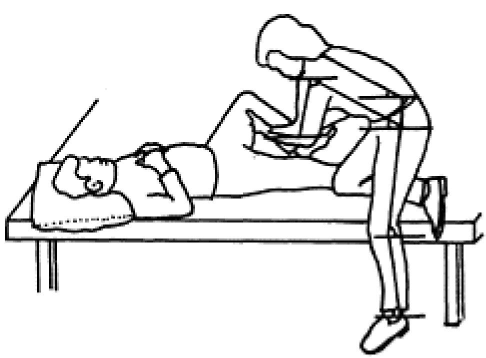

Fig. 3. PT assisting a patient to roll on a raised mat.

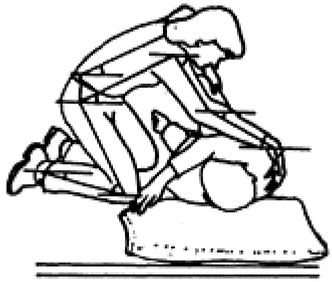

Fig. 4. Passive leg exercises with the PT in a stooped posture.

DISCUSSION

The most important finding in this study, that many PT patient transfer techniques exceeded safe limits, supports other authors findings in nursing analyses (Gagnon et al., 1986; Garg et al., 1991). On the other hand, most PT treatment techniques, such as passive arm movements or resisted leg exercises, did not exceed the AL. Also, this study, like others (Anderson and Chaffin, 1984) showed that bent knee lifting only provided minimal reduction in L_5–S_1 joint compression in comparison with straight leg lifts.

Lifting frequency, cited as a LBP risk factor (Kumar, 1990) was moderately high for both PT departments surveyed. An additional identified problem was the daily average of working two hours in stooped postures. Baty and Stubbs (1987) reported that a cumulative spinal stressor in geriatric nursing was the interactive effect of stooping and infrequent high risk procedures. Many therapists may similarly be at risk for LBP due to the combination of prolonged stooping, repetitive low risk lifts and infrequent high risk lifts.

Calculation of L_5–S_1 loads requires knowledge of mass and joint centers, neither of which have been fully validated (Gagnon et al., 1987). Bryant et al., (1989) reported low reliability in use of motion markers in the lumbar spine. Consequently, this method which produced estimated L_5–S_1 compression loads using theoretical input loads should be generalized with caution.

Other considerations are that many factors, such as rotational effects, were not considered in this symmetry-based model. Nor could the variability of actual patient input in assisted lifts be measured. This variability was considered an unexpected loading condition. Marras et al. (1987) showed that peak spinal compression doubled for unknown versus known loads. Considering that tasks were frequently asymmetric or constrained, and that loads would, in practice, often be unknown, the compression values in this study may be underestimated (Garg et al., 1991). In addition, the compression loads, which were calculated for moderately stringent conditions, would increase for larger patients or smaller PTs.

The complexity of 1ifting humans has been documented in several nursing studies. In this study an additional potential risk factor for PTs has been identified: the risk of treatments and transfers that demand patient input when patient input is unquantified and variable. It is recommended that a dynamic model be used in assisted lifts to: (i) measure actual patient input and look for correlations between input and the strength of the patient's muscles required to perform the task and (ii) to compute the resultant spinal compressions incurred by PTs. Results of such a study would assist in establishing minimum pre-lift patient strength requirements that would ensure that for the assisted lift, the patient is capable and the therapist is safe.

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A THREE-DIMENSIONAL LIFTING ANALYSIS

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A dynamic algorithm of the unconstrained lifting posture, is introduced. The methodology for analyzing the lifting forces is based on an interactive software package, and data obtained from three still pictures taken at the work site. The software system is coupled with the geometrical configuration of the worker's postures as obtained during the lifting act. The model and the software were tested in comparative experiments in the Work Study Lab. at the Technion. The results of the experiments show a good degree of correlation with results reported by researchers for symmetrical lifting tasks.

INTRODUCTION

The Bureau of Labor Statistics (1982) exhibit numbers showing that lifting tasks are responsible for half of the low back injuries, while 10 to 20 percent of work accidents are caused by lifting tasks. Many of these industrial lifting injuries are due to lifting acts, where the worker performs a non symmetrical lifting. The manual lifting act is performed by any individual many times during each day. It is performed differently by male and by female, at work and at home, with different postures at the work site or in leisure activities. For those who study the biomechanics of the human back and try to model its mechanics, the musculoskeletal system, which is maintaining many different postures during the lifting act, and serves as a dynamic controller of spine, is found to be an ultimate mechanism (Gilad and Shani, 1982). Literature is documenting many studies contributing to the modeling of this wonder machine. In this study of lifting analysis, the authors hope to contributes to this effort, by presenting a simplified model for the determination of the lifting act when unbalanced loads are handled. The approach in this model enables the user to evaluate lifting tasks in industrial situations, where loads creates non-symmetrical forces (in the frontal view) on the musculoskeletal system. The model is able to analyze lifting stress due to the handling of unbalanced, and/or an odd-shaped loads. In such events, when a lifter demonstrates a non-symmetrical lift, the 2-D sagittal models are not representative of reality.

The methodology is based on previous studies which model the different reactions acting at the low back level, more precisely at the L5–S1 intervertebral disk, during lifting. When the subject is bending over to reach the object and lift it, a load moment is created as a result of the weight lifted and the horizontal distance from weight to the disk. Back muscles consequently respond and create a counter moment around the spine axis. As a result, the disk is subject to pressures: compression force, perpendicular to the disk and shear force, parallel to the disk. The human intervertebral disk is subject to permanent erosion during its life cycle because of the various activities a man performs, and in particularly the lifting activities, as discussed by Anderson et al (1985). Chaffin and Andersson (1991) stated that a wide agreement exists between researchers, that lifting activities have to be carefully designed to reduce such potential hazards, Ayoub et al. (1980) advocate this statement. In the simplified 3-D lifting model for the analysis of non-symmetric lifting acts, one step further is proposed.

Through biomechanics research history, many models have been developed and constantly evaluated to cover a wider range of tasks (Kroemer, 1984). About lifting models, they range from simple two-dimensional static models to more complex three-dimensional dynamic models. The following list, fairly represent the evolution of lifting tasks analysis using biomechanical modeling:

(1) Static two-dimensional (Chaffin et al., 1970)
(2) Dynamic two-dimensional (Ayoub and Bassoussi, 1976)
(3) Static three-dimensional (Chaffin, 1969)
(4) Dynamic three-dimensional (Kromodihardjo and Mital, 1986)
(5) Low back model (Shultz and Andersson, 1981)
(6) NIOSH recommendations (NIOSH, 1981)

METHOD

Lifting task analysis models must be available to people who specialize in lifting tasks hazards, and must provide reliable results in a minimum of time, when analyzing a task that is to take place in a factory or in any other work place. The parameters input in the model should accurately represent the task, the worker and the surrounding. A computerized approach utilizing a program named “Lifter” was developed at Technion’s Work Study Lab. along these very lines. This model for the biomechanical analysis of lifting tasks, introduces:

– Three-dimensional analysis.
– Analysis of an existing lifting task.
– Analysis based on three postures recorded during the lifting act.
– the program operates from a PC based software package.

The model supports characteristics that have not been fully taken into account by preceding models. Such as nonhomogeneous load analysis which includes the practice of a single or two handed lifting. Lifter provides output figures designed to help the ergonomist or the industrial designer to determine points of potential hazards during a lifting scenario. The program provides:

– Compression and Shear forces acting on the low back at the L5– S1 disk.
– External forces and moments acting at the L5–S1 level.
– Back and legs posture during lift as segment angles.
– NIOSH limits and recommendation for the lift that is being analyzed.

ANALYSIS OF THE LIFTING ACT

The first step is to record the task of interest with a video camera. This record of the lifting act will demonstrate the actual lifting pace and posture in the real 'work site situation'. Figure 1 presents the steps of the procedure to obtain the lifting analysis. The analysis is then based on digitizing three postures captured from three frames of the filmed sequence. Although the model would support any three postures, it is recommended to digitize one picture at the beginning of the lift, one at the mid point, and one at the end of the lift, this will ensure proper covering of the Lifting phases. The program assumes that the lift is performed at constant speed and in one continuous movement. Using the digitized frames and externally obtained data about object and subject characteristics, (load, anthropometry, task frequency, etc), a software package calculates the forces and moments acting on the low-back and presents the result on a graphic screen.

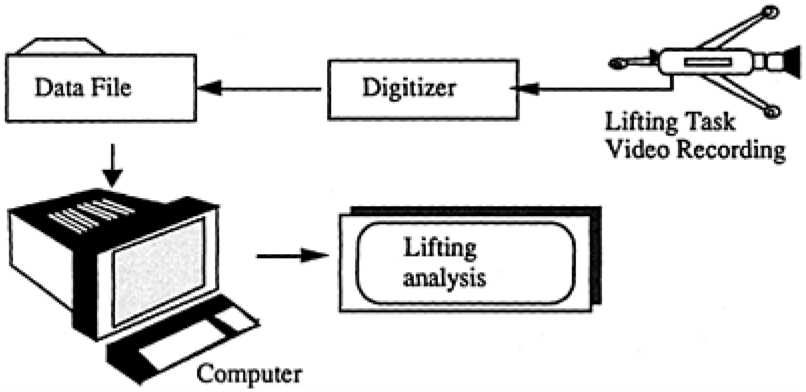

Figure 1 Layout of the 'Lifter' analysis processes.

THE MODEL

A theoretical model was defined, including the features described above. The model is composed of four sub-models interacting with the external world and among themselves, These are: (1) the load model, (2) the 3-D body segment model, (3) the low-back model and (4) NIOSH recommendations serves as practical lifting guidelines to solve the lifting equation.

The load model

It is the aim of this research to find a correlation between the weight distribution in the load and the compression force at the L5–S1 level. The model aims to represent the common loads found to be lifted in an industrial situation, it also allows the user to check the influence of load distribution (Gilad and Boughanim, 1990). The proposed solution assumes that any load can be demonstrated as a rectangular box, its volume is divided into segmental cubes, in this model the load is defined as a volume of 32 segmental cubes. The following parameters are used to define the load: weight, box size, weight distribution within the box.

The box representing the load, is divided into two parts: the front part and the back part, the back part is the closest to the lifter body. Each part is itself divided into 16 equally sized cubes, each cube is homogeneous, thus when setting different weights to the cubes, one can define numerically a non homogeneous load. By assuming that every cube is homogeneous, we conclude that the center of mass of the cube is at its center. It is then trivial to calculate the location of the center of mass of the load. Let us define load parameters:

L	- Length
W	- Width
H	- Height
P	- Weight
$PW_{I,J}$	- Percentage of the total wight in cube I, J I=1, 2, J=1, 2, 3,…, 16
F_L, F_R	- The force applied by the load at the left and right hand.
M_{LT}, M_{RT}	- The moment applied by the load at the left and right hand around X, Y, and Z axis, (T=X, Y, Z).

Divide the load in two parts GR, GL, when numbers are counted from upper left in horizontal rows of four segments. GL includes the following cubes: 1:1, 1:2, 1:5, 1:6, 1:9, 1:10, 1:13, 1:14, 2:1, 2:2, 2:5, 2:6, 2:9, 2:10, 2:13, 2:14, and GR includes the following cubes: 1:3. 1:4, 1:7, 1:8, 1:11, 1:12, 1:15, 1:16, 2:3, 2:4, 2:7, 2:8, 2:11, 2:12, 2:15, 2:16,

$$FL=P*G*PW_{I,J} \quad I, J \text{ in GL}$$

$$FR=P*G*PW_{I,J} \quad I, J \text{ in GR}$$

Moments at the hands can be calculated since we know the location of the center of mass at each half load, thus we can find the torque applied at each hand, by assuming that the load is grasped on both sides. Therefore, this sub-model is able to represent the forces and moments acting at each hand during the lift.

The 3-D body segment model

Lifter body segment model is made of 19 joints linked by 15 body segments. The sub-model calculates the external forces acting on each joint. The mathematical equations are rather classical, but they give a quick and consistent solution. The equations are based on equilibrium between forces and moments. For each segment, we have its anthropometric characteristics (such as weight, length, location of the center of mass). These values are directly derived from the height, weight, sex and age of the subject. Although they are not exact, they represent the statistical population with data close to the subject's. For the purpose of this research it is more than enough, as we intend to deal with the risks to a certain category of worker rather than for an individual. We define the following parameters:

WL - Weight of segment 1
JCML - Distance between joint J to segment L center of mass
J_1–J_2 - Segment length, between joints J_1 and J_2
F_J - Force acting at joint J
M_J - Moment acting at joint J
O_L - Segment angle at the proximal joint with XZ plane

$$J_1=(X1, Y1, Z1), J_2=(X2, Y2, Z2)$$
$$O_L=\text{arc tan } (Y2-Y1)/\text{sqrt } ((X2-X1)^2+(Z2-Z1)2))$$

Since Lifter is a static model, we can say:

$$M_{JY}=F_{JZ}=F_{JK}=0$$

From equilibrium equations, we obtain:

$$F_{JI}Y=F_{J2}Y+W_L \text{ for each joint J}$$
$$M_{J1K}=M_{J2K}+J_1CM_L*\text{Cos } O_L*W_L+J_1=J_2*\text{Cos } O_L*F_{JY2} \; K=X, Z$$

Since the load sub-model calculated the forces and moments acting at the hands, we can calculate with the equations above the forces and moments at each joint. The bottom line of the sub-model is to get the external forces and moments acting at the L5–S1 level. Once we have this information, we enter it into the low-back model in order to calculate the internal forces acting at the L5–S1 level.

The low-back model

This model was introduced by Shultz and Andersson (1981). It takes into account two internal forces that act on the disk and by their actions, contribute to the pressure exerted on the disk. These elements are: the Erector Spinae action and the abdominal pressure.

They act at the low-back level and are a definite factor of the risk level for lifting task. We than have:

SL, SP - Shear force at the L5–S1 level
FM - Force exerted by the erector spine
FC - Compression force at the L5–S1 level
A - Abdominal pressure
VR, HR - Abdominal pressure on the right side
VL, HL - Abdominal pressure on the left side

From statistical data we can find: AC, BC, EC, and FC. We have than to solve the following system:

$$
\begin{aligned}
&SL=F_x\\
&HR+HL+SP=F_y\\
&FC+FA=FM-A-VL-VR=F_z\\
&A*AC-FA*BC-FM*CD=M_x\\
&VL*CF-VR*EC=My\\
&HL*CF-HR*EC=Mz
\end{aligned}
$$

We now obtain a system with 6 equations and 10 unknowns, to solve this system, we need to control some of the variables. Thus, we assume that the sign of a moment will decide which of the internal forces is acting while its opposite will be 0:

if $M_x>0$ then FM=0
if $M_x<0$ then A=0
if $M_y>0$ then VR=0
if $M_y<0$ then VL=0
if $M_z>0$ then HR=0
if $M_z<0$ then HL=0

While FA is empirically given, we have the system reduced to 6 equations with 6 unknowns that can be solved by simple methods. This calculation provides us with the compression and the shear force acting at the L5–S1 level.

NIOSH recommendations

NIOSH (1981) edited a set of equations that calculated the weight that could be lifted for a given lift. These equations were used by the Lifter model, and AL (Action Limit) and MPL (Maximum Permissible Limit) are calculated. This gives the user the possibility of double checking the results he found when calculating the internal forces acting on the disk. As a reminder, AL fits 99% of the men and 75% of women, and MPL is suitable for only 33% of men and 1 % of the women.

After having entered the input data, the program calculates the forces and moments applying at the hands, then calculates the external forces and moments at the disk level, and finally calculates the compression and the shear force at the L5–S1 level. The NIOSH AL and MPL values are calculated from the postures entered. Figure 2 presents the results report of a lifting analysis. The three postures can be revolve around, in order to check any default in the position of the body during the lift. Under each posture, the external forces and moments are presented in addition the thigh and torso angles. The bar graph shows the evolution of the compression and the shear force during the lift at posture recorded at the L5–S1 level. Under the bar graph, NIOSH recommendations are given and must be considered as an entire part of the analysis.

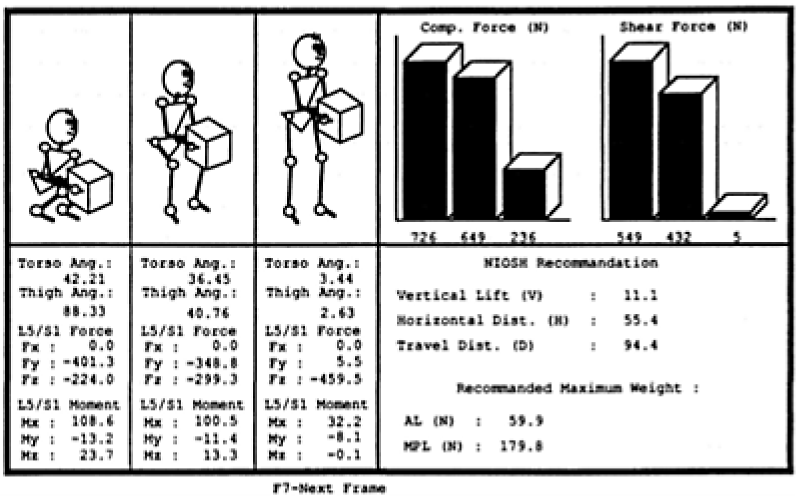

Figure 2 Form of results obtained by ‘Lifter’ analysis.

CONCLUSIONS

When beginning this research, two main objectives were set: the first was to prove that the weight distribution has an influence on the external and internal forces acting at the L5–S1, the second was to develop an effective, practical tool to perform analysis of an unstrained lifting act. Findings shows that increasing the weight of the load sensibly increase the external force acting at the L5–S1 level. This result is consistent with the results found by Kromodihardjo and Mital (1986). Other components of the forces and the external moment rise significantly as well as the compression and the shear force when the weight is lifted. Results show that when the weight is not equally distributed in the load, it does increase significantly the internal forces as well as the moments around the disk.

The results obtained in laboratory experiments, prove that Lifter is accurate and a consistent tool. Now, when the theoretical phase of the research is completed, we know that further research is needed in order to quantify the changes in compression and shear forces when the weight suddenly become unbalanced, when lifting fluids for example, Garg and Saxena (1980). Some instrumentation work is to be done on the recording procedures to simplify the posture capture method. Lifter has been proven a reliable and powerful tool for lifting analysis, but it is to be used by personnel with wide understanding of biomechanics, ergonomics problems and some medical knowledge.

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A COMPARATIVE ANALYSIS OF THE LIFTING TASK: USING A REAR LOADER VERSUS A SIDE LOADER SANITATION TRUCK

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INTRODUCTION

Studies have shown that musculoskeletal diseases rank first in lost earnings and non-fatal illness (Damkot, et al. 1984; Kelsey et al. 1979). Pope (1987a) suggests that musculoskeletal injuries in the workplace have reached epidemic proportions. Of all the musculoskeletal disabling conditions, back pain is undoubtedly predominant. According to Tichauer (1978), one-third of all disabling injuries that occur at the workplace are related to the manual handling of objects. In New York City, the average sanitation worker lifts between 4 and 5 tons of solid waste per day (J.Timpone, personal conversation, November 21, 1987). The loads lifted are often heavy and cumbersome, resulting in a two-handed lift, frequently while twisting at the waist. Workers subject to lifting asymmetric loads outside the sagittal plane are at greater risk to musculoskeletal injuries because of combined effects of flexion, lateral flexion and rotation of the spine (Garg and Badger, 1986). The very nature of the tasks performed by the New York City Sanitation worker necessitates lifting asymmetric loads outside the sagittal plane. To date, few ergonomic studies, i.e., cardiovascular measurements, perceived exertion ratings and a postural analysis of the task, have been done on sanitation workers and lifting.

In 1980, the New York City Department of Sanitation introduced a new truck for collection of city refuse. The new design necessitates the collection of refuse on the side of the truck instead of the rear. This truck was used in 14 out of the 59 Department of

Sanitation districts, at the time of this study (Trainor, 1989). Knowledge about whether or not there is an increased risk of developing a back injury, posed by either truck, does not exist. Back injury represents a significant problem at the Department of Sanitation and an epidemiological survey performed in 1984 indicated that men loading rear loader trucks are at more risk for back injury (Goodman, 1988). It is not known why or how work with either the side or rear loader truck poses more or less back injury, as the weight and type of objects lifted are virtually the same. This problem has been addressed by analyzing the ergonomics of the loading process used in these two forms of conveyance.

Musculoskeletal problems are caused by a variety of factors; a number of which could be traced back to the design of the workplace, the nature of the task or the posture assumed while executing the task (Chaffin, 1987; Keyserling, 1986b; Grandjean and Hunting, 1977). In occupational biomechanics, a substantial amount of information and pertinent research methodology already exists. Recently, Keyserling (1986a; 1986b) developed a system to evaluate posture while performing material handling tasks. It is this postural analysis technique that has been used in this study to compare the ergonomics of the lifting task using the rear loader and the side loader sanitation trucks.

Ergonomic analysis of work tasks and posture have demonstrated that trunk flexion, lateral bending or twisting increase mechanical stresses on the spinal muscles and intervertebral discs (Kelsey, 1975). Repeated micro-traumas to the intervertebral disc, resulting from lifting heavy loads on a regular basis, can lead to disc degeneration (Chaffin and Park, 1973). Prolonged trunk flexion and prolonged elevation of the arms may result in extreme levels of muscle fatigue (Keyserling, 1986a, 1986b; Chaffin, 1973). Hagberg (1982) has shown that repeated or prolonged elevation of the shoulders above 90 degrees resulted in painful levels of fatigue, and, in some cases, tendonitis. The relationship was reproduced between the risk of developing tendonitis and shoulder flexion in a field study (Hagberg, 1984).

Garg and Badger (1986) generally agree that asymmetric lifting (lifting a load at the side of the body) is likely to result in higher local stress concentrations which may have a greater potential for injury precipitation. Because of the combination of flexion and axial rotation of the spine, asymmetric lifting is believed to be more dangerous to the musculoskeletal system (Garg and Badger, 1986). Lifting outside the sagittal plane may also result in poor posture stability, asymmetric muscle activities and loads on the spine (Garg and Badger, 1986). Lifting asymmetric loads results in lower maximum acceptable weights of lift (Mital and Fard, 1986). In comparing the metabolic energy expenditure of lifting asymmetrically and symmetrically, Mital and Fard did not find any significant difference.

The New York City department of Sanitation uses two types of sanitation trucks for the collection of solid waste. Because of the design of the truck hopper, the workers assigned to the side loader have to lift the load higher than those assigned to the rear loader. Consequently, due to the increased height of the lift, the shoulders may play a more active role in collection. The lumbar spine appears to bear more of the load of the lift when using a rear loader truck. Observations made prior to the study, revealed that workers loading a rear loader sanitation truck extend the arms in front of the body and bend forward more than the men assigned to the side loader, increasing the forward bending moment and increasing the load applied to the lumbar spine.

There are several important applications of work posture analysis. One is to obtain exposure data for use in epidemiologic studies of posture-related injury and another is to evaluate a particular job to quantify postural stress and to evaluate awkward postures (Keyserling, 1986a, 1986b). In this investigation the second application was used. In addition to trunk and shoulder postures, the investigators evaluated perceived exertion and cardiovascular strain.

METHOD

This study was conducted in the field, at the district offices (garages) and the medical clinic of the New York City Department of Sanitation. Two districts were initially selected because of the exclusivity of the trucks used in each district. The Brooklyn West 11 district uses rear loaders and the Staten Island 1 district uses side loaders, exclusively. Fifteen men from each district, who met the minimum requirements, were selected from volunteers to participate in the heart rate measurements, video taping and perceived exertion portion of the experiment. The medical records of those men who volunteered to participate in the study were subsequently reviewed to verify that subjects met the criteria for participation. The number of subjects was determined from data collected in a pilot study using postural analysis, video tape data and the method described by Cohen (1977). Using an alpha of 0.05, and a power of 0.80, 30 subjects were needed in the sample, 15 per group.

RESULTS

From October, 1988 to December, 1988, thirty male subjects participated in this study. Subjects were selected from a pool of volunteers representing two Department of Sanitation zones: Staten Island 1 and Brooklyn West 11. The mean age and standard deviation of the side loader group was 38.0 (2.2). The mean age and standard deviation of the rear loader group was 37.6 (2.3). The mean number of years service with the department for the side loader group was 14.3 (5.1). The mean number of years for the rear loader group was 12.1 (5.1). The distance of the collection route in each district was virtually the same. The average side loader vehicle covered 1.5 (0.2) miles per route. The average rear loader vehicle covered 1.6 (0.2) miles per route. The variables tested were age, weight, height, number of years assigned to a truck, total tonnage lifted per route, and total distance travelled per route. The results of the t-test showed no significant differences amongst groups with respect to these parameters.

The mean percentage of time spent in the mild trunk flexion posture for the side loader group and the rear loader group was 17.0 (7.4), and 19.1 (6.1), respectively (Table 1). The mean percentage of time spent in the severe trunk flexion posture for the rear loader group was 0.3 (1.0). The side loader group did not spend any time at all in the severe flexion posture. The mean percentage of time spent in the twisting/bending trunk posture for the side loader group and the rear loader group was 8.4 (4.9), and 5.1 (3.0), respectively. An Analysis of Variance was performed on the trunk data. The purpose of this test was to determine if there was any significant difference in trunk posture assumed while lifting, using two different sanitation trucks. The main effect of posture was significant for the time spent by the trunk in any posture ($F=939$, $P<0.001$). The data did not reveal any significant difference between groups (side and rear loaders) with respect to trunk posture. There was also no significant interaction effect of group by posture.

The percentage of time spent in different postures by the left and right shoulders during the five complete job cycles are presented for side and rear loaders in Table 2. The three way analysis of variance on the percentage of time spent in different postures by shoulder showed significant main effect of posture ($F=682$, $p<0.001$). However, no significant difference was found between the two groups or the left and right shoulders. However, the interaction effect of group by posture was significant ($F=12.15$, $p<0.001$). The side loader maintained their shoulder in more flexed posture longer than the rear loaders. This may increase the moment arm of the external load which will increase the spinal loading.

Table 1. Mean Percentages of Time Spent in each of Four Trunk Postures for the Side Loader and Rear Loader Groups, During Five Complete Job Cycles.

Trunk Posture	Side Loader	Rear Loader
Neutral	74.7 (11.3)	75.4 (6.6)
Mild Flexion	17.0 (7.4)	19.1 (6.1)
Severe Flexion	0.0 (0.0)	0.3 (1.0)
Twisting & Bending	8.4 (4.9)	5.1 (3.1)

Table 2. Mean Percentage of Time Spent in each of Three Shoulder Postures for the Side Loader and Rear Loader Groups, During Five Complete Job Cycles.

	Left Shoulder (N=15)		Right Shoulder (N=15)	
Posture	Side	Rear	Side	Rear
Neutral	62.2 (13.2)	73.4 (8.8)	63.6 (15.1)	72.6 (7.6)
>45--<90	30.4 (10.8)	24.3 (7.9)	29.3 (16.5)	25.4 (7.2)
>90	7.1 (5.4)	2.1 (2.2)	6.1 (4.1)	1.7 (1.9)

CONCLUSIONS

Garg and Badger (1986) suggest that asymmetric lifting is more hazardous than symmetric lifting because of the combination of flexion and axial rotation of the spine. The tested population, males with no recorded recent history of back pain (within the last year), were subjects from the New York City Department of Sanitation. Their work entails considerable lifting, on average 8.1 (side loaders) and 9.6 (rear loaders) tons per two man shift per day. This work is also highly repetitive. Asymmetric lifting is very common, particularly among the subjects assigned to the side loader truck. Because of the design of the truck hopper, their work area is much smaller and more confined than the rear loader hopper. Keyserling (1986a) has suggested that prolonged elevation of the arms may result in extreme muscle fatigue.

There was no significant difference in trunk posture, assumed while lifting, between groups. Loading refuse into either sanitation truck results in similar postural stresses to the trunk. The greatest percentage of total time is spent in the neutral and mild flexion postures (side loader 91.7%, rear loader 94.5%). The rear loader group spent a fraction of a percentage of their time (0.3) in the severe flexion posture, while the side loader group did not spend any time at all in this posture. However, the side loader group spent a slightly greater percentage of their time in this posture (8.4% side, 5.1% rear).

This study examined the differences in cardiovascular strain and posture assumed while loading two different types of New York City sanitation trucks. The results indicated that there was no significant difference between groups with respect to heart rate and perceived exertion.

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THE PHYSIOLOGICAL BASIS FOR MANUAL LIFTING

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Several studies have established the importance of aerobic capacity in repetitive lifting. However, establishing guidelines for frequent lifting based on physiological data requires establishing a value of oxygen consumption that should not be exceeded for a given time period. Based on literature review, loads of 50%, 40% and 33% of $\dot{V}O_{2max}$ can be maintained for durations of 1 hour, 2 hours and up to 8 hours. Using these guidelines the limiting energy expenditure values are recommended to determine allowable weights and frequencies.

INTRODUCTION

Physical effort can be divided into two types of muscular activity: (1) dynamic muscular work such as cranking, walking, climbing, etc., and (2) static muscular work such as holding a tool, maintaining an awkward body posture, etc. Most of the industrial tasks, such as lifting and lowering of loads, are a combination of static and dynamic muscular efforts. In general, static work is more fatiguing than dynamic work. During static muscular work the blood supply to the active muscles may be reduced. Sufficient blood flow to the muscles is necessary to supply the muscles with oxygen and foodstuffs and remove heat, carbon dioxide, lactic acid and other metabolites. Fatigue develops when the applied force is 15% or more of the maximum force. Strength and working capacity decrease with an increase in intensity of effort and with exertion time (Rohmert 1973a). This paper discusses the physiological basis for allowable workloads for lifting. Excellent discussions on static muscular effort are given in Rohmert (1973a, b), Chaffin and Anderson (1990), Eastman Kodak Company (1986) and Grandjean (1988).

ENERGY EXPENDITURE AND HEART RATE

During the performance of a work task, especially if it involves moderate to strenuous exertion, physiological changes take place within the body. Work physiology has as its premise that the measurement of certain of these changes provides indices of the level of stress imposed upon the worker. Alterations in work method, performance level, or certain environmental factors, etc., are reflected in the stress level of the worker and may be evaluated by physiological methods.

So far as physiological measurements made during manual materials handling tasks are concerned, the preponderance of available data in the literature pertains to heart rate and/or energy expenditure responses. These are also the most widely accepted and reliable indicators of the level of physiological demands. As reported by Bink (1962), Bonjer (1962), Lehmann (1958), Wyndham et al. (1966), Chaffin (1972), Moores (1970), Muller (1953), Astrand (1960, 1967) and Garg et al. (1978), etc., by relating the energy expended in a task to the aerobic power of the individual for endurance effort, an objective assessment can be made of the work capacity of the worker for carrying out the industrial task in question without excessive fatigue.

AEROBIC WORK CAPACITIES

It is generally believed that both the intensity of work and endurance time at a given intensity level are related to a person's aerobic capacity for dynamic muscular effort involving large muscle groups. Aerobic capacities for American male and female workers as a function of age were estimated by Chaffin (1972). Cross-sectional population distributions summarized by Cummings (1967) conform to Chaffin's data. A study by Rodahl and Issekutz (1962) of American policemen, however, indicates that persons having relatively sedentary jobs would have lower aerobic capacities than those reported by Chaffin (1972). As a result, Chaffin (1972) estimated that probably 80% or more of American men have an aerobic capacity below 16 kcal/min. This observation is supported by data reported in Eastman Kodak (1986).

Kamon and Ramanathan (1974) estimated the maximum aerobic power for an average 35-year-old male worker to be less than 15 kcal/min. According to the American Heart Association (1972), the maximal aerobic capacity for men of 30 to 39 years of age is 8 to 10.5 kcal/min for people in fair cardiorespiratory fitness classification, 11 to 13.3 kcal/min for people in average classification and 13.6 to 16.8 kcal/min for people in good classification. Further, it is well established that the aerobic capacity decreases with an increase in age (Astrand and Rodahl 1986, Chaffin 1972). The U.S. Department of Health and Human Services (1981) used aerobic capacities of 15 kcal/min and 10.5 kcal/min for maximum permissible limit and action limit, respectively. These limits may be too high, however, for older or deconditioned workers.

Petrofsky and Lind (1978) showed that each type of task has its own maximum aerobic capacity level. This is determined primarily by the number of muscles available for the work. These authors showed that the $\dot{V}O_{2max}$ for lifting (free style method) was substantially lower than the $\dot{V}O_{2max}$ for bicycle ergometer. For example, the values for $\dot{V}O_{2max}$ for lifting 0.91, 6.8, 22.7 and 36.4 kg of loads were 54, 64, 75 and 80%, respectively, of that for bicycling. Similarly, at the maximal working capacities during lifting, the highest heart rates were directly related to the weight being lifted and were significantly lower than the maximum heart rate for bicycling.

Williams et al. (1982) reported slightly different results on seven female subjects. Measured $\dot{V}O_{2max}$ values for treadmill, cycle ergometer and for lifting boxes of 15.9 and 22.7 kg were not significantly different. The differing results were ascribed to the fact that the women in this study used the squat method of lift while the men used the stoop method. Several studies have shown that the squat method of lifting requires more energy expenditure (Brown 1971, Garg et al. 1978, Garg and Herrin 1979, Garg and Saxena 1979, Kumar 1984).

The location of the lift (approximately above or below 75 cm or 30 inches) determines how much of the body weight has to be moved with the load (low lifts) and what muscle mass is available (upper body capacity versus whole body capacity). Lifts above waist level use primarily the upper trunk and limb muscles. Literature shows that the upper body aerobic capacity is about 70% of the whole body aerobic capacity (Garg and Saxena 1985, Eastman Kodak Co. 1986).

LIFTING AS A PERCENTAGE OF AEROBIC CAPACITY

Christensen (1955) and Astrand and Rodahl (1970) proposed that men could perform at up to 50% of their bicycle ergometer aerobic work capacity ($\dot{V}O_{2max}$) in an 8-hour work shift. Serious doubts were expressed by Astrand (1960) and Brouha (1960) that this was too high an expectation and was a fatigue-generating energy expenditure rate. Based on a study of brick layers, carpenters and laborers, Astrand (1967) suggested an average relative load of 40% of $\dot{V}O_{2max}$ as the maximum workload that can be continuously performed without accumulating an excessive amount of fatigue. However, Lind and Petrofsky (1977) concluded that Astrand's estimate of 40% $\dot{V}O_{2max}$ may be an overestimate. Petrofsky and Lind (1978), based on the evidence from oxygen uptake, heart rate and arterial lactate, concluded that a work rate equivalent to 50% of maximum oxygen uptake for the given weight of the box could be maintained for a 4-hour period with 10 minute recovery periods each hour; however, clear evidence of fatigue was found (Petrofsky and Lind 1978b). Blood lactate increased dramatically when $\dot{V}O_2$ levels increased above 1 liter/min. Studies by Michael et al. (1961), Bink (1964), Andrews (1969), Chaffin (1972), Rodgers (1978), and Petrofsky and Lind (1978), etc., recommended 33% of the maximum aerobic power of a normal healthy person as the maximum energy expenditure rate that should be expended for an 8-hour workday. Assuming 15 kcal/min for the maximum aerobic power, for a young healthy male worker, this translates into a physical work capacity limit of 5.0 kcal/min for an 8-hour workday.

Studies by Lehmann (1958), Bink (1962, 1964), Muller (1953) and Barnes (1980) recommended that a work load of 5 kcal/min is the maximum energy expenditure rate that should be expected for an 8-hour workday. As a result, several studies such as Aquilano (1968), Davis et al. (1969), Garg et al. (1986), and Garg and Herrin (1979) used 5 kcal/min as an acceptable physiological criterion to determine the physical difficulty of the job.

Legwork at levels above 5 kcal/min in well-trained individuals has been found to cause increased levels of blood lactate (Ekblom et al. 1968). This is further evidence to indicate that the metabolic demand for oxygen within the muscles is not completely fulfilled when the task is at higher levels than 5 kcal/min. Based on loss of grip endurance following the lifting tasks, Williams et al. (1982) recommended 30% of $\dot{V}O_{2max}$ be used to set lifting standards. A similar value of 4.4 kcal/min was recommended by Karger and Hancock (1982) for 8 hours of continuous work.

PSYCHOPHYSICAL DATA ON OXYGEN UPTAKE LIMITS

Snook and Irvine (1969) reported that when healthy industrial men were allowed to choose the amount of repeated lifting acceptable for eight hours, they chose a level that resulted in an average energy expenditure of 4.9 kcal/min. Similarly, Garg and Saxena (1979) reported a value of 4.6 kcal/min. Based on endurance times when lifting weights equal to 25, 50 and 75% of maximum lifting capacity at rates varying from 2 to 12 lifts/min, Legg and Pateman (1984) recommended that lifting activities should not exceed 23% of treadmill $\dot{V}O_{2max}$. Ciriello and Snook (1983) reported that subjects selected weights at 6, 9 and 12 lifts/min which resulted in oxygen consumption of 0.93 to 1.46 liter/min. The oxygen consumption increased with an increase in lifting frequency.

Mital (1984), Genaidy and Asfour (1989) and Legg and Pateman (1984) measured endurance times using a psychophysical approach. The reported endurance times are not in agreement with each other.

Garg and Saxena (1979) compared a physiological fatigue criterion of 5 kcal/min with psychophysical fatigue criteria. These authors reported that physiological fatigue criteria resulted in more liberal workload limits at low frequencies of lift while the psychophysical method resulted in higher workload limits at higher lifting frequency. This conclusion is supported by others (Asfour et al. 1985, Fernandez and Ayoub 1988, Karwowski and Yates 1986, Ciriello and Snook 1983, Mital 1985, 1987). Based on these data, several investigators have concluded that the psychophysical methodology is invalid for determining acceptable workloads for high frequency lifting tasks (Ciriello and Snook 1983, Karwowski and Yates 1986, Fernandez and Ayoub 1988).

Karwowski and Yates (1984, 1986) showed that female subjects were unwilling to lift the psychophysically chosen weight at frequencies above 6 lifts/min over a period of 4 hours if given the chance to change it. At the end of the 4-hour period, subjects had decreased the weight of the lift by 23% from their MAWL which has been predicted at lifting weights of 8 or 12 lifts/min. These data lead to the suggestion of 25% to 30% of treadmill $\dot{V}O_{2max}$ as the recommended upper limit for O_2 consumption when lifting for a continuous 4-hour period. Similarly, Mital (1984) suggested a value of 28% for eight hours of lifting.

Summary of work capacity limits

In summarizing the data concerning the limits of work capacity, it becomes clear that jobs requiring 50% of treadmill or cycle ergometer $\dot{V}O_{2max}$ will exceed the capability of most workers. Values in the range of 40% of the job specific $\dot{V}O_{2max}$ may be tolerated by some young, healthy and physically fit male workers. However, most data now suggest that the range should be between 25 and 30% of treadmill or cycle ergometer $\dot{V}O_{2max}$ for an 8-hour shift. For shorter or longer work durations, the work as a percentage of aerobic capacity should follow the recommendations of Astrand and Rodahl (1970) and Chaffin (1972).

Trade-off between biomechanical and metabolic stresses

Data from Frederik (1959) and Garg and Herrin (1979) suggests that there is a trade-off between metabolic and biomechanical stresses. According to Garg and Herrin (1979), biomechanical criteria to reduce muscle and vertebrae stresses suggest minimizing the load by using lighter weights and more frequent lifts. Metabolic criterion to reduce energy expenditure suggests lifting heavier weights at less frequent intervals. In other words, to reduce physiological fatigue workers are better off lifting heavier weights at low frequencies than lifting lighter weights at higher frequencies. Lifting more than one light item at a time is often seen in workplaces where workers have some control over the lifting pattern. However, this behavior may produce unacceptable levels of stresses on a worker's low back.

RECOMMENDATIONS

From the literature review, it is clear that there are three major components for determining acceptable levels of energy expenditure. These are (i) design limit versus maximum permissible limit, (ii) lift location (above or below 76 cm or 30 inches) and (iii) an adjustment for the continuous duration of lifting (1, 1–2, or 2–8 hours). At the design limit (DL), at least half of the women and most of the men will find the tasks acceptable. At the maximum permissible limit (MPL) about 25% of the men and a few women will find the tasks acceptable.

Baseline aerobic capacity assumptions

The goal of the lifting guidelines is to protect the large majority of workers from the risk of overexertion injuries. A value of 10.5 kcal/min whole body aerobic work capacity has been used as the baseline for low lifting tasks. It is probable that more than half of the female workforce may find a repetitive lifting task based on a 10.5 kcal/min aerobic work capacity fatiguing because their lifting capacity will be lower than their capacity based on treadmill or cycle ergometer. A design that accommodates 75% of the less fit population would limit workloads to the low moderate effort range for a large majority of the workforce, and that would be an inefficient design. The aerobic capacity basis for lifts above 30 inches (75 cm) is 7.35 kcal/min. This should accommodate about half of the women's and close to 90% of the men's upper body aerobic work capacity.

At the MPL (maximum permissible limit) of the lifting guidelines, an average healthy young male's aerobic capacity of 15 kcal/min or 43 ml O_2/kg body weight min has been used. This represents the upper 25% of the male workforce (U.S. Dept. of Health and Human Services 1981, Eastman Kodak 1986) and is based on treadmill capacity testing. Arm capacity at the MPL for assessing high lifting workloads is 10.5 kcal/min.

Workload criteria-energy expenditure limits vs. work duration

The duration values chosen to determine frequency are 1 hour, 1 to 2 hours, and 2 to 8 hours, and these can be sustained at loads of 50%, 40% and 33% of aerobic work capacity (measured as treadmill capacity), respectively. Table 1 illustrates the limiting energy expenditure values used to calculate the frequencies for high and low lifting tasks of different durations. The values in Table 1 have been determined by multiplying the aerobic capacities at DL and MPL levels (10.5 and 15 kcal/min) by the percent aerobic capacity value for the respective duration and by correction factors for upper body capacity for lifts above 30 inches. In order to partially account for differences between lifting capacity and treadmill capacity the values were also reduced by 10%.

Table 1: Energy Expenditure Limits for Frequent Lifting

Lift Location Height in inches (cm)	Duration of Lifting					
	1 Hour		1–2 Hours		2–8 Hours	
	DL	MPL	DL	MPL	DL	MPL
V<30 (75)	4.72	6.75	3.78	5.4	3.12	4.45
V>30 (75)	3.3	5.4	2.65	4.05	2.18	3.12

Energy expenditure calculations

The following equations from Garg (1976) are recommended to estimate energy expenditure.

Stoop Lift: $E=0.0109\ BW+(0.0012\ BW+0.0052\ L+0.0028\ S*L)\ f$ (1)

Squat Lift: $E=0.0109\ BW+(0.0019\ BW+0.0081\ L+0.0023\ S*L)\ f$ (2)

Arm Lift: $E=0.0109\ BW+(0.0002\ BW+0.0103\ L+0.0017\ S*L)\ f$ (3)

where: E=energy expenditure (kcal/min)
BW=body weight (lbs)
L=weight of the load (lbs)
S=sex (female=0, male=1)
f=frequency of lifting (lifts/min)

Recovery time

The following guidelines are recommended to determine recovery time. If these guidelines are followed, fatigue or overexertion should not occur because there will be adequate time for recovery from any short term muscle fatigue before the next period of lifting starts.

(1) Continuious work duration of one hour or less.

RT=1.2×WT

(2) Continuous work duration of two hours or less.

RT=0.3×WT

(3) Continuous work duration of eight hours or less. No additional fatigue or light work allowance is required other than the fixed mid-morning, mid-afternoon, lunch and the light work allowances given by the company.

where
RT=rest allowance (min.)
WT=working time (min.)

Rest allowance may be replaced by light work allowance depending upon nature of light work and energy expenditure associated with lifting.

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PREDICTION MODELS FOR ASYMMETRICAL LIFTING COMBINATION TASKS

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Manual materials handling is a major source of lower back pain. Many of these injuries arise from the improper handling of materials. Rodrigues (1989) and Fredericks (1991) both presented studies on combination lift and lower manual material handling tasks. This paper combines the data from the two respective studies to successfully develop prediction models for maximum acceptable weight of lift (MAWOL) based on anthropometric measurements. The results of this study indicated that MAWOL can be predicted fairly well. These models and their industrial implications are discussed in this paper.

INTRODUCTION

In this day and age of stiff competition, Corporate America is taking a closer look at the bottom line more so than ever before. Corporations are continuously on the look out for areas of loss no matter how minuscule. One such area of loss which is speedily becoming a major area for concern is the category of workers' compensation costs. With soaring medical costs, stringent federal and state laws coupled with liberal benefits and disability payments, corporations are watching their profits systematically, yet steadily being chipped away. According to a recent study reported in the December issue of Professional Safety, (Manuel, 1991) workers' compensation costs will be approximately $60 billion, nearly double the costs of five years ago. These represent only direct costs, with indirect estimates running as high as four to six times the direct costs. Some insurance carriers have reported that close to 50% of workers' compensation (WC) claims file were ergonomic-related, costing approximately 60% of the WC total dollars.

What is more important though, is that ergonomic-related illnesses/injuries are the fastest growing trend among injuries in most of Corporate America. The reasons for this may be two fold. Firstly, with a requirement to stay more competitive and produce more product per unit time, cycle times have reduced. This may require workers to work faster than ever before, giving rise to the realm of repetitive motion injuries. Secondly, as a result of the information age of the nineties, individuals are better informed about ergonomic-related injuries thereby encouraging more reporting, with a possible consequence of increased workers' compensation costs. In addition to the above, regulatory agencies like OSHA have included ergonomic-related injuries among prime areas of concern for the nineties and beyond. A seven fold increase in fines and a willingness to levy fines on a per case (exposure) basis are some of the ways OSHA is spelling out its concerns for the above injuries.

Back injuries in human material handling can be controlled by good job-human compatibility design, training in safe work practices, and careful worker selection. Regulations like the Americans with Disabilities Act have made the worker selection option very difficult if not impossible. Training, while useful has limited uses and is not quite as preferable as the first option of designing the job to fit the worker. Good job design however, requires the knowledge of human capabilities and limitations. The purpose of this paper is to increase the knowledge base of human capabilities in combination asymmetrical lifting tasks, by providing the designer with prediction equations based on representative variables that are convenient to measure and use.

Rodrigues 1988, has cited several studies that have shown that asymmetrical lifting with boxes have resulted in lower loads being lifted when compared to symmetrical lifting with boxes. These studies used discrete lifting sequences only. While studies with boxes have been many, studies using bags have been fewer and far between (Garg and Saxena, 1980; Osgood, 1980; Jiang, 1981; Aghazadeh, 1982; and Mital and Okolie, to mention a few),

While most lifting studies have been involved with single human material handling (HMH) activities (lifting, lowering, holding, pushing and pulling), very little has been reported on lifting capabilities for combination activities (lift and lower, lift and carry, lift, lower and carry…etc.). The studies like Taboun and Dutta (1984, 1985 and 1986) and Jiang et al., 1986, studied combination tasks, but were carried out with boxes only. Aghazadeh 1984, suggested that loads lifted in boxes differed from loads lifted in bags and using prediction models developed using boxes to predict loads lifted using bags may not be prudent.

Based on the above premise, Rodrigues et al., 1989, studied the simulation of loading of grocery (paper) bags (without handles) into car trunks. This task resembles lifting over an obstruction, a task commonly found in industry. This study used a unique variation of the psychophysical methodology to study eighteen male subjects lifting bags for a lifting frequency of 6 lifts per minute for 6 different obstruction height and depth combinations. The two heights (wooden sills) were 70 cm and 90 cm, and for each of these obstruction heights there were three (sill) depths of 28 cm, 43 cm and 57 cm. The lifting originated 15 cm above the floor. Statistical analyses on the data revealed that the obstruction heights of 70 cm and 90 cm did not effect the amount of load lifted. When the data was studied across obstruction depths however, only the 57 cm depth showed a lower lifted load than either the 28 cm or 43 cm depth. There were no significant differences in the loads lifted for either the 28 cm or 43 cm depths.

Upon reviewing Rodrigues' 1989 study, Fredericks (1991) used plastic bags with handles to study the simulation of loading of grocery bags into car trunks. Twelve male subjects performed an externally-paced task of lifting grocery bags loaded with weights from 15 cm above the floor over a wooden sill. There were two different sill heights of 70 cm and 90 cm, one sill depth of 28 cm and for each of these combinations there were two frequencies, 3 and 6 lifts per cycle. The dependent variable was the maximum acceptable weight of lift (MAWOL). A modified version of the psychophysical methodology was also used to determine the MAWOL. Statistical analysis indicated that there was a significant difference in the weight lifted across the two sill heights as well as the weight lifted at the two different frequencies. A direct comparison of this study with Rodrigues (1989) revealed that individuals performing this experiment had greater lifting capacities with plastic bags with handles than that of paper bags without handles. Figure 1 depicts the experimental layout.

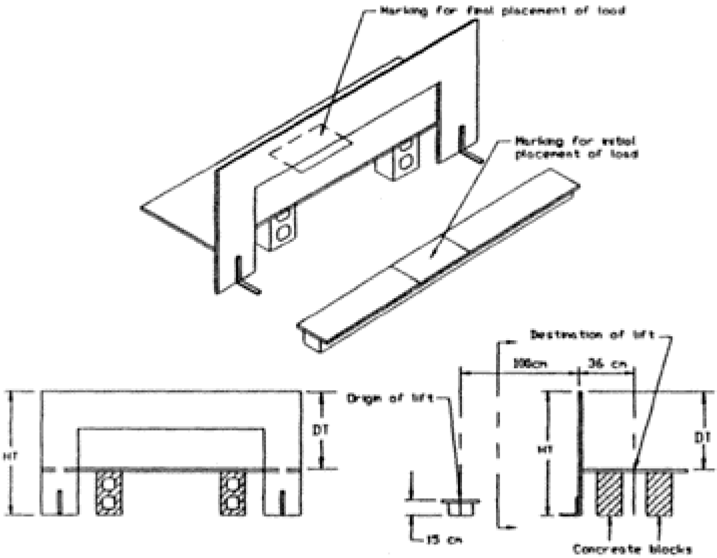

Figure 1. The experimental layout (HT sill height, DT=sill depth).

With the similarities between Rodrigues (1989) and Fredericks (1991), the objective of this paper was to determine prediction models for MAWOL at the common sill height, sill depth and frequency (70 cm, 28 cm, 6 lifts/minute respectively) for plastic and paper bags, utilizing anthropometric measurements.

METHODS

All statistical procedures reported here were performed utilizing the SAS statistical package (SAS Institute, 1982) on the IBM 3081 main frame computer at The Wichita State University.

Before the two sample populations could be considered homogeneous, several tests had to be conducted. Several t-tests were performed on the subjects age, weight, stature and grip strength at an elbow angle of 90 degrees. The results of these tests indicated that all four measures were insignificant (alpha=0.05). Following these initial findings, a stepwise multiple regression procedure (PROC STEPWISE) was performed on each data sets independently.

Stepwise selection is a variation of forward selection where tests are performed at each step, significance of F, to determine the contribution of each predictor already included in the model. It was then possible to identify predictors that were significant at an earlier stage but then lost their usefulness when additional predictors entered the equation. Such a predictor would then be removed from the model.

The parameters chosen for this procedure were significance of the independent variables (F value) with an alpha level of 0.15 to enter the model and 0.15 to exit the model. This was a “stepwise selection” method as discussed in Pedhazur (1982). The results of the stepwise selection indicated that both data sets included the same variables when developing prediction models. Based on the results of these tests and the previously performed t-tests, both data sets were combined. A summary of the physical characteristics of the subjects are presented in Table 1.

TABLE 1. Physical Characteristics of the subjects.

Body variable (N=30)	Mean	STD
Age (years)	23.90	2.66
Weight (lb)	175.68	21.78
Stature (cm)	178.67	7.45
Span (cm)	183.22	8.51
Acromial height (cm)	147.49	6.56
Acromial-dactylion length (cm)	78.75	4.46
Trochanteric height (cm)	97.12	9.48
Biacromial breadth (cm)	42.75	5.46
Chest depth (cm)	24.24	2.01
Abdominal extension depth (cm)	21.98	2.68
Metacarpal III height (cm)	74.11	4.40
Knee height (cm)	53.05	3.93
Grip strength at elbow angle of 180 deg (kg)	49.09	9.04
Grip strength at elbow angle of 90 deg (kg)	48.39	8.59

MODEL CRITERIA

The general criteria used in the development of the data fitting models that are discussed in the following section are listed below:

1. Outlier detection. Outliers were determined by calculating the standard residuals. As a general rule of thumb, observations resulting in a standard residual with an absolute value of greater than 2.0 were checked and dealt with appropriately. These residuals were also plotted against the predicted values. When the points appear to be randomly distributed about the residual mean, an unbiased model is indicated.

2. Multicollinearity. Multicollinearity refers to the situation when two or more independent variables are highly correlated with one another. When this situation exists, it can be harmful to the overall efficiency of the model. This problem can be detected by examining the correlation matrix between independent measures. If potential predictors are highly correlated, then these variables should be reduced to a number of independent variables that best represent the original set. Tests for multicollinearity are also available on SAS.

3. Evaluation of F values. An F statistic is generated for every model and each independent variable within a model. These indicate the significance of the relationship between the independent variable(s) and the dependent measure.

4. Evaluation of R-squared. R-squared represents the coefficient of multiple determination. The value of R-square for a model indicates the percentage (R-square * 100) of variance within the dependent measure that is accounted for by the independent variables in the model.

5. Mallows Cp. If Cp is graphed with p, Mallows recommends the model where Cp first approaches p. When the most adequate model is reached, the parameter estimates tend to be unbiased, and Cp will approximate p. Models with substantial basis will tend to fall considerable above the line Cp=p. Values below the line are interpreted as showing no bias; that is, they are below the line due to sampling error.

6. PRESS Criterion. The prediction sum of squares (PRESS) selection is based on the deleted residuals. Models with small PRESS values are considered good candidate models.

MODEL DEVELOPMENT

A stepwise multiple regression procedure (PROC STEPWISE) and (PROC RSQUARE) were used to develop equations to predict maximum acceptable weight of lift. The RSQUARE procedure finds subsets of independent variables that best predict a dependent variable by linear regression in the given sample. Regression coefficient and a variety of statistics useful for model selection can also be generated (SAS, 1982). The independent measures used were age, weight, stature, span, acromial-dactylion length, trochanteric height, biacromial breadth, chest depth, abdominal extension, metacarpal III length, knee height, grip strength at elbow (90 degrees), grip strength at elbow (180 degrees). Models were selected based on the previous mentioned criteria. Each model was checked for outliers and multicollinearity. The best four models developed are presented in Table 2 on the next page.

TABLE 2. Regression equations.

MAWOL	=11.274+0.744 (KNE)−8.364 (BAG)		(1)
R^2=0.4141	Cp=9.5095	PRESS=2164	
MAWOL	=64.438–0.962 (STR)+2.718 (KNE) +0.344 (BAG)		(2)
R^2=0.5625	Cp=3.0206	PRESS=1656	
MAWOL	=69.318–0.922 (STR)−0.717 (ABD) +2.798 (KNE)+0.038 (BAG)		(3)
R^2=0.5955	Cp=3.1325	PRESS=1640	
MAWOL	=−65.503–0.471 (WT)+3.821 (CH) −1.295 (ACD)+3.799 (KNE)−0.275 (ABD)+0.329 (G90)−0.455 (MET)+ 10.770 (BAG)		(4)
R^2=0.7201	Cp=4.008	PRESS=1344	

where,

STR=stature (cm)
KNE=knee height (cm)
ABD=abdominal extension depth (cm)
CH=chest depth (cm)
G90=grip strength at elbow angle of 90 deg (kg)
MET=metacarpal III height (cm)
WT=weight (lb)
BAG=insert “1” for plastic, “2” for paper
MAWOL=maximum acceptable weight of lift (lb)

DISCUSSION

The only anthropometric variable to appear in all four models was knee height (KNE). This variable showed a positive relationship with MAWOL in each of the four models. One possible reason for the positive coefficient could be that individuals with higher knee heights tended to be taller and hence had a greater ability to clear the fabricated sill height (obstruction). This, in fact was observed by Fredericks (1991). Conversely, the stature (STR) height variable conveyed a negative relationship with load capacity in models 2 and 3. The negative relationship with MAWOL could possible mean that subjects who were taller had to bend considerably more at the waist at the start of the lift. Remember the origin of lift was fifteen cm above the ground. The majority of the subjects chose to perform a back lift as opposed to straight back leg lift. The last variable that appeared in more than one model was abdominal extension depth. This variable exhibited a negative relationship with MAWOL in models 3 and 4.

Several of the variables mentioned, as well as others, have previously appeared in the literature. Variables such as metacarpal III height, acromial-dactylion length and grip strength at an elbow angle of 90 degrees were presented in Rodrigues work in 1988. The variables knee height and stature height were also present in Fredericks work in 1991. For detailed prediction equations refer to Rodrigues (1988) and Fredericks (1991).

It must be mentioned that many models with higher R squared values were developed but excluded due to multicollinearity. Multicollinearity appears to be an unavoidable obstacle when trying to develop prediction models based exclusively upon anthropometrics.

CONCLUSION

Anthropometric measurements are safe and easy to measure. It was the objective of this research to develop prediction models based upon this premise for both paper and plastic bags. Some prediction models were successfully developed for acceptable weight of lift. Such equations would be beneficial to those involved in task design, task modification, or updating existing lifting capacity standards. Further studies involving different task variables are needed in this area. Exploration of other anthropometric, physiological and personnel variables and ratios could lead to stronger regression models.

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OUTLINES OF THE CRITERIA FOR ACCEPTABLE LOAD DURING MANUAL SORTING OF POSTAL PARCELS

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This paper outlines the factors determining acceptable physical load in manual sorting of postal parcels based on field and laboratory studies. At worksites cardiorespiratory strain was aerobic for 98% of the work shift. In the laboratory simulations, local muscle strain was often too high in the parcel lifting and carrying tasks. The psychophysical ratings did not reveale unacceptable high levels of strain. In the postal sorting work an acceptable level for physical load can be reached if the work pattern is individually adjustable and includes adequate rest pauses.

INTRODUCTION

The sorting of postal parcels is a common and typical manual materials handling (MMH) job. The MMH involves mixed dynamic and static work with large muscle groups and its work load effects both on the cardiorespiratory and musculoskeletal system. The ordinary components of the MMH are lifting, carrying, pushing, pulling and holding loads of various weights and sizes. According to the stress-strain concept (Rutenfranz, 1981; Rohmert, 1983) applied to the MMH tasks, the level of overall and local strain depends both on work load (stress) factors of the MMH task and on a worker's individual abilities and skills (Figure 1).

The criteria for acceptable load in the MMH tasks can be based on cardiorespiratory (Asfour et. al., 1988), biomechanical (Chaffin, 1988) and psychophysical (Borg, 1970; Griffin et al., 1984) strain responses. The acceptable load is in the individual zone of adaptation, and does not cause excessive fatigue or injuries to a worker.

The purpose of this paper is to outline the criteria determining acceptable physical load for manual sorting of postal parcels. The consideration of the criteria is based on the results of the field (Louhevaara et al., 1990a; Stålhammar et al., 1992) and laboratory (Louhevaara et al., 1988; Louhevaara et al., 1990b) studies on postal sorting work.

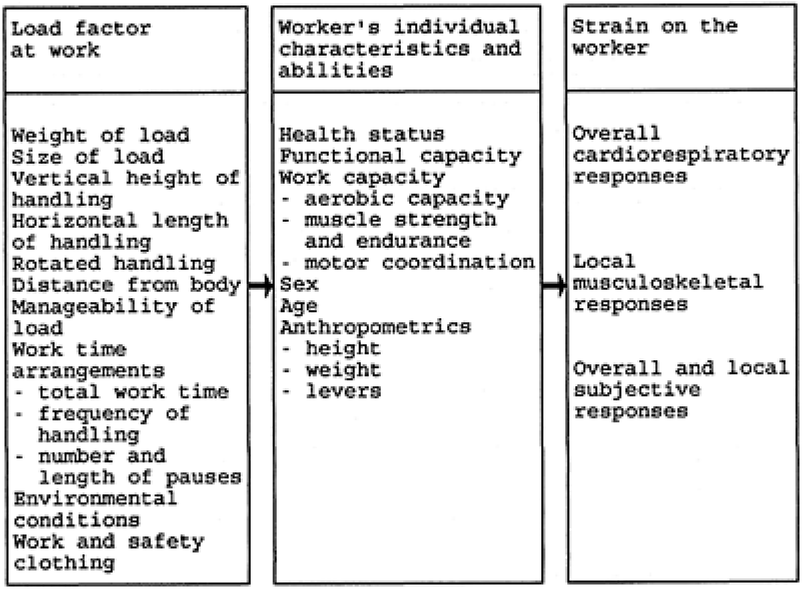

Figure 1. The stress-strain concept modified to the manual materials handling (Louhevaara, 1992).

CARDIORESPIRATORY STRAIN DURING PARCEL SORTING

Cardiorespiratory strain was assessed in the laboratory during simulated manual sorting of postal parcels with 21 sorters (Louhevaara et al., 1988), and during actual work with 32 sorters (Louhevaara et al., 1990a). The subjects were healthy men and their range of age was 23–45 years.

The relative aerobic strain (RAS=% of maximal oxygen consumption, VO2max), heart rate (HR), blood lactate concentration (LA), and relative overall rating of perceived exertion (RPE overall) on the cardiorespiratory system (Borg, 1970) (% of the maximal RPE overall) of the subjects were assessed both in the laboratory and field study.

The simulated sorting tasks

The mean weight of the parcels was 5 kg in the sorting simulation.

During habitual sorting rate of 9±2 parcels/min the RAS was 42±12 %VO2max for cycle exercise at the oxygen consumption level of 1.36±0.38 1/min. HR was 105±22 beats/min, LA 1.8±0.9 mmol/1, and the RPE overall 8±6% of the maximal RPE overall ie. the habitual sorting work was felt to be, on average, “very very light” (Louhevaara et al., 1988).

The actual sorting

During actual sorting work HR was 101+18 beats/min. The sorting tasks were calculated to be anaerobic during 2% of the work shift when the RAS was over 70 %VO2max for cycle exercise and HR was over 140 beats/min (Table 1). LA values determined before the work shift, after the most strenuous work phases, and at the end of the shift were 0.8±0.3− 1.3±0.2 mmol/l. At the end of the work shift the RPE overall reached the levels from 20 to 40% of the maximal RPE overall (ie. from “very light” to “light”) (Louhevaara et al., 1990a).

Table 1. Heart rate (HR, beats/min) and the proportion (% of the work shift) of light (the estimated relative aerobic strain, RAS<33%; HR<90 beats/min), moderate (RAS 33–50%; HR 90–109 beats/min), heavy (RAS 51–70%; HR 110–140 beats/min), and very heavy (RAS>70%; HR>140 beats/min) physical work during all work tasks at five (A, B, C, D, E) sorting centres. The HR values are the means ±SD and the RAS valus are the means.

Sorting cer ntre	HR		RAS				
	n	(b/min)	n	light (%)	moderate (%)	heavy (%)	very heavy (%)
A	10	99±20	8	42	36	18	4
B	6	101±19	2	22	66	12	0
C	6	101±13	1	18	69	13	0
D	4	111±17	3	18	31	50	1
E	5	96±13	3	52	45	3	0
All	31	101±18	17	38	53	7	2

LOCAL MUSCLE STRAIN

The simulated sorting tasks

In order to assess local muscle strain for the shoulder and low back region during lifting and carrying of postal parcels, such tasks were simulated in the laboratory. In the lifting task, the parcel of 4 kg was lifted from a shelf (40 cm above the floor) to another shelf (140 cm above floor) and back 6 times/min. In the carrying task, the parcel was held with both hands while walking on the level at the speed of 2.5 km/h on a treadmill. The subjects were six female (age 26–41 years) and six male (age 23–41 years) volunteers (Louhevaara et al., 1990b).

Muscle strain was quantified by electromyography (EMG) (Jonsson, 1982) and local ratings of perceived exertion for arms (RPE arm), for back (RPE back), and for legs (RPE legs) (% of each maximal RPE). The EMG amplitude and its amplitude distribution probability function related to muscle strength (% of maximal voluntary contraction, MVC) were assessed in the tasks. Based on the function, the following upper strain limits for different levels of contraction has been recommended for a work period from one hour up to an 8-hour work shift: 2–5 %MVC for the static level, 10–14 %MVC for the median level, and 50–70 %MVC for the peak level (Jonsson, 1982; Bjorksten and Jonsson, 1977).

In the simulated tasks, the local strain was not due to sex. In the lifting task, the median limit of 14 %MVC was exceeded both for the upper trapezius and erector spinae muscle. While carrying, strain for the upper trapezius muscle was over 5 %MVC at the static contraction level, and the limit of 14 %MVC was crossed both with the upper trapezius and erector spinae muscle at the median contraction level. Thus, local muscle strain of both muscles could be classified as too high at these contraction levels. In the sorting simulations, there were practically no differences in the overall and local RPEs. Both were below the 50% of the maximal values ie. occasionally reaching the level of “fairly hard” (Louhevaara et al., 1990b).

The actual sorting

In actual sorting work local strain on the musculoskeletal system was evaluated by the observation of poor work postures and by the RPE for arms, back and legs during the work shift. The proportion of the poor work postures for back (bent forward and/or twisted) was, on average, 24% of the time for sorting. Holding a parcel with both arms (arms elevated at 30–90° to the vertical) averaged 46 % of the time for sorting. At the end of the shift the local RPEs varied from 20 to 40% of the maximal values (ie. from “very light” to “light”) (Louhevaara et al., 1990a).

RATING OF ACCEPTABLE LOAD

The postal sorters performed two tests for rating of acceptable load (RAL): The standard RAL-test (RALst) (Griffin et al., 1984) and the work simulated RAL-test (RALw). The latter was developed to imitate actual sorting work (Stålhammar et al., 1992). The subjects were 103 healthy male sorters aged 19–58 years.

The results of the RALw-test averaged 9.5 kg. It was 58% of the mean weight chosen in the RALst-test (16.4 kg) (Table 2). The correlation coefficient between RALst and RALw was 0.84 (Stålhammar et al., 1992).

Table 2. The main results of the test for the standard rating of acceptable load (RALst) and for the work-simulated rating of acceptable load (RALw).

Test	Mean (kg)	n=103 SD (kg)	Range (kg)
RALst	16.4	7.8	4.0–42.5
RALw	9.5	3.4	3.3–21.3

CRITERIA FOR ACCEPTABLE LOAD FOR POSTAL SORTING WORK

The results of the field study showed that the postal sorting at the habitual work rate did not produce acute overall or local symptoms of fatigue for healthy male subjects. In the simulated lifting and carrying tasks, local strain often exceeded recommendated limits for overstrain.

The factors contributing to acceptable physical load during manual sorting of postal parcels can be outlined as follows:

– average weight of parcel is lower than 5 kg
– heavy parcels (>20 kg) can be sorted in pairs
– parcels are mostly handled below the shoulder level
– a trunk is unfrequently (under 30% of the working hours) twisted and/or bent forward, and parcels can be handled near the body
– the maximum length of the shift is 8 hours
– mean sorting rate is lower than 8 parcels/min
– the amount of walking and carrying is under 5 km per work shift
– total number of parcels sorted and handled during a work shift is smaller than 1 500
– time for recovery is at least 20% of the shift length
– the sorters are given as freely as possible to set their own work pattern
– the ambient temperature is in a range of thermoneutral values (15–25°C)
– the sorting work does not require the use of heavy personal protective devices or clothing.

The arrangements of time for work and recovery are critical while considering the levels of acceptable load in postal sorting work. With individually adjustable work pattern including sufficient rest pauses, it is possible to prevent excessive local muscle strain and fatigue as well as injuries in postal sorting work.

The field and laboratory results also suggest that in order to avoid cardiorespiratory overstrain, a sorter should have a maximal oxygen consumption which is at least 2.0 l/min. Furthermore, good muscle strength and spinal mobility are preferable. The manual sorting of postal parcels can not be recommended for the individuals having serious musculoskeletal disorders.

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EVALUATION OF HANDLE POSITIONS AND ANGLES IN MMH TASK

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Handle location and geometry play an important role in container design and effectiveness. An ideal handle position and angle should minimize stress at L5/S1, and minimize average grip pressure on the two hands with force distributed evenly on both hands. Such a handle will be most comfortable for performing a MMH task and reduce the likelihood of compressive injuries on the lumbar spine. The intent of this study was to address an existing anomaly between asymmetric handle positions through a biomechanical analyses and to evaluate handle positions through a measurement of force at the hand/handle interface. A simple two dimensional biomechanical model was developed for evaluating handle positions. The results show that lift height and load are both important factors that affect disc compressive forces. Biomechanically, asymmetric handle position 6/8 and 3/8 were worse than the remaining three handle positions (2/2, 8/8, and 3/7). In a follow up work, force at the hand/handle interface was measured with force-sensing resistors. Five handle positions and seven angles were varied in a static holding task. The results indicate handle positions 2/2, 8/8 and 3/7 to be comparable to each other and superior to position 6/8, which are consistent with the results of the biomechanical analysis. Recommendations are made for the designer of containers.

INTRODUCTION

Considerable research attention has been given to handle positions in MMH tasks. For example, using a standard handle position convention (Figure 1) Coury and Drury (1982) have determined that in static holding of boxes at waist height asymmetric handle positions (3/8 and 6/8) gave the lowest physiological and perceived stress, whereas symmetrical handle position (8/8) minimized forces exerted on the handles by the hands. Similar findings have been obtained in a static box holding task at three holding heights (floor, waist and shoulders) by Deeb et al. (1985). The asymmetrical positions (3/8 and 6/8) were found best at all holding heights, with symmetrical positions (2/2 and 8/8) being recommended for heavy weights. Further studies have also shown that the recommendations derived from the static holding of boxes are valid for dynamic lifting tasks as well (Drury and Deeb, 1986).

Bishu and Wei (1992) have reported some difference between the handle positions 3/7 and 6/8. In a lift and carry task position, 3/7 was found to be best while in an isometric holding task, longest endurance time was observed with position 6/8. The research objectives for this investigation evolved out of the anomaly between handle positions 6/8 and 3/7. Why do subjects psychophysically choose shorter moment arm positions (3/7 or 8/8) as best in lift and carrying task yet show longer endurance time at the longer moment arm positions (6/8)? In order to determine if position 6/8 had better biomechanical advantage, a biomechanical model was developed and used to evaluate respective handle positions.

BIOMECHANICAL ANALYSIS

A simple 2D model was developed to calculate the net disc compressive force at L5/S1 for the handle positions 3/7, 8/8, 2/2, 6/8, and 3/8. The calculations were performed for a range of lifting heights (.8 to 1.1 meters) at a fixed weight, and for a range of lifting weights (10 to 16 Kgs.) at a fixed height.

Figure 2 shows the plot of the disc compressive force for the five handle positions for a range of heights. It is interesting to note that the asymmetric handle positions 6/8, 3/8 result in higher stress levels at L5/S1 than the remaining handle positions (3/7, 2/2, and 8/8). Further there appears to exist an interaction (not tested statistically) between height and handle positions, with handle 8/8 better at greater heights, and handle 2/2 better at smaller heights. According to Figure 2 handle position 3/7 seems to be the best compromise.

Figure 3 shows the plot of disc compressive force for the various weights. As expected, the disc compressive force increases with increasing weights, with the asymmetric handle positions 3/8, and 6/8 being much worse than the other handle positions, which were comparable to each other (Bishu and Wei, 1992). Biomechanically positions 6/8 and 3/8 appear to be the worst while other positions (3/7, 2/2, 8/8) are comparable. As a next step it was argued that the relative effectiveness of the various handle positions would be reflected at the force generated at hand/handle interface.

Further a relationship between the handle angle, handle position, the grasp forces generated at the hand-handle interface, for a given weight and lift geometry, should facilitate improvement in container design. The next objective was to measure the distribution of forces at the hand/handle interface and use the same as a criteria to evaluate handle positions and handle angles.

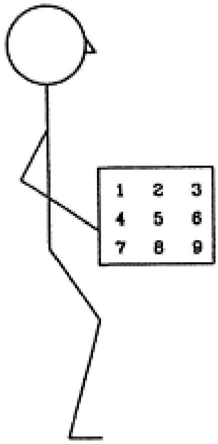

Figure 1. Handle Position Labels
(After Drury et al, 1982)

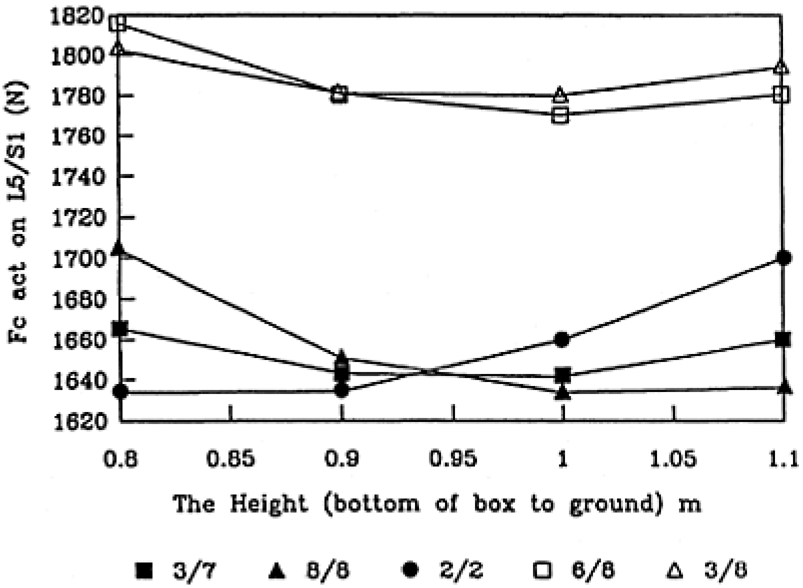

Figure 2. The resulting compression force vs lift height

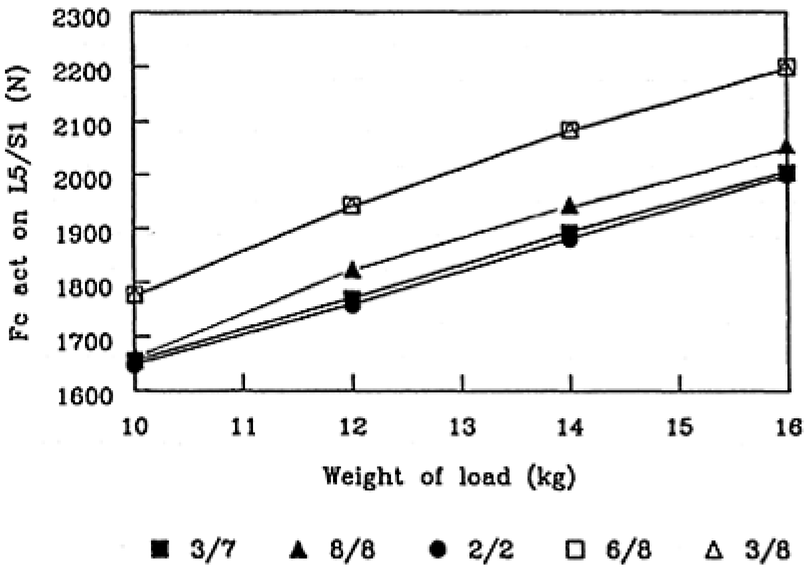

Figure 3. The resulting compression force vs weight of load

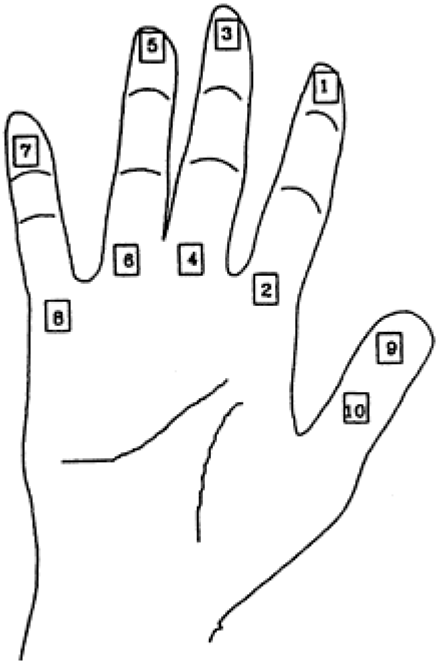

Figure 4. FSR placement on the palmar surface of the right hand

EFFECT OF PRESSURE DISTRIBUTION ON HAND/HANDLE INTERFACE

Subjects

Six male subjects, all chosen from the student population of the Industrial Engineering Department at University of Nebraska-Lincoln participated in the experiment. Subjects were healthy and had no previous history of CTD injuries.

Experiment Design

An generic aluminum box was constructed with circular cutouts at each of the handle coordinates. Two simulated cut-out handles were mounted in each lateral face. The force at the handle/hand interface was collected through a number of force sensing resistors. The complete set up included force sensing resistors, voltage divider, analogue to digital converter, and a host PC for data collection. Ten force sensing resistors were used in each hand in this experiment (see Figure 4).

Five handle positions (3/7, 3/8, 6/8, 2/2, and 8/8) were combined with seven handle angles (0, 15, 30, 45, 60, 75, 90 degrees) to yield 35 treatment combinations. The height of lift was kept constant at 1 meter from floor, and the weight of lift was held at 25 pounds. The order of presentation of the “handle position×angle” combinations were randomized for each subject. FSR readings in pressure units were collected by using a BASIC program, and saved during the experiment as separate files for each subject.

Results

Initially, the data was subjected to a mixed model analysis of variance, and all the main effects were significant. Figure 5 shows the plot of the Handle Position effect. The average pressure with handle positions 3/7, 2/2, 8/8 are smaller than those with positions 3/8, and 6/8. This is somewhat contrary to the findings of Coury and Drury (1982). Figure 6 shows the plot of the Handle Angle effect. The best handle angle appears to be between 60 to 75 degrees. It is seen from Figure 7, which shows the Hand effect, that the average pressure on the right hand is significantly different from that on the left hand. It has been reported (Deeb et al., 1985) that in handling of boxes, the right hand carries the load while the left hand performs the stabilizing action.

Figure 8 shows the mean pressure at the various force sensing resistor locations. It is interesting to note that in positions two (metacarpal region of index finger), three (distal phalange of middle finger), five (distal flange of the ring finger), and nine (distal phalange of thumb) the pressure is higher than in other positions. It is possible that this pattern is because of the biomechanical advantage of the distal phalanges, longer lever arm, and better grasp capability. Although a uniform pressure distribution across all the ten sensor locations was not expected, the observed pattern is interesting and may have some implications for handle design.

DISCUSSION AND CONCLUSIONS

Biomechanically, positions 2/2, 8/8, and 3/7 appear to be the best for lifting, while 6/8 appear to be the worst. The force distribution at the hand handle interface also appears to follow an identical pattern. Therefore, positions 2/2,

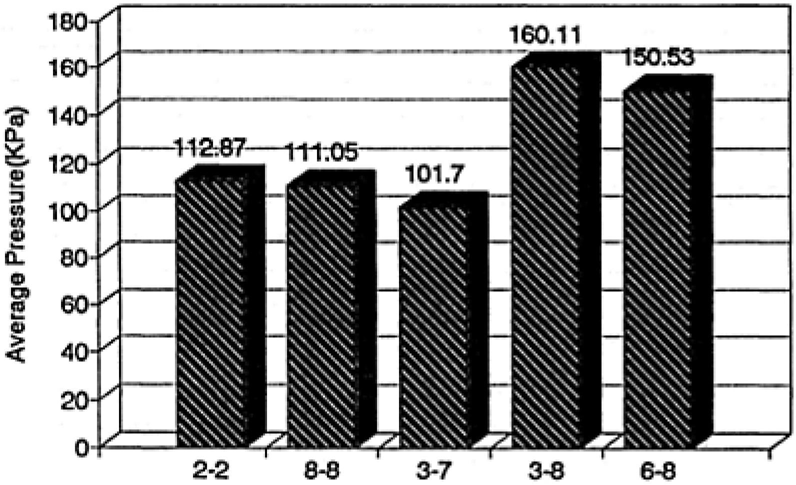

Figure 5. Mean Pressure on Five Handle Positions

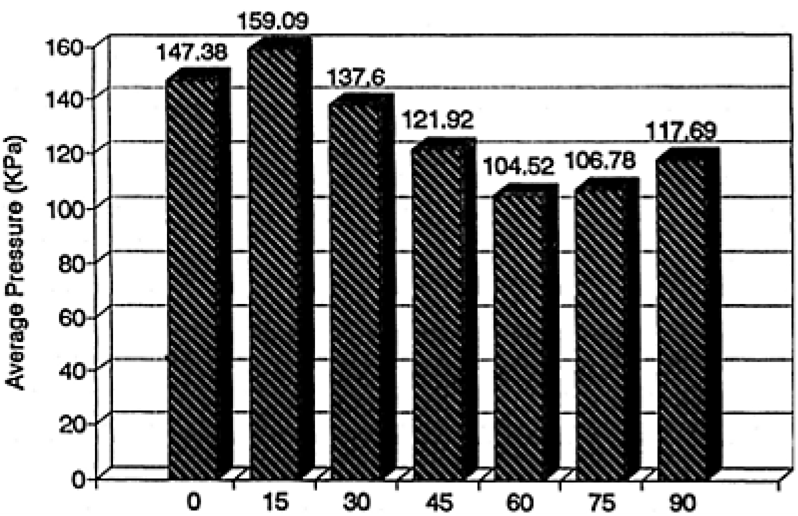

Figure 6. Mean Pressure Over Handle Angles

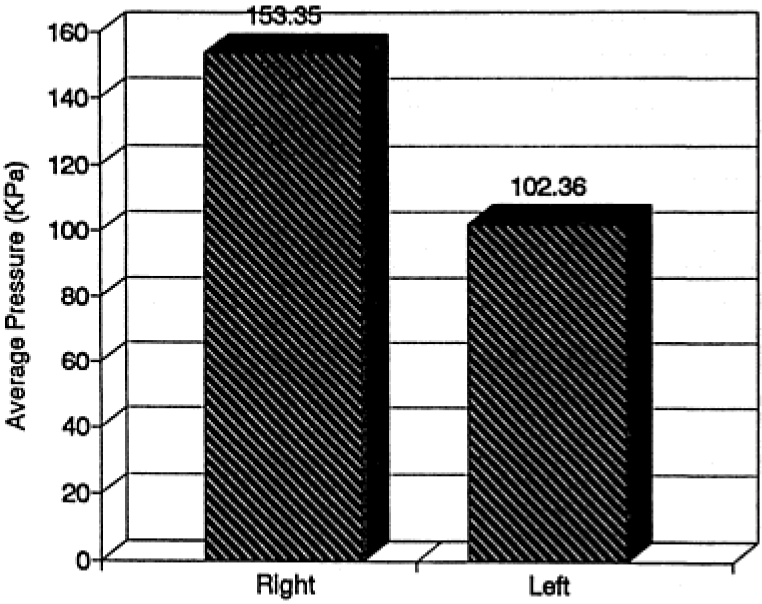

Figure 7. Mean Pressure on Right & Left Handle

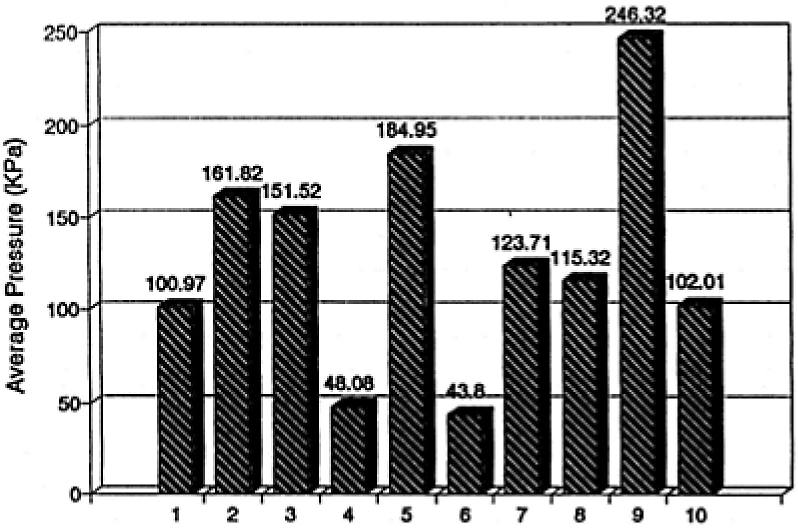

Figure 8 Mean Pressure on Pressure Sensor Location

8/8, and 3/7 are all good while position 6/8 stands out as the worst. The bulk of the energy transfer at the handle/hand interface seems to take place at the metacarpal region and the distal phalanges of the fingers. This does have implication for glove and hand tool design.

Before making any recommendations it would be prudent to consider the various issues in lifting boxes with cut out handles. When a person lifts a box using a handle located at a given position at a given angle, a complex motion of the wrist and elbow ensues. The wrist moves from an ulnarly deviated posture at the beginning of the lift to a radially deviated posture at the end of the lift. To an extent, the elbow angle changes as a compensatory behavior. Therefore like the “bend-back straight-knee” and “straight back-bent knee” styles of lifting, one can visualize “bent-elbow straight-wrist” and “straight-elbow bent wrist” styles in lifting. Given that the wrist posture is one of the frequently reported causative factor for cumulative trauma disorders, and that the wrist posture changes from ulnar deviation to radial deviation during the process of lifting, a variable angle handle may be the solution. The results of this study suggest that the most favorable handle angle is in the range of 60–75 degrees. The best recommendation for the designer should be to design a variable angle handle. Such a device will facilitate adjustment of wrist postures while lifting and hopefully reduce deviated postures; or at least reduce the variability in the wrist posture assumed during lifting and help maintaining a “bent-elbow straight-wrist” posture.

In conclusion, a recommendation for the designer will be to develop a variable angle handle (60–75 degrees) to be positioned at 2/2, or 8/8, or 3/7, with some cushioning recess for the right thumb. In fact position 3/7, although asymmetric for the human, is definitely symmetric for the box, in a sense that the two cutouts are diagonally opposite, and at equal distance from the box centroid. A caveat is in order here. The weight and height of lift were not considered here. They are important factors and can impact the findings obtained in this study, and as a matter of fact are the topics of current research of these authors.

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Traditional and Non-Traditional Indicators of Fatigue in a Controlled Heavy Lifting Task

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INTRODUCTION

Every year an inordinate number of workers succumb to lower back injury. The consequences of these injuries are pain, suffering and major workman's compensation claims. Replacement workers inevitably erode productivity and the quality of life of the injured worker is substantially undermined.

The central questions are how and why did the injury occur? In some cases, the physical arrangement of the task is inappropriate and this may be resolved by a skilled ergonomist and modest investment by the company. In other cases, the worker simply gets sloppy and makes a "mechanical error" in moving a load with immediate, painful consequences. It is our contention that a significant precursor to the "fateful lift" is simple physical fatigue. To date, this has proven to be an elusive hypothesis because there are few standardized criteria in industry to predict when a worker has surpassed a fatigue level which now increases the probability of a low back injury.

The purpose of this study was to examine traditional and non-traditional indicators of effort with a view to monitoring the fatigue process. Many of the measurements have not been applied to the work environment even though they have demonstrated predictive ability in the laboratory. Therefore, the challenge was to see if any combination of the measurement array could identify progressive fatigue in a controlled heavy lifting task.

METHOD

Five healthy male subjects aged 21–31 were studied. All subjects were experienced lifters and physically active. Subject #4 could not tolerate the intra-abdominal pressure (IAP) transducer and was unable to complete the session. The subjects were required to lift, hold for five seconds and then lower a predetermined load, at a rate of six lifts/lowers per minute. This work rate was maintained for four consecutive fifteen minute work periods (total time equals one hour). The loads were lifted utilizing an incremental lifting machine (ILM) that constrained the movement of the load to the vertical direction. Subjects selected a fatiguing load that they felt they could safely lift/lower for the one hour. The ILM was selected to provide a controlled, heavy lifting/lowering challenge and was not intended to simulate a specific occupational situation. The ILM was instrumented with a potentiometer to record the load displacement time histories. This signal was digitally, dual low pass filtered (Butterworth, f_c=3Hz). The maximum lift/lower velocities from the first work period were used to scale the remaining lift/lower velocities. These velocity profiles were then used to ensemble average ten to twelve lift/lower cycles for the EMG, IAP and ILM velocity signals. In each fifteen minute block, subjects worked uninterrupted for six minutes. They stopped briefly to put on head gear to allow ventilation, mouth occlusion pressure ($P_{0.1}$) and functional residual capacity (FRC) measures to be collected. They resumed lifting and two minutes later, 120 s of emg were collected in addition to breath by breath (BBB) data. $P_{0.1}$ measures were collected during the last 30 seconds of this period. FRC data were collected at the end of each lifting trial. Digital sampling was performed at 200 Hz.

Four pairs of disposable surface EMG electrodes (Ag-AgCl, Meditrace, Graphic Control) were applied to the prepared skin, using a centre-to-centre distance of 3 cm: Rectus abdominous (RA) (2.5 cm lateral to the umbilicus), External oblique (EO) (between the anterior superior iliac spine and caudal border of the ribcage), Intercostal (IC) (7th intercostal space approximately 4 cm below the pectoral border), Erector spinae (ES) (3 cm lateral to the midline at the level of L3). The raw EMG signal was full wave rectified, low pass filtered (Butterworth, f_c=5 Hz) and amplified (Input impedance >10 M ohm above 1Hz, CMRR>80 Db at 60 Hz) to produce a linear envelope EMG. Isometric maximum voluntary contractions (MVCs) were performed, prior to each test session, for EMG normalization. The isometric MVC postures utilized were an extension effort in a posture similar to that used at the start of each lift and a sit up against resistance while performing a valsalva manoeuvre. Several repeated efforts were recorded, with the largest amplitude used as the normalization value.

VO_2 was determined on a breath-by breath basis, using a software program (First Breath, St. Agatha, Ontario). Inspired and expired ventilatory volumes were obtained from a volume turbine (VMM-110, Alpha Technologies). The turbine was calibrated using flow rates approximating those experienced in the test sessions, by manually pumping a 3000 ml syringe. A respiratory mass spectrometer (MGA-1100A, Perkin Elmer) was used to determine the fractional concentrations of O_2, CO_2, N_2 found at the mouth. The ventilation and gas concentration values were digitally sampled at 200 Hz using an analog to digital conversion board (DAS-16, MetraByte Corporation, Taunton, MA) and a microcomputer (IBM-PC).

Respiratory drive was measured by occlusion pressure generated at the end of 100 ms ($P_{0.1}$). Occlusion of the inspiratory airway was performed by a solenoid valve (Lucifer, Sperry Vickers) utilizing a logic controller. For each subject, the first logic parameter set was the expiration flow rate required to trigger solenoid closure. The second parameter was the setting of a minimum mouth pressure threshold, to initiate the 120 ms release timing circuit. This pressure level had to be adjusted so that a minimum mouth pressure would start the timing circuit, yet still protect the system against false triggering. Upon initiation, the $P_{0.1}$ controller monitored the BBB expiration channel and when the expiration criteria had been met, activated the solenoid to occlude the inspiratory flow.

The release timing circuit began as soon as the minimum mouth pressure was generated, releasing the occlusion after 120 ms. The mouth pressure produced after 100 ms of occlusion was then recorded as the $P_{0.1}$. To prevent detection of solenoid closure, subjects listened to music through earphones.

Function residual capacity was measured twice at rest and twice during the last segment of each work period using a helium-dilution technique according to Sharratt et al. (1987). The rebreathing gas bag (WSP 5 litre anti-static bag (B.S.S. 3533)) was filled with 1.5–2.5 litres of a 9.05% He-balance O_2 mixture. The end-tidal He concentration, respiration and expiration traces were measured with a four channel strip chart recorder (7474A, Hewlett-Packard). As a subject completed a lift, he was visually signalled to hold the load and to close his eyes. As he reached a normal end-expiratory volume, he was switched (Large 3 way sliding valve, Hans-Rudolph #2770) to the rebreathing bag and given a physical and loud verbal cue to initiate three deep breaths. The subject breathed until He equilibrium was reached, usually less than 10 seconds. The inspiration and He concentration strip chart records were examined to ensure proper transition. The bag was sucked dry and refilled while the subject briefly stopped working. The second FRC was completed after the subject had been lifting for another two minutes.

IAP measurements were made utilizing a pressure catheter (Millar MIKRO-TIP^{R} model PC-350) placed in the stomach via the nasoesophagaeal pathway. The catheter and control unit (Miller model TCB-100) were calibrated daily. Subjects “sniffed” 2% xylocaine gel to lightly anaesthetize the nasopharynx and minimize the “gag” reflex. To ensure the catheter was placed in the stomach, subjects performed three quick sniffs over five seconds. An acute increase in pressure reflected proper positioning of the catheter.

The signal outputs from the measurement devices were grouped and sampled at 200 Hz as follows; micro computer #1: four EMG, ILM position, IAP and heart rate; micro computer #2: $P_{0.1}$, the solenoid controller signal, inspiration volume, expiration volume, IAP and ILM position. As, described, the BBB system utilized its own micro computer.

RESULTS AND DISCUSSION

All of the subjects felt “fatigued” at the end of their lifting session. Although they had not reached the “failure point”, all subjects felt their performance was degraded by the end of the session.

EMG

The changes in peak EMG amplitudes are summarized in Table 1 and an example is provided in Figure 1. As expected, lifting produced more ES activity than lowering. Subjects 1, 2 and 5 showed a significant decrease in the level of ES across lifts ($p<.05$), while subject 3 showed an increase. Typically, an increase in EMG amplitude is associated with fatigue (De Luca, 1984). Petrofsky and Lind (1978) demonstrated increases in erector spinae EMG during 1 hour of lifting at intensities ranging from 25% to 70% of lifting MVO_2. However, a strategy to minimize the effects of fatigue is to preferentially recruit less fatigued muscle fibres, allowing recovery to occur in fatigued fibres. The decrease in ES

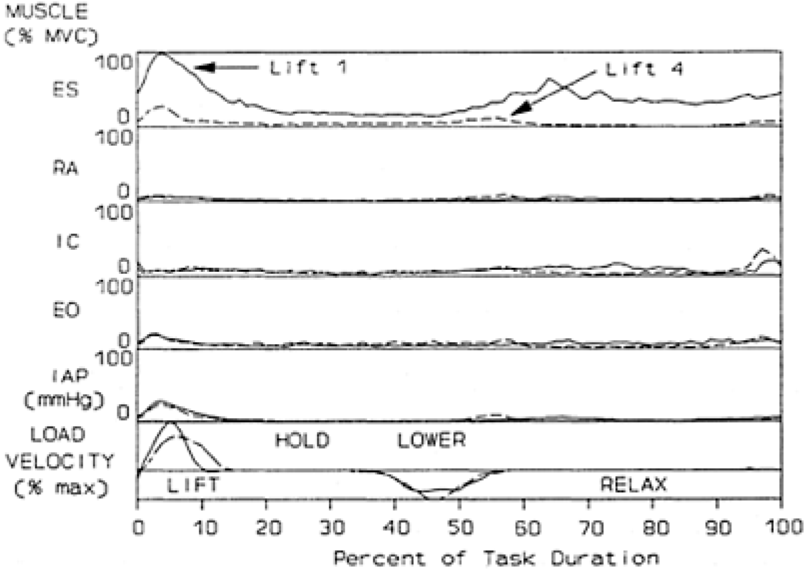

Figure 1 Example of mean EMG and IAP activation patterns and ILM lift/lower velocity profile for subject #1.

activity while moving the same load provides strong support that subjects utilized alternative lifting strategies as time progressed. These subjects appear to be utilizing muscle groups other than those monitored. The ES consists of lumbar and thoracic components. As the duration of the lifting continued, subjects may have utilized the upper ES fibres more than the lower ES fibres. Only subject 3 showed the expected response of an increase in ES amplitude.

Table 1 Peak EMG and IAP values obtained for each lift session.

Subject	1		2		3		4	
Lift #	1	4	1	4	1	4	1	4
ES (%MVC)	99	76	118	33	38	60	68	45
RA (%MVC)	8	8	7	9	4	4	4	8
IC (%MVC)	12	26	21	19	11	3	15	11
EO (%MVC)	25	38	20	35	12	17	32	24
IAP (mmHg)	45	45	28	24	42	34	32	39

Another strategy utilized may be the adjustment of work posture, thereby changing the level of muscular force required in order to perform the task. Subjects were also free to move their feet during the one hour of testing. They may have moved closer to the ILM handles, decreasing the moment of force required about the low back, thus decreasing the force production required of the ES. Although the subjects were experienced lifters, this ILM lift-hold-lower task was unique to all individuals. They may have learned a strategy throughout the lifting task, that incorporates one of the ILM shortcomings. The ILM constrains movement to the vertical direction and therefore, forces applied in other directions (eg. leaning back) may result in force application with a vertical component, thereby decreasing the magnitude of force production required by the ES.

The RA showed very little activity throughout the lifting session. The highest level of activity found was at 11% MVC for subject #5. McGill, Norman and Sharratt (1990) reported similar values for subjects performing single lifts, using 70–90 kg loads. It appears that very little RA activity is required to in order to fulfil its functions during the repetitive lift, hold and lower cycle.

IAP

IAP increased prior to lifting of the load and with load lowering. IAP has been discussed as a supporter of the spine and a possible disc compression relief mechanism. However, the generation of IAP via muscular contraction further increases disc compression (McGill and Norman, 1986). In this study, IAP appears to help stabilize the thoracic cavity, therefore helping to support the spine. The stable thoracic cavity is of assistance in transferring forces through the body. IAP shows a clear pattern of being generated prior to the start of a lift, but only increases once the lowering portion of the task has begun. This strategy may be related to the posture. Prior to lifting, subjects were in a stooped posture and stability of the spine would be very important at the start of the lift. As the lift is performed, IAP increases, helping to maintain stability and transfer force. The hold portion of the lift show that IAP decreases. IAP increases again for the lowering component of the task. It would appear that IAP is not a disc compression reliever, but rather a result of the need for thoracic stabilization.

Ventilation

It would be expected that the lifting task would produce a steady state VO_2. Subjects 1 and 2 showed a substantial increase in VO_2, while subject 3 showed no change and subject 5 decreased (Table 2). These responses are also due to the nature of the lifting task. The starting point for the lift ensured that each subject had to squat to a certain degree.

However, the subjects were free to use whatever lifting style they felt appropriate. Therefore, as a subject became fatigued they may have elected to increase or decrease the amount of squatting performed with each lift. This would increase or decrease the muscle mass involved in performing the lift, concomitantly requiring in a change in VO_2.

Breathing frequency (fb) (Table 3) reveals a different pattern. Subjects 1 and 2 increased their fb. Subject 3 showed little change. Subject 5 had an increased fb despite a decreased VO_2. This would imply that the lifting challenge has somehow altered the ventilatory mechanics.

Table 2 VO_2 (Mean (S.D.)) for each subject for work period 1 and 4.

	VO_2(L/min)		
Subject	Lift 1	Lift 4	Change (%)
1	1.98 (0.14)	2.21 (0.17)	11.6
2	1.26 (0.05)	1.53 (0.05)	21.4
3	1.53 (0.07)	1.56 (0.08)	1.9
5	2.26 (0.07)	2.14 (0.10)	−5.3

Table 3 Summary of breathing frequency for each work period (Mean (S.D.)).

	Breathing Freq. (breaths/min)		
Subject	Lift 1	Lift 4	Change (%)
1	30.4 (2.38)	40.5 (4.09)	33.1
2	19.7 (1.09)	24.9 (4.21)	25.6
3	26.4 (0.54)	25.5 (1.15)	−3.4
5	25.8 (1.29)	33.3 (2.70)	29.2

Increasing airflow is a function of the volume of air inspired and the time available for inspiration. Thus, the measure of mean inspiratory flow (V_T/t_i) provides an indicator of the respiratory response to the metabolic demands of the body. All subjects showed an increase in mean inspiratory flow (MIF) (Table 4) over time reflective of the increased breathing frequency.

Table 4: Summary of Mean Inspiratory Flow

	Mean Inspiratory Flow (L/s)		
Subject	Lift 1	Lift 4	Change (%)
1	2.33	2.53	8.6
2	0.80	1.13	41.3
3	1.25	1.30	3.2
5	1.68	1.84	9.5

The role of the respiratory system is to utilize the respiratory "drive" produced by the brain stem in response to a metabolic demand in order to mechanically produce precise lung airflow and alveolar ventilation (Dempsey, 1986). This is accomplished by control of breathing patterns, specifically the recruitment pattern and the force of respiratory muscle contraction. Interestingly, the metabolic demand only increased for two subjects, stayed constant for another and decreased for another. Based on this information alone, it would be anticipated that the task would only be problematic for two subjects. However, all of the subjects demonstrated increasing respiratory response trends as a result of the lifting challenge. Therefore, the lifting challenge must somehow compromise the respiratory system, as shown by an increase in both the mean inspiratory flow and breathing frequency.

It is generally considered that in normal individuals, the ventilation demands during maximal exercise are not limiting to exercise (Gallagher and Younes, 1989). The muscles of the respiratory system may be coordinated in such a way as to protect them against fatigue (Roussos and Macklem, 1977). If this is indeed true, then the ventilation demands in industrial work activities would not be anticipated to be the major factor in the development of fatigue. However, as demonstrated here, the respiratory system is challenged and does play a contributing role in maintaining the lifting task.

$P_{0.1}$

The lifting/lowering cycle was broken up into two general ILM positions, Top and Bottom. These positions were then further subdivided into phases of the lift or lower cycle to assist analysis of the data, as the $P_{0.1}$ system could not be initiated via a specific event in the lift/hold/lower cycle. Also, sufficient time was provided between each measurement to eliminate any increase in neural drive to breath due to the occlusion. Therefore, due to the small number of $P_{0.1}$ measures that could be made, the $P_{0.1}$ data was collapsed across subjects to study the effects of lift position (Table 5). $P_{0.1}$ tends to increase with the dynamic lift or lower activity and stabilizes or decreases in static postures. This may be reflective of the mechanics of the task. During a static posture, (eg. hold), respiration occurs while the spine is in a stable position and $P_{0.1}$ is minimal. However, during dynamic activity (lift, lower), the spinal stability requirements increase and an increase in $P_{0.1}$ is observed. An increase in respiratory drive may be required in order to breathe and maintain spinal stability. $P_{0.1}$ measures were collected as an indicator of the central drive to breath. Hesser and Lind (1983) found it to be a more representative indicator of respiratory drive than V and V_T/T_j. $P_{0.1}$ has been shown to increase linearly with incremental exercise (Hesser and Lind, 1983) and curvilinearly with CO_2 induced hyperventilation (Whitelaw et al. 1975). However, the effects of a repetitive lift-hold-lower have never been investigated. A link is observed between posture and activity.

Table 5: Relationship between lift/lower position and mean P0.1 (cm H_2O) (number of subjects in each block) for all subjects.

		Lift 1	Lift 2	Lift 3	Lift 4
	Start of Lift	3.55 (2)	1.15 (1)	1.55 (1)	1.55 (1)
Top	End of lift	4.14 (2)	2.85 (3)	4.25 (1)	4.54 (2)
	Hold	2.34 (2)	2.71 (4)	2.97 (3)	2.44 (3)
	Start of lower	2.60 (4)		1.23 (2)	1.73 (1)
Bottom	Lowering		5.50 (1)	1.45 (1)	6.65 (1)
	End of lower		1.40 (1)	1.94 (3)	3.95 (1)
	Rest	3.43 (4)	3.46 (4)	2.88 (4)	3.28 (3)

FRC

The FRC measurements were inconclusive and it is felt that FRC may not truly reflect the respiratory demands of the lifting challenge. Due to the nature of the lifting task, subjects had a breathing pattern that was not at steady state as they completed the lift and hold. This made anticipation of the first breath, and hence turning into the system, after the lift and hold very difficult. It is concluded that for heavy lifting tasks, FRC is not an appropriate measurement tool, unless an automated system could be utilized.

Integration of Study Parameters

In industry, it is desirable to minimize the effects of fatigue, thus preventing injuries and maintaining productivity. A disruption of the muscular coordination required to perform a task may be very dangerous, increasing the opportunity for injury. Secondary muscle groups have been shown to compensate for the primary muscles, resulting in a decrease in motor control (Parnianpour et al., 1988). However, the assessment of fatigue during industrial activities is problematic. Muscular contraction strategies and intensities that are routinely utilized to produce distinct, measurable fatigue in the laboratory, are the exact same strategies that workers avoid utilizing, in order to minimize fatigue. Due to the multiple strategies a worker has available to minimize fatigue, no single indicator is capable of monitoring the fatigue process. Therefore, an array of measurements, EMG, $P_{0.1}$, intraabdominal pressure and breath-by breath respiratory measures were applied to a heavy lifting/lowering challenge.

Table 6 provides an overall view of the changes that occurred in each of the study parameters. With fatigue, it would be anticipated that each of these parameters would increase. As described earlier, there was a large variety of observed responses. This was primarily attributed to the variety of lifting strategies utilized by the subjects throughout the session in order to minimize the effects of fatigue. Choosing any individual measurement parameter would not correctly document that each subject felt fatigued by the end of the session. However, an analysis of all the parameters clearly indicates that fatigue occurred as a result of the lifting challenge. For subjects 1, 2 and 5, three of the five measures show an increase as expected. For subject 3, the lifting task appears less challenging as indicated by VO_2, however, he shows anticipated increases in ES EMG and MIF.

Table 6: Summary of general direction changes observed for study parameters for each subject.

Subject	VO_2	Br. Freq.	MIF	IAP	EMG (ES)
1	inc	inc	inc	no chng	dec
2	inc	inc	inc	dec	dec
3	no chng	dec	small inc	dec	inc
5	dec	inc	inc	inc	dec

The interpretation of the increase in $P_{0.1}$ with a holding task implies that the central drive to the respiratory musculature is being increased. A possible explanation is the dual role required by the respiratory musculature in assisting with ventilation and supporting the spine. As the subject lifted the load, an increase in breathing frequency, VO_2 and mean inspiratoiy flow occurred. These values then decreased during the rest portion of the cycle. The interaction of the ventilation and stability function provides an interesting scenario. Are there times when the respiration function may compromise the stability function? Can the stability function compromise ventilation?

Overall, the data support the utilization of varying lifting strategies across time by each of the subjects. Changes in VO_2, breathing frequency, mean inspiratory flow, $P_{0.1}$ IAP and EMG all indicate that the individuals utilized a variety of lifting strategies. If only one of these parameters had been used, then erroneous conclusions regarding the fatigue process would be reached, for none of the parameters consistently change in the direction associated with fatigue. However, inspection of all parameters clearly shows that for each subject, there were changes indicative of fatigue. A combination of non-traditional fatigue measures have been utilized to provide a more thorough identification of the fatigue process in a controlled heavy lifting task.

CONCLUSIONS

1. There are specific muscle strategies utilized to avoid fatigue.
2. Changes in breathing frequency, mean inspiratory flow, VO_2, IAP, $P_{0.1}$ and EMG must be assessed concurrently in order to monitor the fatigue process.
3. FRC is not an appropriate measure in heavy lifting tasks to document active expiration.
4. $P_{0.1}$ data reveal a trend in the neural drive to breath, with a modest increase during the holding of a load. Larger increases in the drive to breath occur when loads are lifted/lowered.
5. There is a specific IAP generation prior to lifting. The IAP helps stiffen the spine and transfer forces.
6. There are specific time periods during a lift-hold-lower cycle in which an individual is at risk of increasing tissue loads due to the dual function of the thoracic musculature.

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COMMENTS ON THE ASSUMPTION OF MULTIPLICITY OF RISK FACTORS IN THE DRAFT REVISIONS TO NIOSH LIFTING GUIDE

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The consequences of the multiplicative model for combining lifting factors in the proposed 1991 revisions to the NIOSH Lifting Guide of 1981 were examined. It was noted that the assumption of lifting factors multiplicity does not necessarily hold over a broad range of manual materials handling tasks, where a significant degree of overlap and interaction between different risk factors takes place. The assumption of multiplicative effect of these factors on the proposed new load constant must be carefully examined. Some of the alternate methods for combining evidence and lifting risk factors aggregation were proposed.

INTRODUCTION

The ‘National Strategy for the Prevention of Work-Related Musculoskeletal Injuries’ (Millar, 1988) recognizes the low-back overexertion injuries due to manual lifting as one of the leading causes of work-related injuries in the United States. In order to reduce and prevent the onset of such injuries, ergonomic design guidelines for safe limits in manual lifting tasks that would apply to the majority of the US working population are needed (Garg, 1989; Snook and Cirello, 1991). Currently, the National Institute of Occupational Safety and Health (NIOSH) is working on the significant revisions to the 1981 *Guide to Manual Lifting* (NIOSH, 1981). A draft document for such revisions, which is still under development (Putz-Anderson and Waters (1991), stipulates careful evaluation of the proposed new methods. Such evaluation should include both theoretical examination of selected concepts utilized in development of the proposed new Guide of 1991, as well as assessment of practical implications that the proposed Lifting Guide revisions will most likely have on industry.

While preserving the assumption of multiplicity of factors of the 1981 Lifting Guide, the proposed revisions of 1991 consist of several significant changes, including the value of a load constant, the values of several multipliers, and an addition of two new multipliers to account for lifting task asymmetry and box coupling. Although the original validation efforts described by Putz-Anderson and Waters (1991) seem appropriate, it is also important to examine the revised lifting equation for any abnormalities, and identify the range of cases, if any, where the equation does not hold, or where it may produce unrealistic results, contrary to the current state of knowledge in the field of manual materials handling. Such evaluations should be done by examining the mathematical structure and behavior of the revised lifting equation, and by applying alternative methods for aggregation of lifting factors.

DRAFT REVISIONS TO NIOSH GUIDE TO MANUAL LIFTING (1991)

According to Putz-Anderson and Waters (1991), the new lifting equation (shown below) is based on three main components, i.e.:1) standard lifting location, 2) load constant, and 3) multipliers:

RWL(kg)=23*HF*VF*DF*FF*AF*CF*

The lifiting risk factors (multipliers) can be redefined as lifting factors according to the following notation: CF—coupling factor, AF—asymmetry factor, VF—vertical factor, HF—horizontal factor, DF—distance factor, and FF—frequency factor.

The load constant (LC), which was reduced from 40 kg (90 lb) to 23 kg (51 lb), refers to a maximum weight value for the standard lifting location (SLL), defined in the 1981 Guide by vertical reference height of 75 cm, and horizontal reference distance of 15 cm. The reduction in the load constant was done in order to compensate for the increase in horizontal displacement value from 15 cm to 25 cm in the 1991 Draft Revisions (see Table 1).

LIFTING MULTIPLIERS (RISK FACTORS)

Each multiplier value vary from a maximum of 1.0 for an optimal condition to a minimum or cutoff value of 0.0 for a high-strain lifting condition (Putz-Anderson and Waters, 1991). A comparison of multipliers for the 1981 and 1991 lifting equations is given in Table 1. The minimum and maximum values of the multipliers under selected lifting task conditions are given in Table 2 shown below.

Table 1. Lifting equations of the 1981 Guide and 1991 Draft Revisions (after Putz-Anderson and Waters, 1991).

	Risk factors values	
Lifting factor	1981 Guide	1991 Guide
Load constant	40 Kg	23 Kg
Horizontal	15/H	25/H
Vertical	1–0.004[V-75]	1–0.003[V-75]
Distance	0.7+7.5/D	0.82+4.5/D
Frequency	1-[F/F_{max}]	from table*
Asymmetry	not available	1–0.0032A
Coupling	not available	from table*

*For values of these factors see Putz-Anderson and Waters (1991)

where: H= Horizontal location of hands from midpoint between the ankles; measured at the origin and the destination of the lift (cm or in).

V= Vertical location of the hands from the floor, measured at the origin and destination of the lift (cm or in).

D= Vertical travel distance between the origin and destination of lift (cm or in).

A= Angle of asymmetry—angular displacement of the load from the sagittal plane; measured at the origin and destination of the lift (degrees).

F= Average frequency rate of lifting measured in lifts/min. Duration is defined to be: ≤1 hour, ≤2 hours; or ≤8 hours assuming appropriate recovery allowances.

EVALUATON OF THE LOAD CONSTANT

Evaluation of the load constant (LC) value should be made in relation to the multipliers (lifting risk factors) used in the RWL equation, as well as recent data about human perception of load heaviness (OSHA, 1982; Karwowski, 1988; 1991). For example, the U.S. Department of Labor (OSHA, 1982) conducted a study of back injuries that included worker perception of exertion. The questionnaire survey included 906 blue-collar workers who sustained back injuries while lifting, placing, carrying, holding, or lowering objects. A total of 777 males and 129 females participated in the study. The majority of back injuries were muscle strains and sprains. Thirty six percent of workers reported lifting *too heavy* objects, while 14% of workers underestimated the weight of objects before lifting. Twenty percent and thirty-nine percent of the injured workers reported the weight of object lifted less than 18.1 kg (40 lbs), and less than 27.2 kg (60 lbs), respectively. Fifteen percent of the workers stated that the heaviest object they manually lift in their jobs was 18.1 kg (40 lbs). Another 17% of workers typically lifted weights between 18.1 and 27.2 kg (40–60 lbs).

Table 2. Minimum and maximum values of the multipliers in the 1991 Draft Equation.

Lifting risk factor/multiplier	Minimum	Maximum
f_1—coupling factor(*)	0.9**	1.0
f_2—asymmetry factor (minimum at 135° angle)	0.568	1.0
f_3—vertical factor	0.625	1.0
f_4—horizontal factor (max reach)	0.50	1.0
f_5—lifting distance factor	0.82	1.0
f_6*—frequency factor (4 lifts/min and V<75)		
(≤8 hrs time)	0.45*	0.85***
(≤2 hrs time)	0.72*	0.95***
(≤1 hr time)	0.84*	1.0***

*Based on range of frequency from 0.2 to 15 lifts/min
**4 lifts/min [the most representative lifting frequency in industry, after Snook and Ciriello, 1991)
***For lifting frequency of 0.2 lifts/min.

ASSUMPTION OF MULTIPLICITY OF LIFTING RISK FACTORS

Evaluation of the assumption of multiplicity of lifting risk factors in view of different mathematical methodologies for combining evidence of the data will be based on concepts taken from the fuzzy set theory and theory of evidence (Kaufman, 1989; Zimmermann, 1988). It should be observed that using the multiplicative model for combining lifting factors leads to a lifting equation based on the algebraic product of multipliers. Such aggregation method is based on the following assumptions made in the *NIOSH* (1991) *Draft Revisions to the Guide* about the individual multipliers (risk factors):

1) all lifting factors (multipliers) are independent from each other,
2) the effect of more than one factor (multiplier) is synergistic, i.e. the decrement in RWL value (given a constant load value) will be higher for the combined factors than for the overall effect of the sum of effects when each factor acts separately, and
3) in absolute terms, each lifting factor contributes about the same amount of risk to the overall risk of low-back injury due to a given lifting task.

It should be noted, however, that these assumptions do not necessarily hold over a broad range of manual lifting tasks, where a significant degree of overlap or interaction between different lifting factors takes place. Therefore, the assumption of multiplicative effect of these factors on the load constant must be carefully examined, and alternative methods of factor aggregation should be tested in addition to the algebraic product operation. Some of the alternate methods for factor aggregation are discussed below.

ALTERNATIVE METHODS FOR COMBINING EVIDENCE AND AGGREGATION

If the lifting risk factors (called multipliers in the NIOSH equation) are thought of as the degrees s of incompatibility of the load constant (LC) with worker lifting capacity under given task conditions, then the RWL can be represented as LC modified by the fractions from 0 to 1.0. The values of multipliers can be represented as values of the fuzzy set for incompatibility of the LC value with the concept of recommended weight limit (RWL), i.e.:

$$RWL=LC\times f_c, \quad (1)$$

where f_c is the aggregate function of $(f_1, f_2 \ldots f_u)$s the involved factors.

In combining the effects of these independent fuzzy values, the following connective operators can be used to derive the overall modifier value (f_c):

1) $f_c=\min(f_1, f_2, \ldots f_1)$, where $f_i \in [0, 1]$ is the incompatibility value; and i=1, 2,…n, is the number of factors, leading to selection of the minimum f_i value as f_c, (2)

2) $f_c=\max(f_1, f_2, \ldots f_1)$, leading to selection of the maximum f_i value as f_c, (3)

3) $f_c=[f_1 \times f_2 \times f_3 \times \ldots \times f_i]$, resulting in algebraic product of all factors, (4)

4) $f_c=\max[(f_1+f_2)-(f_1 \times f_2), 1]$ for i=2, leading to selection of algebraic sum as f_c, (5)

5) $f_c=(f_1 \times f_2)/[\gamma+(1-\gamma)\,[(f_1+f_2)-f_1 f_2]]$, n>2 and where $\gamma>0$ (is the Hamacher operator), leading to compensatory combination as a function of parameter γ, (6)

6) $f_c(f_1+f_2+\ldots+f_i)/n$, for n-number of factors, leading to selection of the arithmetic average as f_c. (7)

GENERALIZED FUZZY CONNECTIVE OPERATOR FOR COMBINING EVIDENCE

The general model for combining risk factors in the lifting equation should allow for some distinction between the varied contributions that each individual factor has in the overall risk/incompatibility of the task, as well as for some degree of compensation γ (ranging numerically from 0 to 1) between the two extremes. If the combination of evidence is based on a logical approach, then the two extremes are min and max operators (case #1 and #2), leading to the following expression:

$$f_c=[\min(f_1, f_2 \ldots f_i)^{1-\gamma} x[\max(f_1, f_2, \ldots f_i)]\gamma \quad (8)$$

In case of the lifting equation, we are dealing with the combination of incompatibility factors (multipliers) expressed as the algebraic product of their values, which represent the extreme case by assuming lack of any compensation or interdependence between the factors. In order to allow for some degree of compensation, it is proposed to examine, through a computer simulation, the generalized form for aggregating the lifting risk factors (multipliers) as shown below:

$$f_c = (1-\gamma)\left[\prod_{i=1}^{n} f_i\right] + \gamma\left[(1 - \prod_{i=1}^{n}(1-f_i))\right] \qquad (9)$$

and

$$f_c = \left[\prod_{i=1}^{n} f_i\right]^{1-\gamma} x \left[1 - \prod_{i=1}^{n}(1-f_i)\right]^{\gamma} \qquad (10)$$

where n=1, 2, …i, and $\gamma \in [0, 1]$.

The symbol Π stands for algebraic product of f_i values; $[1-f_i]$ is the complement of f_i, which can be interpreted as the degree of compatibility (as opposed to incompatibility) with the sought after RWL value, and γ is the parameter of compensation due to interdependence of the effect of different factors on RWL. For comparison, at present the formula for RWL does not allow for any compensation or interdependence adjustment between factors, resulting in the following equation:

$$RWL = LC\, x \left[\prod_{i=1}^{n} f_i\right]^{\gamma = 1.0} = LC\, x\, [f_1\, x\, f_2\, x\, f_3\, x\, f_4\, x\, f_5\, x\, f_6] \qquad (11)$$

Furthermore, in order to account for varied influence of the involved incompatibility factors, the appropriate weighing factors (w_i) should also be examined, by allowing for example:

$f^1_i = f^{(wi)}_i$, where $(w_1+w_2+\dots w_i)=1.0$.

(12)

The examination of usefulness of the compensatory aggregation of "multipliers" for calculating the RWL values should be done using the computer simulation technique and regression analysis. For example, Table 3 below illustrates the extreme effect of lifting risk factors aggregation with the algebraic product on the RWL value.

Table 3. Example of combinatorial testing of the range of values for aggregated effects of lifting risk factors on RWL based on minimum values as shown in Table 1.

Product effect [f_c]	Single factor effect (minimum value under chosen conditions)							
						(1)	(2)	(8)
	f_1	f_2	f_3	f_4	f_5	f_6	f_6	f_6
f_1	0.9	0.568	0.625	0.5	0.82	0.84	0.72	0.42
f_{1x2}	–	0.511	–	–	–	–	–	–
$f_{1\times2\times3}$	–	–	0.32	–	–	–	–	–
$f_{1\times2\times3\times4}$	–	–	–	0.16	–	–	–	–
$f_{1\times2\times3\times4\times5}$	–	–	–	–	0.13	–	–	–
$f_{1\times2\times3\times4\times5\times6}$	–	–	–	–	–	0.11	0.094	0.055
LC [kg]	23	23	23	23	23	23	23	23
RWL[kg]*	20.7	11.75	7.36	3.68	3.0	2.53	2.16	1.27

*As affected by aggregated multipliers [RWL=LC×f_c]

where: f_1=coupling factor
f_2=asymmetry factor
f_3=vertical factor
f_4=horizontal factor
f_5=lifting distance factor
f_6=frequency factor: (1) ≤1 hr, (2) ≤2 hrs, (8) ≤8 hrs,

CONCLUSIONS

The above review indicates that the multiplicity concept for aggregating the effect of lifting risk factors on worker safety, as applied in the proposed draft revisions to the NIOSH Lifting Guide of 1991, does not necessarily hold over a broad range of manual lifting tasks, where a significant degree of overlap and interaction between different risk factors takes place. It was suggested that the assumption of multiplicative effect of these factors on the proposed new load constant must be carefully examined, and alternative methods of factor aggregation should be tested in addition to the algebraic product operation. Some of the alternate methods for aggregation of the lifting risk factors were presented and discussed

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LOW-BACK PAIN

MEASUREMENT OF INDICES OF ERGONOMIC STRESS IN AN EPIDEMIOLOGICAL STUDY OF MUNICIPAL WORKERS

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This paper summarizes the strategy that was used to assess the risk of low-back injury in a population of municipal workers whose work patterns are much less structured than those encountered in the manufacturing industry.

INTRODUCTION

The cost of overexertion and musculoskeletal injuries borne both by individual workers and collective industry is enormous (Chaffin and Andersson, 1984). Efforts to reduce such injuries have focused upon improving the match between a job's physical demands and the worker's physical work capacity. Previous epidemiological studies of low-back injury have examined risk of injury in various industries using a variety of methodologies. In most cases, study results provide highly-limited descriptions of the exertions performed, or do not use indexes of stress which are used by ergonomists to evaluate or to redesign jobs. When biomechanical indexes of stress to the low-back were carefully studied, useful relationships between job demands and risk of injury were established (e.g., Chaffin and Park, 1973). This paper summarizes the strategy used to assess the risk of lowback injury in a population of municipal workers whose work patterns are much less structured than those encountered in the manufacturing industry.

STUDY PLAN & OBJECTIVES:

The team employed a prospective matched-pair case-control study paradigm to identify factors that increase or mediate the risk of low-back injury in an unstructured work environment. Workers who sustained a back injury while working the City of Baltimore were matched to two uninjured coworkers. The first control match was of the same gender, employed in the injured-worker's work unit in the same capacity, and performed the same work assignments on the date of injury. A second control was selected from a list of workers in other departments who possessed the same job classification. The matching strategy attempted to used the first control (coworker-match) to match physical activities and stressors; thereby, enabling detection of risk factors that were related to differences between workers that were not job-related (e.g., health status and habits, tolerance to psychosocial stress, previous work history, outside activities, etc.). The second control (job classification or job-match) was expected to compare risk among workers who possessed the same job classification (e.g., sanitation worker) but would be performing different types of tasks in different working environments. Further detail concerning the study design and case and control selection procedures is provided in other papers presented by Baker and Myers at this meeting.

Ultimately, the goal of the study team was to: a) develop a multivariate model to describe the importance of, and interplay among, a *priori* low-back injury risk factors (e.g., ergonomic, environmental, psychosocial, and health status indexes) in determining risk of low-back injury, and b) apply this model to the development of improved work methods, health practices, and sociotechnical elements of jobs to reduce both incidence and severity of low-back injuries encountered by a typical municipal workforce.

METHODOLOGY

Logistics and time constraints compelled the team to develop a questionnaire that was designed to administered to cases and to controls within a comparatively short time frame (i.e., about 60 minutes). The questionnaire was designed to obtain a variety of information concerning the nature of the injury, worker characteristics, work history, health habits, and so forth.

From an ergonomic perspective, it was important to confirm that selection of controls did comply with the study design, that responses were accurate and consistent, and that ergonomic indexes that have been linked to risk of low-back injury were characterized in a rational manner. If these objectives had been met, then we expected to find: a) no material differences between ergonomic indexes describing manual materials handling and other stresses between cases and their coworker-matched controls, b) differences between ergonomic indexes between cases and their job-matched controls, c) internal reliability of responses provided by a given worker, and d) accuracy in responses provided to administrators of questionnaires who would possess no formal training in the field of ergonomics.

The questionnaire was divided in to 9 sections: 1) Work History, 2) Work Injuries, 3) History of Back Pain, 4) Ergonomic Measures of a Typical Workday, 5) Ergonomic Measures on the Day of the Injury, 6) Psychosocial Metrics, 7) Health, Smoking, Alcohol Consumption Status and Habits, 8) Demographics, and 9) Anthropometric Information. Sections 5 and 6 were essentially the same but asked the worker to differentiate, if necessary, any differences between work activities on the date of the injury and those encountered during a "typical" work day. Because of limitations on the length of this paper, details concerning the questions and procedures are provided elsewhere (Wiker and Jones, 1992). The general structure of the questionnaire addressing ergonomic measures of a typical workday are described in Table 1.

Table 1. Information obtained in the ergonomic sections of the low-back injury study questionnaire that are concerned with frequency or duration of activities that are putative low-back injury risk factors.

Measure or information	Form of Measure
Length of Time Spent Riding in Vehicles, Performing Seated work, and working While Assuming Various Postures	Time
Frequency of Performing Cardinal Exertions (e.g., Lifts, Lowers, Pushes, Pulls, Carrying, etc.)	Often, Sometimes, Never
Frequency of Assuming Postures Considered Stressful to the Low-Back (e.g. Torso Flexion or Twist, Extended Reaches or Placements of Objects, etc.)	Often, Sometimes, Never
Duration of Operation of Large vibrating Hand Tools Such as Jack-Hammers	Time

Table 2. Additional Information Obtained From Cases Concerning Activity On the Date of the Injury.

Measure or Information	Form of Measure
Activity Performed at the Time of the Injury	Name of PreviouslyDescribed Activity or a Replication of the Activity Description Noted in Table 3.
Days Worked and Duration of Shift Prior to Injury	Time
Frequency of Injury Activity Experienced Prior to Injury	Number of Replications
Free-Form Entry of Worker's Comments Concerning the Cause of the Injury and Recommended Count countermeasures es	Text

Table 3. Information obtained in the ergonomic sections of the low-back injury study questionnaire that address descriptions of tasks that are considered to be the most stressful during a typical workday, or the task performed at the time of the injury.

Measure or Information	Form of Measure
Description of 3 Tasks That are Considered by the Worker to be the Most Stressful Activities Performed in the Course of Their Normal Duties, Or of The Injury Task	Verbal Description, On-Site Measurements, and Descriptions of Type of Physical Exertion (e.g., Lift, Lower, Push, Pull, Press, or Carry/Hold) Number of Coworkers Assisting Description of Tools or Aids Employed Location of Activity (indoors or Outside) Standing Surface Characteristics (e.g., Dirt, Gravel, Grass, Concrete, Wood, or Other) Perceived Quality of Footing (e.g., Good, Uneven, unstable, or Slippery) Time Required to Complete the Activity Maximum, Average, and Minimum Frequency of the Activity Encountered During an Hour and Throughout the Shift Size and weight of Objects Handled Symmetry of Hand Forces and Postures Assumed At the Beginning and End of the Stressful Exertion

Cases and controls were asked to describe postures used to initiate and complete each of the strenuous activities reported in the questionnaire. Respondents described their postures by following a systemtic procedure in which they first described the posture of the torso and lower extremities, and then used more detailed posture diagrams to describe stance, arm postures and, finally, the direction and mgnitude of hand forces. Figure 1 shows the menu of posture diagrams that were used by subjects to report torso angle and stance.

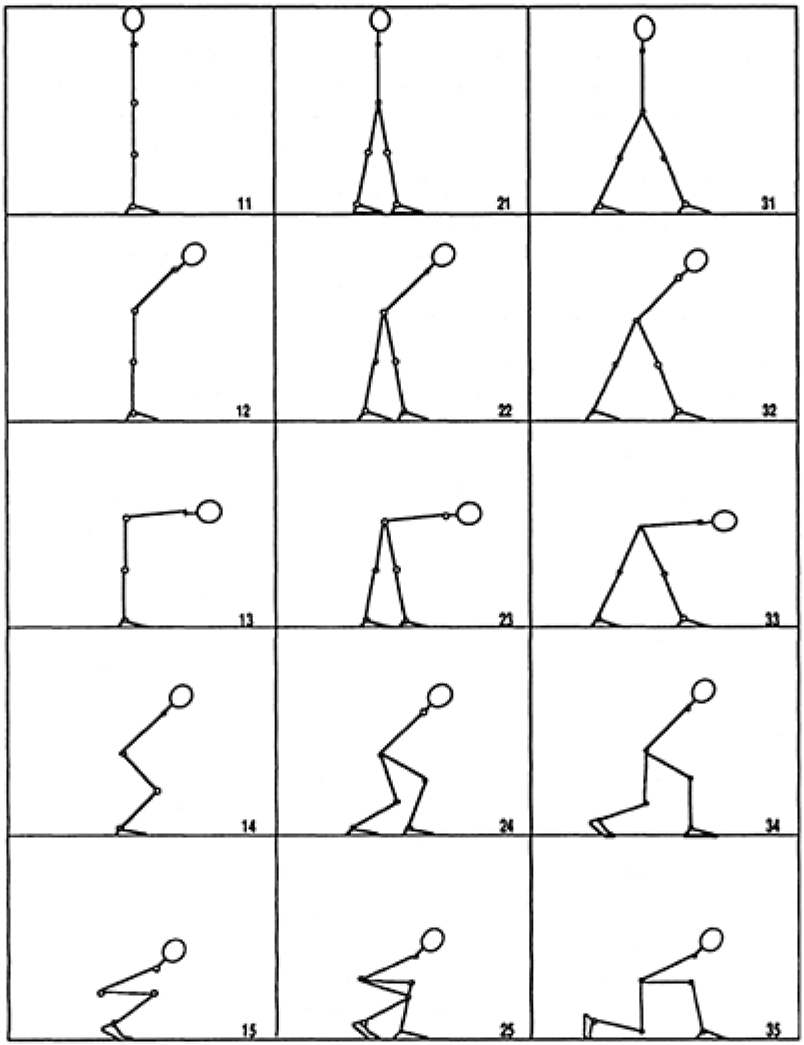

Figure 1. Menu of posture diagrams used.

After selecting the posture considered to be most representative of that employed, the worker was given a single drawing in which both a side and frontal view of the posture was presented. See Figure 2. The second posture diagrams were proportioned in accordance with Drillis and Contini's human body proportions (sited in Chaffin and Andersson (1984). The figures are aligned on an even grid of small squares with the resolution of 28 intervals to the figure's full stature. The distance separating the squares was scaled to the anthropometry of the subject and was used to describe the geometry of the lift and movement of the object from the beginning to the end of the lift.

With the second posture diagram, workers specified which foot was in front of the other, if a split-stance was used, and then marked on the diagram where their hands were positioned in both the frontal and side views. In addition to the position of the hands, workers were ask to show the direction of exertion of each hand. This was accomplished by drawing the direction of forces exerted by each hand in the frontal and side views. This procedure was then repeated for the ending posture.

The descriptions of postures and hand forces were examined for spatial consistency between the frontal and side views of diagrams, and with verbal descriptions of the activity. If the description of the posture, hand force, or description of the stressful activity, were not consistent, then an ergonomist was sent to the accident or work site to perform direct measurement of the postures, hand forces, and to record other information as needed.

If all criteria were met for employment of a NIOSH Work Practices Guide to Manual Lifting (1981) analysis, then Action limits were computed for each activity, given changes in postures described f rom the beginning to end of a lifting task, reported lifting frequencies, and duration's of lifting activity. The severity of the lifting task was gauged by computing the ratio of the load handled over the NIOSH Action Limit. This metric was used because of its wide application throughout industry, and because it serves to combine metrics of biomechanical, physiological, and psychophysical stress.

Postures and hand f orces reported at the beginning and end of manual exertion activities such as lifts, lowers, pushes, or pulls, were combined with measures of anthropometry, to enable estimation of the erector spinae tension, and both compressive and shear forces acting upon the intervertebral disc at L5/S1 using a three-dimensional static biomechanical model (Chaffin and Erig, 1991). The postures used were specified by the posture diagrams with the exception that subjects simply reported the locus of hands, or provided crude drawings of arm postures. Based upon subject drawings, direct observations of jobs, and a sensitivity analysis using the biomechanical analysis, we always positioned the upper and lower arm segments within a vertical plane containing the hand and shoulder as shown in Figure 3.

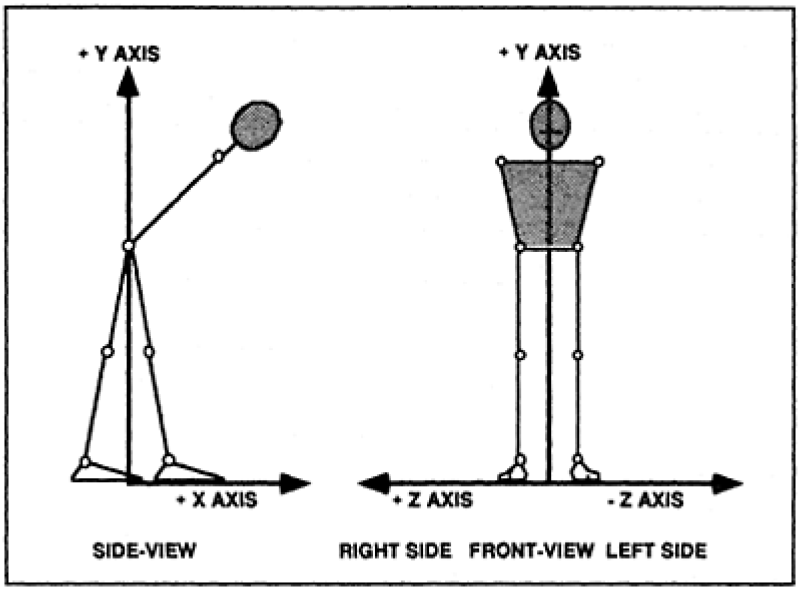

Figure 2. View of the second set of posture diagrams used by subjects to locate hand positions and directions of hand forces.

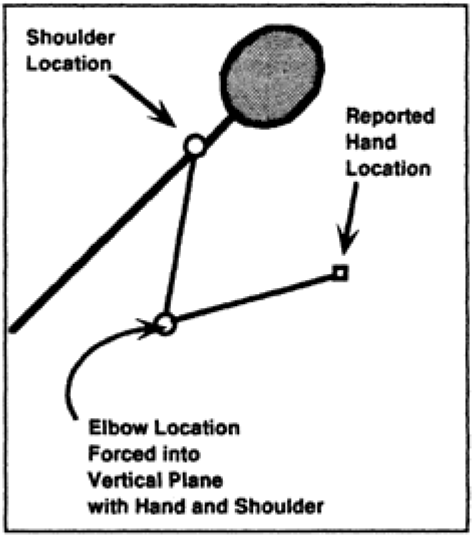

Figure 3. Given the reported position of the hands, arm segments were

aligned within a vertical plane containing the hand and shoulder articulation.

Biomechanical computations were performed if the exertions at the beginning or end of the lift were not highly-dynamic, and if other assumptions of the biomechanical model were not violated.

ANALYSIS AND FINDINGS

Epidemiological findings obtained from 200 case questionnaires, and their 400 matched-controls, are presented elsewhere in these proceedings and detailed presentation of analyses and outcomes of reliability and validity tests of the questionnaire's ergonomic sections are provided in Wiker and Jones (1992).

In sum, ergonomic analyses showed that: a) the majority of overexertion injuries were attributed to one of the three most strenuous tasks described within the questionnaire, b) both the coworker and job classification controls presented similar descriptions of the severity of physical work performed by municipal workers within their respective departments, and c) reports of frequencies and duration of exertions deemed strenuous were also similar.

within a given worker, descriptions of the most strenuous tasks were usually consistent with collateral descriptors of posture, hand force directions, and other metrics describing the work activity. However, workers often showed significant errors in describing the magnitude of hand forces required to perform the task. These errors required on site measurements and corrections prior to conducting any biomechanical or NIOSH WPG analyses.

Among coworkers within the same work unit, we frequently found disagreements in subsets of tasks that were viewed as most strenuous.

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PREVENTION OF BACK INJURIES IN MUNICIPAL WORKERS.

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Advances in Industrial Ergonomics and Safety IV
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The circumstances of injury were studied for 200 municipal workers who sustained acute back injury, defined as back pain initiated by a specific event (Myers et al., 1992). This report describes some of the circumstances of injury and promising preventive measures, with emphasis on the value of eliciting suggestions from injured workers.

METHODS

Trained interviewers conducted in-person interviews of all cases, usually within two weeks of the injury. In the course of the interview, which explored demographic, ergonomic, psychosocial, and other factors, workers were asked about the circumstances under which the back injury had occurred. In addition, they were asked two questions: “To avoid someone else being injured the same way, what would you change?,” and “Is there any other way you think your job could be changed to prevent low back pain?”

Several months later, an ergonomist (TJ) visited about 50 of the workers, typically at the work site. He examined the characteristics of the work site and material, made additional ergonomic measurements to supplement data obtained in the interview, and talked with the workers about how the injury had occurred.

RESULTS

The most common circumstances of injury were related to motor vehicle impacts (51 cases); slips, including slipping and falling from vehicles (36 cases); lifting trash cans (18 cases); and other lifting (29 cases). Workers' responses to the interviewers provided useful and specific suggestions as to measures to reduce the likelihood of similar injuries to co-workers.

Motor vehicle collisions

46 of the 51 workers injured in motor vehicles were in vehicles (usually trucks) involved in collisions with other vehicles. When the direction of impact was reported it most often was from the rear. The other five cases involved: a hard bounce when a truck hit a ditch, an overturn when a wheel came off, hitting a pothole while riding a tractor, a blowout, and skidding on ice at a dump site.

About half of these workers had specific suggestions. These included:

– Keeping seat belts readily available and clean, and providing one for each occupant.
– Padding the seats of trucks and tractors with energyabsorbing materials to reduce the exposure to impact and vibration.
– Changing the route to the dump to avoid traffic and low overpasses.
– Salting the dump area to reduce ice.

Lifting trash cans

The 18 cases that involved lifting trash cans were the most homogeneous group. Typically, workers had tried to lift cans containing rocks, bricks or other building materials. Sometimes these materials were placed in the bottom of a can and covered with household refuse so that the weight was not visually apparent. Water in cans and wet materials were also cited. Workers' suggestions included:

– Placing a weight limit on loaded trash cans.
– Limiting the size of trash cans.
– Not allowing people to put rocks and bricks in cans, providing other disposal methods for such materials.
– Educating the public about the problems created by heavy cans.
– Using a load packer rather than a lift-pack truck, which requires workers to lift cans higher.
– Providing workers with back braces or 'weight belts.'

Other lifting

The 29 workers injured in the course of lifting heavy materials, other than trash cans, were often lifting things into trucks. These included concrete blocks, rocks, a wet mattress, a heavy pole (boom), 200 pound tanks, and a theater stage. Suggestions included:

– Mechanized lifting equipment on trucks.
– Using more men to lift a given weight.
– Having a tailgate that allows rolling things into trucks.
– Providing wheelbarrows rather than requiring bags of cement to be carried.
– Reducing the weight or lifting smaller quantities at one time.
– Providing paid aides to help move books or lift disabled children.

Other events

A wide variety of events contributed to injuries in other workers. Many of their suggestions are broadly applicable:

– Don't put workers on a job without adequate training.
– Provide chairs that are the right height for typing.
– Locate condensing units or other things requiring repair so they are accessible without crawling, stooping, etc.
– Don't work people through the lunch hour; allow workers to stop or slow down when tired.

An ergonomist who visited many of the work sites (TJ) identified additional preventive measures, such as providing handles on street-corner trash cans and reducing their size; replacing non-ergonomic controls on heavy equipment and vehicles, such as the levers for packing loads on garbage trucks; improving steps, hand holds and footing positions on garbage trucks; increasing the size of handles on equipment to the recommended diameter for a secure grip; and incorporating ramps into the tailgates of trucks that transport mowers and other heavy equipment.

DISCUSSION

The majority of Baltimore City municipal workers with back injuries had suggestions that, if implemented, could reduce the likelihood of injury. Research on worker injury too often fails to take advantage of the workers' insights into the circumstances of injury and ways to prevent it. Similarly, the injury reporting forms used by many companies and employers do not make use of this valuable source of ideas for injury prevention. Too often, questions are not asked of the worker, or are asked in such a way that the answer is apt to be: "Be more careful." Asking workers for likely means of keeping their co-workers from being injured in the same manner appears to be an effective means of eliciting useful ideas.

The ergonomist made a number of valuable suggestions. His insight into the problems and potential solutions added substantially to the value of the study. He also concurred with the validity of the workers' recommendations.

CONCLUSION

We recommend a combination of worker input and ergonomic insight when seeking to reduce work-related back injuries.

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POSTURAL SWAY AND BALANCE IN HEALTHY SUBJECTS AND IN PATIENTS WITH CHRONIC PAIN

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INTRODUCTION

The effects of chronic back pain on human performance and functional abilities have been studied by many researchers. In general, chronic back pain has been found to have the following effects on patients' physical performance: 1) reduction of trunk extension and flexion strengths and ranges of motion (Mayer et al. 1985, Suzuki and Endo, 1983) as well as endurance (Smidt et al., 1983; Suzuki and Endo, 1983); 2) inhibition of static strength lifting capabilities (Smith et al., 1985; Hansson et al., 1984; Chaffin, 1974), 3) alteration in sensory perception (Cohen et al., 1983), and 4) reduction in reaction time and hand steadiness (Abdel-Moty, et. al., 1989). One aspect of human performance that received attention in the literature recently is postural sway and balance in chronic back pain patients (Byl and Sinnott, 1991).

The ability to maintain balance and upright posture is a complex dynamic process which depends on many factors, including functions of the visual, vestibular, auditory, somatosensory and motor systems (Iverson et. al., 1990). Balance is a function requiring constant adjustment of muscle activity and joint position to retain the body weight over the base of support. Posture specifies the relationship of the body to the ground as well as the alignment of body segments. As posture is essential for maintenance of human movement, balance is the basis of functional activities. Static balance, which was studied in this project, is the ability to maintain a whole body posture while the relative positions of the center of gravity and the base of support remain unchanged (Carpenter-Alpert, 1985).

The assessment of posture and balance control has been done using several clinical and research-oriented methods. Among these are dynamic posturography, biomechanical techniques, use of ataxiameter, force platform measurements, videographic methods (motion analysis), traditional functional balance tests (questionnaire type), and clinical maneuvers. There are also many other vestibular and neurologic tests. Dynamic posturography is designed to isolate the relative contributions of visual, somatosensory, and vestibular feedback systems (Mirka and Black, 1990), and in the assessment of postural disturbances. Ataxiameters, such as the Wright ataxiameter, measure postural movement in certain direction (Nayak, 1987). The precision of the test using the ataxiameter has been questioned (Brocklerhurst et al., 1982). Computerized force platform analysis has found widespread use. The platform monitors the locus of the resultant ground reaction force. It has been used to analyze balance and sway; and was found to have promising test-retest reliability (Ekdahl et al., 1989). Clinical tests were also found useful in the assessment of physiological reactions to postural stresses (Dikshit, 1987). Quiet standing, head-up tilt table methods, and the application of lower body suction are clinical maneuvers used as a part of this type of evaluation (Dikshit, 1987). The Postural Stress Test is a simple clinical measure of the individual’s ability to withstand a series of graded destabilizing forces applied at the level of the subject’s waist (Chandler et al., 1990). It is intended to evaluate the subject’s ability to avoid a fall as well as the appropriateness of the response (Wolfson et al., 1986).

Over the past few years, the application and use of balance and sway assessment methods in clinical settings has been documented repeatedly. Posture sway was reported to be an indicator of the tendency to fall (Fernie et al., 1982). Until recently, the evaluation of posture and balance in patients with chronic pain was mostly subjective. Computerized balance and sway evaluation systems currently available can aid in this regard. They can provide quantitative description of these attributes which can be useful in the determination of abilities in reference to uninjured subjects.

The main objective of this investigation was to compare sway of patients suffering from chronic pain with that of normal healthy subjects under the same testing conditions.

METHODS

Subjects: A sample of 57 subjects was selected for inclusion in this study. Primary exclusion criteria were blindness, amputation, and inability to ambulate. The sample was divided into two groups: the first group comprised 31 healthy volunteers; while the second group comprised 26 chronic pain patients who were admitted for treatment at the Comprehensive Pain and Rehabilitation Center (CPRC) at South Shore Hospital and Medical Center. The Ergonomics and Bioengineering division, evaluates patients’ performance and functional abilities in terms of strength, flexibility, mobility, psychomotor abilities, as well as postural sway. Evaluations are performed upon patients’ admission to the CPRC and are used to assess the degree of functional impairment and monitor progress and rehabilitation outcome.

Instrumentation: The data collection and analysis was performed using a Kistler™ force platform connected to the Ariel Performance Analysis System (Ariel Life Systems, Inc.). This is a biomechanical motion analysis system that combines force measurements, electromyographic recording, and videographic image processing. For the quantification of forceplate measurements, there are several indices available in the literature to measure sway and steadiness, examples of which are measures of variability of the horizontal forces, measures of the variability of the center of pressure (CP), measures of the total excursion of the CP, average deviation and root mean square of the vectors describing the position and force of the CP in to two horizontal axes of the platform, and total sway based on the area of the ellipse. According to Goldie et al. (1989), there is a lack of agreement about which parameters best describe body sway. There is no strong proof to support the superiority of any one measure over the other.

Procedure: Testing of the patients was carried out as part of the regular initial Ergonomics evaluation. Healthy subjects were informed of the purpose of the study. Biographic information such as age, weight, height, and sex was obtained. The subjects were then asked to remove footwear and items that may affect weight distribution (e.g. objects in pockets). Subjects stood on the force platform in two different stances: tandem and one-legged (preferred foot). In both cases, two readings were taken: one with the subject's eyes open and the other with the eyes closed. Those two stances were selected based on a prior pilot study (unpublished), in which the two stances were found to be most functionally challenging and may discriminate between back pain patients and healthy subjects. The order of testing these four conditions was at random. During each testing condition a period of 10 seconds of postural sway was recorded. Prior to data acquisition, the subject was instructed to stand erect, as motionless as possible. For the eyes open test, the subjects were instructed to look at a target which represented their corresponding eye level. For the eyes-closed test, subjects were instructed to look at the same target before closing their eyes. Leg strength was measured after completion of the test in terms of knee extension static strength.

Data Analysis: Statistical analysis was performed using the SPSS/PC+ software package. For data analysis, an Analysis of Variance (ANOVA) randomized block factorial design was adopted. The independent variables being the groups (healthy/patients) and testing condition (1. tandem eyes open; 2. tandem eyes closed; 3. one-legged eyes open; 4. one-legged eyes closed). Descriptives and correlational analyses were also performed. The dependent variable in this study, sway, was described in terms of the "total area" of sway defined as the x-range (anteroposterior/sagittal sway) multiplied by the y-range (mediolateral/side to side sway). The dependent variable was selected based on a pilot study conducted by our group (unpublished), in which it was found that the area bounded by those two ranges was shown to be the most sensitive parameter to measure sway. Correlations were calculated between the parameters describing the dependent variables and: age, strength, body weight, and height.

Figure 1 shows a sample computer print-out of the sway path of a patient in a tandem posture. The determination of the x and y ranges, is an automated procedure performed using the computerized biomechanical system.

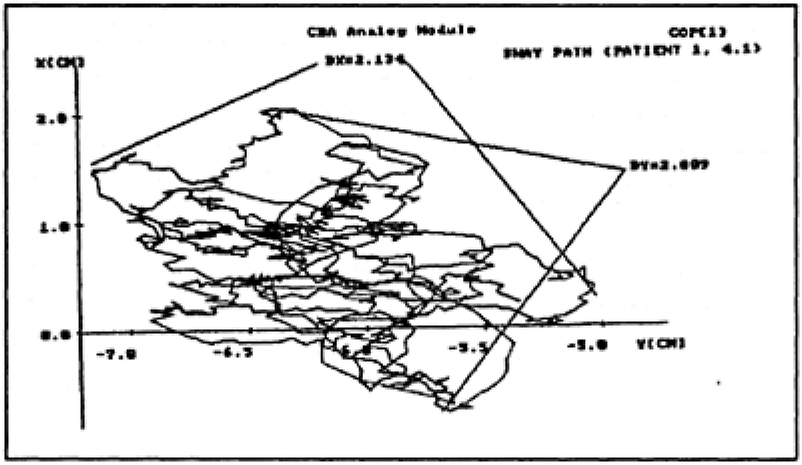


Figure 1 Sway of Subject #P1, 4.1

RESULTS

Descriptive information of the subjects in this study are summarized in Table 1. The group of healthy individuals consisted of 31 subjects (13 males and 18 females). The second group consisted of 26 patients (18 males and 8 females). There was a significant difference ($p<0.05$) in age and weight between the two groups.

Table 1. Summary of the Demographics and Sample Characteristics of Both Groups as Means and Standard Deviations.

	Patients		Healthy	
	Mean	SD	Mean	SD
Age, year	41.2*	9.5	34.1*	8.4
Weight, Kg	81.42*	2.78	67.77*	2.34
Height, cm	172	4.54	167	4.82
Right leg Strength, N	198	23.4	246	25.1
Left Leg Strength, N	186	20.1	243	26.0

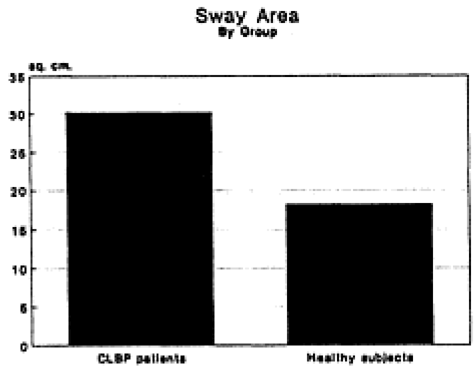
* *significant at the $\alpha=0.05$ level*

Results of data analysis showed a significant positive correlation ($r=0.98$) between the static strength scores of the right and left legs of all subjects. Therefore, a transformation was made and the variable *strength* was calculated as: the average value of the strengths of both legs normalized in terms of the subject's body weight. This variable was used in subsequent correlation analyses.

Overall ANOVA results showed that there was no significant interaction effect (group X testing condition); however, there was a significant difference among groups ($p<0.05$)

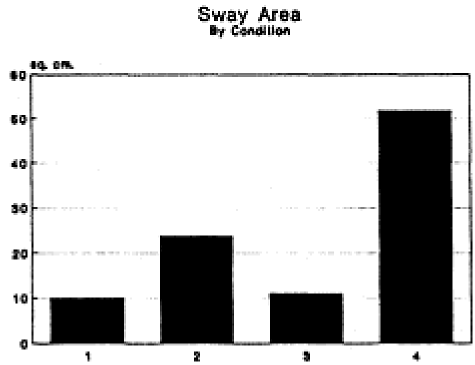
with sway of the patient population being significantly larger than that of the healthy subjects. There was also a significant difference between the four testing conditions.

Fig. 2a is a graphical presentation of the mean area of sway for the two groups (CLBP patients and healthy subjects) and Fig. 2b presents the mean area of sway of the four testing conditions across all subjects.



(a)

Fig. 2a. Sway in Healthy Subjects and CLBP Patients



(b)

Fig. 2b Area of sway in the four testing conditions

1: tandem eyes open—2: tandem eyes closed

3: one-legged eyes open—4: One-legged eyes closed

In order to determine the testing posture that best discriminates between the healthy population and the CLBP patients, a one-way ANOVA was conducted for each of the four testing conditions. Results showed that there was a significant difference ($p<0.05$) between the two groups (healthy and patients) in both eyes opened conditions and the tandem, eyes closed condition. Although, the sway was largest in the one-legged, eyes closed testing position, there was no significant difference between the patients and the healthy population in this case. Fig. 3 shows the difference in sway between the CLBP patients and the healthy population being tested.

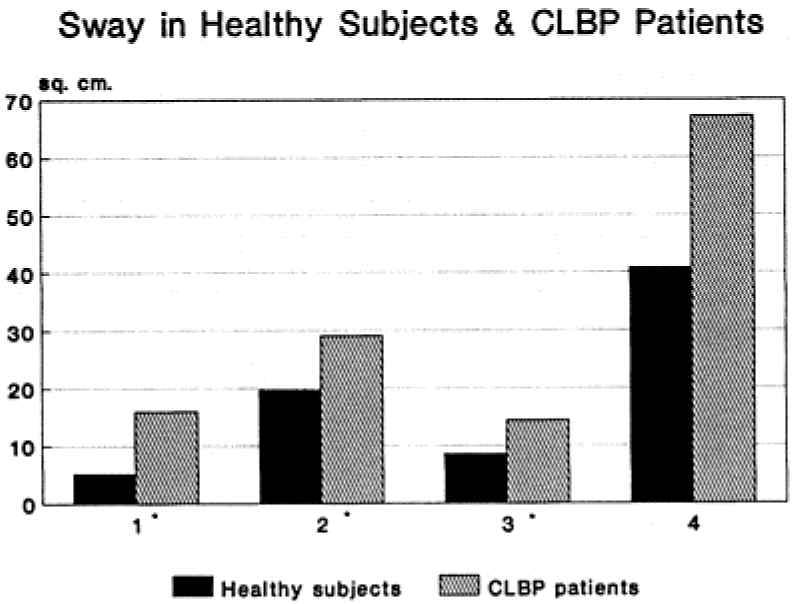


Fig. 3

Difference in sway between CLBP patients and healthy subjects

**significantly different at the $\alpha=0.05$ level*

Since there was a statistically significant difference between groups in age and weight, correlation analyses were performed in order to investigate the relationship between sway and those variables. Results of this analysis showed that, there was no significant correlation.

While performing the evaluation, five patients and one healthy subject could not perform the one legged, eyes closed test. Two patients couldn't perform the one-legged, eyes open test and one patient and one healthy subject could not stand in tandem, eyes closed.

DISCUSSION AND CONCLUSIONS

The evaluation of performance and functional abilities in chronic low back pain patients is an important process in effective rehabilitation. Until recently, emphasis in such evaluation was on strength, flexibility, mobility, and soft tissue factors. The advancement of computer technology has allowed the introduction of computerized biomechanical system that can aid in obtaining performance measures not otherwise available. In particular, the utilization of force platforms for measuring body sway and center of pressure has added a new dimension to the evaluation of human abilities and physical characteristics.

The purpose of this study was to compare sway in chronic low back pain patients to that of healthy subjects. Sway was defined in terms of the area determined from the vectors describing the position of the center of pressure. Sway was measured while subjects assumed one of the following stances: *tandem eyes open; tandem eyes closed; one-legged eyes open; and one-legged eyes closed.*

Findings suggest that sway is greater in the chronic low back pain patients than in healthy subjects. This is in accordance with the findings of Byl and Sinnott (1991) who conducted their study using eight different testing conditions. They report that the results of their study showed that "body sway was generally higher for the LBP subjects compared with the *healthy back* subjects….". It was also found that sway in the eyes closed conditions was larger than that for eyes opened for the same stances. Although the highest sway area was recorded for the one-legged, eyes closed stance, however, only the two tandem cases and the one-legged, eyes opened position were significantly discriminating between the two groups.

In conclusion, for the sample and conditions of this study, chronic low back pain patients were found to sway more than healthy subjects. Whether this difference can be attributed to one factor (age, height, weight or leg strength of the subject), or whether it is due to pain interference with the afferent neural feedback mechanism is not yet fully known. More studies are needed to indicate which factor(s) may be the most responsible for increased sway.

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TRUNK MUSCLE ACTIVITY AND INTRA-ABDOMINAL ACTIVITY DURING CHANGES IN TRUNK POSITION, VELOCITY AND ACCELERATION

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The field of industrial biomechanics is rapidly moving towards an understanding of how dynamic body motions influence the behavior of the musculoskeletal system. It is important to understand how the musculoskeletal system responds to these factors since the muscles are at a biomechanical disadvantage and become the primary sources of joint loading during work. Previous attempts to understand the effects of trunk acceleration upon the activity of the trunk musculature have shown that the trunk muscles that have the greatest mechanical advantage relative to the spine increase their activity to a greater degree than do muscles located closer to the spine. However, these studies required the subject to subjectively control trunk acceleration and did not involve significant trunk torque. Therefore, changes in starting positions, changes in instantaneous trunk velocity and larger load moments could significantly alter the response of the musculature. The present study controlled trunk torque, position, velocity and acceleration levels while subjects performed simulated trunk lifting motions in symmetric and asymmetric postures. The electoromyographic (EMG) activity of ten trunk muscles and intra-abdominal pressure activity were observed in response to these trunk kinematic changes. The results indicated that as trunk torque and trunk velocity increased the EMG activity and degree of coactivation of the trunk muscles increased as expected. However, as trunk acceleration increased the EMG activity of many of the trunk muscles decreased. It is believed that the ballistic nature of the motion may decrease coactivity and the subsequent forces imposed upon the spine. An EMG-assisted biomechanical model was used to help interpret the results.

INTRODUCTION

During manual materials handling activities, the trunk's internal support mechanisms, such as the trunk muscle forces and intra-abdominal pressure (IAP), not only support the spine but also load the spine. This is due to the close proximity of the muscles to the spine compared to the location of the lifted load relative to the spine. Since the trunk musculature is at a biomechanical disadvantage relative to the load, exerted muscle forces are often significant and can be the primary loaders of the spine. Thus, it is important to determine how the muscles and IAP behave during lifting so that accurate assessments of spine loading could be used to minimize the risk of injury during work.

Most research that investigates how the trunk structures behave during lifting have focussed upon isometric exertions of the trunk (Andersson et al. 1976; Seroussi and Pope, 1987) or, more recently, isokinetic actions of the trunk (Marras et al, 1984; Marras and Mirka 1992). However, during most manual materials handling tasks the trunk not only moves through a series of positions in space at various velocities, but also exhibits changes in trunk accelerations that may be associated with different actions of the trunk musculature and IAP. Marras and Mirka (1990) found that when subjects were asked to maintain constant trunk accelerations while exerting minimal torque the muscles with the greatest mechanical advantage increased their activity the most. However, it is not known whether this same trend would occur if the trunk torques were similar to those required by the trunk when lifting or if the trunk starting positions were changed. Therefore, the goal of this research was to determine how the trunk musculature and IAP behave during the generation of trunk velocities and accelerations that are commonly found in the workplace.

METHODOLOGY

Twenty males between the ages of 21 and 33 years served as the subjects in this study. All subjects were healthy and had never experienced a significant low back disorder.

The independent variables in this study consisted of: 1) six trunk position combinations in the sagittal and transverse planes, 2) trunk angular isokinetic velocity (0, 15, and 30 deg/sec), and 3) trunk angular constant acceleration (0, 20, and 40 deg/sec/sec). All of these variables were investigated as subjects produced either 0, 40, or 80 ft-lbs of torque about the lumbro-sacral junction. The dependent variables in this experiment consisted of the electromyographic activity (EMG) of the latissimus dorsi (LAT), erector spinae (ERS), external oblique (EXO), internal oblique (INO), and the rectus abdominus (RCA) muscles on both the right and left sides of the body. IAP was also observed as a function of the experimental conditions.

A KIN/COM isokinetic dynamometer was adapted so that trunk position, trunk isokinetic velocity and trunk constant acceleration could be controlled as the subjects performed trunk motions similar to those observed in occupational circumstances. Customized software was written that permitted the dynamometer to move under constant acceleration conditions. Subjects controlled trunk torque by observing their instantaneous trunk torque data on a computer display. Thus, the conditions of this experiment examined trunk muscle and IAP activity under constant velocity, constant acceleration and constant force condition combinations.

RESULTS

Statistically significant reactions were observed for most muscles and IAP as a function of all independent variables. Table 1 shows a summary of the significant multivariate and univariate differences. Changes in the trunk position, velocity and acceleration resulted in statistically significant differences in the activity of most trunk muscles. As trunk velocity, trunk symmetry, and trunk torque increased trunk muscle EMG and muscle coactivation also increased. However, as trunk acceleration increased trunk muscle EMG decreased as did trunk muscle coactivation.

IAP only responded significantly to position and trunk torque becoming greater as the trunk became more asymmetric and flexed. Increases in velocity and acceleration had no effect on IAP.

DISCUSSION

This study has shown that the activity of the trunk muscles can be predicted as a function of the various dynamic motion components. IAP appears to be not affected by motion but is a result of trunk position and torque. This information could be used to enhance our understanding of trunk loading during dynamic lifting and can assist in the development of three-dimensional trunk motion models. Specifically, this information can facilitate the understanding of trunk muscle co-activation patterns and their effect upon spine loading under occupational circumstances.

In order to determine the effects that these motion components have on the loading of the spine the muscle activities were used as input to an EMG-assisted model currently under development at the Biodynamics Laboratory. This model is based upon a model developed by Marras and Sommerich (1991). The results of the model runs for this experiment are shown in figures 1 through 3. These

Table 1. Multivariate (MANOVA) and univariate (ANOVA) statistical significance summary.

Independent Variable	MANOVA	IAP	LATR	LATL	ERSR	ERSL	RCAR	RCAL	EXOR	EXOL	INOR	INOL
POSITION (p)	***	***	***	**	***	***	***	***	***	***		***
TORQUE (T)	***	***	***	***	***	***	***	***	***	***	***	***
VELOCITY (V)	***		***	*	***	***		**	**	**	***	***
ACCEL (A)	***		***	**	***	***	**	*	**		***	***
P*T	***	***	**	***	***	***	***	***	***	***		***
P*V				*		*	**	**	*			**
P*A	*				***	**						
T*V	***	*	***	***	***	***	**	***	***	***	***	***
T*A												
V*A	*				**	**						

***—SIGNIFICANT AT THE .0001 LEVEL
**—SIGNIFICANT AT THE .01 LEVEL
*—SIGNIFICANT AT THE .05 LEVEL

figures summarize spine loading averaged for all subjects under all trunk torque conditions. Figure 1 shows that predicted spine compression increases significantly as a function of both velocity and trunk asymmetry. These trends were due to an increase in coactivation with velocity and asymmetry. Figure 2 shows predicted spine compression as a function of acceleration for the various velocities. This figure shows that as acceleration increases compression decreases especially for the 15 deg per sec velocity conditions. This trend is due to the reduction in coactivation as acceleration increases. There is also a significant trade-off between compression and anterior shear associated with acceleration and velocity. When coactivation decreases anterior shear increases as shown in figure 3. Thus, the nature of the loading changes significantly as a function of trunk motion components and it is important to document the nature of these motions in the workplace.

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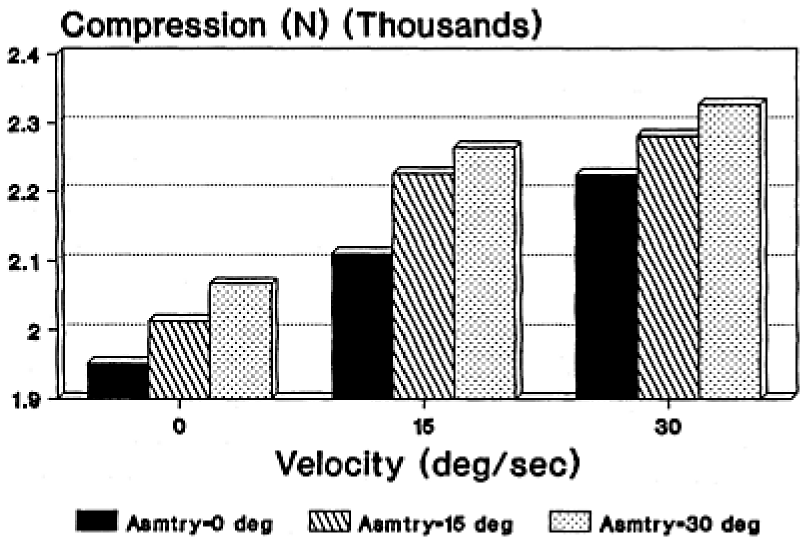

Figure 1. Predicted spine compression as a function of trunk velocity and asymmetry.

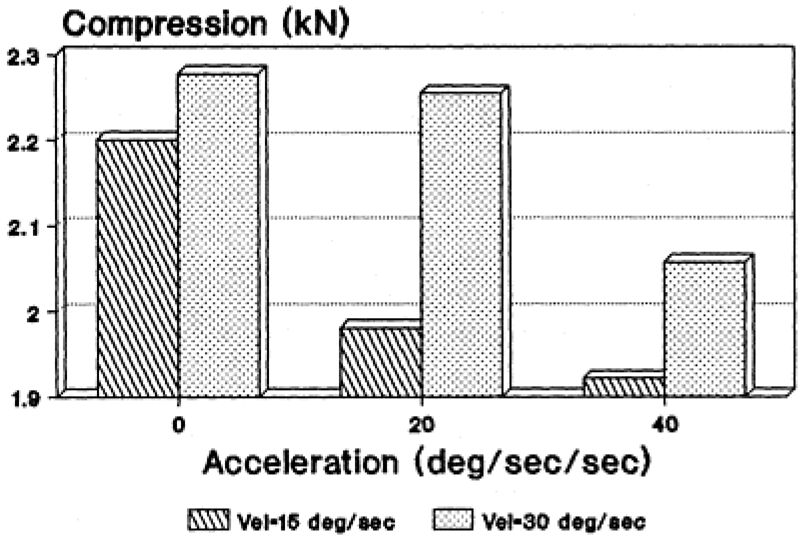

Figure 2. Predicted spine compression as a function of trunk acceleration and velocity.

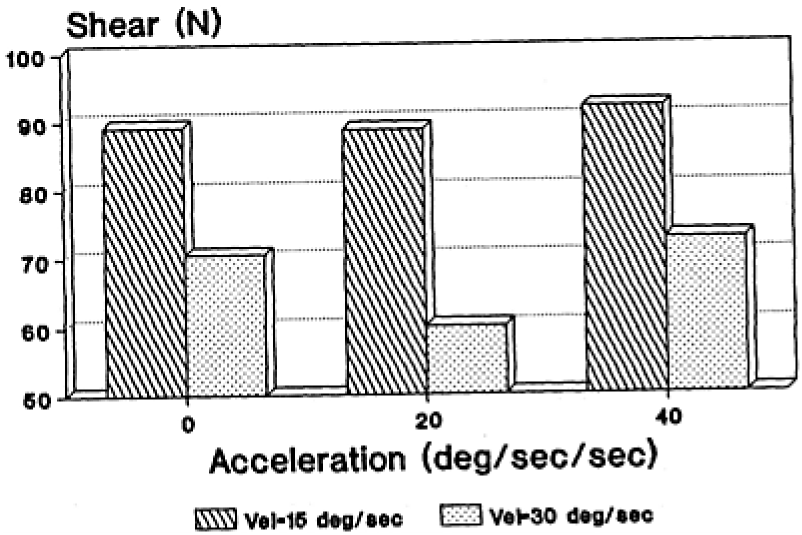

Figure 3. Predicted anterior shear as a function of trunk acceleration and velocity.

TRUNK MUSCLE RESPONSE TO AXIAL TWISTING MOTION

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Many epidemiologic investigations have identified trunk twisting or torsional motions on the job as a factor which increases the risk of suffering an occupationally related low back disorder (LBD). However, few biomechanical studies can be found in the literature which describe how the trunk supporting structures (muscles) behave under dynamic trunk twisting motions. A laboratory experiment was performed to determine how the trunk musculature respond to trunk twisting while the trunk is moving at different rates of velocity and in different positions. Twelve healthy males were placed in a device which permitted the trunk to twist in three different positions while twisting velocity and torque were varied. The electromyographic activity of ten trunk muscles and intraabdominal pressure (IAP) served as the dependent measures. The results provide new information as to how the trunk muscles are recruited and activated during work. These findings also provide information which assists in the interpretation of spine loading while twisting.

INTRODUCTION

Torsional motions of the spine during work are often considered an ergonomic risk factor for low back disorder (LBD). Epidemiologic studies often cite such actions as significantly increasing risk. A study by the U.S. Department of Labor (1982) showed that twisting or turning was associated with a LBD event by 33 percent of workers. Snook (1978) reports that 18% of low back compensation are associated with twisting. Kelsey et al (1984) found that the risk of LBD increased in those subjects that lifted more than 11.3 Kg of weight and twisted their trunks compared to those that did not twist. Furthermore, the risk was present with fewer repetitions for workers that twist. Few biomechanical studies have been performed

that assess the behavior of the trunk's internal musculature. The behavior of the musculature is important since the trunk's internal support mechanisms, such as the trunk muscle forces and intra-abdominal pressure (IAP), not only support the spine but also load the spine. This is due to the close proximity of the muscles to the spine compared to the location of the lifted load relative to the spine. The trunk musculature is at a biomechanical disadvantage relative to the load, thus, exerted muscle forces are often significant and can be the primary loaders of the spine. Hence, it is important to determine how the muscles and IAP behave during lifting so that accurate assessments of spine loading could be used to minimize the risk of injury during work.

Only a few biomechanical investigations of axial twisting appear in the literature. Pope et al (1986) investigated the activity of the trunk musculature as ten subjects attempted to produce axial torques under static exertion conditions. They found that the external oblique muscle activity was proportional to the axial torque produced. There was also significant differences in muscle activity between the right and left erector spinae muscles. Finally, they also found that the antagonist muscle activity was much more substantial than expected.

Traditionally, most biomechanical assessments have been limited to static assessments of the trunk and have focused primarily on the increased spine compressive loading associated with increases in the moment imposed upon the trunk. Recently, McGill (1991) evaluated the electromyographic (EMG) activity of six trunk muscles while subjects produced maximum voluntary isometric and isokinetic twisting exertions. The isokinetic exertions were tested under both 30 and 60 deg/sec conditions. This study found lower EMG activity of the trunk muscles under the isokinetic conditions compared to the isometric conditions. McGill also found significant latissimus dorsi and erector spinae activity related to motion but not to involved specifically in the generation of torque. When the EMG data were used in an EMG-driven model the model was not able to account for the trunk torque activity. Both Pope et al and McGill suggest that the increased coactivity may play a role in the control or stability of the trunk during twisting.

In both of these previous studies the trunks of subjects were rotated during upright standing. It is rare that this type of torsional load is applied to the trunk during work. Therefore, the purpose of the current study was to evaluate the role of the trunk musculature and IAP when trunk twisting occurs in postures other than the upright posture.

METHODS

Twelve college students served as subjects in this experiment. None had a history of low back disorder and each participated in a training session prior to the day of experimental testing. This enabled the subject to become familiar with the experimental protocol.

A twisting reference frame (TRF) was used to control subject trunk twisting. A Kin/Com isokinetic dynamometer was used to control velocity and measure torque in the TRF. The isokinetic motion from the Kin/Com was transferred through a chain and sprocket arrangement to a vertical rotating axis which was oriented so that it passed through the L5/S1 intervertebral joint of the subject. The TRF held the subject’s pelvis stationary and permitted motion from the spine only. An inner harness was mounted on the subject within the TRF. Two load cells were placed at the interface of the harness and the TRF so that the twisting torque exerted by the subject could be measured. The torque was displayed on-line on a computer monitor so that the subject could monitor the amount of twisting torque they were exerting. In addition to the subject's twisting torque, the monitor also displayed a target torque and two tolerance lines indicating the the torque tolerance permitted for a trial.

There were four independent variables in this study. The first independent variable was the axial rotation (A) of the shoulders relative to the pelvis about the local zaxis which runs along the axis of the spine. This variable will be called twist angle and three levels of this variable were used: −15 degrees (prerotation), 0 degrees (sagittally symmetric) and 15 degrees (fully twisted). The names prerotated, sagittally symmetric and fully twisted will be used throughout this paper to describe the above three angles. The second independent variable was the twisting torque (T) exerted about this zaxis. Twisting torque had two levels: 10 and 20 ft-lbs of torque. Three levels of twisting velocity (V) were used: 0, 10 and 20 deg/sec. The fourth independent variable, which will be called trunk position (p), consisted of the combination of two posture related variables. Three levels of this variable were used. The first position consisted of a sagittal angle of 0 and trunk rotation of the pelvis of 0 (position S0, R0). In other words the subject was standing straight up in the anatomical position. The next position included a sagittal angle of 15 degrees while the pelvis was still not axially rotated (S15, R0). The final position consisted of a sagittal angle of 15 and a rotation of the pelvis of 15 degrees (S15, R15).

The normalized EMG of ten trunk muscles and IAP were the dependent measures of this study. The muscles sampled were the right and left pairs of the 1) latissimus dorsi (LATR, LATL), 2) erector spinae (ERSR, ERSL), 3) rectus abdominus (RCAR, RCAL), 4) external oblique (EXOR, EXOL) and the 5) internal oblique (INOR, INOL). The intraabdominal pressure (IAP) was collected using an telemetric intra-abdominal pressure pill which was inserted rectally.

The experimental design for this experiment consisted of a randomized design with restrictions on randomization for the variable "trunk position". Our design counterbalanced the order of presentation of the position variable while within a level of the variable "trunk position", the presentation of conditions was completely randomized.

Before the subjects performed the experimental conditions maximum isometric exertions as well as resting conditions were performed with the subjects positioned in the various experimental positions. This was necessary so that the EMG signals could be normalized within each muscle.

RESULTS AND DISCUSSION

The statistically significant findings from this study are summarized in table 1. Table 1 shows the results of a MANOVA and subsequent ANOVA analysis. This table shows how the various muscles and IAP contribute to the various experimental variables. All muscles were involved in changes of at least one of the experimental variables. It is interesting to note that both the external oblique and rectus abdominus muscle groups played a role in each of the individual experimental variables. Pope et al. found similar results for the external oblique muscles. It is also interesting to note that changes in torque levels and twisting angle resulted in changes in activity of almost all muscles. Changes in twisting

Table 1. Significance summary for multivariate (MANOVA) and univariate (ANOVA) effects.

Independent Variable MANOVA	IAP	LATR	LATL	ERSR	ERSL	RCAR	RCAL	EXOR	EXOL	INOR	INOL
TORQUE (T) ***	***	***	***	***	***	***	***	***	***	***	***
VELOCITY (V) ***		*			***	***	***	***	***		***
ANGLE (A) ***	*	***	***	***	***	***	***	***	***		***
POSITION (P)	*					**	*	**	***		
P*T ***		*	*		*	**			*	**	*
P*V	*	**									
P*A ***			**	***	***	***	***	***	***	*	**
T*V											
T*A ***			***		***	***	***	***	***		***
V*A ***					***			**	***		

***—SIGNIFICANT AT THE .0001 LEVEL
**—SIGNIFICANT AT THE .01 LEVEL
*—SIGNIFICANT AT THE .05 LEVEL

velocity resulted in muscle activity changes in all rectus abdominus and external oblique muscles as well as the erector spinae and internal oblique muscles on the left side only. Many significant interactions occurred within position and trunk angle conditions as well as within torque and trunk angle conditions. All of these findings suggest that coactivation does increase during twisting motions and that the velocity of motion is a significant factor in determining muscle usage. These findings regarding coactivation also agree with the findings of Pope et al.

Intra-abdominal pressure was affected by three of the independent variables: twisting torque, twisting angle and trunk position. These results correspond very well with earlier research which has shown IAP to be dependent on the trunk position and exerted torque (Marras and Mirka, 1990). The absolute levels of IAP were low as compared to those elicited during trunk extension exertions indicating that IAP may be performing a somewhat different task during twisting as compared to lifting. The effect of increasing the torque from 10 to 20 ft-lbs was to increase IAP by just over 50%. Slight increases were found as a function of twisting angle with the prerotated case showing the least IAP and the fully twisted position showing the greatest IAP. Trunk position also was a significant factor with position S0, R0 (vertical) showing the least IAP (8.6 mm Hg) and position S15, R15 showing the greatest levels of pressure (15.75 mm Hg).

Two of the oblique muscles (LATR and INOR) were relatively unaffected by changes in the independent variables. Although they showed significant increases in activity with greater twisting torque and greater twisting angle, the differences were slight as compared to other muscles. The line of action of these muscles indicates that their activity opposes the trunk motion (antagonism).

The line of action of the right external oblique and the left internal oblique suggest that they would be the primary muscles used to perform this task. This hypothesis is confirmed by the current data. Both were greatly affected by changes in twisting angle, twisting torque and twisting velocity. Increases due to increases in twisting torque from 10 to 20 ft-lbs of torque were on the order of 250%. Increasing the velocity from 0 to 20 deg/sec created increases in these muscles of 30% while moving from prerotated positions to fully twisted positions caused increases of approximately 275%. These trends are shown in figure 1. When the interaction between twisting angle and trunk position is considered EMG activity at position S15, A15 was significantly lower for both of these muscles. This may be due to the increasing contribution of the passive components at these extreme positions as well as increases in the amount of additional muscle force provided by other muscles of the trunk, namely the left latissimus dorsi.

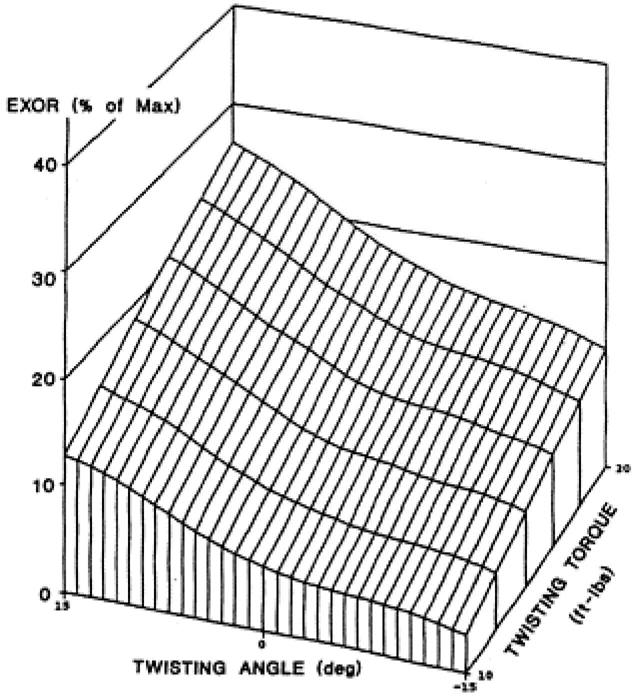

Figure 1. EMG activity of the External Oblique muscle shown as a function of twisting angle and twisting torque.

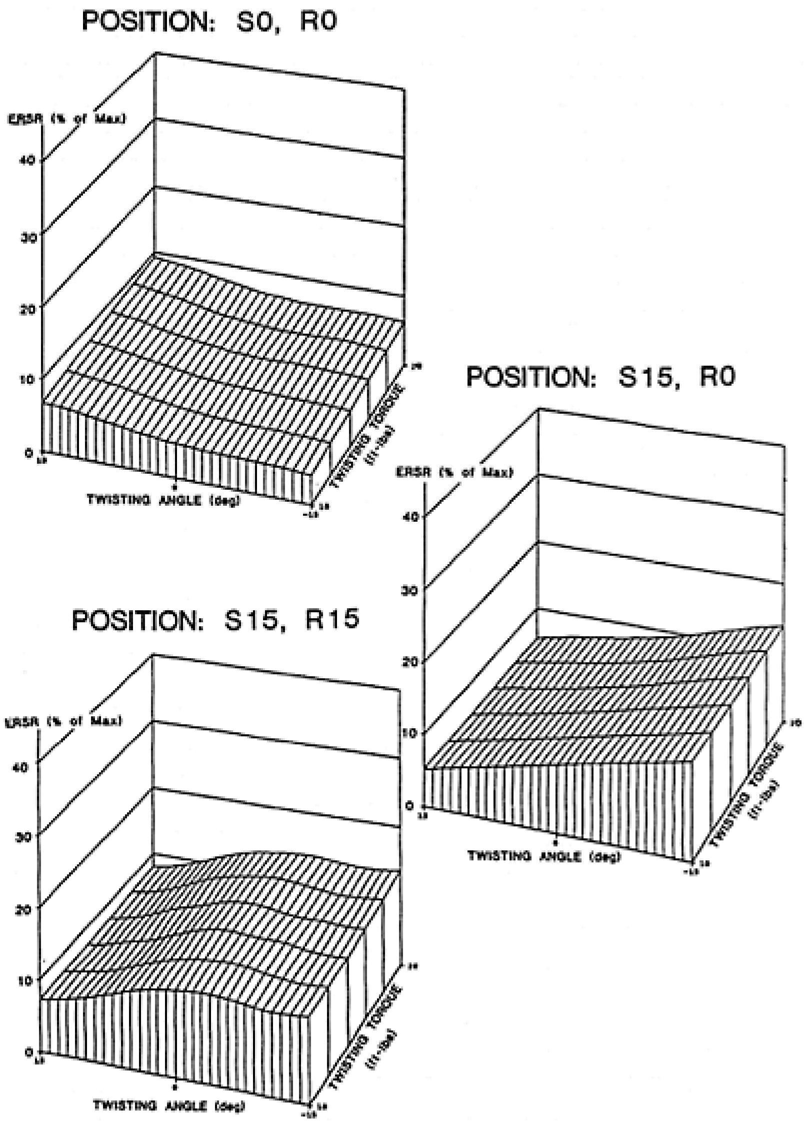

Figure 2. Right Erector Spinae activity shown as a function of twisting angle and torque in the various experimental positions.

Vertically Oriented Musculature

The muscles put this category are those muscles whose line of action when a subject is standing in a sagittally symmetric posture with no sagittal angle are for the most part in the vertical direction. However, when the trunk is twisted, bent forward or bent to the side, the line of action of these muscles changes to a point where significant moments in the transverse plane can be generated. Therefore, it can not be assumed that these muscles are incapable of exerting twisting torques.

The two muscles in this category which seem to show significant muscle activities were the left erector spinae and the left rectus abdominus, but the role of these two muscles seems to much different. The response of the left erector spinae muscle is similar to that of the EXOR, the INOL and the LATL. This muscle exhibits significant responses to the twisting torque and the twisting angle. The left rectus abdominus on the other hand showed increased activity at twisting angles on the extended end indicating that this muscle was acting as an antagonist muscle for the twisting task.

A muscle which had a very interesting response to the independent variable position was the right erector spinae. This muscle showed the opposite trends in muscle activity as compared to all of the other muscles of the trunk. While all the other muscles showed significant decreases at the more complicated trunk postures the ERSR showed significant increases in EMG activity. Figure 2 shows these responses as a function of the various trunk positions tested. This figure indicates that the right erector spinae was the primary muscle for maintaining these postures. In addition it appears that it must act to maintain stability as the left erector spinae is adding to the twisting moment. Also, contrary to all the other muscles, the right erector spine had significant increases at the more prerotated postures. Presumably this results because the line of action of this muscle is such that: prerotation does not indicate more passive muscle force. Therefore, in order to stabilize the trunk against all the increased passive muscle force exerted by the other muscles its activity must increase.

CONCLUSIONS

This study has shown that the trunk muscle activities associated with trunk twisting motions are significant for all trunk muscles. This study has also been able to determine which muscles are involved in the generation of torque, velocity, trunk angle, and trunk rotation. As with previous studies we have shown that the trunk muscles coactivate during twisting. However, unlike previous studies we have shown that far more of the musculature is involved in twists performed in trunk positions that deviate from upright. This information could be used to assist in understanding how the spine is loaded during twisting.

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TRUNK MUSCLE ACTIVATION: THE EFFECTS OF TORSO FLEXION, MOMENT DIRECTION, AND MOMENT MAGNITUDE

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INTRODUCTION

A limitation in previous biomechanical models predicting the mechanical loading of the lumbar spine has been the statically indeterminate system of equations necessary for complete description of the forces and moments. Historically, a common means in simplifying this problem has been to assume negligible coactivation by antagonistic muscles (Schultz and Andersson, 1981). In doing so the number of unknowns was reduced allowing the system of equations to produce a unique solution. However, more recent literature has suggested that the muscular coactivation is not negligible, especially as loads upon the trunk become asymmetric with regards to the mid-sagittal plane (Ladin et al., 1989; Zetterberg et al., 1987). Therefore, models which have employed such means to reduce the quantity of unknowns so that a solution can be computed would have underestimated the mechanical loading of the spine.

Earlier work from this laboratory has focused on describing the trunk muscle activations while the torso was maintained in an upright posture (Lavender et al., 1992). Presently, limited data is available showing trunk muscle responses to forward flexion conditions. Schultz et al. (1982) have described the electromyographic activities of the trunk muscles in response to flexed postures and external loads which were symmetric with respect to the midsagittal plane. Marras and Mirka (1992) recently reported the response of the trunk muscles to isokinetic conditions with small amounts of asymmetry (30 degrees or less). This investigation seeks to extend these finding to more extensive asymmetric conditions. Specifically, this investigation was designed to quantify the trunk muscle activities using surface electromyography (EMG) when the trunk was in flexed postures and was subjected to asymmetrically applied moments.

METHODS

Subjects

Nineteen male subjects between the ages of 19 and 41 volunteered their services for the experiment. The subjects were asked to sign an approved consent form prior to participating in the study. Anthropometric measures which describe this sample characteristics (both mean and ranges) are as follows: stature 177.8 cm (162.7 cm−193.5 cm), weight 74.4 kg (61.4 kg−95.0 kg), trunk breath 28.2 cm (23.3 cm−34.8 cm) and trunk depth 20.9 (17.3−26.8).

Experimental Design

The experiment was structured as a randomized blocks design in which each of the subjects served as a replication. The independent variables evaluated in this study were the trunk flexion (30 or 60 degrees of trunk flexion), the magnitude of the applied external moment (20 and 40 Nm), and the direction of the applied external moment. The moment directions, shown in figure 1, were in a plane normal to the longitudinal axis through the torso in each of the flexed postures. The moment directions included: mid-sagittal plane anterior (0 degrees) and posterior (180 degrees), and 5 asymmetric directions at 30 degree intervals to the subjects' right side between these two conditions (30, 60, 90, 120, and 150 degrees). The sequence of the moment direction and moment magnitude conditions were randomized within each level of trunk flexion. The sequence of the trunk flexion conditions was counter-balanced for the 19 subjects. All moments were applied, in planes normal to the trunk flexion, to a harness which had attachment points on the front, rear, and side. The trunk flexion postures were determined with an electroinclinometer and maintained with the help of a video monitor.

The dependent measures consisted of the EMG activities from eight muscles crossing the transverse plane at the L3/L4 level. These included the left and right Erector Spinae (ERSL and ERSR), Latissimus Dorsi (LATL and LATR), External Obliques (EXOR and EXOL), and the Rectus Abdomini (RABL and RABR).

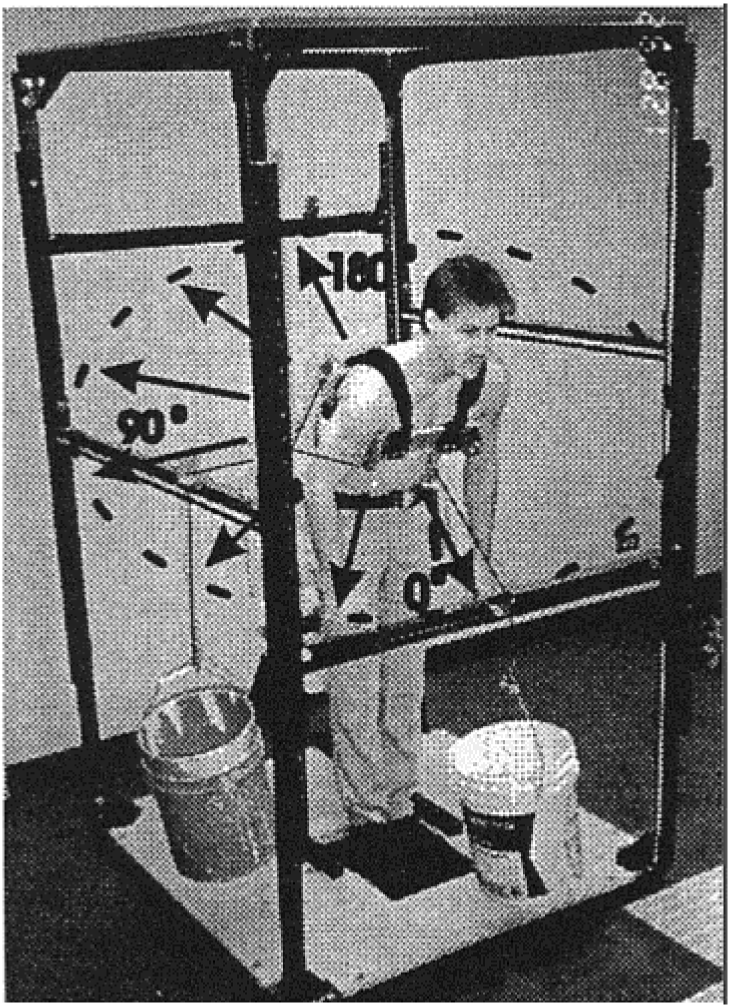

Figure 1. This figure shows a subject in the reference frame. Weights were suspended from the harness such that the vector sum (resultant) of the sagittal and frontal plane components pulled in the specified moment direction. The moment directions were in a transverse plane which was perpendicular to the torso at the level of the harness.

Apparatus

Subjects were fitted with a harness having 3 attachment points: 1) front, center of the chest, 2) rear, over the spine at the lower tips of the scapulae, and 3) on the side, along a cable connecting the front and rear of the harness. The front and the rear of the harness consisted of padded aluminum plates. The sensor from an electronic inclinometer, Cybex EDI 320, was attached to the rear plate of the harness.

The magnitude of the external loads were computed using the moment arm (the distance between the L3/L4 intervertebral disc and the harness in an upright posture) for each subject. This procedure assured, despite variability in subject anthropometry, external moments and application points which were consistent across subjects.

During the experiment the subjects stood in a reference frame apparatus. This structure included a stand to which the subject's pelvis was strapped. The reference frame provided a structure by which external loads were applied via dynamometers and suspended weights. A stationary video camera was positioned to obtain a view of the subject from the mid frontal plane. This image was displayed on a video monitor positioned in front of the subject to provide feedback as to his trunk posture.

The external moments were created by connecting cables to the harness which ran via pulleys to one or two buckets containing weights. The cables and weights exerted forces on the harness in a plane normal to the harness (tilted 30 or 60 degrees). The weight(s) in the bucket(s) were either: 1) The specified moment magnitude, or 2) The magnitude of the vector components in the sagittal and frontal planes which would create a resultant moment with the desired magnitude and direction on the torso.

The EMG data were collected using surface electrodes. The signals were amplified and rectified with a bandpass frequency range of between 20 and 600 Hz. These signals were further processed with an analogue RMS conversion. The RMS data were then sampled at a frequency of 10 Hz. The RMS data were stored on a personal computer for later analysis.

Procedure

The muscles of interest were located by palpitation with the subjects in an upright posture. EMG electrodes were placed on the muscles as follows: 1) Erector Spinae: L3/L4 level, 3 cm. lateral to the midline, 2) Latissimus Dorsi: T7 level, over the belly of the muscle, 3) External Oblique: umbilicus level, 2 cm medial from the iliac crest, angled 45 degrees, and 4) The Rectus Abdomini: level of the umbilicus, 2 cm lateral from the midline. The harness was placed on the subject such that the anterior attachment point was at the level of the nipples and the rear attachment point was at the tip of the scapula.

Each subject was strapped to the stand in the reference and instructed to flex his torso in the sagittal plane until the desired posture condition was achieved on the harness mounted inclinometer. At this point the reference frame was adjusted so that all force applications would be normal to the torso.

For the purposes of EMG normalization subjects performed maximal voluntary contractions (MVC's) in which they attempted to flex, extend and twist the torso in each of the trunk flexion conditions (30 and 60 degrees). The trunk extension MVC was videotaped to provide the reference posture described below.

In obtaining the desired flexed postures subjects were only instructed not to rotate their pelvis. Since the flexion could occur at throughout the lumbar and lower thoracic vertebrae a method was need to insure subjects obtained the desired posture in a consistent manner. This was achieved by filming the torso extension MVC from the vantage point of the mid-frontal plane. Following the MVC the tape was replayed and a curve was drawn on the monitor along the posterior edge of the torso. Prior to each of the 14 experimental conditions tested in the designated posture, subjects were instructed to bend forward and place their torso along the curve drawn on the screen. This insured that the method of trunk flexion would be repeated and that the surface electrodes would be sampling the same muscle tissue from which the MVC data were collected.

During the 14 trials EMG data were collected for 10 seconds after the subject adjusted his posture under the external load in accordance with the curve on the monitor. Subjects were given sixty seconds to rest between each moment application within a posture condition. During this period the subjects were encouraged to stand upright so as to minimize muscle fatigue. Subjects were given approximately 5 minutes to rest between posture conditions as adjustments to the reference frame were required.

Data Treatment

The RMS data were averaged over the ten second data collection period for each muscle under each experimental condition. The averaged EMG values were then normalized relative to the maximal values observed during the MVC trials for each trunk posture as follows:

$$NEMG\,(i, j)=(o(i, j))-\min(i, j))/(MVC\,(i, j)-\min(i, j)) \quad (1)$$

Where:

i=individual muscles from 1 to 8.

j=trunk flexion condition of either 30 or 60 degrees

NEMG (i, j)=	the normalized EMG signal for muscle i under flexion condition j.
O (i, j)=	the averaged RMS value observed for muscle i under flexion condition j.
MVC (i, j)=	The maximum observed value for muscle i during the four MVC's under each flexion condition j.
min (i, j)=	The minimum observed value for muscle i under each flexion condition j during the load supporting trials.

The statistical analysis proceeded by first testing the main effects and the interactions with a multivariate model composed of the eight dependent measures. The effects found significant with the multivariate analysis of variance (MANOVA) were then further tested with a univariate analysis of variance (ANOVA). These latter procedures were used to evaluate each individual muscle's response to the independent variables. Post-hoc tests were employed to evaluate the differences between means for the moment direction conditions.

RESULTS AND DISCUSSION

The outcome of both the multivariate and univariate statistical analyses are summarized in Table 1. In addition to finding significant main effects, the MANOVA found two significant two-way interactions: The flexion angle by moment direction interaction and the moment magnitude by moment direction interaction. Univariate ANOVA's were then employed to show that the significant flexion angle by moment direction MANOVA interaction could be attributed to the response of the LATR, the LATL, and the EXOR. Similarly, the moment magnitude by moment direction interaction was due to the responses of all muscles but the RABL.

INDEPENDENT VARIABLE		DEPENDENT MEASURE								
	PARAMETER	MANOVA	LATR	LATL	ERSR	ERSL	EXOR	EXOL	RABR	RABL
FLEXION ANGLE	F	12.08	29.73	22.98	38.06	10.42	NS	7.39	NS	NS
	df	(8,479)	(1,480)	(1,480)	(1,480)	(1,480)		(1,480)		
	p	<.001	<.001	<.001	<.001	<.005		<.01		
MOMENT MAGNITUDE	F	10.78	38.48	26.97	NS	19.64	15.41	7.89	NS	NS
	df	(8,479)	(1,480)	(1,480)		(1,486)	(1,480)	(1,480)		
	p	<.001	<.001	<.001		<.001	<.001	<.01		
MOMENT DIRECTION	F	20.78	17.02	8.08	120.0	68.03	NS	NS	NS	NS
	df	(48,2361)	(0,480)	(0,480)	(0,480)	(0,480)				
	p	<.001	<.001	<.001	<.001	<.001				
FLEXION ANGLE*	F	1.37	–	–	–	–	–	–	–	–
MOMENT MAGNITUDE	df	(8.479)	–	–	–	–	–	–	–	–
	p	>.05	–	–	–	–	–	–	–	–
FLEXION ANGLE*	F	1.83	4.76	7.97	NS	NS	2.58	NS	NS	NS
MOMENT DIRECTION	df	(48,2361)	(0,480)	(0,480)			(0,480)			
	p	<.004	<.001	<.001			<.05			
MOMENT MAGNITUDE	F	3.23	3.04	2.28	7.02	9.84	2.93	3.31	2.22	NS
MOMENT DIRECTION	df	(48,2361)	(0,480)	(0.480)	(0,480)	(0,486)	(0,480)	(0,480)	(6,480)	
	p	<.001	<.01	<.05	<.001	<.001	01	<.01	<.05	
FLEXION ANGLE*	F	0.75	–	–	–	–	–	–	–	–
MOMENT MAGNITUDE*	df	(48,2361)	–	–	–	–	–	–	–	–
MOMENT DIRECTION	p	>.05	–	–	–	–	–	–	–	–

Table 1. Statistical results from the MANOVA and ANOVA tests conducted on the data set. ANOVA's were only performed on the main effects or interactions found to be significant under the MANOVA. For each test showing a probability of

type I error less than 0.05 the F-ratio (F), the degrees of freedom (effect, error), and the significance level are reported. Interaction effects are indicated with an “*”.

The main effect for the trunk flexion angle is shown in figure 2 for those muscles in which the flexion main effect was significant but the flexion by moment direction interaction was non-significant. This data indicates that two erector spinae muscles increased their activity in response to the increased trunk flexion angle whereas the EXOL showed decreased activity due to the same change.

Three muscles, the LATR, LATL, and the EXOR showed significant trunk flexion by moment direction interactions. Figure 3 shows data from one of these muscles which typifies the form of this interaction. For the latissimus dorsi muscles, the greater response to the 60 degree flexion condition was only apparent with moment directions which were less than 90 degrees. With moment directions at or beyond this value the differences in the EMG activities due to posture became negligible. Conversely, in the EXOR the response becomes sensitive to the trunk flexion condition only with moment direction conditions greater than 120 degrees. Under these conditions the 30 degree trunk posture results in greater EXOR activity.

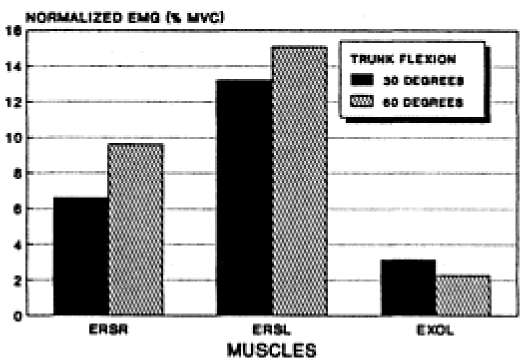

Figure 2. The means values for the three muscles which showed only a significant main effect due trunk flexion. Three additional muscles not shown here showed a significant trunk flexion by moment direction interaction effect.

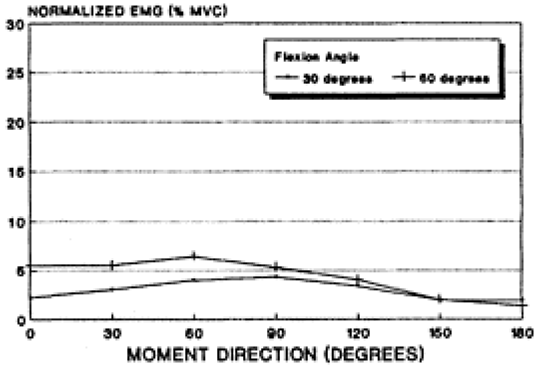

Figure 3. This figure illustrates trunk flexion by moment direction interaction effect in the LATR muscle's response. The values plotted represent the means taken across the 19 subjects.

The interaction effect between the moment magnitude and the moment direction is shown in figure 4a for the ERSR and figure 4b for the ERSL. In both muscles the output was greater under the 40 Nm condition at 0 degrees when compared with the 20 Nm condition. However, with a moment direction greater than 150 degrees the 20 Nm load produced greater muscle tension. As in upright postures, with the load anterior to the body, increased moment magnitude leads to greater the erector spinae activity. But when the applied moments had a posterior direction, the 40 Nm load acted to counter-balance the moment generated by the torso whereas the 20 Nm moment was insufficient to counter-balance the torso, and therefore required additional muscle force.

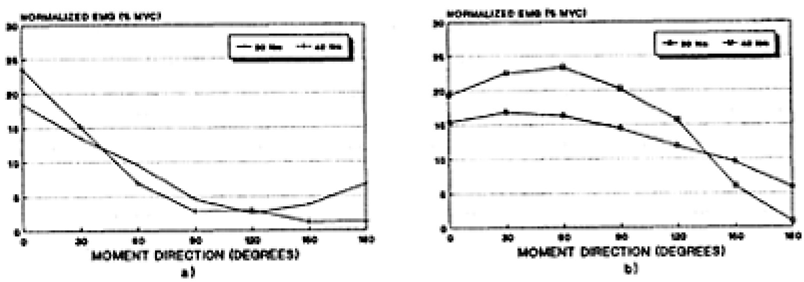

Figure 4. These figures show the significant interaction effect between the moment magnitude and the

moment direction for the ERSR (a) and
the ERSL (b).

The data collected in the current experiment shows how the mass of the torso interacts with externally applied loads in two forward flexed postures. When compared with earlier work which described the trunk muscle response under similar asymmetric loading conditions but with the trunk in an upright posture (Lavender et al., 1992), the current results showed greater erector spinae activity even under more extreme asymmetric conditions. Again relative to this previous study, the torso mass reduced much of the anterior muscle activity required to stabilize the torso with load having a posterior directional component.

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Isometric and Isoinertial Axial Trunk Rotation: The Effects of Kinematic Constraints, Levels of Resistance, and Direction of Exertion on the Motor Output and Muscle Activity.

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INTRODUCTION:

Quantification of trunk muscle performance has been a major goal of many health care professionals. Functional evaluation with computerized dynamometer has become so common that users must decide among the features provided by competing technologies. One issue that has not been fully explored is the concept of kinematic constraints inherent in the design of the dynamometer. Both in-vivo and in-vitro studies have shown the motion of spine to be highly coupled. Lateral bending accompanies the primary motion of axial rotation. Numerous attempts have been made to measure the segmental range of motion three dimensionally in the lumbar spine with the purpose of quantifying abnormal coupling and diagnosing instabilities (Dvork et al., 1991). Weitz (1981) found that abnormal axial rotation of a lumbar vertebra, while the patient was laterally bending, had clinical relevance.

Trunk muscle torque generation capabilities have shown coupling during maximum isometric exertions which can only be quantified by multi-axial dynamometers. Such couplings were manifested the most during axial rotation (Parnianpour et al., 1988). The internal loading of spine depends not only on the external load but also on the recruitment of trunk muscles. Better quantification of loading of spine is vital to our understanding of biomechanical causation of spinal disorders.

The purposes of this study are to determine: a) the effects of direction (right and left axial rotation) and the kinematic constraints (locked and unlocked accessory axes) on the isometric rotational torque and mean EMG activities of selected trunk muscles; b) the effects of resistance (nominal and 50% of maximal voluntary contraction [MVC]) and the kinematic constraints (locked and unlocked accessory axes) on the isoinertial motor output (axial torque and velocity) and the mean activities of selected trunk muscles.

METHOD:

Fifteen healthy male volunteers with no previous history of back pain participated in this study. The average (range) age, height, and weight of these subjects were: 31 (25–40) years, 178 (170–192) cm, and 72 (57–84) kg, respectively. The B200 Isostation, a triaxial dynamometer, was used to measure the exerted torque, position, and angular velocity of the trunk simultaneously. The myoelectric activities (EMG) of ten selected trunk muscles were recorded concurrently with surface electrodes. Electrodes for left and right obliques (LOB, ROB), rectus abdominis (LRA, RRA), medial (LME, RME), and lateral (LLE, RLE) erector spinae were placed at the L3 level. Left and right latissimus dorsi (LLD, RLD) were monitored at the T12–L1, to avoid potential interference from the chest restraint of the dynamometer.

Subjects were positioned in an upright posture with L5/S1 aligned with the flexion/extension axis of the dynamometer. They were instructed to perform maximum isometric trunk exertion to the left and right (direction) with accessory axes in the frontal and sagittal planes being locked and unlocked (kinematic constraints). The instructions followed the safety precautions, asking for 5 seconds of maximum effort with no jerky exertions. Repetitive dynamic axial trunk movements were performed against a nominal resistance (7 Nm) and 50% of MVC calculated from isometric tests with the accessory axes being locked and unlocked. Subjects were asked to perform five repetitions as fast and accurate as possible with maximum effort. The software identified the third cycle which was used for data analysis. The orders of tests regarding the locked/unlocked, direction of exertion (left and right), and resistance levels (nominal and 50% MVC) were randomized and each test were replicated once. Practice trials were performed in order to familiarize the subjects with the equipment and the task.

The preamplified raw EMG signals were processed by the analog circuits to evaluate the RMS-EMG. The ten RMS-EMG and nine mechanical signals were collected synchronously at the rate of 200 Hz and 50 Hz respectively. The descriptive and multiple analysis of variance (MANOVA) with repeated measures design were used for the data analysis (SPSSx, 1986). The significance level was chosen at $p<.05$ in this study.

RESULTS:

The mean triaxial torques are normalized with respect to the maximum axial torques generated during the isometric exertions (Figure 1). The mean myoelectric activities of the ten selected muscles during the axial isometric trunk exertions are depicted in Figure 2. The triaxial torque and velocity, and the mean RMS-EMG of the ten muscles are presented in Figures 3, 4, and 5, respectively. The triaxial torques are normalized with respect to maximum axial torque generated during the dynamic axial rotation. Multivariate analysis of variances are presented in Tables 1 to 2. The univariate analysis of variance was also performed but are not presented here due to lack of space. During isometric axial trunk MVC, the kinematic constraints only significantly affected the abdominal muscles while all muscles were affected by the direction of exertion (Table 1). The net mechanical output in the primary plane of exertion, axial torque, was not affected whether the accessory axes were locked or not (Tables 1 and 2). The accessory torque generated in the coronal and sagittal planes during isometric exertions were considerable when these axes were locked (Fig. 1). The torques

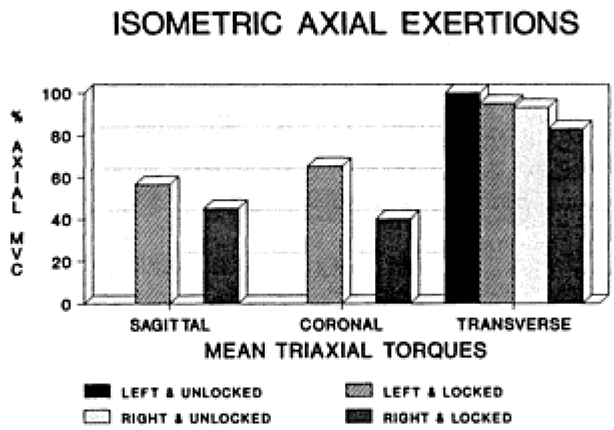

Fig. 1. Mean triaxial torque output during right and left maximal isometric axial exertions with accessory axes being locked and unlocked, (Data is normalized with respect to Maximum Axial Torque).

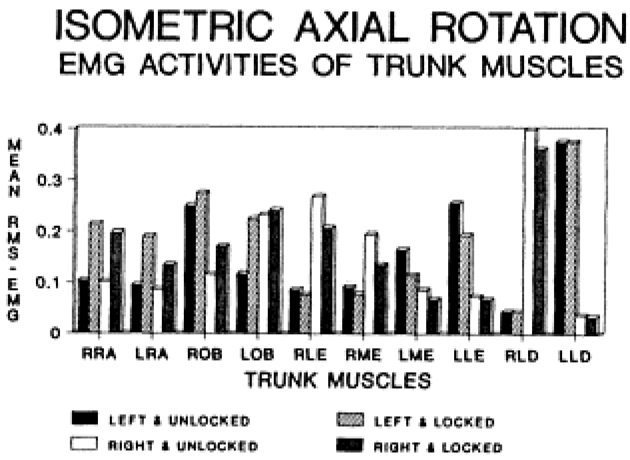

Fig. 2. Mean RMS-EMG activities of ten selected trunk muscles during right and left maximal isometric axial exertions with accessory axes being locked and unlocked.

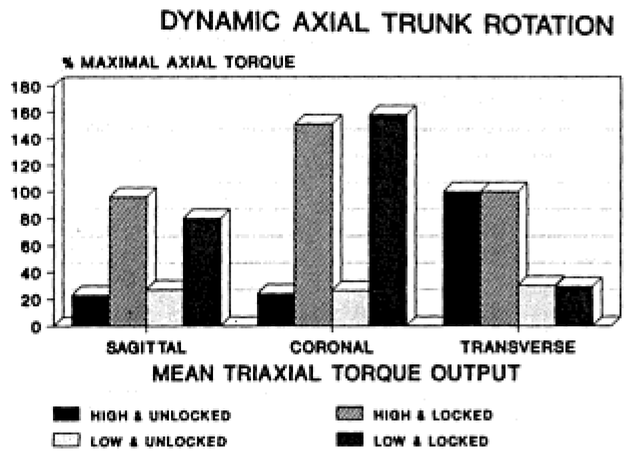

Fig. 3. Mean triaxial torque output during repetitive dynamic axial rotation against two resistance levels (High=50% MVC, Low =7 Nm) with accessory axes being locked and unlocked, (Data is normalized with respect to Maximum Axial Torque).

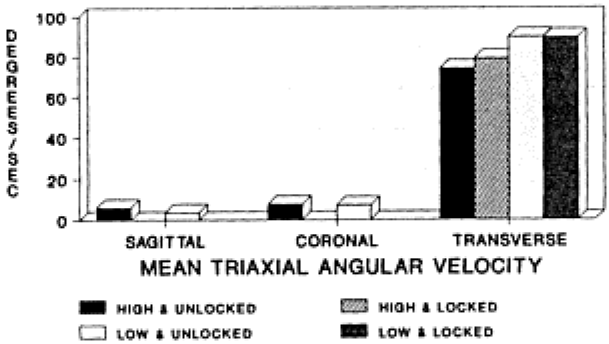

Fig. 4. Mean triaxial angular velocity (°/sec) during repetitive dynamic axial rotation against two resistance levels (High=50% MVC, Low=7 Nm) with accessory axes being locked and unlocked.

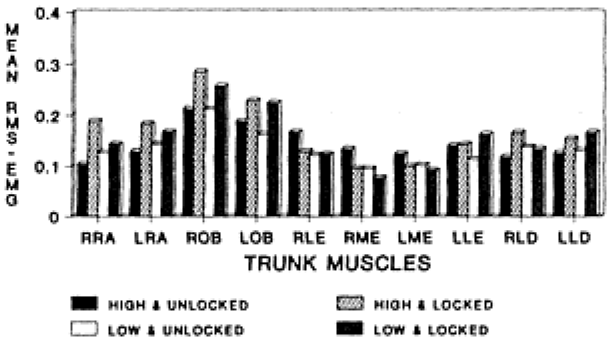

Fig. 5. Mean RMS-EMG activities of ten selected trunk muscles during repetitive dynamic axial rotation against two resistance levels (High=50% MVC, Low=7 Nm) with accessory axes being locked and unlocked.

Table 1. Multivariate Analysis of Variance (MANOVA), Testing the Effects of Direction (Right and Left Axial Rotation) and Kinematic Constraints (Locked/Unlocked Accessory Axes) on the Axial Rotation Torque and Mean Values of the Activities of Four Selected Trunk Muscle Groups, during Maximal Isometric Rotation

(N=15)	F values		
Dependent Parameters	Direction (D)	Constraints (C)	D by C
Rotation Torque	6.0**	1.7	0.8
Rectus Abdominis	3.7*	3.9*	1.4
Obliques	41.5**	3.8*	1.9
Latissimus Dorsi	116.9**	1.0	1.0
Erector Spinae	9.1**	1.7	2.2

*P<.05 P<.001

Table 2. Multivariate Analysis of Variance (MANOVA), Testing the Effects of Resistance (Nominal and 50% MVC) and Kinematic Constraints (Locked/Unlocked Accessory Axes) on the Axial Rotation Torque and the Mean Values of Activities of Four Selected Trunk Muscle Groups, during Maximal Repetitive Left and Right Axial Trunk Movement.

(N=15)	F values		
Dependent Parameter	Resistance (R)	Constraints (C)	R by C
Rotation Velocity	13.2**	1.4	1.9
Rotation Torque	53.2**	0.2	2.2
Rectus Abdominis	0.5	6.1**	0.9
Obliques	1.6	6.7**	1.2
Latissimus Dorsi	0.2	2.4	0.1
Erector Spinae	4.6*	1.6	1.7

*P<.05 **P<.001

generated in the sagittal and coronal planes were 57% and 67% of the maximum torque generated in the transverse planes, respectively. The trunk strength for the left axial rotation was significantly higher than right axial rotation.

During the dynamic repetitive trunk movements, the motor output (axial torque and velocity) in the primary plane was not affected by the kinematic constraints. The results of MANOVA indicated the abdominal muscles were significantly affected (Tables 2). On the contrary, significant effects of resistance on rotation torque and velocity, and muscle activities of erector spinae muscles were found (Table 2). ANOVA showed that the right erector spinae (RLE and RME) were affected by resistance. MANOVA results showed no significant interaction effects during isometric and dynamic tests (Tables 1 and 2). Although the kinematic constraints did not affect the motor output in the primary plane, the recruitment patterns (and spinal loading) were affected significantly.

DISCUSSION:

The dynamic torque are reported here are the signals measured by the strain gauge assembly about each axis of the B200 Isostation. The value of dynamic torque is closely related to the set resistance and it represents the provided resistance by the machine. The resistance is provided independently by a set of three hydraulic pumps. Due to the hydraulic nature of the provided resistance, the there might be a difference in the set resistance and the measured torque (the provided resistance). This difference is function of the velocity of the movement. Our preliminary evaluation points to the following conclusion that the discrepancy is on the order of one tenth of the angular velocity. In order to calculate the net muscular torque generated, one must consider the contributions of inertial and gravitational effects. During axial rotation, the gravitational components should be very minimal, since the transverse plane is equi-potential with respect to gravitational field. We did not compensate the inertial contribution due to the lack of data regarding the moment of inertia of the equipment. Such correction are necessary to relate the RMS-EMG and the kinematic data to the kinetic of the spinal axial rotation.

Analytical models such as finite element models, have shown high sensitivity of motion segment response with respect to kinematic constraints (Shirazi-Adl, 1989, 1991). Shirazi-Adl el al. (1986) has described that the stress and strain of the motion segment is related to its instantaneous axis of axial rotation. The model of intact motion segment predicted that under small axial torques the instantaneous axis in located in the center of the disc, and shifts posteriorly towards the compression facet as the torque increases. The removal of the facet affects this shift. The risk of injury to the motion segment is increased if the axial torque are combined with lateral and sagittal bending moments, as present during asymmetric lifting task. Torsional injuries due to axial rotation and compression force has not been collaborated by the model (Shirazi-Adl et al. 1986).

The influence of the measurement device on the kinematics and kinetics of the spine is not fully explored. What are the effects of inherent design characteristics of the commercial devices on the validity of the measurements? For example, it is demonstrated that the total axial rotation of the lumbar spine is less than 10 degrees (Buchalter et al. 1989). The B200 measures up to 45 degrees of axial rotation in each direction. This discrepancy may be explained by fixed posterior location of the axis of the dynamometer with respect to the mobile instantaneous axes of axial rotation of the spine. The gimbal construct of the B200 Isostation allows the flexion/extension and lateral bending axes of the dynamometer float with the spine; however, the axial rotation axis of the B200 is fixed. This design cause considerable cross-talk between the torques that are measured in the transverse and coronal plane. Upon rotation in the sagittal and coronal plane, the measurements of the axial rotation is no longer valid without proper corrections. Due to small rotations in the sagittal and coronal plane motion in this study, the latter effects are not strong enough to weaken our conclusions.

The clinical criteria for selection of appropriate tool for spinal evaluation is far from being clear. This study attempts to clarify the effects of kinematic constraints on the recruitment and motor output of trunk muscles. The power of classification of anatomical injuries from the coupled torque or motion during functional evaluation has remained an illusion due to technical difficulties and large variability in the healthy population. From the motor control perspective, the condition with locked accessory axes, relieves the demands on the CNS to completely balance the moment about these axes. The reactive moments provided by the mechanical lock prevent the injury to the passive structures. It was postulated that this reduction of load on the CNS may reveal new recruitment pattern with higher degree of efficiency (i.e., greater torque in the primary [intended] plane of motion with lower EMG activities). The results of the preliminary analysis did not support this hypothesis.

The relationship of EMG and muscle tension (torque output) in complex structures such as spine during unregulated dynamic activities is not known. However, the mean activities of these muscles should partially reflect the internal loading of spine given the fact that velocity was not affected by the kinematic constraints (Table 2).

The confounding variable that may have affected our results (internal loading) are the spinal curvature and intersegmental displacement. They reflect how the motion was distributed among the lumbar motion segments and the load sharing among the substructures (i.e., facet, disc). Such detailed studies are not feasible at present.

Clinical Relevance:

The clinical question is whether the accessory axes should be locked or unlocked during functional evaluation of trunk during axial rotation. The selection could be argued to be only a matter of choice since kinematics constraint had no significant effect on the primary motor output. However, the large generated coupled torque and significantly different muscle activities point to different loading conditions for the spine. The present study cannot resolve the clinical question but help to raise a more fundamental issue regarding the selection criteria. Besides the requirement of validity and reliability, a partial list of the selection criteria is: safety, subject's comfort, job specificity, simulation of physiological conditions, interpretability and complexity of generated data, cost and time required for administration of the test. The weighing coefficients for these factors, which are not known to the authors, require both theoretical and empirical investigations in the future.

Conclusion:

The effects of kinematic constraints imposed by the existing dynamometers on the motor output and recruitment patterns of trunk muscles during dynamic and isometric axial rotation were investigated. Despite lack of change of the motor output in the primary plane, locking the accessory axes caused significantly higher activities for obliques and rectus abdominis muscles both during isometric and dynamic axial rotation. The effects of resistance levels during dynamic axial rotation were significant for motor output and erector spinae muscle activities. During isometric axial rotation, direction of exertion significantly affected both motor output and recruitment patterns of all selected muscles.

The results of this study raise the questions regarding selection criteria for the optimal quantification techniques and tools for functional trunk performance evaluation. These questions demand further analytical and experimental investigations.

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THE INTERCORRELATION AMONG ISOMETRIC, ISOKINETIC AND ISOINERTIAL MUSCLE PERFORMANCE DURING MULTI-JOINT COORDINATED EXERTIONS AND ISOLATED SINGLE JOINT TRUNK EXERTION

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INTRODUCTION

Musculoskeletal injuries have been identified as the second of ten leading work-related injuries in the United States. Surveys of different states indicate that back strain and sprain constitute 9–26% of all industrial insurance claims and 26–42% of all wage replacement and health care costs (Volin et al. 1991)· Physically heavy work, frequent bending and twisting, lifting and sudden forceful incidents, and repetitive work have been associated with the increased loss of work time due to back pain symptom (Frymoyer et al. 1983). More than half of all compensable back pain incidents have been related to manual material handling (Bigos et al. 1986).

Many studies have investigated the relationship between strength/fitness and the incidence of low back pain (LBP). When the job's lifting requirements approach or exceed the worker's isometric strength capacity, a three times greater probability of a musculoskeletal disorder was observed (Chaffin et al. 1978).

The widespread use of static isometric test may be attributed to the simplicity and safety of the protocols and the required technology and lower costs of test administration. Biomechanical models of lifting tasks have shown, however, that the magnitude of the external load is greatly underestimated if the dynamic factors are not considered. The recruitment patterns of trunk muscles, thus internal loading of spine, is significantly different under isometric and dynamic condition (Marras and Rielly 1988). The widely conflicting results found in the literature regarding the relationship of an individual's strength to the risk of developing LBP may be due to inappropriate modes of strength measurements, i.e., lack of job specificity (Battie 1989, Parnianpour et al. 1990).

Despite proliferation of various technologies for measurement, basic questions such as "What needs to be measured and how can it best be measured?" remain unanswered. Strength is one of the most fundamental dimensions of human performance and has been the focus of many investigations. There is general consensus about the abstract definition of strength: the ability to generate tension in a muscle. However, since there is no direct method for measurement of muscle tension in-vivo, the strength has often been measured at the interface of a joint (or joints) with the mechanical environment. Different modes of strength testing have evolved based on varying technological sophistication. The practical implication of contextual dependencies of the strength measures on the provided mechanical environment is often neglected.

From a physiological point of view, the measured force or torque applied at the interface is a function of (a) the individual's motivation (magnitude of the neural drive for excitation and activation processes), (b) environmental conditions (muscle length, rate of change of muscle length, nature of the external load, metabolic conditions, pH level, temperature, and so forth), (c) prior history of activation (fatigue), (d) instruction and descriptions of the tasks given to the subject, (e) the control strategies and motor programs employed to satisfy the demands of the task, and (f) the biophysical state of the muscles and fitness (fiber composition, physiological cross-sectional area of the muscle, cardiovascular capability). It cannot be overemphasized that these processes are complex and interrelated (Kroemer et al. 1990). General manual material handling tasks require a coordinated multi-link activity which can be simulated using classical psychophysical techniques or the robotics-based lift task simulators. It has been suggested that dynamic lift simulation is close to the actual requirements of lifting tasks encountered in the industries (Mayer et al. 1988a). Unfortunately, the intercorrelations among various modes of tests are poorly quantified (Parnianpour et al. 1987, Freivalds et al. 1987).

The purposes of the current study were to investigate the correlations among the isolated isokinetic trunk strength with isometric, isokinetic, and isoinertial lifting capacities in healthy male and female populations.

METHODS AND MATERIALS

A total of 43 subjects volunteered to participate in this study (22 females, 21 males). The subjects were screened for any of the following contraindications as established by Loredan for the Lido Lift Rehabilitation System. The average (SD) age, weight and height of subjects were 29.1 (6.6) years, 68.1 (11.7) kg, 1.70 (0.10) m, respectively. Written informed consent was obtained from the subjects prior to testing.

Each subject attended two data collection sessions which were conducted on separate days. The testing equipment used was the Lido Active Back System and the Lido Lift Rehabilitation System. The order of the test trials were randomized for each subject. The study was performed at the New Mexico Occupational Performance Center using the Lido Active Back System and the Lido Lift Rehabilitation System.

The isokinetic tests for the Active Back System were performed at three speeds: 30°/sec, 90°/sec, and 120°/sec. The order of each set of tests was randomized. An endurance test at 120°/sec ended this exercise session. A total of eight repetitions were performed. Three repetitions were warm-up, two at 50% effort and the third at 75% effort. The subject immediately began the 4th to 8th repetitions at 100% effort, and data were collected from these repetitions. The endurance test was performed at 120°/sec. The subject performed as many repetitions in one minute as could be accomplished at 100% effort. The effect of gravity was considered by the software and the compensated data used for analyses.

The Lido Lift is a functional lifting assessment system. The tests for the Lido Lift Rehabilitation System were performed using the following protocol. The test consists of three components: isometric, isokinetic, and gravity inertia (isoinertial). Both isometric and isokinetic tests produce predictions of maximal lifting capacity. The gravity inertia test is a real world simulation designed to refine the isometric and isokinetic predictions and verify maximum capacity for lifting as stated by Loredan. The isokinetic lift protocol was then performed by the subject. Three warmup lifts were performed, two at 50% effort and the third at 75% effort. Five lifts were then performed at 100% effort and these data collected. The lift heights as established by Loredan were from 10.2 cm to 91.4 cm. The lifting device was a two-grip T handle 30.5 cm in length. These heights and apparatus were consistent for all subjects. Foot position was set at 40.6 cm apart facing forward. A square stance was used in testing. The Lido Lift software analyzes this data and selects the three repetitions with the lowest coefficient of variation, including the highest force repetition. Lifting posture (a confounding variable) was determined by the subject's preferred lifting technique.

The isometric tests were performed at two different heights as established by Loredan's standardized isometric test protocol. The height for the arm strength test was 109.2 cm or adjusted such that the elbow joint was at a right angle; the height for the leg strength test was 38.1 cm. Each subject was tested for a maximal effort for three repetitions of five seconds. A 20-second rest period was provided between each repetition. Heart rate was monitored at the end of each exercise bout and after a three-minute rest. Foot position and testing device were the same as for the isokinetic test.

For each subject, the maximal predicted capacity from the isometric test was then averaged with the maximal predicted isokinetic capacity to provide a starting weight for the gravity inertia lift. A two-handled box measuring 29.2 cm× 25.4 cm×22.9 cm with handles at 15.2 cm was used. The box was weighted by the computer system. If the subject lifted the box at a rate greater than 0.3 g (the gravitational acceleration being equal to 9.8 m/s^2), the weight of the box was increased by 2.3 Kg. This was continued until the subject could not lift the box with acceleration higher than 0.3 g above a height of 61 cm, thus meeting the criteria set by Loredan for a maximal lift. Foot position was standardized, as stated earlier. The lifting height was set from floor to 91.4 cm, which was measured from the bottom of the box.

The performance parameters for isokinetic tests were: the peak and average torque, work, joint angle at peak torque for flexion and extension movements at 30°/second, 90°/second, and 120°/second. The parameters of the endurance test at 120°/second were total work in flexion and extension. The peak power, force, and average work during raising and lowering were selected for isokinetic lift during raising and lowering. The selected parameters for isoinertial lift were the maximum load, peak force, velocity, and acceleration during raising and lowering. Descriptive statistics and Pearson correlation among those selected parameters were computed using SAS.

RESULTS

The correlation coefficient among various strength measure during isokinetic, isometric, and isoinertial testing are presented in tables 1 to 3. The upper triangular elements are the Pears correlation and the lower triangular elements are p values (significance levels) for tables 1 and 3. The Spearman correlation coefficients are shown for males and females in Table 2. The upper triangular elements are correlations for males and the lower triangular elements for females.

Intercorrelation among trunk isokinetic strength parameters across different velocities was highly significant. The linear relationships ranged from 0.58 to 0.95 ($p<0.001$). The peak torque at 120°/second was selected for illustrative purposes to represent strength parameters for isolated trunk isokinetic tests (Tables 1 and 2). The correlation coefficient between isometric arm and leg strength was highly significant ($r=0.78$, $p<0.0001$; table 3). The linear relationship between the isokinetic lift parameters was moderate ($r=0.61$, $p<0.0001$; table 3). The correlation between load and peak force during isoinertial lift was highly significant ($r=0.99$, $p<0.0001$; table 3). The correlation between the flexion and extension total work during endurance test was significant ($r=0.62$, $p<0.0008$; table 2). Isokinetic trunk flexion and extension peak torque at 120°/sec had low correlation with peak force during isokinetic lift (ranging from 0.38 [$p=0.006$] to 0.72 [$p<0.004$]) (Table 1). These correlations indicate that, at best, only 52% of variations in isokinetic lift parameters is predicted by the isokinetic trunk peak torque at 120°/sec. The correlation between isokinetic trunk peak torque with isoinertial parameters were all significant at a weak level, ranging from 0.53 to 0.72 ($p<0.005$; table 1). Isokinetic peak flexion torque had stronger correlation with isometric arm and leg strength, 0.81 and 0.75 ($p<0.005$) respectively. However, isometric strengths had stronger linear relationship with isoinertial tests than with other tests (ranging from 0.76 to 0.86 [$p<0.0001$; table 1]). The isometric leg strength had high correlation with peak force during raising of isokinetic lift ($r=0.85$, $p<0.0001$; table 3).

Peak force during raising of isokinetic lift had high correlation with the isoinertial load and peak force ($r>0.87$, $p<0.0001$). The endurance measures had positive correlation with the strength parameters ranging from 0.33 (NS) to 0.85 ($p<0.001$; table 1).

DISCUSSION

Each subject was tested in both sessions, however due to technical difficulties the data for the isokinetic trunk sagittal movements were only partially recovered. Therefore, for these tests the total subjects were 26 (12 males and 14

Table 1.

Pearson Correlation Coefficients amongst the Various Strength Measures during Isokinetic, Isometric, and Isoinertial Testing for Males (n=12) and Females (n=14) Together

N=26	PTF120	PTE120	PFLEG	PFARM	PFR38	PFL38	PLGI	PFGI	WF120	WE120
PTF120	1	0.70*	0.75	0.81	0.72	0.38†	0.72	0.69	0.85	0.66
PTE120	0.0001**	1	0.53	0.35†	0.58	0.30†	0.53	0.53	0.53	0.60
PFLEG	0.0001	0.0056	1	0.78	0.78	0.41	0.86	0.85	0.73	0.68
PFARM	0.0001	NS	0.0001	1	0.72	0.34	0.76	0.73	0.78	0.54
PFR38	0.0001	0.0025	0.0001	0.0001	1	0.57	0.87	0.86	0.73	0.62
PFL38	NS	NS	0.0500	NS	0.0003	1	0.54	0.54	0.33†	0.52
PLGI	0.0001	0.0049	0.0001	0.0001	0.0001	0.0005	1	0.99	0.75	0.81
PFGI	0.0001	0.0053	0.0001	0.0001	0.0001	0.0005	0.0001	1	0.71	0.81
WF120	0.0001	0.0060	0.0001	0.0001	0.0001	NS	0.0001	0.0001	1	0.62
WE120	0.0003	0.0013	0.0001	0.0046	0.0009	0.0077	0.0001	0.0001	0.0008	1

*Pearson Correlation Coefficients
**p values

†NS—Not Significant ($p>0.05$)

Table 2.

Spearman Correlation Coefficients amongst the Various Strength Measures during Isokinetic, Isometric, and Isoinertial Testing for Males (n=12) and Females (n=14) *$p<0.05$

N=26	PTF120	PTE120	PFLEG	PFARM	PFR38	PFL38	PLGI	PFGI	WF120	WE120
PTF120	1	0.70*	0.75	0.81	0.72	0.38*	0.72	0.69	0.85	0.66
PTE120	0.0001**	1	0.53	0.35*	0.58	0.30*	0.53	0.53	0.53	0.60
PFLEG	0.0001	0.0056	1	0.78	0.78	0.41	0.86	0.85	0.73	0.68
PFARM	0.0001	NS	0.0001	1	0.72	0.34	0.76	0.73	0.78	0.54
PFR38	0.0001	0.0025	0.0001	0.0001	1	0.57	0.87	0.86	0.73	0.62
PFL38	NS	NS	0.0500	NS	0.0003	1	0.54	0.54	0.33*	0.52
PLGI	0.0001	0.0049	0.0001	0.0001	0.0001	0.0005	1	0.99	0.75	0.81
PFGI	0.0001	0.0053	0.0001	0.0001	0.0001	0.0005	0.0001	1	0.71	0.81
WF120	0.0001	0.0060	0.0001	0.0001	0.0001	NS	0.0001	0.0001	1	0.62
WE120	0.0003	0.0013	0.0001	0.0046	0.0009	0.0077	0.0001	0.0001	0.0008	1

*$p<0.05$

PTF120 Peak Torque during Isokinetic Back Flexion at 120 degrees per second
PTE120 Peak Torque during Isokinetic Back Extension at 120 degrees per second
PFLEG Peak Force during Isometric Leg Lift
PFARM Peak Force during Isometric Arm Lift
PFR38 Peak Raising Force during Isokinetic Lift at 38 cm/sec
PFL38 Peak Lowering Force during Isokinetic Lift at 38 cm/sec
PLGI Load Lifted during Isoinertial Lift

PFGI Peak Force Exerted during Isoinertial Lift
WF120 Work accomplished during 1 minute of Isokinetic Back Flexion at 120 degrees per second
WE120 Work accomplished during 1 minute of Isokinetic Back Extension at 120 degrees per second

Table 3.

Pearson Correlation Coefficients amongst the Various Strength Measures during Isokinetic, Isometric, and Isoinertial Lifting Tests for the Whole Population (Data for Males (n=21) and Females (n=22) are Pooled Together)

N=43	PFLEG	PFARM	PFR38	PFL38	PLGI	PFGI
PFLEG	1	0.76*	0.85	0.47	0.87	0.85
PFARM	0.0001**	1	0.75	0.60	0.71	0.69
PFR38	0.0001	0.0001	1	0.61	0.88	0.87
PFL38	0.0022	0.0001	0.0003	1	0.60	0.61
PLGI	0.0001	0.0001	0.0001	0.0005	1	0.99
PFGI	0.0001	0.0001	0.0001	0.0005	0.0001	1

*Pearson Correlation Coefficients
**p values
PFLEG Peak Force during Isometric Leg Lift
PFARM Peak Force during Isometric Arm Lift
PFR38 Peak Raising Force during Isokinetic Lift at 38 cm/sec
PFL38 Peak Lowering Force during Isokinetic Lift at 38 cm/sec
PLGI Load Lifted during Isoinertial Lift
PFGI Peak Force Exerted during Isoinertial Lift

females).

The raw data are presented with no attempt to normalize the values. DeLitto et al. have critically assessed normalization with respect to body weight. They objected to predicting strength based on body weight, since it accounted for very small proportions of the variance in isokinetic extension in strength. In this data base, the body weight had very poor linear correlation with strength parameters ranging from 0.47 ($p<0.01$) to 0.77 ($p<0.0001$) (Delitto et al. 1989). Therefore, we selected to present data without normalization.

Direct comparison with the existing literature is difficult since no other single study has investigated all the mode of strength testing used in our study. Mayer et al. found very poor correlation among isokinetic lift (at 46 cm/sec and 76 cm/sec) and the isoinertial lifting capacity. The linear correlations ranged from −.09 (NS) to 0.62 ($p<0.05$) (Mayer et al. 1988). Battie at al. (1989) found correlation coefficients to range from 0.5 to 0.85 when comparing isometric strength in arm, leg, and torso lift positions. The correlations were significantly higher among women (from 0.74 to 0.85) than among men (from 0.5 to 0.68). The results of isometric arm and leg lift are higher in our study compared to their age matched groups in Battie at al. (1989). Zeh et al. (1986) also found higher correlation between the arm lift and torso lift for females (r=0.69) than for males (r=0.5). They suggested that strength in a different position was poorly predicted. The Spearman correlation among the selected strength measures for males and females are shown in table 5. Our preliminary results, as shown in table 2, are in agreement with Battie et al. (1989) and Zeh et al. (1986).

CONCLUSION

The results of this study confirm the theoretical prediction that strength will be dependent upon the measurement technique. Since muscle action requires external resistance, the effect of muscle action will depend on the nature of the resistance. We need to examine the premises regarding functional assessment and strength measurement. The implicit assumption is that a generic strength test exists that can be used for preplacing workers (pre-employment) and predicting the risk of injury or future occurrence of low back pain. The problems about the aforementioned assumption are manifold, however we discuss the major concerns related to this study. The results of this study and others in the literature point to low correlation among various strength measures. In addition, the validity of injury model for low back pain has been questioned and hence prevention of low back pain has proven close to impossible. The data show prevention of chronicity to be a more effective measure for cost containment. Furthermore, human behavior is highly overdefined and no single parameter should be expected to predict the outcome of a highly complex set of processes in physical and psychosocioeconomic realms (Battie et al. 1989, Troup et al. 1987, Hadler 1987, 1989).

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A CONTINUOUS PASSIVE LUMBAR MOTION DEVICE TO RELIEVE BACK PAIN IN PROLONGED SITTING

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A method for providing continuous passive motion to the lumbar spine of a seated individual has been developed and evaluated. A lumbar backrest support cyclically increases and decreases in size to promote movement of the low back. A feedback system controls the amount of force against the spine in different postures. Information was collected on cycle rate, rate of change of lumbar support and maximal force induced to the spine, as well as subjects' evaluations of comfort. The device can be incorporated in the backrest of either office or vehicle seating.

INTRODUCTION

Sitting is the most common posture in today's workplace, particularly in industry and business. Three quarters of all workers in industrial countries have sedentary jobs. An estimated 45% of all American workers are employed in offices, and this number is projected to grow significantly through the year 2,000 (U.S. Congress, 1985). Over 27 million workers commute at least one hour to work, and seven million workers have occupations that involve sitting and operating a vehicle. As society moves towards more information processing and industrial automation, sitting will become even more prevalent. Also, as societies becomes more sedentary, the worldwide incidence of occupational low back pain and related disability will increase. This paper examines the relationship between these trends and describes a promising intervention: continuous passive lumbar motion.

Low Back Pain and Seating

Low back pain, long recognized as the most common musculoskeletal disorder in industrial countries, is a major cause of disability and absenteeism from work. In the adult population, 60 to 80 percent of the American public will at some point suffer from low back pain. Moreover, it is a source of staggering social and economic costs stemming from medical treatments, lost earnings and compensation payments. In the United States, 11.7 million people, or 5.2% of the population, are impaired and 2.3% are disabled by low back pain (National Center for Health Statistics, 1981). Cats-Baril and Frymoyer have estimated that the combined direct and indirect costs might be as high as 100 billion dollars per year. In addition to the financial burden to individuals and society, low back impairment and disability severely restrict personal productivity and quality of life.

In the workplace, low back pain has been closely associated with heavy manual lifting, repetitive lifting, lifting with simultaneous twisting and bending, and exposure to vehicle vibration. However, recent research has shown that people who sit for prolonged periods of time are more prone to low back pain than those whose jobs allow them to change positions frequently (Hult, 1954; Eklund 1967; Magora, 1972; Kelsey, 1975; Lawrence, 1977). Vehicle and computer operators, assembly workers, and others are often required to assume static postures for long periods of time. Sedentary static work postures involving contorted or constricted postures, static muscle loading, and long term joint loading, especially in the extreme range of motion, can cause discomfort Reinecke et al. (1985, 1987) have demonstrated that posture is correlated with back discomfort. Subjects with no history of back pain could not tolerate unsupported seated postures for extended periods. Reinecke et al. report a mean tolerance time for static sitting, in an upright posture, as 67 minutes. The authors conclude that individuals are better able to sit for prolonged periods when they can change their posture throughout the day.

Wood and McLeich (1974) found “unexpected intervertebral disc morbidity” in insurance and bank workers, who spend long periods of time sitting at work. Bergquist-Ullman (1977) also found an increase in sick-leave due to acute low back pain for workers who must sit for prolonged periods of time. Kelsey (1975) and Kelsey and Hardy (1975) found that people have a risk of disc herniation three times higher than the average if they spent more than half of their workday in a car.

Motion During Sitting

Prolonged immobility can have deleterious effects on the spine. Holm and Nachemson (1983), who investigated the effects of various types of spinal motion on metabolic parameters of canine invertebral discs, found that spinal movement alters spinal loads and produces variations in nourishment. The report that nutrient transport in and out of the disc improves with lumbar movement. The authors conclude that moderate motion should be sufficient to cause solute and metabolic transport and to stimulate the aerobic metabolic pathway, at least in the most mobile intervertebral disc of the canine spine.

These findings may have significance for the human spine as well, since previous studies have demonstrated nutritional similarities between canine and human discs. Further, Grandjean (1980) maintains that alternately loading and unloading the spine (through movement) is ergonomically beneficial, because the process pumps fluid in and out of the disc, thereby improving nutritional supply.

Good seating should allow a worker to maintain a relaxed, but supported, posture and should allow for freedom of motion over the course of the day. Chaffin and Andersson (1984) maintain that the two most important considerations in seating are adequate back support and allowance for movement or postural change. Excessive contouring and padding can be detrimental if they restrict motion. Active movement or postural change are inevitable, and in fact desirable, throughout the day. Schobert recommends changing postures around a relaxed, upright, seated posture to minimize muscular activity and the static muscular load needed for sitting. Many researchers have agreed that motion should be incorporated in seating while the body is being supported in different postures.

Continuous Passive Motion

Treatments for musculoskeletal injuries of the shoulder, hand, knee, hip, and ankle joints have often included motion. A common treatment is continuous passive motion (CPM), which moves the joint through a range of motion passively. Continuous passive motion and early mobilization for treatment of ligamentous injuries to the knee provide such benefits as improved ligament strength and joint stability (Dehne 1971, Salter 1982, Burks 1983), Compared with total or partial immobilization, early mobilization produces stronger, stiffer, and better vascularized tendons in total or partially immobilized tendons. We hypothesize that CPM can be used to increase nutrient transport in and out of intervertebral discs, shorten the period of rehabilitation, speed recovery time, and enhance mechanical properties and the healing of soft tissue.

A device that provides CPM to the lumbar spine during sitting has been designed and developed for clinical evaluations (Hazard 1991). The device includes an inflatable support that increases and decreases the amount of support for the individual at the lumbar region. During a simple cycle, the lumbar support bladder inflates, causing lordosis at the spine, than deflates to allow a more kyphotic posture. The amount of support or pressure within the bladder is controlled by a regulator system and can also be adjusted by the individual. A feedback device insures that a consistent amount of pressure is applied to the back regardless of changes in posture. For example, when one leans forward, the bladder increases in size until it reaches a preset maximum pressure. When one leans backward and pressure on the bladder increases, extra air is vented off, until a preset pressure level is reached.

In developing a CPM device for the lumbar spine, several variables were considered. This study was designed to to determine which features should be adjustable and which could be standardized. These features included maximum pressure in the bladder sufficient to induce motion, rate of air flow into the bladder to control inflation and deflation, and cycle rate.

METHODS

Subjects

Twenty subjects (12 females and 8 males) free of low back pain were tested. The mean age of subjects was 37 (range 21–55) years old. Twelve subjects were tested in the office environment, and eight in motor vehicles. Of the subjects tested in the office environment, all spent at least 75% of their work day sitting. Subject tested in the motor vehicle environment drove a minimum of three hours a day.

Apparatus

The lumbar support dimensions were 13 cm. high by 25 cm. wide. The air bladder inflated to a maximal thickness of 11.5 cm. and deflated to .32 cm. Pressure within the bladder could be adjusted from 5 mmHg. to 550 mmHg. Air pumped into and out of the bladder had a flow rate that could be adjusted from 1 to 35 liters per minute, and cycle rate could be adjusted from 1 to 120 seconds.

Procedure

n the office environment, a high-back task chair was used, with the lumbar support bladder placed under the chair's upholstery. On the motor vehicle seat, the support was affixed to the outside covering. On all seats the lumbar support was adjusted to the L3 region of the spine.

Each subject was tested for five days. There were five different testing conditions, as described below; conditions 2, 3, and 4 were randomized across days 2, 3, and 4.

Condition 1:	Subject sat in CPM chair but the cyclic lumbar support was deactivated
Condition 2:	The CPM device was set at a "fast cycle rate" of 4–30 seconds of increasing pressure and 4–30 seconds of reduced pressure.
Condition 3:	The CPM device was set at a "slow cycle rate" 60–120 seconds of increasing pressure and 60–120 seconds of reduced pressure.
Condition 4:	Subjects were able to vary cyclic rate between 4 and 120 seconds.
Condition 5:	Subjects were allowed to select any cycle rate or no CPM.

Each day subjects rated comfort with a visual analog scale. They also recorded cycle rate of increasing and decreasing pressure, maximum pressure values for the bladder during the pump cycle, and flow rates of air pumped into the bladder and air vented out of bladder.

RESULTS

For all twenty subjects the average maximum bladder pressure for the induced lordotic stage was 70 mmHg. (S.D.: +/− 60 mmHg). Flow rate of air into the bladder averaged 6.5 liters per minute (S.D.: +/−1). The average flow rate of air out of the bladder was 2.5 liters per minute (S.D.: +/−.5). The average cycle rate at the "fast" level was 28 seconds (S.D.: +/−5) and the average for the "slow" rate was 75seconds (S.D.: ,+/−20). On Day 4, the average time was 64 seconds (S.D.: +/− 30).

On day 5, when given the choice of having the CPM on or off, all subjects chose to have the device turned on. Seventy five percent (n=16) of the 20 subjects reported greater comfort when the device was turned on (One subject reported no difference in comfort and three reported greater comfort when the device was turned off). Comfort ratings showed 16 of the 20 subjects reported increase comfort when using the device then turned off. One showed no change and 3 reported decreased comfort.

Some of the subjects reported that they preferred the lumbar support lower then L3 or at about the L5–S1 position. The cord connecting the power supply to the chair hindered some subjects in the office environment and the noise of the pump was at times annoying. However, several subjects reported a reduction in the stiffness often associated with prolonged sitting.

CONCLUSIONS

A pneumatic continuous passive motion device has been designed and fabricated to provide simultaneous back support and lumbar movement. The device can be incorporated in the backrest of either office or vehicle seating. The device provides increasing and decreasing pressure against the low back, thereby promoting continuous motion of the lumbar region. Subject preferences suggest that the level of pressure against the spine should be adjustable between 5 and 150 mmHg. The rate of air flow into and out of the bladder can be set at 6.5 liters per minute and 2.5 liters per minute, respectively. Cycle rate should remain adjustable between 55 and 95 seconds per cycle. Several subjects commented on the difficulties of becoming entangled with the .5 cm flexible tubing connecting the pneumatic system to the chair. To alleviate this problem, the tubing has been replaced with a precoiled extension tube. The size of the pump will be reduced in a production model thus reducing the noise level of the unit

The most important finding of this study is that seated subjects reported greater comfort with pneumatic CPM than with static eating. Their preference was evident not only from their self-reports, but also from their behaviors, as reflected by their Day 5 choices. The device promises to be effective in relieving the painful effects of static posture during prolonged sitting. Since CPM improves comfort for seated subjects, it may be that seating-related pain and occupational disability can be reduced and even prevented through long-term CPM use. This promising intervention and its physiologic effects on disc nutrition and musculo-ligamentous mechanics warrants further research.

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SLIP AND FALLS

SLIPS, TRIPS AND FALLS—THE ALTERNATIVE APPROACH

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Slips, trips and falls are at the top of the UK list of accident causes that result in major injuries. This paper considers the reasons why people become exposed to environments that almost encourage such accidents, and promotes the approach of designing the hazard out of the task, in preference to protecting the worker by the provision of personal protective equipment. However, the pressure to reduce costs is strong and human factors interventions are considered to be expensive; it is therefore vital that the potential benefits of applying ergonomics principles, with respect to improved work efficiency, must be demonstrated if attitudes are to be altered and the level of slipping, tripping and falling accidents is to be reduced.

INTRODUCTION

Slipping, tripping and falling accidents (STFAs) in the UK which result in a major injury (generally, defined as those involving an amputation, fracture or other injury requiring hospitalisation) regularly form the largest single accident causation category reported to the Health and Safety Executive. In 1988/89 there were 9903 major STFAs out of a reported accident total of 19,944—almost 50% (Thomas, 1991). At a less severe level of injury, but still requiring three or more days absence from work, STFAs were the alleged cause of 26% of all such reported injuries; second only to those resulting from lifting and handling activities (which comprised 33% of the total).

Clearly, the costs associated with such accidents are enormous, whether they be related to aspects of the medical treatment, health or company insurance, lost production, provision of temporary staff cover or, not least, the level of personal suffering. Not surprisingly, therefore, considerable resources have been devoted to research studies of the mechanisms of slipping, the type of gait pattern under various environmental conditions and the effectiveness of slip resistant shoes and flooring. Whilst this approach has progressed our understanding of these problems and indeed, of the design requirements for shoe soling and flooring materials, there is, as yet, little evidence that the application of this knowledge has been effective in reducing the widespread occurrence of such accidents. Why should this be?

Possibly the answer lies with our perception of the level of risk associated with such apparently mundane problems. On the whole the provision of special shoes or flooring appears to be restricted to industrial operations where the hazards and hence the risks to safety are particularly obvious; for example, in engineering, mining and other extractive industries and some kitchen and hospital environments. Whilst anecdotal evidence would suggest there to have been a resulting improvement in safety in those areas it should not be assumed that the provision of such specialised materials would necessarily, nor would in all cases, result in a reduction of STFAs.

Even when scientific evidence is available to support the use of anti-slip materials (eg. Manning, 1991), it is necessary that this is recognised and supported by appropriate personnel in the particular industry. Unfortunately, various reasons, from the state of industrial relations to the costs involved in such an exercise will affect the decision, with the management’s perception of the associated risk also having a strong influence.

THE ALTERNATIVE APPROACH

Thus it is necessary to consider alternative measures that essentially reduce the risks of STFAs by designing the hazard out of the task. Indeed, a recent European Directive that deals with the general provisions for safety at work (Commission of the European Communities, 1989) requires the employer to seek to eliminate the hazard at source rather than protecting the worker by the provision of personal protective equipment which should be a secondary option, chosen only if the danger cannot be reduced by reasonably practicable means.

In the context of slipping accidents this may be interpreted to mean that the provision of footwear with specialised soling (whilst being a sensible precaution) should not be the only action taken by the employer to reduce the likelihood of accidents. Quite simply, the employer’s duty is to assess the work and workplace in order to identify where the origin of the hazard might be and then to do all that is reasonably practicable to prevent there being a risk to workers.

Hence, from an ergonomics point of view a critical area in need of research and investigation is not simply the slip resistance coefficients of two surfaces that may come into contact, but the reasons *why those surfaces might come into contact under conditions that are anything other than optimal*. This approach would address such situations as for example, where contamination of floor surfaces might reduce friction (what is the source of the contamination and how can it be eliminated?); where the velocity of the heel strike is excessive as for example when running (why was there a need for the worker to hurry and was this foreseeable?).

Equally, this philosophy can be applied to tripping accidents in that the environmental aspects may be at fault in reducing the capacity of the individual to identify the hazard, for example, poor lighting or distractions caused by other activities going on nearby.

These factors all argue for positive action by employers and employees alike to identify work practices, defective equipment or poor environmental conditions that contribute to a risk of slipping and tripping accidents.

There are numerous examples of products or work systems where the user or worker is expected to compensate for the design deficiencies by adapting his behaviour, and often thereby putting himself at risk. If an accident results, the subsequent investigation often identifies human error as the cause of the accident with perhaps "further training" recommended as the means to avoid future occurrences.

With slipping and tripping accidents forming between 20 and 33% of all reported occupational accidents in the UK each and every year this is not a problem that appears to be responding to an improved training approach. A proper examination of many "human error" accidents will probably reveal deficiencies in the design of the work system or workplace such that it was almost inevitable, when the system came under pressure, that there would be a mismatch between the requirements of the task and the operator's ability to fulfil that need. It is therefore important that designers, architects and engineers should receive training in ergonomics principles in order that they should have a better understanding of human capacities and limitations. They should not expect the human operator or worker to act in a particular prescribed manner nor to behave in a certain way; it should be expected that workers will on occasion exhibit unusual and even irrational behaviour patterns.

That is not to imply that any of these can necessarily be predicted but that the system into which the worker is placed should be designed if possible in a 'fail safe' manner or at least to be 'forgiving' if the worker should not carry out his duties in the taught manner.

Unfortunately, all too often there are examples where pressure of work increases the risks by reducing the flexibility or buffering capacity that systems are designed to have when working at their normal, sub-maximal rate. For example, floor cleaning and general workplace tidying are often amongst the first casualties when costs have to be reduced and/or productivity increased, and in these circumstances a worker may slip whilst rushing, or might trip over items awaiting storage. Savings achieved by reducing the lighting levels or by extending the intervals between machinery services might either independently or in concert increase slipping and tripping risks by reducing the visibility of, for example, oil contamination on the floor around a defective machine.

The argument that allows this situation to prevail is that reductions in services and manpower or in energy consumption can be easily measured—the financial savings are demonstrable, and any increased costs attributable to the resulting greater number of accidents, or further work absence, would be borne by the company as a whole; however, any extra investment required for the provision of a workplace or system that is designed to avoid STFAs would be the responsibility of the particular department. In the present difficult financial climate we should not be surprised that line managers are reluctant to invest in systems that may not provide tangible returns for some time when their employment prospects are determined by their success in achieving short term budgetary targets.

CONCLUSIONS

Although to the detached observer the message is clear, that *short term financial savings will inevitably lead to increased expenditure,* to those struggling to maintain solvency it is usually insufficient and inappropriate to claim the moral high ground and to argue that they should provide a safe workplace for their employees; any pressure for change must be linked to a clear (financial) benefit for the organisation. Hence, it is vital, if we are not to store up problems for the future, that the ergonomic and economic arguments are made for the proper design, operation and maintenance of appropriate systems which includes the buildings in which the work is conducted. Buildings designed for aesthetic purposes rather than for the inhabitants are monuments to the architect's apparent inability to understand human needs and behaviour; thus, polished floors, wrongly positioned hand-rails or handles, confusing lighting and. concealed steps are often prime contributors to slipping, tripping and falling accidents.

In Europe (from the beginning of 1993) workplaces and activities must be assessed by the employer, the potential risks identified and action taken to correct the problem. Removing the hazard from the work in this way must be a better and more effective option than protecting the worker from the hazard which tends to be a relatively hit and miss affair that is largely dependent on managerial support. The potential benefits of this approach are not limited to a reduction in the number of accidents but, if introduced correctly, it should at the same time improve work efficiency. There is also no reason why, if considered at the outset, this approach should not be complementary to the aesthetic requirements of the designer.

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SLIP DISTANCE FOR SLIP/FALL STUDIES

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An experiment was conducted to use slip distance to investigate simultaneously both tribological and biomechanical factors of slipping. Five subjects were asked to walk on five floor surfaces at a fixed cadence of 80 steps/minute. As a result, slip distance exponentially decreased as the static COF increased for the tribological approach. For the biomechanical approach, slip distance increased logarithmically as stride length increased. The biomechanical parameter, stride length, was also dependent on the tribological parameter, static COF. The stride length for the floor materials also decreased as the static COF increased.

INTRODUCTION

The National Safety Council (1985) reported that an estimated 11,700 Americans meet their death each year by falling; 12.5 million are injured in falls, of which 500,000 require emergency medical treatment Each accident involved incapacity for work of more than three days (Buck and Coleman, 1985). Manning et al., (1988) reported that approximately 62% of these accidents were caused by slipping and 17% by tripping.

Epidemiological, tribological, biomechanical and psychological approaches have been studied to reduce slipping accidents. From those studies, slipping has been shown to be a very complicated phenomenon.

The tribological approach studied the friction between shoe soles and floor surfaces for both static and dynamic COFs. Ekkubus and Killey (1973) emphasized static COF because the foot is static in relation to the floor in walking. They argued that a dynamic COF would only be valid after the foot has started to slip, and, therefore, cannot relate to normal walking conditions. However, the reason for the common use for static COFs (Rhoades and Miller, 1988) may simply be that dynamic COFs are more complex to measure. To measure static/dynamic frictions, many slip resistance testers have been invented. According to Brungraber (1977), static COFs can be measured by drag type or articulated strut devices. With these testers, different floor COFs have been measured to determine the safe limit for floor materials and to validate their slip resistance testers. From the American Society for Testing and Materials (ASTM, 1975) standard, static COFs greater than 0.5 are considered non-hazardous.

To study the biomechanical approach, gait parameters such as walking speed, stride length and cadence have been studied under different situations. Researchers such as Herman et al. (1976) and Crowinshield et al. (1978) investigated the stride length and cadence changes under different walking speeds: slow, normal and fast Furthermore, Laurent and Pailhous (1980) investigated the effect of an imposed stride length on walking speed and cadence, and the effect of an imposed cadence on walking speed and stride length. The findings were almost consistent in that increased speed was accomplished by increases in both the stride length and cadence. Love and Bloswick (1988) investigated how slip tendency varied as a function of walking speed and load carrying method. The slip tendency was defined as the maximum value of the lateral foot force divided by the normal foot force for a 25 millisecond interval during the heel-strike phase of the activity. The slip tendency varied slightly with walking speed and carrying method. As far as walking speed was concerned, fast walking had a higher slip tendency than slow walking. Since walking speed is the product of stride length and cadence, stride length and cadence also influence slip tendency.

For the tribological approach to slip/fall studies, the static coefficient of friction (COF) for floor materials has been measured in the lab to establish safe guidelines, thus ignoring gait pattern changes. Gait parameters have been measured against different walking speeds but have not involved the COF. In other words, human subjects and different floor materials have not been simultaneously used for tribological or biomechanical studies.

The objective of the current study was, therefore, to investigate the tribological and biomechanical parameters of slip distance. The slip distance introduced by Leamon and Son (1989) was used to determine slipping performance. They classified slips into microslips, slips, and slides with respect to slipping distance. The microslip was identified as a sliding movement which was brought under control within a short distance of approximately one cm. Leamon and Li (1990) changed the definition of a microslip to 3 cm. These slips are frequently, if not normally, undetected by the subject When the slip becomes an uncontrolled forward movement of the leading foot, greater than 10 cm, this situation was termed a slide. In between 3 and 10 cm, the term slip was used. The current study also examined static COFs and stride length to find their relationships with slip distance.

METHOD

To measure static COFs for floors, five measurements were taken from each floor and averaged. These mean values of static COFs represented different floor conditions. A completely randomized design was used for the study. Each subject was then asked to walk five times on each floor surface. Slip distances (cm) were considered the dependent variables while different floors (static COFs) were considered the independent variables. Since cadence was fixed at 80 steps/min, stride lengths (cm) were calculated for reference.

Subjects

Five paid male students participated in this experiment The subject's age ranged from 26 to 34 years and averaged 29.5 (±2.7) years. The averages for height and weight were 171.1 (±2.8) cm and 72.6 (±3.3) kg, respectively.

Equipment

Five different floor materials were chosen for the experiment: plywood, ceramic tile, vinyl tile, sandpaper on plywood and a sheet of steel. The dimensions of the simulated floor were 250 cm×60 cm. To reduce the visual effect of floor materials, the color for all floor materials was the same, light brown.

To collect three dimensional position data, an ExperVision Motion Analysis System was used, with a sampling rate of 60 Hz. This provided three-dimensional measurements of the heel to ±0.01 centimeter.

An artificial leg was designed and built to measure static and dynamic COFs. It was fabricated to simulate the slipping movement of the foot from the knee. The COF values were measured as the ratio of horizontal and vertical forces applied to make a foot slide. Static COF was measured at the time the foot started moving whereas dynamic COF was measured while the foot kept sliding. As mentioned before, only static COF was measured in this study because it was easy to measure (Rhoades and Miller, 1988) and no slips were expected with non-slipperly floors (Ekkubus and Killey, 1973).

Procedure

In order to analyze the subject's movement, retro-reflectors were attached at the anatomically significant body positions such as heel, toe, ankle, and hip of the subject's left side.

Each subject was asked to walk on a specially prepared floor surface five times with a cadence fixed by a metronome (80 steps/min). Prior to this experiment, each subject was given an opportunity to walk around the laboratory to familiarize himself with the pace of the metronome. After a 20 minute adjustment period, subjects were then asked to walk across a floor sample. While the subjects were walking along this path, they were to keep their eyes on the metronome positioned at a 1.5 meter height and to try to maintain the speed that they practiced.

RESULTS

The static COFs for the floors were significantly different (p-value=0.0001) and are shown in Table 1. Since the main effect was significant, the Student-Newman-Keul

(SNK) multiple comparison tests were performed and the significant groups are also shown in Table 1. Each group represents an independent group. In other words, each group is significantly different from the others. The floor materials in the same group are not statistically different even though their mean values are different With SNK multiple comparison, the static COFs were classified into the three groups based on a 0.05 significance level. Ceramic tile and steel were the most slippery floors while sandpaper was the least slippery floor. Vinyl and plywood were classified into group B, moderate among five floors. Based on ASTM standards (1975), steel and ceramic were categorized as poor walkway floors. Only sandpaper was above the standard for a non-hazardous floor.

Table 1. COF and SNK groups for floors

Floor	COF	SNK Group
Sandpaper	0.67	A
Vinyl	0.47	B
Plywood	0.45	B
Steel	0.41	C
Ceramic	0.40	C

The floor effect for slip distance (SD) was insignificant (p-value=0.1139) based on a 0.05 significance level. The slip distances for floors are shown in Table 2. Based on the classification of Leamon and Li (1990), all slip distances were considered microslips. These slips were possibly undetected by subjects. Since a relatively small sample size was used, the floor effect was not statistically significant However, it showed a trend between slip distance and stride length according to the floors. Therefore, an analysis for slip distance and stride length against floors was performed because it was expected to be beneficial.

Slip distance for ceramic was the longest while that of sandpaper was the shortest which was expected because of static COF values. Stride lengths (SL) for floors are also shown in Table 2. The floor effect for stride length was also nonsignificant (p-value= 0.8569). Compared with a standard table of Waters et al (1988), stride length was classified between normal and slow speeds which was consistent with the fixed cadence of 80 steps/min. Like slip distance, stride length for ceramic was the longest while that of sandpaper was the shortest As stride length increased, slip distance increased. However, there was an exception, vinyl. Stride length for vinyl provided a smaller than expected slip distance. Without vinyl, there was a logarithmic relationship between slip distance and stride length in the above range of slip distances.

When a comparison was made between slip distance and static COF values (Figure 1), slip distance tended to exponentially increase as COF values decreased. However, the measured COF for vinyl obtained a greater than expected slip distance. The possible reason for overestimation for the COF and underestimation for stride length was because of a PVC shoe sole of the artificial leg. Since the vinyl and shoe sole materials were all elastomers, the friction between them was much higher than the rest of the other floors. In other words, the elastomer acts differently compared with the other materials as far as the friction is concerned. Without vinyl, the COF values decreased exponentially as slip distance increased.

Table 2. Slip distance and stride length for floors

Floor	SD (cm)	SL (cm)
Ceramic	1.4712	136.60
Steel	1.1744	136.50
Vinyl	1.2024	134.73
Plywood	1.0664	136.20
Sandpaper	0.9908	134.69

Stride length decreased as COF values increased, although the values did not prove to be statistically significant A reason for the lack of significance might be due to the microslips that occured for the steel and ceramic floors, and the interaction between the elastomers (shoe heel and floor surface) for the vinyl floor.

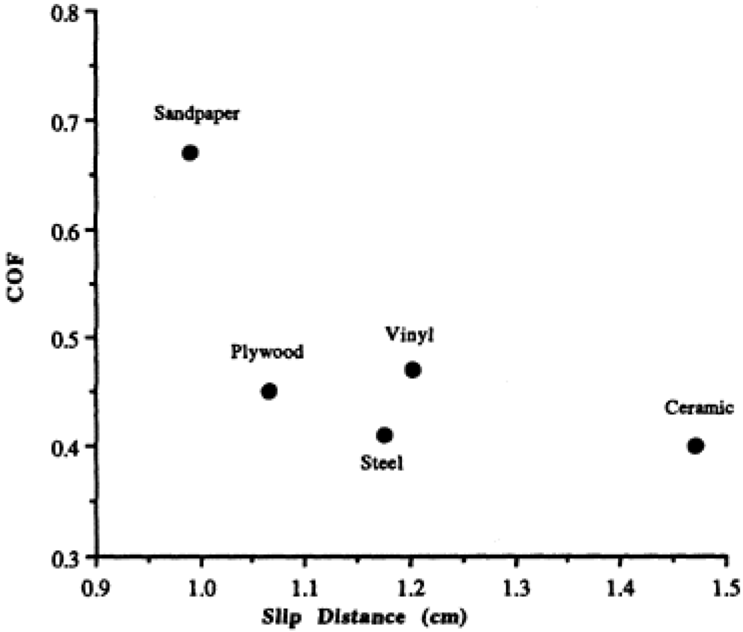

Figure 1. Comparison of slip distance and COF.

CONCLUSION

Due to the small sample size, trends in the data (with regard to slip distance and stride length) did not yield statistically significant results. For the tribological approach, the slip distance had an exponential relationship with static COF values while the slip distance had the logarithmic relationship with stride length for the biomechanical approach. The stride length decreased as the static COF increased. In other words, the biomechanical parameter, stride length, was also dependent on the tribological parameter, static COF. However, the vinyl tile acted differently for the trends of the static COF and stride length compared to the other materials because of the friction with another elastomer of the PVC shoe sole of the artificial leg. Additional research should be conducted to determine if the trends were in fact insignificant, or if the small data size caused them to be statistically insignificant

In conclusion, slip distance appears to be related to both tribological and biomechanical Slip distance has promise to be a good measure for tribological and hanical approaches individually and simultaneously.

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COUNTERMEASURES AGAINST FLOOR SLIPPERINESS IN THE FOOD INDUSTRY

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INTRODUCTION

Slipping accidents cause a great number of injuries in the food industry. In Finland, e.g., the number of slips and falls was greatest (124 accidents) in 1989 for butchers and sausage makers (National Board of Labour Protection, 1990). Maintaining good hygiene in the working area demands the use of relatively smooth flooring materials that are easy to clean. Such floors are often slippery in the presence of contaminants (e.g. water, cooking oil, grease, or spilled food). Floor slipperiness has been studied widely, but contradictory results have been reported (Brungraber, 1976). The problem is also recognized in various fields in the food industry (English, 1984).

Slip resistance seems to be a purely physical phenomenon which is quantitatively determined by the coefficient of friction between the interacting surfaces and the possible contaminants. Human behaviour, environmental conditions and work tasks also affect the risk of slipping. An injurious slip occurs unexpectedly and usually at once after the heel of the shoe and the floor surface come into contact (Strandberg, 1983). Thus, the frictional phenomenon is likely to be more important for pedestrian safety than any other single risk factor.

The aim of this study was to find countermeasures for reducing slips and falls in the food industry. Typical floor coverings from six food production plants were selected for analysis that consisted of friction measurements, both apparative and walking experiments, and a cleaning study.

METHODS

The anti-slip properties of five ceramic tiles, six epoxy and one acrylic resin flooring, and one concrete flooring with an acrylic additive were analysed (table 1). A smooth stainless steel floor was used as a reference surface. The ceramic tiles were also treated with a chemical agent (Steponet, Nippu) to improve their anti-slip properties by affecting the microstructure of the tile surface.

Table 1. Analysed floor coverings.

Flooring No. and type		Surface type	Roughness Ra [μm]
	Original ceramic tiles		
1.	Glazed	Smooth	0.5
2.	Semiglazed	Rough	11.5
3.	Unglazed	Raised-patterned, smooth	2.0
4.	Unglazed	Smooth	2.0
5.	Unglazed	Smooth	2.0
	Anti-slip treated ceramic tiles		
6.	Same as no. 1	Smooth	1.0
7.	Same as no. 2	Rough	12.5
8.	Same as no. 3	Raised-patterned, smooth	2.0
9.	Same as no. 4	Smooth	2.0
10.	Same as no. 5	Smooth	3.0
	Polymeric floorings		
11.	Acrylic	Ground, rough	14.0
12.	Epoxy	Ground, rough	15.0
13.	Epoxy	Quartz add. 0.3 mm, smooth	2.0
14.	Epoxy	Quartz add. 0.6 mm, semirough	5.0
15.	Concrete	Acrylic add., semirough	6.0
16.	Epoxy	Ground, rough	12.0
17.	Epoxy	Ground, lacquered, rough	9.0
18.	Epoxy	Ground, lacquered, rough	15.0
	Reference flooring.		
19.	Stainless steel	Smooth	0.5

Apparative friction measurements

The friction measurements were performed with a laboratory apparatus (Grönqvist et al. 1989), which simulates human foot motions and forces applied to the floor during an actual slip. Thirteen types (A to M) of footwear (leather shoes and rubber boots) with solings made of rubber, PU and PVC were used in the assessments. The tread in shoe type J was artificially removed. All the footwear were new, except type G which was a used shoe.

Soap solution (Berol 482, active content 0.5 % sodium lauryl sulphate) and glycerol (89 % by weight), which corresponds to the slipperiness of cooking oil, were used as contaminants.

The heel-slide (μ_{kl}) coefficient of kinetic friction, where the contact angle between the shoe sole and the f floor was 5°, was measured. This way of measurement represents the most hazardous phase of gait from the viewpoint of slipping.

Altogether 494 footwear-contaminant-flooring combinations were analysed. During the tests the shoe was attached to an artificial foot and lowered onto the floor surface with a vertical velocity of 0.1 m/s. The other measurement parameters were as follows: normal force 700 N; time interval of each measurement 0.10–0.15 s from the application of normal force; horizontal sliding velocity 0.4 m/s. Five repeated measurements were taken from each footwear-contaminant-flooring combination. The standard deviations were less than +/−12% of the mean. For each flooring type, the mean µk1 of all footwear types and for each f footwear type, the mean µk1 on all f flooring types was reported as a final result.

The floorings and the footwear were classified into five slip resistance classes (table 2). Friction values were also compared with floor surface roughness values (arithmetic average roughness, R_a). The roughness values in table 1 represent the means of 10 or 20 consecutive measurements with a Taylor-Hobson Surtronic 10 R_a-stylus instrument.

Table 2. Slip resistance classification according to Grönqvist et al. (1989).

Coefficient of kinetic friction, μ_{kl}	Slip No.	resistance class Explanation
>=0.30	1	Very slip-resistant
0.20–0.29	2	Slip-resistant
0.15–0.19	3	Unsure
0.05–0.14	4	Slippery
<0.05	5	Very slippery

Walking experiments

Four previously measured footwear types (F, G, J and M) were selected for the walking experiments. Seven healthy men (age 25–43 years; height 165–183 cm; weight 60–98 kg) walked along a straight path which was covered with the reference surface. A safety harness was used to protect the test persons against falling. The friction utilization, i.e. the ratio F_H/F_V of the horizontal (in the walking direction) and vertical forces applied to the floor during one step, was measured with a Tamtron force platform (size 400×600 mm). The time interval of each measurement was 0.10–0.15 s from the heel contact with the floor. In one spot, where the force platform was positioned, the path was contaminated with glycerol. The length of each slip was measured, and the test persons were asked to evaluate the slipperiness of the footwear in 420 walking trials. The paired comparison method (Nagata, 1987) was used to establish the evaluation scale from 1 (slippery) to 5 (slip-resistant).

Cleaning study

The cleaning study was carried out as follows: The floor coverings (all except the reference surface) were first disinfected and then recontaminated with two dirt suspensions (water and dairy cream based), both containing Pseudomonas aeruginosa bacteria. Bacterial cell density in the suspensions was 10^8–10^9 cfu/ml (cfu, colony-forming units). The surviving bacteria were analysed after the clean-up of the floorings with a commercial cleaning agent (Sumabac DS, Leverindus). The concentration of the cleaning agent was 1.0 dl/8 l of water in the first test series and 0.5 dl/8 l of water in the second one. Two or four parallel swab samples (each 10 cm^2) were taken from the ceramic tiles and polymeric floorings, respectively, and transferred into physiologic saline (5 ml). Automated turbidometry was used in the microbiological analysis (Bioscreen, Labsystems). The results calculated by the applied computer programme (BioRTN, Labsystems) were expressed as corresponding plate count values, cfu/ml (=equivalent to cfu/2 cm^2). All samples were analysed in duplicate. The detection limit of the method is 50–10^2 cfu/ml. Only values higher than 10^2 cfu/ml are considered significant.

RESULTS

The kinetic coefficient of friction (μ_{kl}) of the analysed 19 floor coverings was 0.29 on average. With soap solution, the mean was 0.37 and with glycerol 0.20. The slipperiness of different floor coverings (figure 1), however, varied greatly. The anti-slip treatment of the ceramic tiles increased the μ_{kl} by 74% on average compared with the original tiles. The treatment was more effective with soap solution than with glycerol.

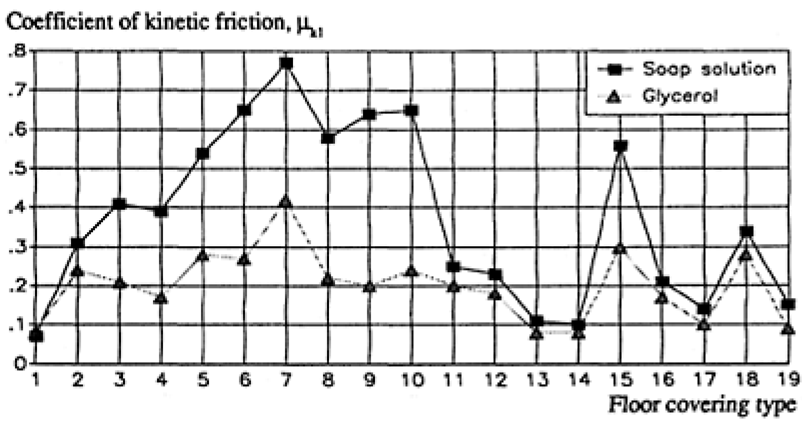

Figure 1. Coefficient of kinetic friction (μ_{k1}) of 19 flooring types (mean value of 13 footwear types). A slip is unlikely to occur during normal walking when μ_{kl} is at least 0.20.

Most of the measured floorings were either very slip-resistant or slip-resistant with soap solution. However, three epoxy floorings (nos. 13, 14 and 17) and one glazed ceramic tile (no. 1) were slippery, and even more hazardous than the slippery reference surface (no. 19). With glycerol, only one floor covering, an anti-slip treated ceramic tile (no. 7), was very slip-resistant, ten floors were slip-resistant and the rest were unsure or slippery.

No overall correlation was found between μ_{kl} and R_a values for the different floorings. This result is contradictory with our earlier study (Grönqvist et al., 1990), in which we measured mainly compact floor materials (e.g. deck plates, vinyl carpets, and glazed tiles), whereas the present study also deals with porous floors like unglazed tiles and anti-slip treated tiles. If the ceramic tiles and the porous concrete flooring (no. 15) are left out, a statistically significant ($p<0.01$) correlation is found for the other floors (nos. 11–14 and 16–19) both with glycerol ($r=0.86$) and with soap solution ($r=0.82$).

The slipperiness of different footwear types is shown in figure 2. The type of footwear seems to affect the coefficient of kinetic friction, and hence pedestrian safety, considerably less than the type of flooring and/or the contaminant. The most slip-resistant footwear type was a used safety shoe (type G) with a microcellular PU-soling. Its μkl was 0.40 on average on all 19 floor coverings. When the same safety shoe type was measured as new (type F), the coefficient of kinetic friction was 30% lower.

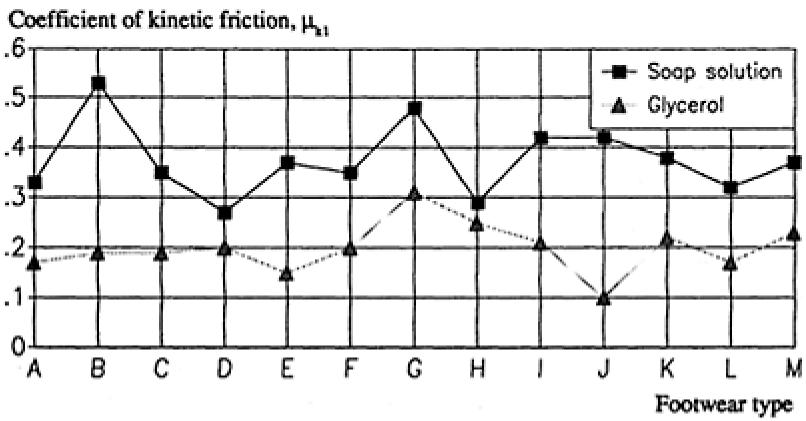

Figure 2. Coefficient of kinetic friction (μ_{kl}) of 13 footwear types (mean value of 19 flooring types). A slip is unlikely to occur during normal walking when μ_{kl} is at least 0.20.

Footwear with either microcellular (types B, F, G, and K) or compact (A, H, I, L and M) PU heels and soles were in general less slippery than footwear with PVC (C) or rubber (D and E) solings. Shoe type J without any tread was the most slippery one on floorings contaminated with glycerol, but the even heel surface was quite able to penetrate the soap solution.

The ceramic tiles, the original as well as the anti-slip treated, were much easier to clean than the epoxy, the acrylic and the concrete floorings (figure 3). Only the roughest (Ra> 14 μm) epoxy and acrylic floorings were relatively slip-resistant (nos. 11, 12 and

18), but it was very difficult to clean them. The slippery epoxy flooring no. 14 and the slip-resistant concrete flooring with the acrylic additive (no. 15) were less difficult to clean than the other polymeric floorings.

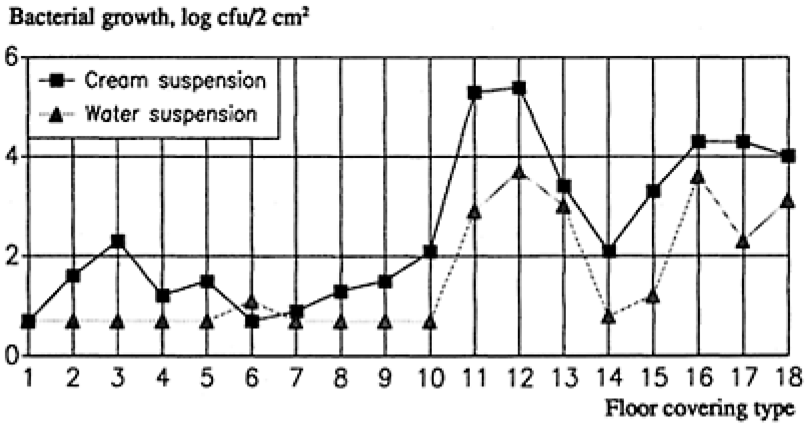

Figure 3. Bacterial growth (log cfu/2 cm^2) on 18 flooring types after the cleaning procedure shown as mean values of 2 or 4 parallel swab samples analysed in duplicate. Only log cfu values above 2.0 are significant.

All seven test persons subjectively assessed the four footwear types in the same rank of slipperiness (table 3). The friction utilization (F_H/F_V) during one step did not correlate either with the subjective feeling of slipperiness or the length of a slip. The apparative kinetic friction values (μ_{kl}) for footwear types G (0.22), M (0.13), F (0.06) and J (0.01) on the stainless steel floor contaminated with glycerol, however, showed a statistically significant correlation with the subjective evaluations in the walking trials: Pearson's product-moment correlation coefficient was 0.97 ($p<0.05$).

Harris and Shaw (1988) found previously that floor roughness correlates with users' opinion ranking in wet conditions, and that there was an implication that kinetic friction can give a useful indication of the slip resistance of wet floors.

Table 3. Footwear rank, friction utilization during one step, slip length and subjective feeling of slipperiness in 420 walking trials on a stainless steel floor contaminated with glycerol.

Footwear type, Rank	Friction utilization, Mean F_H/F_V	Length of slip <5 cm	>=5 cm No. of trials	Subjective evaluation, Mean points
G	0.11	96	9	4.6

M	0.13	70	30	3.9
F	−0.09	43	62	2.7
J	0.04	2	103	1.5

CONCLUSIONS

The following factors seem to determine the anti-slip properties of contaminated floors and footwear: 1) the macroscopic structure (e.g. profile, asperities); 2) the microscopic roughness (e.g. R_a); and 3) the microscopic porosity of the floor and the footwear tread surface. Countermeasures against floor slipperiness are most effective when these three factors are brought together in a balanced way. The microscopic porosity and roughness of floor coverings seem to be the most important countermeasures according to this study. The importance of good housekeeping of floors (i.e. removal of slippery contaminants) should of course not be forgotten.

Unglazed, rough, raised-patterned and/or porous ceramic tiles are recommended as flooring materials in the food industry, where good hygiene and easy cleaning are required. Also anti-slip treated glazed ceramic tiles (i.e. treatment of the tile surface with a chemical agent that changes its microstructure) seem to provide adequate slip resistance in high risk areas, where the floors are wet or otherwise contaminated. In other industrial branches with a high risk of slipping but lower standard of hygiene, also very rough epoxy or acrylic resin floorings could be satisfactory.

Footwear with microcellular PU heels and soles are recommended in high risk areas. They seem to provide better frictional properties than other solings made of compact materials. Double density PU solings with a compact tread surface, however, are often more durable against wear and corrosive substances than microcellular solings.

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THE EFFECTS OF SHOE ANGLE, VELOCITY, AND VERTICAL FORCE ON SHOE/FLOOR SLIP RESISTANCE

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INTRODUCTION

Slip and fall injuries seen in the workplace are estimated to be as high as 300,000 per year in U.S. including 1,200 to 1,600 deaths (Szymusiac and Ryan, 1982). Measurements of the frictional capabilities of the shoe-floor interface are often used to determine the surface slipperiness. These measurements are applied by industry, shoe and floor manufacturers, and the legal system as a criterion for rating slip potentials. Static coefficients of friction are routinely used in making evaluations regarding the safety of a floor, however, there is some debate on the validity of this measure. Dynamic COF (DCOF) has been shown to be equally if not more important in slip potential estimations based on biomechanical studies of gait and falls (Strandberg, 1983; Perkins and Wilson, 1983; Redfern, 1988).

The purpose of this research was to investigate the effects of varying parameters of the shoe-floor interface on the DCOF using a new, recently developed device (Redfern and Bidanda, 1991), termed the programmable slip resistance tester (PSRT). This device allows testing of a shoe-floor interface under more biomechanically relevant conditions. The specific objective was to determine the effects of biomechanically relevant variables such as shoe angle, heel velocity, and vertical force on DCOF recordings.

METHODS

The PSRT measures the DCOF of a shoe/floor interface under varying conditions that better reflect the interactions of the shoe and floor during human gait (Redfern and Bidanda, 1991). Velocity profiles for the dynamic shoe/floor tests can be programmed. A shoe mount is installed on the tool fixture in order to position the shoe at known angles during contact with the floor. Vertical force levels are established by placing weights on the spindle and using the vertical stepper motor to lower the weighted shoe during contact with the floor. A floor base mounted on linear bearings was installed on the machine table. This base is then in contact with a force transducer that measures the shear forces on the floor during the test. These shear forces are recorded by the microcomputer via an analog to digital converter at 200 Hz. DCOF readings are then calculated by dividing the shear forces by the vertical force used. A mean DCOF is then estimated for each trial.

Four flooring surfaces were used: vinyl tile, vinyl tile (waxed and buffed), smooth stainless steel plate, and concrete. Three surface contaminants, water, a low viscosity oil (SAE 10), and a higher viscosity oil (SAE 30) were used to simulate common flooring conditions in industrial settings. Four floor surface settings were therefore used: dry, wet, light oil, and heavy oil. Three shoes with different soles materials were use in the tests: PVC, urethane, rubber. The velocities used were: 1, 5, and 15 cm/s. The shoe angles were: 0, 5 and 15 degrees. A full factorial design with 5 replications per cell was used in the tests.

RESULTS

An ANOVA was performed on the collected data to determine which variables had significant effects on the DCOF. The effect of the primary independent variables and their first order interactions were investigated at a $p<.05$ level. Significant variables along with their associated sum of squares and the percent of the total sum of squares are presented in Table 1. Shoe type, velocity, floor type, contaminant condition and their interactions (except floor*speed) were found to be significant. Vertical force was only significant as a first order interaction with shoe and condition. The angle variable was not found to be significant. The contaminant condition variable accounted for a majority of the sum of squares in this analysis. Shoe type along with its first order interactions with other variables also accounted for a relatively large portion of the variance in the data.

Table 1. Significant variables ($p<.05$) attained in the ANOVA with the percentage of total sum of squares.

Variable	% SSTO
Condition	46
Shoe	15
Shoe*Condition	14
Floor*Condition	5
Shoe*Floor	4
Floor	3
Condition*Speed	2
VForce*Shoe	<1
VForce*Condition	<1
Shoe*Speed	<1

Rubber soles had, in general, the largest DCOF for the dry and wet conditions. The differences in DCOF between shoes is less distinct, however, in the oily conditions. Speed had different effects depending on the condition. The DCOF increased with speed in the dry and wet condition. For the oily conditions, however, increases in speed tended to decrease the DCOF. The effects of floor type were mixed across the different shoes. For the hard PVC soled dress shoe, the concrete floor had the highest DCOF levels. The DCOFs for the PVC sole on the other three floors reduced dramatically for both water and oil conditions. In general, the steel floor performed better under dry and wet conditions, and the concrete floor was generally better for the oily conditions. The vertical force only had a minor effect on the slip resistance measurements. For the rubber sole, a slight decrease in DCOF was found as the force was increased was found.

DISCUSSION

Slip resistance testing can allow an analysis of the shoe-floor interface to identify hazardous conditions and assist in designing safer environments. An underlying problem, however, is that different testing methods give different results (English, 1991). Studies of the biomechanics of gait (Redfern, et al., 1992b) and falls (Strandberg, 1983) show that the critical point when most slips occur is at the initial heel contact which is a dynamic event. Dynamic friction is therefore believed to be more relevant than static measures in slip prevention (Strandberg, 1983). The device used in this study, the PSRT, is believed more effective than other sled type devices since it has the ability to better model the heel contact event during DCOF recording. The question then arises regarding the influence of biomechanical factors (such shoe angle, velocity, and vertical force) and external factors (such as flooring, shoe type and contaminant) on the DCOF. Both were addressed in this study.

Speed was seen as a factor in slip resistance measurement, particularly as an interaction with floor condition. The choice of speed during testing must be decided based on the biomechanics of gait. Velocity of the heel at contact is reported to be between 10 and 20 cm/s for normal gait (Redfern, et al., 1992b) and can increase to a level of from 40 to 50 cm/s for slips (Strandberg and Lanshammer, 1981). Testing velocity should probably be at levels seen during normal gait and not after slip has already occurred.

Within our range of testing, vertical force was found to have a relatively small influence on DCOF. This result was also seen by Redfern, et al. (1992a) for dynamic sled tests. This is however, not true in static COF testing using a sled type device where the COF increased as the vertical force increased (Redfern and Adams, 1988). It may indicate that the choice of vertical force is not critical in determining slip potential using DCOF, but would be important in static measurements.

The choice of appropriate shoe angle during testing was addressed in this study. Some debate has ensued regarding the most appropriate angle to perform slip testing. A low heel contact angle of 5–6 degrees was adopted by SATRA (Perkins and Wilson, 1983) and Gronqvist, et al. (1989). The results of the present study indicate that changing shoe angle between 5 and 15 degrees does not have an effect on DCOF, indicating that the choice of angle is not of practical significance.

From this and other studies conducted, it appears that a smooth steel surface performs adequately under dry and wet conditions when the shoe material is relatively soft. A harder shoe material on a steel surface is less slip resistant under these conditions. A textured floor, such as concrete, offers the best choice fo an oily surface. It was interesting to note that the best performance under the high viscosity oily condition was by the hard shoe on the concrete surface. These values were higher than those taken with the rubber sole which had twice the COF readings wet and dry. This result may have implications in shoe design strategies for work in areas where oily conditions are prevalent. Harder soled shoes on a rough surface seem to have better slip resistant properties than softer materials. In wet conditions, however, softer soled shoes are indicated. The results support the idea that shoe design for specific contaminant conditions could increase slip resistance and possibly decrease the possibility of falls and injury.

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A PRACTICAL SYNTHESIS OF BIOMECHANICAL RESULTS TO PREVENT SLIPS AND FALLS IN THE WORKPLACE

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INTRODUCTION

Slips and falls at work continue to exact a toll in injuries, lost time, and attendant effects such as decreased productivity. This in spite of improvements in tribometric techniques to assess shoe/floor coefficients of friction, increased knowledge of the biomechanical responses to walking on slippery surfaces, and a burgeoning of research in postural control. Why haven't slip and fall problems in the workplace gone away? One aspect of the problem that has not received systematic attention is how best to transfer the research findings to the workplace. This paper will summarize recent biomechanical findings and make recommendations for approaches to prevent slips and falls at work.

Tribometric research related to slips and falls was reviewed by Strandberg (1983 and 1985). Surface dissipative processes in terms of the hydrodynamics of contaminants between the shoe and the floor and bulk dissipative processes from the viscoelastic characteristics of the shoe heel and sole materials (and sometimes from compliant flooring as well) contribute to the tribometric mechanisms of slips. Many investigators have documented the kinematics of the shoe/floor interaction during gait in an effort to provide input to comprehensive viscoelastohydrodynamic models of shoe/floor interaction. However, these models are strictly mechanical and do not take into account the neurological mechanisms of the humans inside the shoes. Kinematic evidence of behavioral changes made when walking onto a slippery surface is now available (Andres and O'Connor, 1990, and Andres, et al., 1991). Modifications in muscle activity patterns when walking on different surfaces with varied friction give further proof that the person wearing the shoes can affect the outcome of exposure to slippery situations (Andres et al., 1991). Finally, just because a person experiences a foot slip does not mean that a negative outcome (e.g. fall) will result. Research into postural responses to transient perturbations has demonstrated that the walking human can adapt rapidly to many types of balance challenges (Nashner, 1980, and Dietz et al., 1985). All of these research areas have been expanding, yet fall prevention remains elusive.

As the research has proliferated, so has the availability of products to prevent slips and falls. Slip resistant shoes and shoe sole designs are advertised, as are slip resistant floor materials. These materials can be entire floor surfaces or mats that can be placed in known trouble spots. There are also several floor treatments available ranging from slip resistant floor waxes to slip resistant grit paint, non-slip tapes to floor-etching treatments. All of these shoe and floor products are aimed at increasing the available coefficient of friction (COF) between shoe and floor, although no consideration has been given to the question of how much friction is too much (and hence could increase the risk of tripping). Finally, many products have emerged to prevent a negative outcome even if a worker should slip; these include the wide array of safety harnesses that are available. Few, if any, of these products have been systematically validated as decreasing slips and falls in spite of their theoretical and common sense appeal as useful products. Furthermore, no single approach can abate the complex problems posed by the presence of slippery conditions in the workplace. A systematic transfer of technology and research findings is needed to help prevent slips and falls over the long term.

RESEARCH RESULTS

Two research investigations into the biomechanical and kinesiological mechanisms of slip and fall prevention will be summarized in this section to focus on the leap from theory to practice. Six college-age male subjects participated in the first investigation to determine kinematic, kinetic, and kinesiological adaptations to slippery surfaces. The subjects were required to walk on three different coefficient of friction (COF) surfaces; 1) dry tile 2) tile with water, and 3) tile with glycerin (with mean COF's of 0.79, 0.76, and 0.05 respectively). The entire 10 m walkway was either dry or wet. The subjects walked at their preferred pace (preferred walking speed, PWS) which was determined on the dry surface and at their adapted slippery pace (slippery speed, SS), which was determined on the glycerin surface. Subjects were allowed to walk on each surface for at least 10 trials before they were tested; each condition was tested until 20 successful trials were obtained. There was a total of six conditions for each subject: the two speeds on each of the three surfaces. The kinematic data was collected by a 200 Hz video camera and recorder. The angle of incidence of the foot (absolute angle of the foot) and the ankle angle (relative angle between shank and foot segments) and the leg angle (upper and lower leg treated as one segment) were analyzed in the sagittal plane at heel strike. Vertical and horizontal (antero-posterior) ground reaction force (GRF) data were collected at 600 Hz. Vertical GRF parameters included the first maximum force and the relative time to its occurrence, and the minimum force during mid-stance and the relative time to its occurence. Horizontal GRF parameters included maximum braking force and the relative time of its occurrence. Ankle flexor and extensor activities were acquired as RMS-EMGs sampled at 600 Hz, and temporal parameters included durations of flexor and extensor activities, cocontraction (or temporal overlap) of flexor and extensor activities, and the latency from flexor onset to heel-strike.

The first obvious kinematic change was that subjects walked slower on the slippery surface: SS=1.23 m/s, PWS=1.55 m/s. Since step frequency did not change, step length was shortened at the slippery pace. Therefore findings are presented by speed. Foot angle of incidence significantly decreased for PWS on the slippery surface compared to the dry surface. No ankle angle changes were found, and the changes in leg angle were between the PWS and the SS conditions.

The relative time to first maximal vertical GRF, the first maximal force, and relative time to the mid-stance minimum force differed between the speed conditions. At PWS, the first maximal force on the slippery surface was less than on the dry surface and relative time to the mid-stance minimum force was less for the dry surface than for the slippery surface. The relative time to maximum braking force was less on the dry surface than on the slippery surface for both PWS and SS. Maximum braking forces were greater on the dry surface than on the slippery surface for both speeds. Contact time only varied with speed.

Durations of the first and second ankle flexor bursts, the ankle extensor burst, and the latency from ankle flexor onset to heel-strike were not affected by conditions. Cocontraction between the first flexor burst and the extensor burst was significantly greater for the slippery surface than for the dry surface at PWS.

These results represent gait parameters of subjects who have successfully adapted to walking on slippery surfaces. The second investigation forced subjects to adapt over a much shorter time span. Six college-age males voluntarily walked onto a target area on a 15 m walkway that was either slippery (coated with glycerin) or non-slippery. Subjects walked at their freely chosen pace determined on the non-slippery surface; speed was kept constant by measuring the time it took to walk 3 m with timing gates which ended 2 m before the target area. Step frequency was also fixed by requiring subjects to synchronize their steps with a metronome beating at their freely chosen step frequency. After passing the final timing gate, subjects were allowed to adjust their gait to walk over the target area without falling (the metronome was turned off). A successful trial occurred when the subject's approach velocity was within 5% of the freely chosen speed, steps were synchronized with the metronome, the right foot landed in the target area, and the subject continued to walk through the target area and beyond without falling. Two days of testing took place after an acclimation session: each day the subject performed 20 successful trials for each surface condition, with the order of conditions balanced over days.

Lower limb kinematic data were acquired in the sagittal plane at 200 Hz for the step prior to and the step onto the target area. Reflective markers were placed on the fifth metatarsal head, calcaneus, lateral malleolus, lateral femoral condyle, the greater trochanter, mid-iliac crest, and the base of the neck. Several kinematic parameters were derived including: right and left step lengths and the ratio between them, angle of incidence between the shoe and the floor at heel-strike on the target area and the instantaneous angular velocity, the peak to peak displacement of the HAT (head-arms-trunk) segment over a stride, and average horizontal velocity of HAT segment over a stride.

Right and left step lengths were the same when the target area was non-slippery (ratio of right to left=0.979), but the right step was shortened when the target area was slippery (ratio=0.911). The angle of incidence was 22.6° on the non-slippery surface, but decreased to 19.5° on the slippery surface. The foot was lowered at 254.8 deg/s on the non-slippery surface, but this angular velocity decreased to 202.7 deg/s on the slippery surface. Peak to peak HAT displacement decreased from 8.6 cm on the non-slippery surface to 7.9 cm when the target area was slippery. Horizontal velocity of the HAT decreased from 1.49 m/s in the non-slippery condition to 1.41 m/s when the target area was slippery.

These latter results describe the different adaptations that take place in the two steps prior to and including landing on a target area that is slippery. The combined message of these two studies is that walking humans can adapt to walk continuously over extremely slippery surfaces; in fact this adaptation takes place in essentially one step cycle when the subject is aware that a slippery surface is being approached. Let us now examine the practical implications of these results.

CONTROL STRATEGIES

Two types of controls are possible: engineering controls and administrative controls. The former involves product selection to change the workplace, whereas the latter does not involve workplace modification but rather maintenance, posted warnings, enforcement, and worker training. The following discussion presents some of the pro's and con's of both types of controls.

Engineering controls would start with changing the floor surface to greatly increase the COF available. On the positive side: 1) particularly bad spots can be targeted, 2) changing a floor surface does not involve employee choices, and 3) this option can be relatively inexpensive because there are several options to choose from (from floor mats to entire surfaces). However, these surfaces may: 1) create a trip hazard, 2) interfere with operations (for example the requirements of the FDA for floor cleanability in the food industries), or 3) wear excessively depending on traffic. The same advantages and disadvantages will emerge with the use of floor treatments (slip resostamt wax, grit tape strips, surface etching, or grit paint), although the cost may be less.

Another option that borders on both engineering and administrative controls is the mandating and purchasing of shoes for all employees. On the positive side, the bulk dissipative properties of the shoe sole and heel materials could be uniform and quantified, and several of these types of shoes include other safety features (such as steel-toes) as well. However, there may be worker resistance to wearing mandated shoes because of the loss of individual expression, and the purchase of shoes for every employee could conceivably be quite costly. The greatest disadvantage of this approach is that good shoes used poorly can still result in slips and falls. Of course, workers could all be tethered to safety harnesses throughout their shift, but mobility would be sufficiently limited to make this option untenable at most work-sites. Engineering controls alone will not yield a slip and fall-free workplace.

Some combination of administrative controls with engineering controls is necessary to render the engineering controls more effective. Administrative controls in the present context include maintenance, posted warnings, and training. The advantages of choosing to supplement engineering controls with maintenance are that the response to a spill can be quick, proper application and use of slip resistant waxes does not take more time than improper techniques, and maintenance personnel can also identify other safety hazards while looking for slip and fall hazards. On the down side, a more aggressive maintenance policy may increase personnel requirements and increase scheduling demands for routine floor cleaning.

Since subjects adapt quite rapidly to an apparently slippery floor surface, another administrative approach would involve posted warnings to provide workers with time to change their gait before stepping on the slippery surface. These warnings can be either temporary (in case of a spill) or permanent (in case of one area where operations often result in lubricants on the floor). The disadvantages of posting warnings are 1) they require supervision so that all workers comply with the warning, and 2) the warnings must take Human Factors into account (such as lettering size, warning placement, visibility, etc.).

The last administrative control for discussion is the training of workers to prevent falls. The positive aspects of this approach include: 1) humans adapt to slippery surfaces naturally, so common sense is being reinforced, and 2) an increased awareness of the surroundings and tasks being performed (particularly those that increase slip, trip, or fall potential). The difficulty with this administrative approach is that proper instruction is required. This instruction should include descriptions of what to look for as slip, trip, or fall hazards. The workers should be instructed on how to alter their gait when walking over slippery surfaces is necessary (i.e. decrease stride length, decrease the angle of shoe incidence with the floor at heel contact, decrease speed, and decrease the angular velocity of the foot segment). The final lesson should be taught with a safety harness, having the workers walk onto a slippery patch while trying out the various suggested adaptations. This could serve to demonstrate the importance of heeding the posted warnings and maintaining vigilance for slip and fall hazards.

SUMMARY

A comprehensive slip and fall prevention program will combine engineering approaches (such as floor mats or high COF floor surfaces and treatments) with administrative approaches (stepped up maintenance, posted warnings, and worker training). Otherwise, one aspect of the problem may be traded for other problems, and slips and falls will continue to take their toll in industry.

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Body and Ladder Mechanical Stresses Analysis in a Climbing Strike

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This paper presents the findings of the peak forces generated in the articulated joints and the foot/floor contact point of ladder while the individual is engaged in ladder climbing. It is identified in this paper that the ladder's friction forces have a time variant nature as a result of biodynamic movements. There was a greater posterior displacement of the body's center of gravity and smaller peak center of gravity shearing forces in climbing the 75 degree ladder than the 70 degree ladder and a larger biomechanical load evident while climbing at 106 steps/min than at 86 steps/min.

INTRODUCTION

In addition to proper selection, inspection, and positioning of equipment, body movement plays a significant role in ladder safety. Dewar (1977) reported that in a total of 248 ladder related occupational accidents, 66% of cases occurred when the ladder slipped; the remaining 34% of cases were attributed to an error which occurred during the climbing action. Too often such accidents occur because the individual does not perceive the degree of physical safety or danger (Juxptner, 1976). An ergonomics analysis on the interaction of a person and the ladder will help in the identification of the potential hazardous conditions in climbing. In fact, the stability of the ladder is determined by the friction forces generated at the foot/floor contact point, which is a function of the nature of the material, the roughness of the contacting surface, and the climbing posture. While in motion. ladder slip accidents had occurred when the maximum value of the force of friction was less than the shear force created by the pushing force which resulting from body movement. Accidents also occurred when the subject misplaced his/her feet or otherwise 'stumbled' when climbing. In this case, the hand's gripping forces play significant role in regaining balance. To obtain further understanding of the slip/fall hazards involved in climbing activity, an insightful analysis of the interaction between the body part and the ladder, especially, in a climbing strike is required. Moreover, the question of the dynamic changes of the friction forces (the friction coefficients) as a function of body movement remain undiscussed in any related studies.

Ladder slant and climbing velocity are considered to be two major variables in the determination of the effect of body movements on ladder safety. According to NIOSH, a ladder angle of 75 degrees with the horizontal is usually recommended as a safe angle in setting up a ladder on the basis of friction requirements to prevent the foot of the ladder from slipping. However, a 70 degree ladder angle is most commonly used, and the reason for this may be due to the increasing concerns of the possibility of falling backward plus increased awkwardness in climbing of a steeper angle. The effects of ladder angles on ones body movement will be further explored in this study. Two climbing speeds were discussed in the study, they are 86 steps/min and 106 steps/min; They were considered to be slow and fast climbing conditions. The speed variable contributes to the dynamic force components which, in addition to the static force, increases the resultant biomechanical stress on the body segments and the resultant forces transmitted to the ground significantly.

The objective of the study is to provide an integrated description of ladder forces as a function of body movement in a climbing strike. The task was accomplished by carrying out a two dimensional dynamic biomechanical analysis using videography. In particular, this paper presents the finding of a study conducted to determine peak forces generated in the articulated joints and the foot of ladder while the individual is engaged in ladder climbing. The significance of these biomechanical and mechanical stress analyses is discussed in relation to the test conditions.

METHOD

Experimental procedure

Four healthy male subjects voluntarily participated in the experiment conducted for the purpose of gathering videographic data. The subjects were 25 to 28 years old, 162 to 172 cm in height, and 51 to 60 kg in weight. After a familiarization session, each subject performed four variant climbing task with 2 repetitions of each. These variations were (1) slant angle (70 degree and 75 degrees with the horizontal), and (2) climbing speed (86 steps/min and 106 steps/min). The aluminum ladder was 2.9 m in length, 6.3 kg in weight, and 0.303 in rung separation. All tests were performed in the laboratory where the ladder was set upon a multi-component force platform.

The actual motion studied in this paper is somewhat restricted. It was assumed in this study that subjects climbed with a symmetric gait. The subject were asked to move both hands simultaneously. For ease of modeling, only the behaviors of the left side of body segments were recorded. All movements of the upper half of the body (hand, elbow, shoulder, and hip joints) during the strike are considered symmetrical and no movement can violate any physical constraint of the ladder.

Adhesive markers were attached to the subject’s wrist and six joint centers. These represented the lateral aspects of the estimated center of rotation: (1) Left metatarsal, (2) Left ankle, (3) Left knee, (4) Left hip, (5) Left shoulder, (6) Left elbow, and (7) Left wrist. The origin and orientation of principal axes were defined according to Chaffin and Anderson (1984). 2-D motion recording was accomplished using the Expert Vision motion analysis system. A recording was made for each subject performing the simulated climbing task at 60 Hz shuttle speed. The camera was placed perpendicularly to the plane of action at a distance of 5 meters. The subject was asked to climb three strikes, however, only the complete middle strike was subjected to analysis in each task condition. The video recording were digitized and the digitized data was filtered, using a Butterworth digital filter of the fourth order with the cut-off frequency of 6 Hz (Kromodihardjo and Mital, 1987). As a result, the moving trajectories of the spatial position of the joint centers were obtained.

Biomechanic analysis

In performing this biomechanical analysis, the skeletal system was considered to consist of eleven mechanical levers (lower arms, upperarms, head-neck-trunk, upper legs, lower legs, and foots) whose rotations about the joints generate the movement of the body. The descriptions of the physical properties of the limb segments have been thoroughly studied in the field of anthropometry. At any posture during the course of climbing, every segment of the human body is subjected to forces which are in a state of dynamic equilibrium. That is, the sum of the reactive hand forces (f_h_x(t), f_h_y(t)), the reactive joint reactive forces (f_x(t), f_y(t)), and the forces generated at the center of gravity of the human body (f_cg_x(t), f_cg_y(t)) must equal to zero in order to maintain the stability of the ladder. The calculation of the forces, using method of moment, was based on the anthropometric parameters of the individual and video data of the four different task conditions. The modeling assumptions of the linkage system as well as the calculating model of the biomechanical stress follow Chaffin and Anderson (1984). The forces were computed by adding the dynamic effects of linear accelerations to the gravity effect of the segment weights. The flow of data acquisition and data analysis procedure are presented in Figure 1 for illustrative purposes.

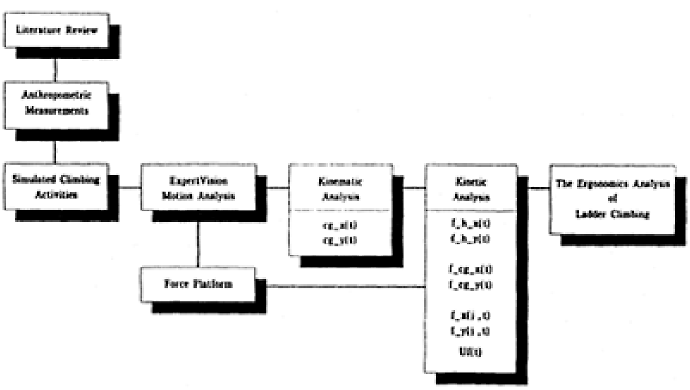

Figure 1. Data acquisition and data analysis procedure

RESULTS

The climbing kinematics

Since climbing is a repetitive activity, one strike is used as the time period to describe the motion. Table 1 presents the temporal data during the climbing strike. The strike began with a double stance phase when both feet are on the ladder, followed by a single stance phase when only one foot is in contact. The small standard deviation of the temporal measures, both strike

Table 1. The temporal characteristics of the climbing strike

ladder angle climbing speed	70		75	
	86	106	86	106
Time of strike (sec)	1.43+0.06	1.21+0.07	1.40+0.03	1.24+0.07
Time of contact (sec)	0.83+0.02	0.67+0.07	0.80+0.05	0.71+0.02
Contact/strike (%)	0.58+0.02	0.55+0.04	0.57+0.03	0.57+0.02
Range of hip joint(degree)	109+2– 115+2	109+4– 117+4	106+2– 115+4	106+3– 118+4
Range of knee joint(degree)	35+3– 88+3	34+4– 87+4	34+4– 84+4	33+3– 83+4
Range of ankle joint(degree)	99+2– 143+2	100+2– 143+2	96+3– 140+2	96+3– 139+2

time and contact time, indicated the consistency of the climbing behavior of the four subjects. The contact time and strike time ratio ranged from 55% to 58%. This was smaller than Dewar’s 61% to 63% due to the faster climbing speed used in this study, however, it was within the range of the ratio (54% to 63%) of natural walking (Winter, 1987).

A lateral view regarding the calculated path of the center of gravity of the body segment for each task variation is shown in Figure 2. The two step-like components, starting with a more vertical movement followed by a more horizontal movement, can be explained by the changing pattern of leg support in which (1) the body is supported on one leg which extends and moves the body upwards (0–37% and 51–85%) and then (2) when this leg is almost fully extended the body move forward (38%-50% and 86%-100%), bringing the center of gravity over the support of the opposite foot ready for that leg to extend (Dewar, 1977). Observing the moving trajectories of the center of gravity of the body, the ‘vertical’ components for the 75 degree ladder are slightly longer than those for the 70 degree while the ‘horizontal’ components are shorter. As far as the climbing speed is concerned, the paths at 106 steps/min did not show as much variance as those at 86 steps/min while climbing at the two angles in the first 70% of the strike time. It appears that individuals displayed less control of body motion while climbing at a faster speed.

The climbing kinetics

Figure 3 shows the model calculated normal and shear joint reaction forces of the first half of the strike. They are the reaction forces acting on the hand, the hip, and the knee joint during the single stance phase. It is apparent that the forces acting on the hand played a significant role in balancing the body in the horizontal direction. This is especially true when the body is moving from the double stance to the single stance where a maximum horizontal hand reaction force was generated. The lower extremity joints also experienced the largest outward forces, in the same time, it initiated the flexion of the right knee. In the vertical direction, the lower extremity joints (hip

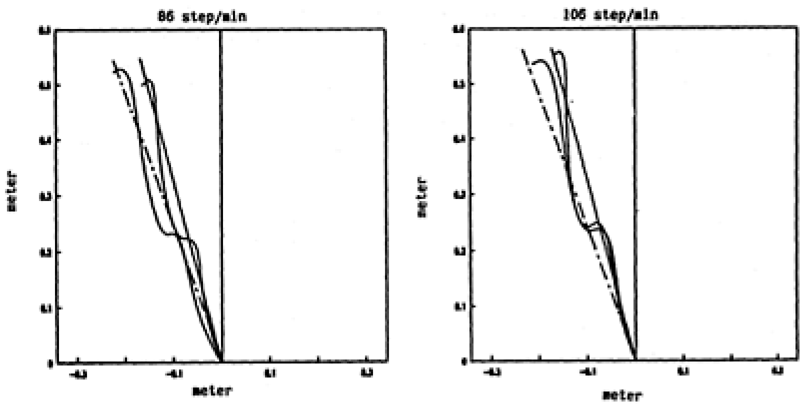

Figure 2. The calculated path of the center gravity

and knee) contributed more than the upper extremity joints, in helping the body move upward. There were two peak vertical joint reaction forces of the standing leg, one occurring before the right foot lifted off, the other peak occurring before the appearance of the second double stance phase.

Figure 4 illustrates the calculated force components generated at the the foot of ladder which were resulted from the interaction of the body with the ladder. Two similar force cycles, both horizontal and vertical forces, were observed in

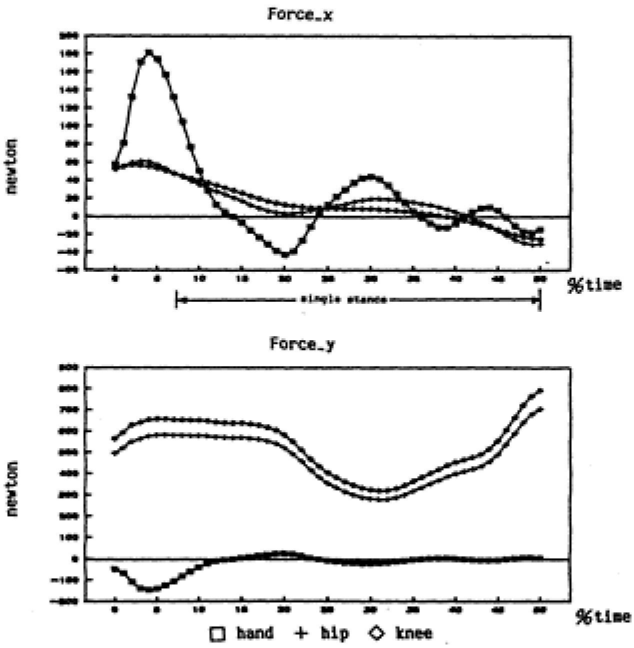

Figure 3. The horizontal and vertical joint reactive forces

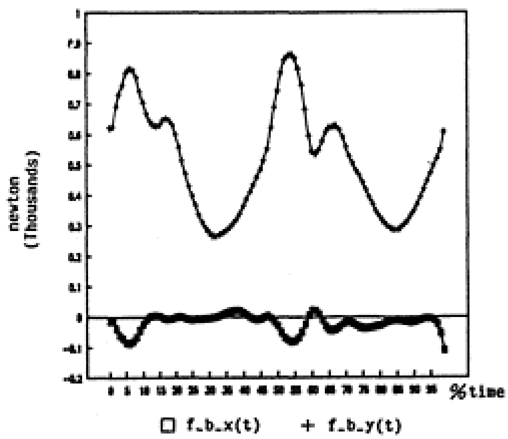

Figure 4. The horizontal and vertical ladder foot forces

the plot of forces trajectories of one complete strike. The peak vertical force occurred just before the foot lifted off. It is identified that before the time the right foot is lifted off the rung, the shearing force relative to the normal force, which can be thought of as the required coefficient of friction necessary to prevent ladder slipping, is large until the forward momentum of the body carries the body center of mass over the foot. To the center of the single stance phase, the normal force is continuously reduced thus the required Ut(t) is reduced. Toward the end of the first half of the strike, the normal forces are higher and the shear forces are increased, however, in the opposite direction, and thus the required Ut(t) to prevent slipping increases until the right foot completes its swing. The required Ut(t) ranged from −0.1 to 0.08 which is within the safety range of 0.2 (Strandberg, 1983).

Body mechanics as a function of the task variables

The five degree difference in ladder angle significantly affected the maximum horizontal forces in the center of gravity of the body and the maximum horizontal forces at hand. Table 2 shows the average peak forces when climbing at two ladder angle using two different speeds. As shown in the table, the average peak horizontal center of gravity force was 148 Newton for climbing at 70 degrees compared to the peak force of 125 Newton for climbing at 75 degree. While climbing at a steeper angle, there is less horizontal movement per time unit which resulted in a smaller maximum forward horizontal center of gravity forces against the wall. However, the average peak horizontal hand force was 59 Newton for climbing at 70 degrees compared to the peak force of 87 Newton for climbing at 75 degrees. The increased hand load can be explained by the increasing concerns of the possibility of falling backward plus increasing awkwardness in climbing in a steeper angle. The differences in these values were significant at the five percent level.

A fast climbing speed affected the maximum horizontal and vertical forces of the center of gravity of the body and the maximum vertical forces of the hand. Table 2 shows the average peak center of gravity forces and the hand forces when climbing at 106 steps/min and 86 steps/min. As shown in the Table, the average peak center of gravity force components were 166 Newton

Table 2. Average peak forces during the climbing strike

Task	max. cg force horizontal (Nt)	max. cg force vertical (Nt)	max. hand force (pull) (Nt)	max. hand force (push) (Nt)	max. hand force vertical (Nt)	Ut (%)
Subject						
I	135	828	73	−19	−175	0.119
II	121	698	26	−73	−115	0.169
III	137	696	54	−73	−120	0.170
IV	151	748	133	−42	−211	0.152
Slant Angle (Degree)						
70	148	739	59	−62	−123	0.156
75	125	746	87	−41	−187	0.150
Climb Speed (steps/min)						
86	115	722	64	−42	−142	0.157

106	157	763	82	−63	−168	0.149

in horizontal and 764 Newton in vertical direction for climbing at a faster speed compared to the peak force of 148 Newton in horizontal and 721 Newton in vertical direction for climbing at a slower speed. This indicated when subjects climbed at a faster speed they had more horizontal and vertical accelerations resulting in a higher maximum forward force and a maximum downward force than the slower one. The average peak forward hand force was 62 Newton for climbing at 106 steps/min compared to the peak force of 40 Newton for climbing at 86 steps/min. The average peak downward hand force was 168 Newton for climbing at 106 steps/min compared to the peak force of 142 Newton for climbing at 86 steps/min. The differences in the two values was significant at the five percent level.

CONCLUSIONS

The results of the study shed some light on the stresses that are generated when individuals are climbing. The small standard deviation of the temporal data indicated the consistency of the climbing behavior of the four subjects. A lateral view of the calculated path of the center of gravity of segment body shows a ‘step-like’ pattern, which is in consistent with Dewar’s path of the pelvic griddle. The consistency in the plot of the force platform measured ground reaction forces and the model calculated center of gravity normal forces provided the evidence of the validity of the motion data and the biodynamic models.

It was indicated in the study that the forces acting on the hand played a significant role in balancing the body in the horizontal direction while the body moved from the double stance to the single stance phase. The lower extremity joints contributed most in helping the body move upward. It was identified in the paper that the ladder’s friction forces have a time variant nature as a result of biodynamic movements. There were two peak friction coefficients, in opposite directions, occurring in each half of the strike. There is a potential for climbing hazard unless high-friction forces and/or slip-resistant forces are provided in 7% and 38% of each half of the strike time.

The five degree difference in ladder angle significantly affected the maximum horizontal forces in the center of gravity of the body and the maximum horizontal forces at hand. The increased load can be explained by the increasing concerns of the possibility of falling backward plus increasing awkwardness in climbing at a steeper angle.

A fast climbing speed affected the maximum horizontal and vertical forces of the center of gravity of the body and the maximum vertical forces of the hand. This indicated that subjects climbing at a faster speed had more horizontal and vertical accelerations resulting in a higher maximum forward force and a maximum downward force. It appears that individuals displayed less body control while climbing at a faster speed.

This paper describes the development and feasible validation of a dynamic 2D biomechanical analysis of body and ladder mechanical stress. Such an analysis will be of assistance to the understanding of various body segment interactions with the ladder during a climbing strike. It is also of value in the prevention of ladder accidents by identifying the timing of the climbing hazard potential points.

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THE EFFECT OF PERSONAL, ENVIRONMENTAL AND EQUIPMENT VARIABLES ON PREFERRED LADDER SLANT

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The effect of ladder length, subject height, wall type, and type of ladder slant cue device on preferred ladder angle was evaluated. Subjects tended to prefer ladder angles more than 2 degrees shallower than the recommended 75.5 degrees. In general a steeper ladder angle was selected when the ladder was placed against a ledge than a standard wall. An angle closest to 75.5 degrees was most consistently selected when using a plum-bob apparatus developed by the experimenters.

INTRODUCTION

Falls from ladders account for a significant number of accidents and injuries each year. The U.S. Consumer Product Safety Commission (ANSI, 1983) indicates that there are approximately 200,000 injuries each year associated with ladders. Safety Sciences (1978) notes that nearly ten percent of occupational falls occur from ladders. In the Federal Republic of Germany between 1959 and 1961 approximately two percent of all occupational accidents resulted in falls from ladders (CIS, 1966) Axelsson and Carter (1991) note that ladder accidents account for nearly 5 percent of all reported occupational accidents in the Swedish construction industry. They also note that sliding of the ladder base was a common contributing factor in ladder accidents. The U.S. Bureau of Labor Statistics (BLS) found that in 42 percent of accidents involving ladders the user was moving and in 56 percent the ladder slipped, fell, or broke (BLS, 1983). ANSI (1983) notes that 22 percent of ladder accidents involved slipping by the user and 56 percent involved a slip of the ladder.

The BLS study noted above also found that in nearly 60 percent of ladder accidents, the user had received no training in the safe use of ladders. CIS (1966) and ANSI (1983) note that misuse is a significant cause of ladder accidents. The Division of Safety, Standards, and Compliance of the U.S. Energy Research and Development Administration (1976) notes that most misuse of "straight" extension ladders stems from user failure to recognize limitations of ladder (ie. standing on top rung or over extending his/her reach) and inability of user to adjust the ladder to a "safe" angle of inclination.1. The angle of inclination recommended by American National Standards Institute (ANSI, 1990) for fixed ladders is 75.5 degrees (between the ladder and the ground).

METHOD

The objectives of this study were to determine the slant at which ladders were "set-up" as a function of the ladder working length (13′, 18′), support wall type (standard, ledge), ladder slant cue device (manufacturer information, plum-bob apparatus, none), and subject size (short, average, tall).

Subjects

Test subjects were 24 paid male volunteers. The test subjects equally represented the following three height classes:

Class 1 5′1″–5′6″ (short)
Class 2 5′6″–5′10″ (average)
Class 3 5′10″–6′3″ (tall)

All test subjects fell within the 5th to 95th percentile h eight and weight of the average male civilian population (Salvendy, 1978). The weight of each test subject was verified to be proportional to his height.

Equipment

The equipment used in this experiment consisted of two aluminum Werner Extension Ladders. The extension ladders were nominally 16′ and 28′ with a work load rating of 200 lbs. The extended lengths used in this experiment were approximately 13′ (12.93′) and 18′ (17.94′) respectively. Prior to testing, the manufacturer supplied "ladder feet" were remove to allow easier adjustment of the ladder slant. A rug was used to supply a firm, slip-resistant surface on which to set the base of the ladder. The different types of support wall type (standard, ledge) are shown on Figure 1.

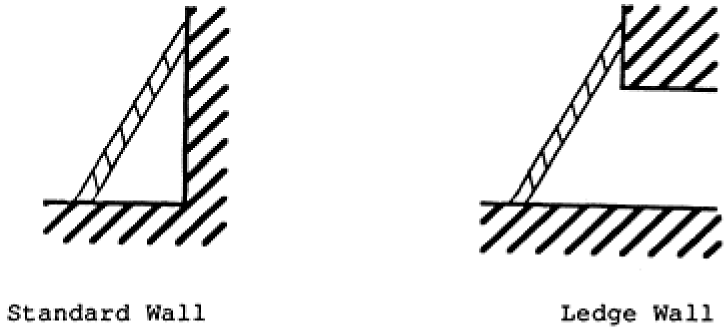

Figure 1. Two support wall types

Each ladder was labeled with the traditional “backward L” to assist with the placement of the ladder at the correct 75.5 degree slant. The manufacturers instructions note that the long part of the backward L should be “straight up, parallel to wall” and that the foot of the backward L should be “level, parallel with ground”.. The manufacturers instructions also indicated that the “Distance from ladder base to base of support wall type wall must be 1/4 the working length of the ladder”. Each ladder was also equipped with a small plum-bob apparatus approximately 3 inches long. When the plum-bob was aligned with a mark, the ladder was at the correct slant. Each of the cue mechanisms was hidden when the other was being used and neither was visible when the user set up the ladder according to personal preference. A sketch of the plum-bob apparatus is shown on Figure 2.

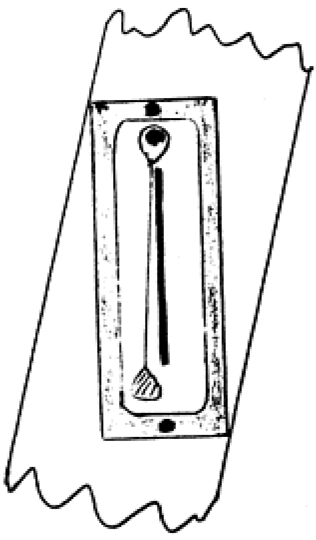

Figure 2. Sketch of plum-bob apparatus.

Procedure

Each subject received the same instructions. The subjects were instructed to place the ladder against the wall (standard wall or ledge) using one of the three different cue device (personal preference, information on ladder supplied by ladder manufacturer, plum-bob apparatus). After each placement the ladder was returned to an “unreasonable” angle prior to the next trial. The subjects were instructed not to climb the ladder but to assume that they would be performing light work such as painting after climbing 50–70 percent of the way up the ladder. The order of ladder length and wall-ledge was randomized and within each ladder length and wall-ledge combination the order of ladder slant cue device was randomized. Each subject was presented with each ladder placement condition 5 times for a total of 60 ladder placements per subject.

[2 lengths]×[2 wall type]×[3 slant cue device]×[5 replications]=60 trials

The average duration of each test session was approximately one hour for which the subjects were paid $10.

RESULTS

The results of the experiment are summarized in Table 1 and presented graphically in Figure 3.

Table 1 Preferred ladder slant as a function of standard, cue mechanism, and ladder length. (n=24, All values in degrees between the ladder and the floor.)

	SHORT LADDER (13′) AVE (SD)	LONG LADDER (18′) AVE (SD)
LEDGE WALL		
Personal Preference	74.4 (2.3)	73.5 (3.2)
Manufacturer info	74.4 (1.9)	75.2 (2.4)
Exp Apparatus	76.2 (0.5)	75.4 (0.6)
STANDARD WALL		
Personal Preference	72.7 (3.2)	73.2 (2.5)
Manufacturer info	73.1 (1.9)	74.2 (2.8)
Exp Apparatus	75.6 (0.5)	74.9 (1.0)

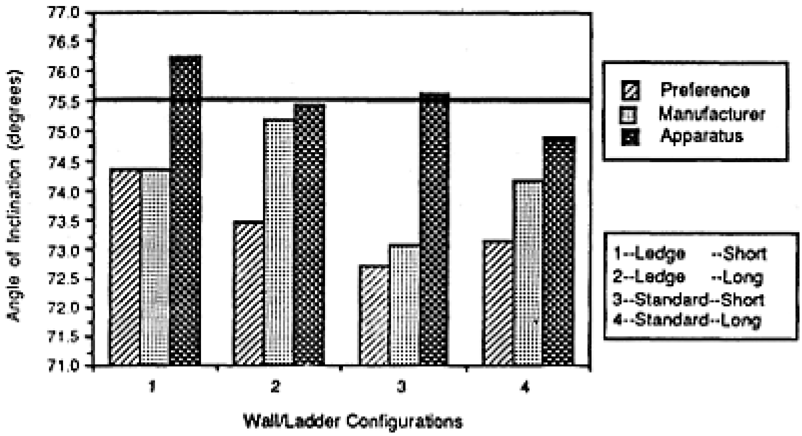

Figure 3. Preferred ladder slant as a function of ladder cue, wall, and ladder length, (n=24).

A preliminary analysis of the data does not indicate that ladder working length, support wall type, ladder slant cue, or user size had a statistically significant effect on the angle at which the ladder is placed. Several tendencies, however, were observed.

The results indicate that there is a tendency for subjects to have a personal preference for ladder slants shallower than the 75.5 degrees recommended by ANSI (and many other organizations). The data appears to suggest that the use of the ladder slant cue information provided by the manufacturer results in a ladder slant closer to the recommended 75.5 degrees. At the end of the experiment it was discovered that the “backward L” was affixed to the ladder at an incorrect angle. If used as stated by the manufacturer (long part of the backward L “straight up, parallel to wall” and the foot of the backward L “level, parallel with ground”) a slant of nearly 79 degrees would result. The average slant when using the manufacturers information was 74.2 degrees or nearly 5 degrees less. This suggests that if the “backward L” had been placed at the appropriate angle (indicating a ladder slant of 75.5 degrees), the users may have placed the ladder at approximately 5 degrees less or around 70 degrees.

Subjects were much more likely to place the ladder at the correct angle when using the plum-bob apparatus than when depending on personal preference or the labeling provided by the manufacturer. The small standard deviation when using the plum-bob apparatus indicates that it also allowed them to be more consistent in this placement. The plum-bob apparatus appeared most helpful (placement closest to the recommended 75.5 degrees) for the shortest subjects when placing the short ladder on the ledge wall. This is presented in Figure 4.

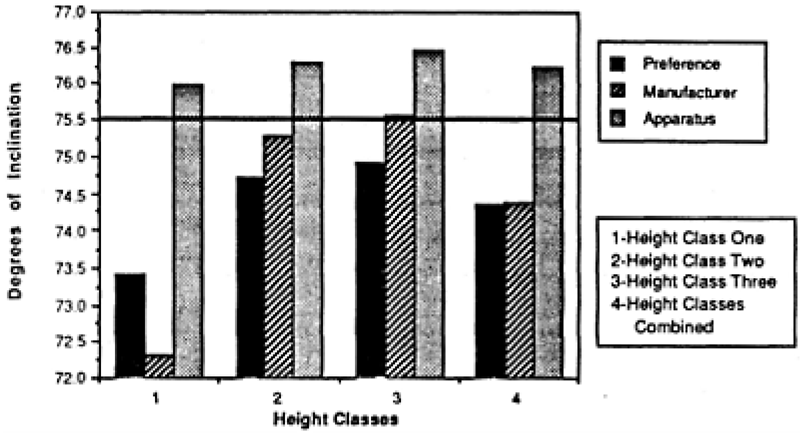

Figure 4. Preferred ladder slant for the short ladder on the ledge wall as a function of ladder slant cue and subject anthropometry, (n=6).

It was surprising to the experimenters that, when using personal preference, the subjects placed the ladder at a steeper angle, and came closer to the recommended 75.5 degrees, when placing the ladder against the ledge than against the wall. Perhaps the absence of the wall made the observed ladder angle less intimidating so a steeper angle was acceptable.

CONCLUSIONS

Ladder users tend to place ladders at a slant shallower that the recommended 75.5 degrees. The use of the plum-bob device resulted in a consistent placement of the ladder at the correct angle. This suggests that consideration should be given to the use of a simple device (plum-bob, bubble level, etc.) to facilitate the proper ladder placement. In addition this type of device is not dependent on the existence of other visual cues such as vertical walls or horizontal lines. The accuracy of the placement of the manufacturer's information (backward-L) should be reviewed.

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Methods Used on Atypical Climbing Systems

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Proposed changes in standards and regulations will likely result in the increased use of atypical climbing systems such as spiral staircases, ship's ladders, alternating tread stairs and attic ladders. This paper suggests that the intended method of descent will be less obvious with certain non-traditional systems, and that user behavior may be correlated with the user's categorization of the system as a "stairway-like" or "ladder-like" system. This hypothesis is supported by a pilot study involving truck cab access (climbing) systems, and could potentially lead to a method of predicting usage patterns. Finally, recommendations related to the application of atypical climbing systems are presented.

INTRODUCTION

Traditionally, falls have been primarily prevented through standardizing and regulating the physical environment. This not only makes our environment better suited to our biomechanical and perceptual limitations, but also reduces variance in the physical environment, thus making the environment more predictable for locomotion. With respect to climbing systems, predictability is achieved through provisions within standards and regulations related to various system features including dimensional uniformity, step separation, and handholds. Primary among these provisions to control climbing system designs are recommendations and regulations related to the slopes or "effective angles" permitted for ramps, stairs, and ladders used in general industry. Traditional "effective angles" for ramps, stairs, and fixed ladders in the U.S.A. have been roughly 0 to 30 degrees, 30 to 60 degrees, and 75 to 90 degrees, respectively. Also noteworthy is that effective angles between 60 and 75 degrees have been traditionally discouraged (OSHA, 1976), which has made the distinction between stairway and ladder systems more apparent.

In contrast to past practices, it is likely that atypical climbing systems will be increasingly used in work and home environments. Proposed changes in OSHA regulations would no longer discourage effective angles between 60 and 75 degrees, and expressly permit non-traditional systems such as spiral staircases, ship's ladders, and alternating tread stairs to be introduced into general industry (Figure 1). In the home consumer market, attic ladders (sometimes called "attic stairs") are also increasingly used (Figure 1). Thus, as shown in Figure 2, the new taxonomy of climbing systems proposed by OSHA (1990) is much more complex than the traditional taxonomy. With a more complex variety of climbing systems the intended method of use will be less clear for some systems.

Falls may occur when climbing systems are used in ways which are not intended or accommodated by the system designer. In particular, people may fall if they descend certain stairway systems using ladder methods, and similarly may fall if they descend certain ladders using stairway methods. This problem may be particularly acute with users that are unfamiliar with the climbing system, especially when they have not observed other individuals using the system in the intended manner. The important distinction between the two usage methods is that stairways are ascended and descended with the user facing opposite directions (i.e. facing in during ascent and facing out during descent), while ladder systems are ascended and descended facing the same direction (i.e. moving backwards during descent). Unless a system is designed to safely accommodate both methods, it is naturally desirable to predict how atypical systems will be used.

This paper briefly discusses the use of affordance modeling and categorization modeling techniques toward predicting which of the two basic alternative methods users will apply. Then, using a categorization approach, pilot study data is presented regarding climbing methods and driver's categorization of the climbing systems used to access the cab area of medium and heavy duty trucks. Finally, specific recommendations related to the application of atypical climbing systems are presented.

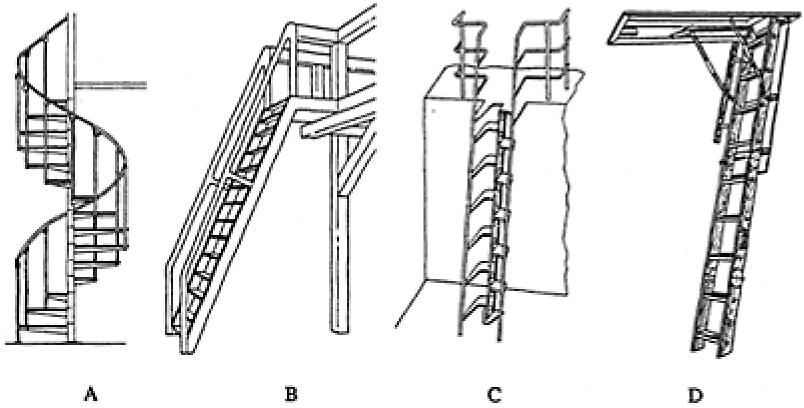

Figure 1: (A) Spiral Staircase, (B) Ship's Stairs, (C) Alternating Tread Type Stairs, and (D) Attic Ladders (Terms for A, B, and C from OSHA, 1990)

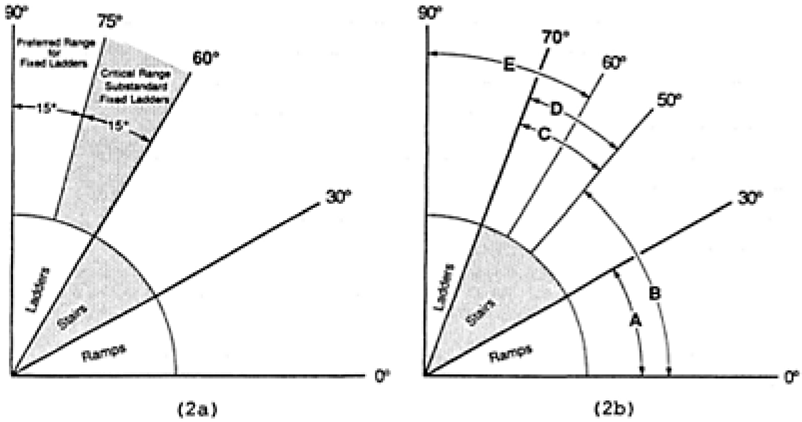

Figure 2: (2a) Traditional angles for ramps, ladders, and stairs (adapted from OSHA, 1976).

(2b) OSHA’s proposed angles (A) Ramps (0–30 degrees),

(B) Typical Fixed Stair (0–50 degrees),

(C) Ship Stairs (50–70 degrees),

(D) Alternating Tread Stairs (50 −70 degrees), and

(E) Ladders (60–90 degrees) (terms for 2(b) from OSHA, 1990)

BACKGROUND

Affordance Modeling

An appealing approach to predict how people will interact with climbing systems involves the application of affordance theory (Gibson, 1968, 1977). The term “affordance” was coined by Gibson in his classic 1968 text, *The Senses Considered as Perceptual Systems,* as simply “what things furnish, for good or ill.” Later he refined his definition as indicated in the following passages:

> “The affordances of the environment are what it offers animals, what it provides or furnishes, for good or ill…. Subject to revision, I suggest that *the affordance of anything is a specific combination of properties of its substance and its surfaces taken with reference to an animal.* …Note that

> the properties of substance and surface are physical properties but they are not described in classical physics, only in ecological physics."
>
> Gibson, 1977

Gibson (1977) described varies potential affordances of objects in the environment as including (using Gibson's terms) support, walk-on-able, sit-on-able, bumb-into-able, get-underneath-able, climb-on-able, or fall-off-able, and grasp-able. Several of these affordances have been the subject of extensive research, including: traversability (E.J.Gibson, 1991), sit-on-able (Mark and Vogele, 1987), bump-into-able (Zohar, 1978), step-up-onto-able (Warren, 1984), walk-through-able (Warren and Whang, 1987), and grasping (Zaff, 1989). At a more abstract level, Gibson's theories regarding perception and his promotion of an ecological approach have been adopted by many researchers, including Newell (1991) and Rasmussen (1986). Preceding Gibson, the work of Bernstein may also be considered as an ecological approach to the study of human movement (Turvey and Kugler, 1984). Thus, constructing a model of human climbing based on basic "elemental" affordances would seem to have significant foundation.

Particularly for "low level" aspects of how objects are used, present affordance theories can provide a valuable approach to evaluate certain specific aspects designs (c.f. Norman, 1988). In complex climbing situations, for example, the designer may consider whether particular object feature (e.g. a small surface in a horizontal plane) might afford a non-intended use (e.g. use of the surface as a step). Viewed in this way, one might consider the theory of affordances as being an extension of traditional ergonomic (biomechanical) approaches related to functional anthropometry and reach envelopes.

While having strong appeal, difficulties with an affordance approach toward predicting climbing method are foreseen. In particular, atypical climbing systems often afford usage both as a stairway and as a ladder. To date, affordance theories have not progressed to the point where "valances" (see Gibson, 1968) or other measures of the strengths of alternative affordances might be evaluated. In other words, with present theories an affordance basically exists or does not exist, with no apparent means to address intermediate values which might be assigned for climbing systems. Thus, application of present affordance theories to predict which of the two basic alternative climbing methods will be used with an atypical climbing system does not appear practical at this time. Nevertheless, further development of affordance theory to accommodate such issues is worthy of significant research.

Categorization Approach

As an alternative to Gibson's perceptually based theory of affordances, the choice of climbing method may be considered from a cognitive viewpoint. In particular, the user's choice between two alternative methods might be predictable through the application of theories related to knowledge representation. With respect to the performance of motor activities, alternative approaches involve the application of theories related to production systems (Anderson, 1983), script theories (Shank and Abelson, 1977; Rummelhart and Ortony, 1977), and categorization (Rosch, 1978). With both production systems and script theories, actions are related to a set of conditions which may be represented by concepts or categories. For this paper, application of script theory is predominant because it more readily and intuitively represents the interaction of diverse concepts related to objects, actions, situations and sequences. With script theory, when a subset of variables related to a particular schema have been assigned appropriate values, the remaining values are assigned default values and the schema is said to be instantiated. Variables which may instantiate a “use like a ladder” schema versus a “use like a stairway” schema may include the absence, presence, or configuration of discriminating features such as steps, rungs, and handrails, or other conditions such as the height above ground, or the “effective angle” of the climbing system.

In this paper the *action* categories “use like a ladder” and “use like a stairway” alternatives are considered isomorphic to the basic level *object* categories of “ladder” and “stairway”. Basic levels of objects are defined as an intermediate level of abstraction which people use most commonly in everyday language, learn first as children, and for which one can name the greatest number of distinctive features. Basic levels, superordinate levels, and subordinate levels also exist for various action categories, but common verbs for “use like a ladder” and “use like a stairway” are not apparent. Instead, these action categories seems to be subordinate instances within the basic level action category labeled “climbing”. Thus, while the object categories “ladder” and “stairway” are at a basic level, the method for using these objects is not at a basic level. The authors therefore suggest that how a person behaves with respect to atypical climbing systems may be more directly predicted by measuring how such systems are categorized as objects rather than asking subjects to categorize how they might interact with the object.

An advantage of the categorization approach is that it requires very little data. With atypical climbing systems, one could simply use a forced choice procedure to determine whether subjects categorize an atypical system as a “ladder” or “stairway”, and then use this as a prediction of how the system will be used. A potential difficulty with this approach is that basic level object categorization may not have an isomorphic relationship to usage patterns. For example, the two basic level categories of “ladder” and “stairway” are of reduced predictive value if three categories actually exist. In particular, there may exist a subordinate level, unlabeled category for systems which can be used with either a ladder or stairway method of use.

Recognizing these potential problems, a initial question related to the viability of this approach is whether or not behavior observed with an atypical climbing system is consistent with the user’s categorization of the object as a “ladder” or “stairway” system. This question is addressed in the following pilot study of a class of climbing systems that are distinct from traditional stairways and ladders.

PILOT STUDY

Method

The methods used by truck drivers to climb down from their cabs were observed and recorded as “face in” (ladder-like) or “face out” (stairway-like). Medium and heavy duty conventional trucks and tractors with at least one exterior step between ground level and the cab floor were considered for observation. High profile cab over engine (COE) models were excluded since a ladder climbing method is nearly always used with such vehicles (Heglund, 1989). Observations were made in a local business district where both medium and heavy duty trucks deliver a variety of goods. Immediately after descending, drivers were directed to look at the access system and asked, "About the collection of steps and handholds you used, would you consider this to be more like a ladder or more like a stairway?" The response to this categorization question was recorded and followed with, "If I asked you for a simple name or label for this collection of steps and handholds, what would you call them?"

Results

Both egress methods were observed, with 9 of 13 using a "face out" method. Most drivers provided categorization responses readily, usually within 15 seconds. Only one driver hesitated noticeably, initially indicating that it was not a stairway or a ladder. Categorization was not random ($p<0.05$), but was highly correlated with observed behavior. All four drivers that used a "face in" method categorized the system as a ladder, while 7 of 9 drivers that used a "face out" method categorized the system as a stairway. Although not directed to do so, some subjects verbalized their decision process, with most speaking about the features of the access system. At least one driver, however, appeared to base his response on how he used the system rather than solely considering features of the system. The two drivers that faced outward but categorized the system as a ladder offered explanations. One explained that for safety reasons he needed to face outward to view traffic, while the other driver said his face outward, squat and jump method placed less strain on his body. For the question regarding names or labels for the system, no driver offered an alternate name or label for the climbing systems found on their trucks. Some replied, "Just steps". Most simply said, "I don't know".

Discussion of Field Study

As predicted, categorization in the forced choice task was consistent with behavior. It is not absolutely clear, however, that subjects categorized based solely on the features of the object. It is possible that responses were partly inferred based on the method they used with the access system.

It should also be noted that, consistent with Heglund's (1989) more extensive study, most drivers faced outward during egress. In contrast to the "face out" behaviors observed, some manufacturers and user groups recommend that drivers "face in" during egress so that three points of contact may be maintains at all times (Rhoades and Miller, 1989; TMC, 1989). These results indicate that this recommended method is often not being used, which suggests that further study or some sort of intervention is needed. Rather than trying to change driver behaviors, the authors suggest that the appropriateness of the "three point contact" criteria which is the basis for the "face in" recommendations should first be reconsidered. In particular, a two point contact system (i.e. a stairway-like, face out system) may be preferred under many conditions.

DISCUSSION

Both script and production based theories claim that knowledge is organized hierarchically, and would predict that use of a specific instance of a ladder or stairway invokes general rules (or a script) related to use of ladders or stairways, respectively. Applying Rosch's (1978) "basic levels" hierarchy to describe objects in this paper, the term "climbing system" is used to describe the superordinate level, and the terms "stairway" (or "stairs") and "ladder" are used as basic level category labels for climbing systems. At the subordinate level are objects including ship's stairs, alternating tread stairs, attic ladders (sometimes called "attic stairs"), and selected vehicle access systems. This type of model is supported by the pilot study, in which a user's behavior pattern with a subordinate level system (i.e. select vehicle access system) was consistent with the user's categorization of the product among basic level alternatives ("stairway" or "ladder") related to alternate product usage patterns (facing out versus facing in during descent).

To extend this work to predict climbing methods requires developing a practical categorization procedure which can be used to determine whether a proposed design is subordinate to the ladder or stairway category. Unfortunately, this may be difficult to do without resorting to mock-ups, since categorization may be highly dependent on spatial relationships. Also, it is not known if looking at the object would be sufficient; rather, actual use of the object may be necessary in order for categorizations to stabilize.

The need for such a prediction methodology would be greatly reduced if ramp, stair, and ladder categories were made to be clearly distinct to users. It appears, however, that these categories are becoming much less distinct. This is evidenced by the elimination of the so-called "critical range" (see Figure 2a) of effective angles which have previously been discouraged. Many of the atypical systems discussed in this paper have effective angles within zones described by Diffrient et. al. (1974) as "critical zones" or "indecisive areas".

Beyond physical characteristics, distinction between systems is also confused by the introduction of taxonomies which promote four or more basic categories rather than the three traditional categories of ramp, stairs, and ladder. In particular, OSHA's (1990) taxonomy has five basic categories (see Figure 2b), and current military standards include four basic categories, with "stair ladders" serving as the label for the new class of objects (Woodson et. al., 1992). Confusion can obviously result among users when conflicting category labels exist among authoritative sources.

This decreasing level of discrimination between climbing systems suggests that, absent any intervention, usage patterns with certain systems will likely be contrary to the intentions of employers or system designers. This problem may be especially serious for systems which do not safely accommodate both climbing methods. To lower confusion it is usually advisable to exclusively call a system a ladder or a stair, depending on how it is intended to be used. An attic access system, for example, should be consistently called an "attic ladder" if ladder climbing methods are advised. An example of a current categorization problem is found within proposed safety regulations. In particular, OSHA's proposed term of "ship's stairs" suggests a different usage pattern than the alternate label of "ship's ladder". Diffrient et. al. (1974) used the term "ship's ladder", and explicitly indicated that this system should be descended "backwards" (i.e. with a "face in" method). If "face in" descent is intended for such systems, then the term "ship's ladder" should be used.

Beyond gross usage patterns, there are other characteristics among various climbing systems which are related to safe product use. For example, with certain stairway systems the use of a handrail is critical, while with others it is not. Many climbing systems may be appropriate for use without training or instruction, but others may not. Some systems may be an appropriate means of emergency egress, while others may not. With the increased application of non-traditional systems we recommend the development of an application matrix for various systems. Such a matrix would classify, for example, those climbing systems which would be appropriate for the task of material handling; and point out that while traditional stairways can accommodate a user carrying a load with two hands, alternating tread stairs and spiral stairs can only accommodate a user carrying small loads with one hand. With ladders, and perhaps also with ship's stairs, both hands should be available for grasping the climbing system, so the capability of safe load handling is very limited.

In conclusion, manufacturers of atypical climbing systems should consider both how they intend their system to be used and how their system should not be used. Then, if such knowledge is critical to safe use of the product, the manufacturer should consider whether or not this knowledge is adequately communicated by the product itself. If not, an alteration of certain design features or providing additional product use information may be considered to achieve desired usage patterns.

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COGNITIVE ERGONOMICS

THE EFFECTS OF UNEQUAL RELEARNING RATES ON PERFORMANCE CURVES

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Prior forgetting curve research examined relearning as if its parameters were identical to those of learning. This study determined that for a moderately-high cognitive task the initial learning rate was 87% and the relearning rate was 73%. Since the steeper relearning rate reduces time lost to learning, there was an 89% reduction in this model's forgetting parameter. Thus it is quite apparent that assuming equal learning and relearning rates may result in conservative time estimates.

BACKGROUND

Engineers have long appreciated the value of being able to predict performance times. Several mathematical models have been developed with the aim of improving one's ability to make more accurate predictions (Globerson, Levin and Schtub, 1989). Though much effort has been devoted to predict learning rates, little research has been done to examine the effects of forgetting for typical manufacturing type tasks. Globerson, et al. (1989) and Sparks and Yearout (1990) concurrently examined the impacts of forgetting in the work place. Both of these experiments investigated the effects that an extended break may have upon the traditionally accepted negative exponential model.

Globerson, et al. (1989) examined subjects performing a data entry task which would be typical of those found in an office environment. This task consisted of key punching 16 personal information forms. At the completion of the 16th form, a break was taken. Breaks were sub-divided into six separate groupings and ranged between 1–2 to 54–82 days. Performance times were defined as the time required to complete a given form.

From this experiment, the investigators introduced a parameter which was defined as the forgetting parameter (FP) (equation 1).

$$FP=TLO/TLA \quad (1)$$

Where “TLO” is the time lost due to forgetting and “TLA” is the time of the last iteration prior to the break (see figure 1).

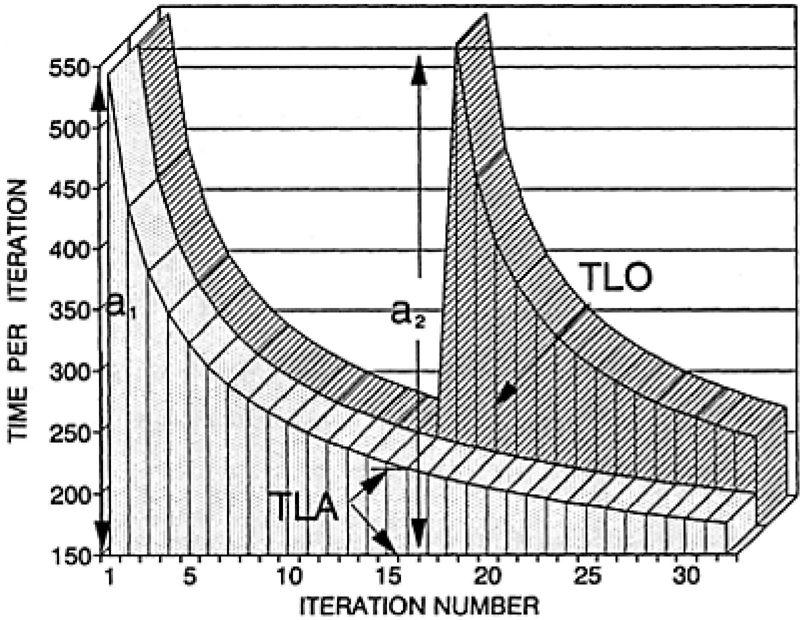

Figure 1. Time Lost to Learning (TLO) Due to a Break versus Time of the Last Iteration Before the Break (TLA).

For the card punch task, Time Lost to Learning (TLO) was calculated by using equation 2.

$$TLO = \sum_{i=1}^{16} a_2 s_i^{-m} - \sum_{i=17}^{32} a_1 s_i^{-m} \quad (2)$$

Where “a_1” is the first iteration performance time, “a_2” is the first iteration performance time after the break, “s” is the iteration number, “m” is the learning function, “17” is the first iteration after the break, and “32” is the last iteration recorded. It must be noted that for this example Globerson, et al. appeared to have assumed that total forgetting has taken place and that the learning function, “m” after the break, remains the same as the initial learning.

The Sparks and Yearout (1990) experiment examined two tasks: the traditional peg board task and a video task. The break period for this experiment was 28 days. Not only was there some retention after a 28 day break, but the learning rates after the break were statistically significantly different from the original learning rate as well. Table 1 illustrates these differences. These independent rates before and after the break are consistent with Bogartz's (1990) findings.

Table 1: Before and After Break Learning Curve Parameters

	Performance Time (sec.) (a)		Learning Function (m)	
Task	Initial	After Break	Initial	After Break
Peg-Board	27.25	21.44	0.074	0.012
Video	0.046	0.032	0.136	0.082

This study's purpose was to examine learning and relearning rates for tasks that better simulate typical manufacturing tasks. Learning and relearning rates then would be compared to determine if there were truly significant costs savings in terms of time lost to learning between models with equal versus those with unequal rates.

METHOD

Introduction

This study was conducted to develop models that could assist manufacturers in predicting the impact an extended break may have on worker performance. Twenty eight days after the initial test subjects were again tested. The test group was instructed to refrain from performing any similar type task during the 28 day break.

Task

Subjects used a personal computer to create spreadsheet graphs. Task data was arranged in five rows and two columns. Task instructions were graph number, variable names, and graph type (bar, line, or pie). From this data and accompanying instructions, subjects entered data, set graph series and type, labeled and printed the graph.

Procedure

All tests were administered at the same computer workstation in the UNCA Owen computer laboratory. Test time was approximately three hours. After the sample test, subjects were exposed to 29 randomly ordered unique task data sets. Performance time began with the subject striking the first key and stopping when the graph began to print. Upon completion of 15 graphs, the subject was required to leave the workstation for a five min. break to compensate for any fatigue bias. Collected data was the iteration number, performance time and errors.

Subjects

Eighteen volunteer subjects, whose ages ranged from 18 to 25 years, were selected based on their inexperience in using personal computer spreadsheets.

Design

Subjects were randomly divided into either a test group or control group. The test group contained ten subjects, five male and five female. The control group contained four male and four female subjects. All subjects were scheduled exactly 28 days later for the follow-up test.

Criteria

Criteria for the task was performance time and errors per iteration. Performance time began when the subject struck the first key and ended when the computer indicated that the procedure to print the graph was activated. Errors (any misspelled words, incorrect data points, or type graph error) were recorded from the printed graphs after the test period.

RESULTS

Steady State

Steady state was determined by initially plotting performance time means against their respective iteration. Since a Levine's Test (significance level of 0.05) determined that the variances for performance time means were not equal, Satterthwaite's Approximation was used (Milliken and Johnson, 1984). By the 12th iteration, there were no significant differences between performance times. Thus at this point, learning was determined to be in a steady state condition and were not significantly different from the original model. After the 28-day break, the control group's means remained in the steady state condition. However, not until the sixth iteration after the break did the test group's means return to steady state.

Basic Model

A regression analysis was performed on both groups of pre-break data (iterations 1–29). The resulting model had a mean square error and multiple correlation coefficient of 1248.21 and 0.38 respectively. The learning rate was 87 percent and is consistent with those learning rates for similar type tasks reported by Konz (1990).

Relearning Model

Significant forgetting for the test groups was reflected in the performance times between the 30–35th iterations. Thus these six iterations were isolated for analysis. Performance time means for each group were compared iteration by iteration. Since group variances were still found to be unequal, Satterthwaite's Approximation was again used. The initial performance time (1st iteration; mean= 211.7 sec., standard deviation=57.5 sec.) was not significantly different from that of the test group's first iteration after the break (30th iteration; mean=221.6, standard deviation=62.0 sec.). After the 35th iteration the performance time means for the control and test groups was no longer significantly different. The relearning model resulting from a regression analysis depicted a 73% learning rate. Its mean square error and multiple correlation coefficient was 1277.5 and 0.58 respectively. Thus the resulting model to calculate time lost to learning after the break is equation 3.

$$TLO=\sum_{j=1}^{5} 211.7x_j^{-.43}-\sum_{i=30}^{35} 211.7x_i^{-.201} \qquad (3)$$

Where "j" is for the first iteration after the break and "i" is the iteration number for the initial model.

Figure 2 superimposes equation 3 over equation 2 and clearly shows time lost to forgetting (TLO).

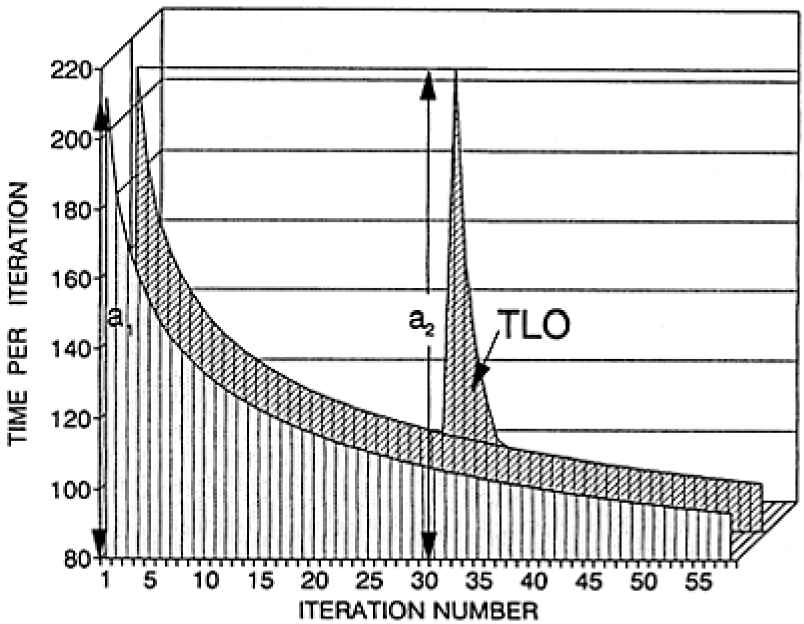

Figure 2: Time Lost to Forgetting (TLO) for a Break of 28 Days. Spreadsheet Graph Task.

Time Lost to Learning (TLO) Comparison

The parameters from this experiment along with those from Spark's study were then analyzed using the assumption that re-learning equals the initial learning rate and the empirical data showing re-learning is not equal to the initial learning rate. Results of the calculations are shown in Table 2. A reduction in the forgetting parameters (FP) of as much as 89% for the spreadsheet task to 80% for the peg-board and VDU tasks were realized.

Table 2. Equal Learning and Relearning Rates versus Unequal Rates Comparison.

Task	% Forget.	Equal TLO	Rates FP	Unequal TLO	Rates FP	% Reduction in FP For Unequal Rates
Graph	100	827	7.69	92	0.86	8
PegBoard	78	375	18.65	20	3.93	80
VDU	70	0.77	29.23	0.03	5.99	80

CONCLUSIONS

The utility of predicting performance times after extended breaks will increase as modern manufacturing continues to emphasize cellular technology, shorter production runs and higher cognitive skills. A conservative approach to determining time lost to forgetting could result in not realizing full worker potential. If forgetting and relearning are to be considered in predicting worker productivity, industrial engineers and manufacturers should not assume equal rates before and after an extended break. Developing relearning rates for tasks and break periods may prove both impractical and not cost effective. Therefore one should consider that a potential savings in predicted performance times as high as 80% could be lost.

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A USABILITY EVALUATION OF THREE CAD SOFTWARES

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Using the system usability approach, three popular computer-aided design (CAD) application softwares were evaluated. The softwares evaluated were: I-DEAS, ME-10 and AUTOCAD. Each software was evaluated on the basis of 11 different usability criteria including visual clarity, consistency, compatibility, informative feedback, appropriate functionality, flexibility and control, error prevention and correction, and user guidance and support. The results of usability evaluation are discussed in this paper.

INTRODUCTION

Computer-aided design is most simply described as "using a computer in the design process" (Chang et al., 1991). The CAD permits a designer to design a product, by providing a relational data base which includes information on materials, product, and manufacturing process, and thereby improving the quality and efficiency of the design function. Furthermore, if a CAD system is integrated with a computer-aided manufacturing (CAM) system, the two together can initiate automatic fabrication of the designed product. A good CAD system also permits the design to be downloaded to a program that develops a bill of materials and manufacturing process plans. The computer in a CAD system is used in both the representation and analysis. The application of CAD for representation is not limited to drafting. Rather, it involves representation through wire frame modeling, boundary representation, and solid modeling and analysis through kinematic simulation, circuit analysis and simulation, and finite element modeling. A CAD system consists of hardware such as interactive graphic facility, a central processing unit and operating system software, and application software (CAD package) for creating images, manipulating images, performing design calculations, and design analysis. **The application software is the heart of the CAD system.**

The key word in *computer-aided design* is **"aided"**. Therefore, the primary goal of a CAD system should be to assist the designer in carrying out the design function, not to replace him/her. This means that the interface between the CAD system and the user (designer) must enhance the communication with the user. In other words, the usability, or “user friendliness”, of the *CAD system* should be maximized by permitting the user to: (1) carry out the *necessary* design tasks successfully, without difficulty and unnecessary stress, excessive errors, etc. and (2) use any of the functions the system is capable of, and is designed for, without requiring him/her to remember too much information and without frustration. Unfortunately, most computer-based systems that require an end-user to make use of the functions and capabilities they provide leave the user frustrated, angry, and disappointed (Baker, 1975; Bertino, 1985). The cumbersome data entry procedures, obscure error messages, intolerance to minor errors, confusing menus and task sequences, lack of consistency, cluttered screens, etc. do not allow many functionally excellent computer-aided systems to be fully utilized (Eason et al., 1975).

Given the various difficulties the users might encounter and the need to have a CAD system that can truly assist designers, it is crucial that computer-aided systems and products be formally and thoroughly evaluated for usability. The emphasis of the usability evaluation must be on the practical considerations of the system-user interaction rather than on theory. An unusable system, no matter how sophisticated functionally, will eventually be cast aside by the end-user (Booth, 1989).

In general, the usability evaluation of a system or a product can be performed on different occasions depending upon the need. For instance, during the system developmental stages, prior to commercializing the prototype or while searching for a suitable computer-aided system from amongst several different systems that are available. This study focused on the usability evaluation of three commercially available and widely used computer-aided design systems that have very different functional capabilities: I-DEAS, AUTOCAD, and ME-10. Following is a brief description of each of these CAD systems.

COMPUTER-AIDED DESIGN SYSTEMS

Integrated Design. Engineering. and Analysis System (I-DEAS)

I-DEAS is a complete Mechanical Computer-Aided Engineering System (MCAE) for use by engineering departments. It provides full functional design, analysis, drafting, testing, and numerical control (NC) programming in support of mechanical design automation and can be used for integration of key functions, such as design, analysis, drafting, testing, and manufacturing, into each phase of the product development. The I-DEAS application software consists of five families:

1. Solid modelling,
2. Drafting,
3. Numerical control,
4. Finite element modelling and analysis, and
5. Wireframe analysis.

Each family consists of other subfunctions that are available through cascading menus. For example, the solid modelling family consists of the following functions: (a) construction geometry, (b) object modelling, (c) feature definition, (c) assembly modelling, (d) pearl data transfer and manager, (e) mechanism design, and (f) drawing layout and component attributes.

The solid modelling family available in I-DEAS provides a complete 3-D solid modelling capability for each part. Objects are constructed using a Constructive Solid Geometry (CSG) interface. Several primitives, such as sphere, cone, cylinder, block, are available. The objects can be manipulated by orienting, combining, cutting, deforming, or editing the object's history tree (Constructive Solid Geometry-CSG) using a "work bench" concept. The object information is stored using a hybrid CSG-B-Rep (boundary representation) data structure. The feature definition function provides the ability to define any part feature, such as a slot, step or a hole, and uses these features in subsequent solid model of parts. The assembly modelling function provides the ability to check assemblies of parts, check for any part interference, and provides the ability to animate the assembly sequences. The solid modelling family provides outside interface to data in the form of IGES (Initial Graphics Exchange Specification) or the ASCII Universal File Format.

The drafting family is a 2–1/2 dimensional drafting package that can be used to construct conventional orthographic projection drawings. Isometric, perspective and other projections can also be constructed from the orthographic views. The I-DEAS Drafting provides several methods for geometry creation. One of the most useful is the "on-screen T-square." In this mode, it is possible to apply the same layout approach as on a drafting board equipped with a drafting machine. It is also possible to switch on the T-square, set it to an angle, and use the mouse or cursor to run the electronic pencil along the vertical or horizontal direction. The drafting module has interfaces to IGES, ASCII and NC languages such as APT and COMPACT II.

The I-DEAS Numerical Control family provides the capability for tool path visualization for different machining processes such as milling, turning and cutting. The Finite Element family provides tools for complete finite element analysis of objects including automatic finite element mesh generation. The Frame Analysis family performs linear and non-linear analysis, limit analysis, modal analysis, and harmonic and forced responses as well as seismic shock-spectra analysis.

The I-DEAS provides the following major advantages:

1. Flexibility: it includes several modules that could form the basis for product development from concept through production,
2. Hardware independence: it is available in a variety of workstation platforms (SUN, DEC, HP, etc.),
3. Open architecture: it can be integrated into existing engineering environment through existing or customized interfaces,
4. Industry standards: it supports industry standards for graphics, networking, windows and data exchange, and
5. Programming capability: it has its own programming language, Ideal, that can be used for programming the various operations in IDEAS.

AUTOCAD

AUTOCAD is a personal computer-based CAD system. It supports all the two dimensional drafting functions for creating multi-view drawings. Some basic 3-D wireframe primitives, such as cube, cone, and sphere, can be modelled but CSG boolean operations are not supported for creating objects. AUTOCAD can thus be classified as a 2-D drafting package with some wireframe 3-D solid and surface capabilities. It is by no means a true solid modeler. Knowledge of basic CSG modelling techniques to create objects is not required in AUTOCAD. AUTOCAD is primarily used in the 2-D drafting mode to create multiple views of an object. It is also possible to project a particular view onto a plane to create a wireframe isometric view of the object. AUTOCAD provides graphic interfaces, IGES and DXF (AUTOCAD specification) in text file format, through which graphic data can be extracted. It also contains an additional feature, AUTOLISP, which is a LISP like language that allows the user to create limited capability programs for AUTOCAD.

Mechanical Engineering 10 (ME-10)

ME-10 is a two dimensional drafting system developed by Hewlett Packard and is oriented towards mechanical engineering. It provides for general 2-D drafting capabilities. The user interface consists of an on-screen menu and a menu on the digitizer tablet. The user can choose commands or functions from either the tablet menu or the on-screen menu.

METHODS

Users

The usability of the three CAD systems was evaluated by “real user participation” method (Kishi and Kinoe, 1991). The users were not considered either particularly friendly or hostile (Hewett, 1986). In all, eleven users participated in the evaluation.

While users may be classified as novice (beginners who are learning the system), occasional (users who know the system but use it on an infrequent basis-once a week, fortnight or month), and frequent (users, most likely experts, who use the system on a daily basis), a good computer-aided system is one which can accommodate all of them by considering all their needs. The users who participated in this evaluation could be classified as occasional users; all were familiar with all three CAD systems and used them on a regular, but not daily, basis.

Usability Measures

A number of usability measures have been described in the published literature. Some of these measures are: time to perform the task, errors that occur at user interface, verbal and visual protocols, patterns of use, visual scanning patterns, and attitude. Most of these measures are, however, ineffective means of evaluating the usability of an interface as they really do not identify the problem areas and areas that need improvement. Many are also sensitive to distortions or do not account for the varied background and speed of learning of users (Norman, 1983; Shackel, 1981; Ericsson and Simon, 1980).

In order to evaluate the usability of the three CAD system interfaces to carry out realistic tasks using these systems and to avoid the problems associated with the various usability measures, the method (The Evaluation Checklist) developed by Ravden and Johnson (1989) was used.

The Evaluation Checklist

The evaluation checklist consists of sets of specific questions aimed at assessing usability (Ravden and Johnson, 1989). Each set of questions pertains to a specific criteria. This checklist was modified to suit our needs. This meant selecting appropriate evaluation criteria, paraphrasing questions in each set, eliminating or adding questions in each set, and modifying the answer format. A total of nine different criteria are included:

1. Visual clarity—Information presented on the screen should be clear, well-organized, unambiguous, and easy to read.
2. Consistency—The way the system looks and works should be consistent all the time.
3. Compatibility—The way the system looks and works should be compatible with user conventions and expectations.
4. Informative feedback—User should be given clear, informative feedback on where he/she is in the system, what actions he/she has taken, whether these actions have been successful, and what actions he/she should take next.
5. Appropriate functionality—The system should meet user needs.
6. Flexibility and control—The system should be flexible in structure and present information suitable to control the system.
7. Error prevention and correction—The system should minimize user errors and must also have the facility to detect and check errors.
8. User guidance and support—Informative, easy to use and relevant guidance and support should be provided.
9. System usability problems—Problems experienced when using the system should be identified.

The number of questions in each set of questions pertaining to these criteria ranged from 6 to 21. These questions, though specific, are too numerous to be included in the limited space here. The answer format for these questions was also modified by replacing the original 4 choices for frequency of occurrences (always, most of the time, some of the time, never) to a 7-point scale (1=never, 7=always, 4=average). In addition to the questions in the set, an overall assessment question for each criterion was also asked. For example, for visual clarity criterion the question was “Overall, how would you rate the system (I-DEAS, AUTOCAD or ME-10) in terms of visual clarity?” A 7-point scale (1=very poor, 7=very good, 4=neutral) was used for marking the answer.

In addition to set of questions for the above 9 criteria, user answered specific questions concerning the structural aspects (13 questions), sketching and drawing characteristics (12 questions), and computational capabilities (11 questions) of each CAD system. These questions were designed by the authors and required answers on a 7-point scale. Overall, each user answered 150 specific usability questions in his/her evaluation of each of the three CAD systems.

RESULTS

The answers of all users to each specific question (values between 1 and 7) for each evaluation criterion were averaged for each of the three system. The average values for all questions for each criterion were tabulated separately. Next, the values for all three systems for each evaluation criterion were grouped in one table for statistical analysis.

The Kruskal-Wallis Test was used to analyze the response data. Data for each evaluation criterion were analyzed separately. Thus, eleven different Kruskal-Wallis tests were carried out. Each test compared the three CAD systems for a specific criterion. The final results of data analysis are summarized in Table 1.

Table 1. Summary of Kruskal-Wallis tests on usability evaluation data.

Criterion	CAD system comparison	Systems different?
Visual clarity	AUTOCAD vs. I-DEAS vs. ME-10	Yes (Alpha<0.05)
	I-DEAS vs. ME-10	Yes (Alpha<0.05)
	AUTOCAD vs. ME-10	Yes (Alpha<0.10)
	I-DEAS vs. AUTOCAD	Yes (Alpha<0.05)
	Best>worst: AUTOCAD>ME-10>I-DEAS	
Consistency	AUTOCAD vs. I-DEAS vs. ME-10	Yes (Alpha < 0.05)
	I-DEAS vs. ME-10	Yes (Alpha < 0.05)
	AUTOCAD vs. ME-10	No (Alpha≥0.10)
	I-DEAS vs. AUTOCAD	Yes (Alpha<0.05)
	Best>Worst: AUTOCAD>ME-10>I-DEAS	
Compatibility	AUTOCAD vs. I-DEAS vs. ME-10	Yes (Alpha<0.05)
	I-DEAS vs. ME-10	Yes (Alpha<0.05)
	AUTOCAD vs. ME-10	Yes (Alpha<0.05)
	I-DEAS vs. AUTOCAD	Yes (Alpha<0.05)
	Best>Worst: AUTOCAD>ME-10>I-DEAS	
Informative feedback	AUTOCAD vs. I-DEAS vs. ME-10	Yes (Alpha<0.05)
	I-DEAS vs. ME-10	Yes (Alpha<0.05)
	AUTOCAD vs. ME-10	Yes (Alpha<0.05)
	I-DEAS vs. AUTOCAD	Yes (Alpha<0.05)
	Best>Worst: AUTOCAD>ME-10>I-DEAS	
Appropriate functionality	AUTOCAD vs. I-DEAS vs. ME-10	Yes (Alpha<0.05)
	I-DEAS vs. ME-10	Yes (Alpha<0.05)
	AUTOCAD vs.ME-10	No (Alpha≥0.10)
	I-DEAS vs. AUTOCAD	Yes (Alpha<0.05)
	Best>Worst: ME-10>AUTOCAD>I-DEAS	
Flexibility and Control	AUTOCAD vs. I-DEAS vs. ME-10	Yes (Alpha<0.05)
	I-DEAS vs. ME-10	Yes (Alpha<0.05)
	AUTOCAD vs. ME-10 I-DEAS vs. AUTOCAD	Yes (Alpha<0.05)
		Yes (Alpha<0.05)

	Best>Worst: AUTOCAD>ME-10>I-DEAS	
Error prevention & correction	AUTOCAD vs. I-DEAS vs. ME-10	Yes (Alpha<0.05)
	I-DEAS vs. ME-10	No (Alpha≥0.10)
	AUTOCAD vs. ME-10	Yes (Alpha<0.05)
	I-DEAS vs. AUTOCAD	Yes (Alpha<0.05)
	Best>Worst: AUTOCAD>ME-10>I-DEAS	
User guidance & support	AUTOCAD vs. I-DEAS vs. ME-10	Yes (Alpha<0.05)
	I-DEAS vs. ME-10	Yes (Alpha<0.05)
	AUTOCAD vs. ME-10	Yes (Alpha<0.05)
	I-DEAS vs. AUTOCAD	Yes (Alpha<0.05)
	Best>Worst: AUTOCAD>ME-10>I-DEAS	
Structural aspect	AUTOCAD vs. I-DEAS vs. ME-10	No (Alpha≥0.10)
Sketching & drawing charac.	AUTOCAD vs. I-DEAS vs. ME-10	No (Alpha≥0.10)
Computational aspects	AUTOCAD vs. I-DEAS vs. ME-10	Yes (Alpha<0.05)
	I-DEAS vs. ME-10	Yes (Alpha<0.05)
	AUTOCAD vs. ME-10	Yes (Alpha<0.05)
	I-DEAS vs. AUTOCAD	Yes (Alpha<0.05)
	Best>Worst: I-DEAS>ME-10>AUTOCAD	

In 7 out of 11 included in Table 1, AUTOCAD was considered far superior to either ME-10 or I-DEAS. ME-10 was better than I-DEAS in 8 of the 11 criteria; it was superior to AUTOCAD in 1 of the 11 criteria. The three CAD systems were considered similar as far as the structural aspect and sketching and drawing characteristics were concerned. I-DEAS was considered the best CAD system among the three systems as far as computational aspects were concerned; computational aspects of ME-10, surprisingly, were considered superior to AUTOCAD. Overall, AUTOCAD was considered most usable, followed by ME-10 and I-DEAS.

The most significant AUTOCAD usability problems were:
Lack of guidance, understanding how to carry out the tasks, finding needed information, knowing where and how to input information, an inflexible HELP facility, awkward input device (mouse), frequently too many steps to remember, and finding needed information.

The most significant problems with ME-10 were:
Knowing what to do next, losing track of where you are in the system, screen clutter, awkward input device, slow system response, lack of guidance, tablet and menu, unexpected actions by the system, spending too much time correcting errors, extra care to avoid errors, finding needed information, and an inflexible HELP facility.

The most significant problems with I-DEAS were:
Lack of guidance, working out how to use the system, poor system documentation, difficult to read information, spending too much time to correct the errors, extra care to avoid errors, understanding how to carry out tasks, knowing what to do next, finding needed information, having to carry out the same task in different ways, losing track of where you are in

the system, an inflexible HELP facility, having to remember too much information, unexpected actions by the system, poor guidance to the user, and obtaining menus.

DISCUSSION

The results of the usability evaluation were mixed in some ways. The intuitive conclusion that usability declines with enhanced functionality was true in the case of I-DEAS but not in the case of AUTOCAD, which was considered more usable than ME-10-a CAD system which is comparatively least sophisticated. If one goes by only the system usability problems, all three CAD systems have significant problems; ‘it is just the degree and extent of difficulty that differs. In that regard, all three CAD systems are severely lacking. Given the increasing popularity of I-DEAS for solid modelling and finite element analysis, it is important that its interface with the end-user be significantly improved. One way to accomplish it would be through user interface simulation.

CONCLUSIONS

Of the three CAD systems evaluated for usability, AUTOCAD was considered most usable. This was followed by ME-10 and I-DEAS, which was considered least usable but functionally the best.

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ERRORS IN DETERMINING REQUIRED DISTANCE FROM DANGER POINT FOR OPENINGS IN FIXED GUARDS

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For machine hazards guarded by fixed guards, safety standards allow a gap in the guard for inserting things, provided the gap is sufficiently far from the hazard that a person could not insert any part of their hand far enough through to be harmed. The relationship between gap size and safe distance is presented in several safety standards as a diagram. This study found that typical users of the standard sometimes misunderstand the diagram and select distances that are not as safe as intended.

INTRODUCTION

Occupational safety standards in Western industralized countries include provision for openings in machine guards for loading and unloading parts/material for processing. These standards make this allowance subject to the provision that a minimum distance (B) is maintained between the opening and the point of operation or other hazard point. The length of B depends on the height of the gap (A). The gap height for a slotted opening is the shorter of the two sides. Both dimensions, A and B, used in the standards were chosen on the basis of hand, wrist, and arm anthropometry.

To illustrate how a standard setting committee would go about developing a standard, consider the case of small gaps. Anthropometric data would be consulted to determine what gap height would be small enough that not even the tip of the little finger could get through it. This would involve a decision about the percentile of people to fully protect. Using a one-percentile value would mean that only one percent of the population could insert the tip of their little finger through the gap. This one percent would not be protected. Consequently, a standard setting committee might select a gap height somewhat smaller than the one-percentile value (A_1). The standard would then provide that a gap less than or equal to that height is allowed even if the distance of the gap from the hazard (B_1) is zero.

For a gap height large enough to allow insertion of the tip of the little finger, a different stopping point would be used. The first (distal) joint of the little finger would serve as a stopping point for a finger being inserted through the gap. By selecting a gap height value for the one-percervtile person, the expectation would be that 99 percent of the population could only insert their little finger as deep as their first joint. Other fingers are thicker and could not be inserted this far. Once the value of the gap height is determined from anthropometric data, a standard setting committee would choose a somewhat smaller gap height (A_2) for the second specification of safe distance. To select a safe distance for this gap height the committee would again consult anthropometric data for length of fingertip to first joint of the little finger. A high percentile value would be sought in order to have a standard that would protect people with long fingers. For example, a committee might use the 99th percentile length and then choose a somewhat longer distance for B_2.

Several sources of data on the anthropometry of the hand, wrist, and arm provide useful information. Some of the landmark sources are Garrett (1971), National Aeronautics and Space Administration (1978), and a pair of papers by Davies et al. (1980). An experimental approach to assess validity was used by Thompson and Booth (1982).

As a result of the empirical approach to deriving the gap-distance relationship, no mathematical formula exists to simply and correctly calculate one value from another. Instead, a diagram is included in standards (e.g., British Standard for Safeguarding of Machinery 5304:1975; Australian Standard 1219:1987-Metalworking Power Presses). In the United States the Occupational Safety and Health Administration regulations use a similar figure except distances are expressed in inches and there are some extra lines and words that make it even more complicated (CFR 1910.217).

Safety personnel or manufacturing engineers are expected to use the diagram without making any mistakes. The purpose of this experiment was to determine if the expectation of mistake-free use is realistic.

METHODS

Subjects were ten students taking a graduate level class on “Machines and Structures Safety”. The diagram shown in Figure 1 was discussed during a lecture. Students were told to expect test questions on the use of the diagram. A test given three weeks after the lecture included four questions requiring use of the diagram in Figure 1.

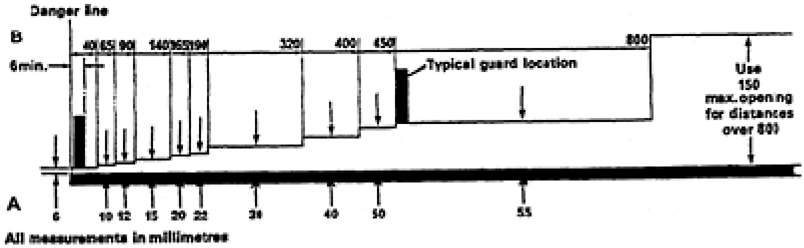

Figure 1. Diagram used in test.

Also included on the test was a narrative explanation of the diagram found in the British Standard 5304:1975 and quoted below.

> "When it is necessary to provide a slotted opening in a fixed guard for the purpose of feeding material to, or removing it from a machine, the opening should not allow a person to gain access to the dangerous parts. The larger the opening, the greater should be the distance of the guard from the dangerous parts.
>
> While the effectiveness of any fixed guard should always be judged by a test to see that finger tips cannot reach beyond a safe limit, a guide to the relationship between gap A in a guard and its distance B from the danger point can be obtained from the diagram. For example, if it is necessary to provide an opening 30 mm deep then the guard should be set not less than 190 mm from the danger point."

The first two test questions gave a gap size, A, and asked students to find the safe distance, B. The last two questions gave B and asked students to determine the allowable gap, A. Answers were considered correct even if the student put a greater than sign when it should have been greater than or equal to; similarly for less than answers that should have been less than or equal.

RESULTS

Results are presented in the Table 1. The first three columns show the question, correct answer, and percentage of wrong answers. The last column indicates if the error would have made the set-up safer (S) of more hazardous (H) than the correct answer.

Table 1. Summary of errors.

Question	Answer	% Wrong	Effect of Errors
Given A=22 find B	≥165	20 %	S, S

Given A=38 find B ≥320	10 %	H
Given B=400 find A ≤50	30%	S, S, S
Given B=300 find A ≤30	40%	S, S, H, H

For the two questions in which a gap size (A) was given, there were three errors. Two of the errors would have led to a safer guard placement than required by the standard. One error would have led to a more hazardous guard placement.

For the two questions in which a minimum distance (B) was given, there were seven errors. Five of the errors would have led to a safer (smaller) gap size than required by the standard. Two errors would have led to a gap size larger, and more hazardous, than that intended by the standard development committee.

DISCUSSION AND CONCLUSIONS

Concerning the issue of subject representativeness, some background on the subjects is appropriate. Nine of the ten subjects were employed full time in technical jobs while taking university classes in the evening. The other was a final year engineering undergraduate student. Eight of them were graduate students in the Safety Science Department pursuing a graduate degree in either safety science or ergonomics. Backgrounds such as these are believed to be reasonably representative of people who perform safety work in those manufacturing facilities with conscientious safety programs. Less conscientious firms that try to get by without a professional safety person would be more likely to make mistakes using the diagram.

This study did not include any attempt to assess the quality of the distances found in the diagram. It is entirely appropriate that these values would differ from country to country due to differences in population anthropometry and availability of representative data.

Another way of presenting the information in the diagram is by using a pair of tables. Table 2 may be used for a situation in which the gap height is given and the minimum distance is sought. Table 3 is for situations in which the distance from the hazard is set and the allowable gap height is sought.

Table 2. Given gap height, A, determine minimum distance, B. All dimensions are in mm.

Gap Height	Minimum Distance
0–6	≥0
6.1–10	≥40
10.1–12	≥65
12.1–15	≥90
15.1–20	≥140
20.1–22	≥165
22.1–30	≥190
30.1–40	≥320
40.1–50	≥400

50.1–55	≥450	
55.1–150		≥800
greater than 150 not allowed		

Table 3. Given minimum distance, B, find allowable gap height, A. All dimensions are in mm.

Minimum Distance	Gap Height
0−39.9	≤6
40–64.9	≤10
65–89.9	≤12
90–139.9	≤15
140–164.9	≤20
165–189.9	≤22
190–319.9	≤30
320–399.9	≤40
400–449.9	≤50
450–799.9	≤55
≥800	≤150

It is concluded from this small study that the method of presenting the relationship between B and A is such that errors in use are forseeable. Three of the ten errors would have made the set-up more hazardous than the correct answer. Therefore, a clearer way of presenting the material is needed. A new way of presentation is provided in a more recent British standard (BS 5304:1988) using only five pairs of A-B values. It has a drawing of a person inserting a particular body part through a slotted opening. Below each drawing are the applicable range of A values and B values. This way of presenting the information should be tested to determine if any particular error patterns are apparent.

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COGNITIVE ERGONOMICS OF A MAIL ORDER FILLING COMPANY, EFFECT OF WAITING, AND WORK DENSITY ON RECOGNITION TIME

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Filling mail order requests require pickers to recognize whether an item is in his/her work territory and then fill the order. This study investigates cognitive issues associated with order recognition, specifically waiting time between recognition and work density in a computerized simulation of the mail order picking task. Results indicate that increasing work pace and work density do not reduce performance significantly. This may be due to an efficient recognition strategy which facilitates "chunking" and divided processing of order codes.

INTRODUCTION

This is the third in a series of investigations of a local plant of a national company that fills about 25,000 orders which translates to 50,000 items distributed per day. For this industry, large scale automation is not feasible due to the diversity of the products, fluctuation of demand, and small batch sizes. Therefore this operation depends primarily on human effort to recognize, retrieve, and distribute items that are ordered.

The facility has a picking line with continuous belt and roller conveyer on two floors. This conveyer system has tote buckets (0.61 m×o.30m) which carry an order. As illustrated in figure 1., the picker reads the order form on a tote bucket, recognizes whether an item on the order form is in his/her territory, makes a decision, and finally takes action. If an item is in the picker's area, then he/she will retrieve the item, place it in the tote box, and check the item off the order form. If the order form is completed, then the picker will put the tote box on another conveyer which takes it to shipping where it is boxed, verified, taped, addressed, and routed to a specific truck dock.

Location address codes are used to inform pickers where to retrieve items from. The coding system is compatible with the floor layout. Floors are divided into subsections called bays. Each bay has four rows "D" through "A" in descending order from top to bottom and five or six columns which are based on product size. A typical location address code consists of four specific location specifications, for the

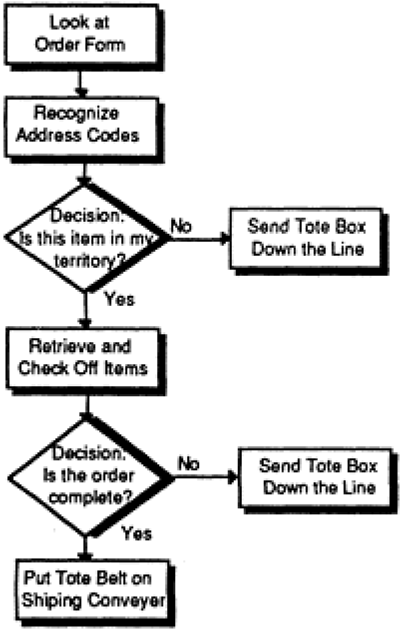

Figure 1. Order Filling Task

code "ZZ 19 A4", ZZ is cue that the order is on the first floor, 19 is the bay number, and A4 means that it is in row A column 4.

The cognitive issues for this task can be described as follows: (1). Recognition is occurring when a picker is in the process of determining whether items on the order form are in his/her territory; (2). Acquisition is the process of retrieving an item after it has been determined that the item is in a picker's territory. In a previous study (Bishu, et, al., 1991a), color, position, and highlighting visual cues were varied systematically in a computerized version of the order filling task to determine their affect on recognition time and error rate. Fourteen subjects (seven experts and seven novices) participated in a factorial study. Primary findings include: (1). Color improved performance of novices while position enhanced the performance of experts, (2). experts were slower but more accurate than novices, and (3). highlighting had no influence on performance.

In a follow up study, acquisition time was studied by varying shelf labeling and address information presentation in computer-simulation order filling task. Fourteen subjects (seven experts and seven novices) participated in this factorial study. Important findings included: (1). experts were slower but more accurate than novices, (2). continuous displaying of address information increased accuracy but decreased acquisition time, and top to bottom labeling ("A" to "D" as opposed to the current system of "D" to "A") improved performance time (Bishu, et. al., 1991 b).

Two other concerns, which may influence the cognitive demands of order recognition task, are the waiting time for an order and the work density. The waiting time is an indication of work pace which depends on how quickly and frequently tote boxes come on the conveyer. Waiting time involves the cognitive issues of time stress and arousal. The work density is the frequency at which an operator has items on the order form that must be filled. Work density deals with the cognitive issues of expectation and vigilance.

The interval between trials is probably one of the most important influences on performance in a serial reaction time paradigm. The most important factor in a forced paced task is interstimulus interval (Wickens, 1984). Increasing the rate of pacing did not induce corresponding reductions in performance for both RT and accuracy (Waganaar and Stakenburg, 1975). Broadbent (1971) attributes this result to arousal effects, that is, increasing pace increases subject arousal which improves reaction time and accuracy. This study will examine the effects of task pace (waiting time) and the frequency of stimulus presentation (work density) on order filling recognition.

METHODS

Task

The same generic order picking paradigm employed by Bishu. et. al., (1991a) was modified for this experiment. This computer simulation of the picking task was performed in a laboratory on an IBM PC at the University of Nebraska-Lincoln. The program generated location address codes for the subjects to view and recognize whether or not the items corresponding to the address code was in their territory. Subjects were responsible for items with the floor code ZZ and columns 19–22. Subjects pressed the 4 key for a "Yes" response and pressed the 6 key for a "No" response. There were four experimental conditions with a hundred trials in each condition.

Subjects

Ten subjects were taken from the student pool at the University of Nebraska-Lincoln. All subjects were considered as novices to the order filling job. Each having only general training on the task paradigm before they were tested.

Experimental Design

A 22 factorial design was used in this study. Two levels of waiting time between trials (five and ten seconds) and two levels of work density (85% and 35%) were factorially combined to yield four treatments. Each subject performed all the treatment conditions.

Procedure

The order of presentation of the treatment conditions was randomized. Each subject performed 100 trials for each treatment. A trial consists of the following steps:

1. The location address was displayed on the screen and the clock was started,
2. The subject responds by hitting the "Yes" or "No" key,
3. The number possible "Yes" responded is determined by the level of work density,
4. The response time and the response accuracy is computed by the computer, and
5. The next trial is presented with either a five or a ten second delay.

RESULTS

The data were analyzed using SAS package and an ANOVA procedure was run for the main effects of waiting time and work density for both response time and error rate. Results shown in figure 2. indicate that while the corresponding mean response time at a waiting time of 5 seconds was 1.02 seconds and response time for a 10 second waiting time was 1.24 seconds. However, this difference was not statistically significant. The mean error rate for a 5 second waiting time was 3.5% while the mean error rate increased to 5% for the 10 second waiting time, with difference also being statistically insignificant effect. Curiously, work density had virtually no effect on response time or error rate.

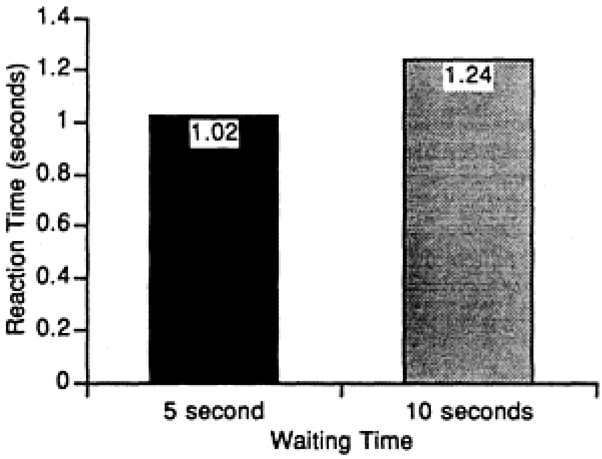

Figure 2. Mean reaction time for different waiting times.

DISCUSSION

The recognition time and the error rate was not significantly increased when the work pace was doubled. This may be due to the fact that the recognition task was simple enough to allow operators work just as efficiently at the fast pace. Consider, that it is a single task with simple detection and recognition of a code and placing that code into two response categories (yes or no). Figure 3. illustrates that subjects can divide the recognition task into the following steps: (1). determine whether the item is on the operator's floor (any code beginning with ZZ); (2). If it is not on the operator's floor, then respond "no"; (3). If it is on the operator's floor, then check whether the item is in the operator's territory (columns 19–22); (4). If it is, then respond "yes", otherwise respond "no". By sub-dividing the recognition strategy, operators are perhaps able to reduce demands on memory which reduces cognitive load. In addition, a faster work pace has been shown to increase arousal (Broadbent, 1971) which may compensate for any detrimental effects due to work pace which is consistent with the observations of Waganaar and Stakenburg (1975).

Surprisingly higher stimulus frequency had no significant effect on response time. There was no effect due to expectancy.which implied that operators did not recognize orders any faster when they expected a majority of the items to be in their territory. Again, this may be due to the fact that they employed an efficient recognition strategy discussed above. Due to the fact that such a strategy made their task simple, the work pace did not cause significant time stress effects.

The implications for order filling are that the design of order coding numbers can facilitate "chunking" which reduces cognitive load during order recognition. Having the code divided functionally so that operators need not process parts of the string they do not require reduces cognitive load. The results of this study show that code design is a more important factor in code recognition than either waiting time or work density. If a mail order company designs their operations to employ coding that facilitates more efficient information processing, they will be able to use varying work paces and work densities. Typically, mail order companies have diverse product lines, fluctuating demand, and continually changing products. This environment requires operations to be flexible. Well designed order codes allow engineers and managers to assign operators to work bays with a variety of work densities and work paces. A limitation of this work is that the effects of work pace and work density on order acquisition is unknown. These factors may play a more significantly role in performance when the recognition task is followed by the acquisition task.

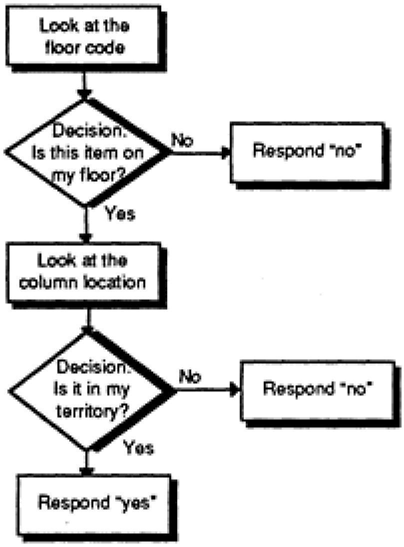

Figure 3: The two stage order code recognition strategy.

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USING COMMUNICATIONS ANALYSIS TO MEASURE ROLE RELATIONSHIPS DURING SIMULATED EMERGENCIES

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INTRODUCTION

Background

Proper operation of modern technological systems requires that the social subsystems function in optimal ways. To ensure safe, efficient operations, each subsystem should be designed to fulfill a specific function. Usually the functions are highly specific, and specific tasks performed by each component are equally specific. In most technological systems, only the human operator is allowed flexibility of role and task.

One of the unique features of the human subsystem is this flexibility of role. It can be argued that the ultimate safety feature of a nuclear power plant, high speed train, or “jumbo-jet” is the flexibility of the human operators. It can also be argued that this flexibility (also known as variability) may result in unsafe conditions as well.

Since 1985 the current authors have investigated the relationship between characteristics of the human subsystem and performance in nuclear power plant control rooms (Wheeler, et al, 1988; Toquam, et al, 1991). To date we have collected performance data from over 600 simulated sessions in a nuclear power plant. These sessions have involved both routine operations and simulated abnormal events.

During early phases of the project, we found that social variables, specifically stress and leadership characteristics, moderate the relationship between individual and crew abilities and performance. This observation lead to an interest in the mechanisms that might explain what was causing this moderation.

Communications Patterns

One of the more popular ways to evaluate organizational processes is through observation of communication interactions among group members. Observations of communications within a group can be made of in several ways. The direction and flow of communications can be determined (Bavelas, 1953) by recording the linkages between the people involved in the communications event. These linkages should also include the transfer of topics from one person to another as the information moves through the group. This is a relatively simple process when individuals are involved in “table-top” activities (e.g., business meetings), because the observer can usually determine the object of the communications through observation of eye contact, head turns, and the like. In a nuclear power plant control room, however, the accuracy of observations drops significantly and the difficulty of making them increases substantially. A second possibility is to analyze the content of the communications (Ericsson and Simon, 1984; Sanderson, et al, 1989; Wheeler and Fleming, 1991). While this technique provides the richest and most reliable data for determining the interactions that take place within a group, it involves preparing a verbatim transcript of the communications; this is often prohibitively expensive. In this project we estimate that between 5,000 to 10,000 person hours would be required to generate transcripts of the control room communications during the training simulations. A third possibility is to categorize the communications as they occur (Bales, 1950); this approach yields information about the relative frequency of communications categorized into a limited range of types. This has the advantage of being relatively easy to do and it is a process that can be done in real time.

All three of the major approaches to communications analysis, (i.e., flow, categorization, and content) provide indications of the role being filled by the speaker. In terms of simplicity and ease of use, however, categorizing communications has considerable advantages over the other approaches (Bales, 1950). To ensure that use of this simpler approach is appropriate, it is first necessary to determine if the method is sensitive enough to detect differences between roles, where such role differences would be determined by situational variables.

Developing a working hypothesis

To minimize the risk of human variability, particularly during critical operations, most systems designers develop detailed procedures which dictate how the human subsystem should interact with the rest of the system. In control rooms, such as in nuclear power plants, aircraft cockpits and process control rooms of chemical plants, these interactions are specifically structured by emergency procedures. Implied by such procedures is the concept that individuals within a group have specific roles. In general, there are role divisions in terms of coordination, action, and support.

The basic operating crew of a nuclear power plant consists of three distinct functions. These include: (1) a Senior Reactor Operator (SRO), who is responsible for the coordination and direction of the other members of the crew; (2) a Reactor Operator (RO), who is responsible for the operations of the systems associated with the nuclear reactor; and (3) a Turbine Operator (TO), who is responsible for the operations of the systems associated with the electrical generating equipment. A malfunction of either the reactor system or the electrical generation system may lead to a serious accident. Therefore, emergency procedures are developed which implicitly result in a shift of the functions of coordination, action, and advice that depends on the task requirements of the emergency. It should be noted that role relationships are relatively static during routine operations, with the SRO providing coordination, the RO generally concerned with action, and the TO providing support. Because routine operations are the norm, and emergencies are generally encountered in simulations, we can expect that there will be a strong tendency to remain in the role of primary experience.

If communications categorization is a potentially useful tool for evaluating the subtle changes in processes caused by social stress and leadership characteristics, the technique should be sensitive enough to detect differences in the roles that occur during different simulated emergencies. This paper describes the results of this attempt.

METHOD

Setting and Instrumentation

Data collection took place in a high fidelity nuclear power plant control room simulator that had been specially instrumented for the purpose of the study. Instrumentation included the use of four fixed video cameras which had sufficient overlap to cover the entire simulator and wireless microphones attached to the neck of each of the crew members. Recordings were obtained during the entire simulation which generally lasted between 20–30 minutes.

Subjects

Subjects participating in the study were experienced nuclear power plant control room operators undergoing annual week long retraining. Prior to this training, they were briefed as to the general purpose of the study, as well as on the use of the equipment. On the first day of training, we administered a number of ability tests and personality measures. We also had the subjects fill out a short questionnaire following each simulation. With the exception of these activities, we had no other contact with the subjects. The study simulations were interspersed with other training scenarios throughout the week, subjects were not informed if they were in a study simulation or just one of the training simulations.

Data Collection

Raw data for the communications categorization was obtained from the video and audio recordings taken during the simulation periods. These recordings were then reduced to categories by nuclear power plant engineers familiar with the terminology of the control room. Observers were trained on the technique using a tape made during the pilot study. The categorization scheme used was a modified version of the original Bales categorization scheme. The modification was intended to make the categories more appropriate to the structured interactions that take place in a nuclear power plant control room during an emergency. Table 1 shows the categorization used.

Table 1. Modified Bales Categories.

1. Asks for information.
2. Gives report on alarm status or other system condition.
3. Provides information requested.
4. Gives instructions for some control action.
5. Makes suggestions.
6. Release of tension
7. Demonstrates frustration, anger, or makes a derisive comment.
8. Give acknowledgment of either a report or information provided.
9. Talking to oneself such as reviewing pending actions.
10. Unable to code, garbled, unclear

Data Analysis

Raw data from the communications categories was transformed using a log transform. The log transform allowed the data to be analyzed without having to consider the differences in actual responding between crews or as a result of different emergency procedures.

The transformed data was then factor analyzed to determine the factor structure of the categorization scheme. Analysis of Variance (ANOVA) of the factor scores was then used to determine if there were significant differences between the factor scores of the various emergency scenarios. Once this was determined, a separate factor analysis was performed for each scenario in an attempt to understand the factor structure, and thus, the likely role relationships, for routine operations, and each of the emergency scenarios.

RESULTS

Initial Factor Structure

A principle components analysis of 352 normal and emergency scenarios resulted in six factors with eigen values exceeding one. A principle axis analysis of the same data indicated the same factor structure existed using both approaches so all remaining analysis were restricted to the principle components technique. Definitions of the factors are as follows:

> Factor 1 accounts for 35% of the variance and consists of communications that indicate what might be considered normal task and role relationships between the SRO and the remaining two crew members. This factor is characterized by the condition in which the RO and TO provide the SRO with requested information and the SRO directs them to take a specific action.

Factor 2 accounts for 9.9% of the variance and consists of communications that indicate frustration on the part of the crew accompanied by suggestions from the RO and TO to overcome these frustration.

Factor 3 accounts for 6.7% of the variance and consists of communications that indicate an attempt by the crew to reduce stress or tension.

Factor 4 accounts for 6.1% of the variance and consists of communications that indicate the SRO is given general guidance to the RO and TO as they conduct coordinated actions.

Factor 5 accounts for 4.1% of the variance and consists of communications that indicate the TO is trying to understand what is happening in the plant.

Factor 6 accounts for 3.6% of the variance and indicates a state of frustration or anger by the SRO and possible the TO.

Anova by Scenarios

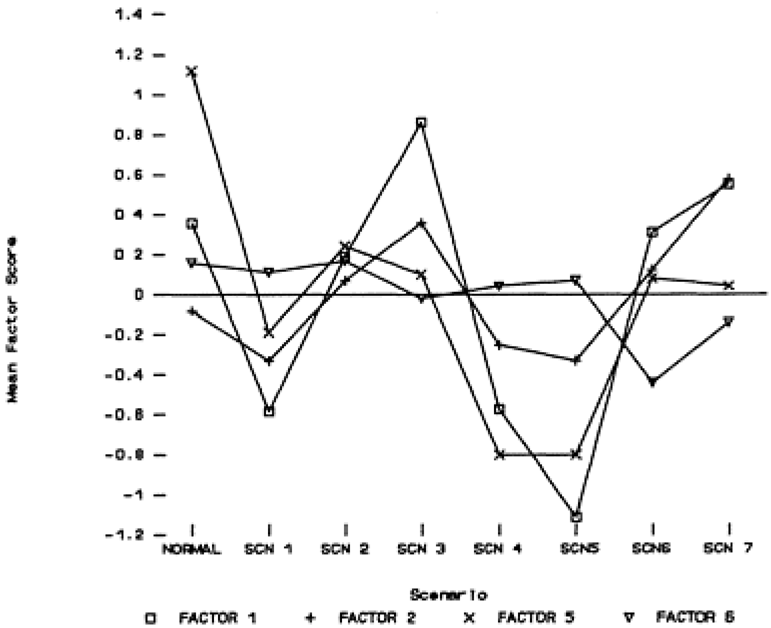
Analysis of Variance (ANOVA) were then conducted of the six factors that had been generated in the initial factor analysis. Four of the resulting analyses showed significant main effects for scenario indicating that their was a difference in factor loading that was dependent on the emergency scenario. Table 2. shows a summary of the ANOVA results.

Table 2. ANOVA Summary of Factor Scores by Scenario

Factor	F	Sig
One	21.541	p<.0005
Two	7.271	p<.0005
Three	.717	N.S.
Four	.163	N.S.
Five	11.799	p<.0005
Six	2.170	p<.05

Scenario Based Factor Differences

Figure 1 shows the mean factors scores across the normal and seven abnormal scenarios (SCN1-SCN7) for the factors that were statistically significant (F1, F2, F5, and F6). As can be seen in the figure, the pattern of scores is quite different across the range of scenarios. The pattern of factor scores for each condition is also interpretable.



Factor 1 has a pattern across the scenarios that is indicative of the sort of communications you would expect from a situational variable of differential ambiguity. In all but three of the most ambiguous conditions (SCN 1, SCN 4, and SCN 5), the mean scores on this factor tend to be moderately high. However, in these three conditions where ambiguity is high, the factor scores are well below normal (specific guidance from the SRO isn't offered when the situation is ambiguous).

Factor 2 has a pattern across the scenarios that is indicative of the sort of communications you would expect from a situation that was either highly complex, mimicked other situations, or was difficult to diagnose. This factor tends to follow the same course as does Factor 1 (frustration follows ambiguity).

Factor 5 has a pattern across the scenarios that is indicative of the sort of communications you would expect from an individual (TO) who has an active monitoring role during normal operations and under relatively unambiguous conditions. This is consistent with both the structure of most emergency procedures and his relative inexperience in the plant.

Factor 6 has a pattern across the scenarios that is indicative of the sort of communications that you would expect from an SRO who is usually able to either control the situation directly or has time to search for solutions.

CONCLUSIONS

Several conclusions can be drawn from the body of this report. First, is that the simple communications categorization scheme we used yields a factor structure consisting of six distinct and interpretable factors. Second, that the magnitude of these factors varies as a function of the situation (i.e., normal condition or abnormal scenario) and that for four of the six factors the resulting differences are statistically significant. Third, that the resulting patterns of factor scores are both interpretable and consistent with what we would expect from the scenario involved. These findings supports the assumption that the pattern of communications is not constant, but rather depends on the situation. This in turn supports the hypothesis that communications patterns, task and role relationships, change despite of the use of detailed emergency procedures, extensive training and well ingrained habits.

The modified Bales communications categorization scheme is both an economical way to collect information on the communication process within a nuclear power plant control room and appear to be suitable for examining the relationship between these processes and the link between individual and crew characteristics and performance.

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TOWARDS COGNITIVE ENGINEERING WORKBENCHES CONSIDERING TIME FOR THE “INTELLIGENT” DESIGN OF OPERATOR ASSISTANCE TOOLS

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In this article, we will first of all study the problematic issues of knowledges and of temporal strategies used by the human operator in the control rooms of complex industrial process. We will then check off and discuss the different tools and the current knowledge engineering workbenches which are susceptible to make the knowledge acquisition, structuralization and formalization easier for the ergonomist and the knowledge engineer. Finally, we will emphasize on certain temporal tools available in Artificial Intelligence which can contribute to the development of knowledge engineering workbench considering explicitly the time.

INTRODUCTION

As a consequence of the technological development, the human operator of the industrial process control room is less and less involved in manual control tasks. However, he must more and more realize complex cognitive tasks to solve problems (Rasmussen, 1986; Moray 1986). In complex processes, the tendency consists of assisting the operator by tools which are based on Artificial Intelligence techniques. One can find in the literature a lot of studies which contribute to the development of assistance systems (see for instance the works of Helander, 1988; Millot, 1988; Boy, 1990; Tendjaoui et al., 1991, and so on). To be really efficient, it is important that these tools consider how the operators use time in their different tasks. However, the acquisition, the structuralization and the formalization of knowledges and of temporal strategies pose obviously a problem which is not solved yet. The ergonomist and the knowledge engineer themselves are practically unprovided with in such a field. At the present time, cognitive engineering workbenches are starting to come out. But, these workbenches do not seem to be really adapted to the problematic issues of human tasks in control room. The coming of temporal logics in Artificial Intelligence makes now the study and the realization of knowledge engineering workbench possible considering explicitly the time. This particular point constitutes the main idea of our article.

Our article consists of three main parts. In the first one, we will study the problematic issues of knowledges and of temporal strategies used by the human operator in the control rooms of complex industrial process. In the second one, we will check off and discuss the different tools and the current knowledge engineering workbenches which are susceptible to make the knowledge acquisition, structuralization and formalization easier for the ergonomist and the knowledge engineer. We will make clear that there is a lack of knowledges in terms of temporal aspects. In the third one, we will emphasize on certain temporal tools available in Artificial Intelligence which can contribute to the development of knowledge engineering workbench considering explicitly the time.

TEMPORAL KNOWLEDGES AND STRATEGIES OF THE HUMAN OPERATOR IN A CONTROL ROOM

For many years, the problematic issue about time has lead to active research in psychology (seethe works of Piaget, 1946 and Fraisse, 1957 quoted by Decortis, 1988).

As for the study of the temporal dimension of the human operators activities in the control rooms of complex industrial process, it has dealt with a new trend of research in work psychology for only about ten years. It already begins to bring results which contribute to better understand the intervention of the time in the human operator's reasoning and knowledges. Many field studies now contribute, without any doubt, to the specification of the future assistance tools. The reader will refer for instance to pioneer studies of De Keyser et al. (1987), Dorner (1988), Decortis (1988) or De Keyser (1990).

For example, in a control room of continuous steel casting, De Keyser et al. (1987) explain that the part of direct actions given to the operator is weak but, on the other hand, the control room changes into a “dispatch” room. In addition to the supervision of process and actions in the form of orders which modulates the actions of other workers, the operator manages and coordinates all the activities surrounding the casting machine. Thanks to information exchanges with the staff, he detects or collects the technical failures, he works out a pre-diagnosis and appeals to the department concerned, in addition to other administrative tasks. The operator must then be in interaction with many other workers. According to many field studies, the subjects developed by the operators when they communicate verbally are different: dated or undated facts, numerical data, tendencies, estimations related to a chronology of actions, qualitative valuations, judgments, references to the past, reactions to certain operator's decisions. These different types of verbal communications are used as a support for information and make the estimation, the judgment and the diagnosis easier in some situations. They are used as a collective memory which can be refreshed by the operator and from which he can constantly draw information. They include the notion of time according to different aspects.

Many other works show well the cognitive wealth of the human operator's work. For example, in his study about the temporal dimension of operators cognitive activity when a thermal power station starts, Decortis (1988) emphasizes on many temporal aspects of the work realized by the operator, such as: (1) durations of changes of states concerning process parts are estimated according to the content of events, temporal limits and variation speeds, (2) he reasons temporally on process elements which are more or less interdependent, (3) basing on an estimation about the duration of the action and of the annex events duration, he must judge when the right time is to intervene, (4) he must manage in an optimal manner the action simultaneity, (5) he synchronizes collective actions realized by different intervening parties, (6) he reduces the time for events in order to make up delays, (6) watching the evolution of events, he waits before intervening at the right time, (7) according to the situation of the process running, the operator must adapt himself and develop strategies oriented towards two aspects: (i) chronological and sequential strategies, (ii) simultaneity strategies.

With regard to such temporal aspects, De Keyser (1990) discuss the difficulties that the operator can face when evaluating, integrating, coordinating or planning the machine system, and the errors which can be associated with these situations.

These different works show the importance of the real needs concerning he human operator's assistance in control rooms. In the development process of assistance tools in complex systems, the tendency consists of using computerized tools, particularly for acquiring and formalizing the knowledge. But these tools are not really adapted yet to the temporal problematic issue of assistance. A study in this field is dealt with in the following paragraph.

REVIEW OF THE METHODOLOGIES AND TOOLS FOR KNOWLEDGE ACQUISITION IN RELATION TO THE DEVELOPMENT OF ASSISTANCE TOOLS

Whatever the application considered may be, the current approaches to knowledge acquisition can be based on a large variety of methods, techniques and tools, most of them are imported from other sciences (psychology, linguistics, epistemology, software engineering, artificial intelligence…) and adapted for being computerized.

Many tools, which are specific to one or several acquisition techniques, are currently existing. We can mention, for example: ETS (Boose, 1985) based on repertory grids techniques, MACAO (Aussenac, 1989) based on protocol analysis, ROGET (Bennet, 1985) and MORE (Kahn, 1985) based on interviewing techniques. Many other tools are described by Boose (1989). However, each of these tools seem to be too specific for a given task. In any case, none of them really enables to represent explicitly the notion of time.

New researches try to combine many knowledge acquisition techniques in order to look like toolboxes, like AQUINAS, a kind of knowledge acquisition workbench including repertory grid, interviewing and scaling techniques (Boose, 1989). The Esprit project called ACKnowledge is about the study and then the integration of machine learning and the techniques and tools for knowledge acquisition, to result in a coherent computing environment called KEW (Knowledge Engineering Workbench). The workbench associates techniques for knowledge collect (cards sort, repertory and scaling grids) and machine learning techniques (by generalization). The selection of these techniques depends on the type of knowledge to deal with and the way these knowledges are represented. At some points of the process, the obtained elements of knowledge are included and the quality of the knowledge base which is being built, is evaluated in order to establish what should be complemented, refined or made coherent (Julien, 1991). In comparison with the various temporal strategies brought into operation by a human operator in a control room of complex systems, these workbenches seem to be insufficient in spite of the variety of techniques that they offer to the designers.

At the origin, the first knowledge acquisition methods, associated with the life cycle of a knowledge-based system, were often based on the rapid prototyping. A prototype was first of all developed and then refined until the final knowledge-based system was obtained. This incremental approach has lead the development of many knowledge-based system methodologies (Hayes-Roth et al., 1983, Nassiet, 1987, Benkirane et al., 1991). This process, also called structured acquisition of knowledges (Johnson, 1988) enables to collect the knowledge and to develop field models, independently from any other setting up. By extension of methods issued from other sciences, these researches have resulted in the development of very formalized and powerful methodologies, such as KADS and KOD which are briefly described below. Such methodologies seem to be particularly attractive with respect to the field concerned

The KADS methodology, issued from the area of epistemology, has the aim to guide the process of knowledge based system development, from the organization of the domain to the development of the whole system. Based essentially on the construction of several models, it breaks the domain organization into stages where the problem is decomposed into component parts and the analysis of knowledge is separated from its machine implementation. KADS has three modelling levels: (1) a language to describe the conceptual model; this model constitutes an intermediate representation between the expert’s data and the design/implementation of the knowledge based system; (2) a design module describing how the conceptual model and the external needs can be represented within an appropriate framework; (3) a module of modalities to specify the co-operation and the communication between the knowledge based system and the user. The success of KADS has been represented by the marketing of a tool called OPEN KADS. The workbench has proved itself in large applications and especially on the SACHEM (Système d’Aide à la Conduite des Hauts fourneaux En Marche) project developed for SOLLAC. This project consists of realizing an intelligent system based on expert knowledges to help the decision taking, in order to supervise the blast furnaces in metallurgy. The KADS methodology does not explicitly mention how to manage the temporal notions. We can think that, on the strategy level, where is represented the strategic reasoning about a problem, it is possible to take into account temporal constraints of a process. However, it has to be underlined that the designers of KADS are now thinking of the management of time in the methodology.

The KOD methodology (Knowledge Oriented Design) concerns the acquisition of an expert’s knowledges (but only by interviewing techniques), their modelling based on the retranscription of the verbalizations, and finally a specification of the knowledge base according to a multiple step analysis of the verbal data. Also based on a knowledge modelling, the KOD methodology offers a cognitive model which is used as an intermediary between the natural language of the expert (practical model) and the computer language in which the knowledge based system will be implemented (computing model). On the cognitive level, the expert uses “taxonomies”, “actinomies” and schemes of interpretation and reasoning (Vogel, 1988). From this data acquired from the verbalizations of the expert, the practical mode allows to obtain a specification of the expertise, which states precisely the field and the phases of setting up the expertise. The practical model is leading the collect of data in order to make the future knowledge structuralization easier. Then, the collected data is reduced in order to recognize the manipulated units in the expert’s speech (cognitive model). KOD is now called K-Station which is available on the market. The time notion is not explicitly considered in the K-Station. However, this notion is explicitly mentioned by Vogel when he deals with the “actinomy” by decomposing it in elementary sequences, which are combined in order to produce complex sequences. Vogel suggests that Allen’s model (see the next paragraph) enables to calculate the temporal relations between the events.

Despite of promising researches which are envisaged or led with the goal of taking explicitly into account the time, many temporal aspects are however insufficiently dealt with in the tools, techniques and methods which are susceptible to contribute to the realization of assistance systems for the human operators in the control rooms of industrial complex systems. So, even if knowledge acquisition finds its resources in different fields, the temporal tools in the artificial intelligence are not claimed a lot. Nevertheless, in the following paragraph, we will see that different temporal tools are able to deal with problems related to dynamic complex processes.

THE POTENTIAL CONTRIBUTION OF TEMPORAL TOOLS IN RELATION TO KNOWLEDGE ACQUISITION AND MODELLING

In artificial intelligence, we can see the emergence of logical formalisms and tools for the explicit management of time, when a problem is being solved (Bestougeff, Ligozat, 1989). For a considered application, it is necessary to choose the most adequate primitive temporal entities. The systems based on “points” are used the most, because the are easy to model. In fact, a representation based on punctual entities does not represent naturally the notion of duration. The need of extensive entities has led to different definitions for the interval: sub-sets of points, couples of points for instance (Libert, Dergal, Millot, 1990). According to these authors, a second important choice concerns the relations between these entities. In all the cases for the representation of time, a fundamental relation is the one of precedence. This relation can then be refined in several notions, such as: “has begun strictly after/before”, “has started simultaneously at”, “just before/after”, and so on. When there are temporal intervals, other relations come naturally, for instance the insertion between two time intervals. Finally, a critical point concerns the circumstantial choice of the properties that the relations between the temporal entities must satisfy. In certain applications, it is possible to use a discrete modelling. For others applications, a continuous point of view is necessary.

In artificial intelligence, the basic models which are the most used to model the time are those of Allen (1984) and McDermott (1982). These models have been at the origin of many studies, extensions and realizations leading to deduction systems. For example, the NEMO inference engine based on the temporal model of Allen is used to realize real-time knowledge based systems to assist the supervision of industrial processes (Tang, 1990; Gambiez et al., 1991).

According to Allen (1984), time is an abstract notion which only exists with regard to the evolution of the universe, and thereby which is perceptible only thanks to environment changes. The practical representation of time is therefore linked to the evolution of the environment, i.e. to the concepts of event, state, situation, succession of states and so on. This model is essentially based on time intervals. A set of thirteen basic binary relations describes all the possible ways two intervals can be related to each other. Three entities are then, taken into consideration: the properties about intervals, the events and the processes during an interval.

According to McDermott (1982), the time is considered in a continuous manner and basic entities of the model are a set S of states a set T of instants. So, this model uses the notion of world state representing a photograph of the world at a fixed time. The definition of temporal points as elementary entities for the representation of time comes from this model. Some facts are identified with subsets of the set of states. In this model, an event can have a duration. This one corresponds with a succession of states in which the event happens only one time, and is missing in the states near this succession. McDermott has introduced afterwards notions enabling the manipulation of basic entities.

In spite of their limits, the McDermott and Allen's models have introduced a basic formalism, which is used as a reference for different models full of promise for an efficient management of the temporal relations. The reader will refer for example to temporal models developed by Ghallab and Alaoui (1989), Ermine and Cauhapé (1990).

Each of the quoted temporal approaches can contribute to a time modelling in the knowledge engineering workbenches, which are used by the designers in the process of assistance tools development for the operator in complex systems. The integration of these temporal aspects requires a close collaboration between work psychologists, ergonomists, knowledge engineers, automatists and computer scientists.

CONCLUSION

The strong computerization and automatization in complex industrial processes lead to needs about systems considering explicitly the time, for the assistance of the human operators in control rooms. The development of such assistance systems requires the use of more and more improved tools, able to acquire, structuralize and formalize expert knowledges and strategies. We can consider that these tools are only being studied, realized or validated in the industrial and university research laboratories.

However, to obtain efficient tools able to facilitate the development of assistance systems which are adapted to the temporal needs of the human operator, it is necessary to organize work groups composed of work psychologists, ergonomists, knowledge engineers, automatists and computer scientists. Each of these intervening parties indeed has complementary knowledges concerning: (1) the real needs of the human operators in control rooms, (2) the tasks to be performed, (3) the characteristics of the man at work, (4) different technical, ergonomical and methodological aspects related with knowledge acquisition, structuralization and formalization, (5) techniques, tools and methods issued from artificial intelligence, and so on.

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COMPUTER AIDED ERGONOMICS

AN EXPERT ADVISOR FOR WORKPLACE EVALUATION

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INTRODUCTION

The architecture of an expert system for ameliorating the conditions of workers at workplace is described. The methodology of how to incorporate ergonomics factors, a particular architecture of an expert advisor approach, and the use of an intervention man/computer dialog, is under development at the Technion—Israel Institute of Technology. The project aims to enhance the design of working conditions to be resulting of poor arrangements, or due to lack of knowledge for creating a safe working layout. An extensive range of knowledge on ergonomics and Human Factors subjects has been gathered and organized into a computer program—the expert advisory system. It is intended to be used as an evaluation and design tool by a wide variety of users, and has thus been made easy to operate, whilst providing guidelines and design suggestions, regarding workstations and their surroundings.

It has been noticed in many practical examples that incorrect or inadequate workplace design and operation have decidedly negative effects on working capability, productivity, and on worker health and well-being. It is believed that more and better knowledge about ergonomics factors, and easy accessibility to such knowledge, can contribute significantly to the successful planning of manned working cells and work spaces, with a resultant improvement in working conditions and outputs. It can enable those dealing with the ill-effects of poor conditions, such as medical personnel, to see more clearly the connection between ill-health and incorrect posture brought about by these conditions. The need for guidance is thus indispensable; the need for an easily accessible and automated guide is vital if such guidance is to be provided to all those concerned with the quality of working life. Such a guide, would prompt the user for information about the worker and the working environment, it would provide him with insight regarding those conditions best favoured for the given situation. Today the technology exists for creating and utilizing such advisors: expert system technology, we as few other research groups, are working on harness of this technology to the benefit of work safety.

At first sight, it may seem pretentious to try to incorporate the whole subject of ergonomics in a single computer-based system. No system can be so comprehensive as to be able to answer all questions addressed to it; nor has a given problem a single or totally-definable solution. Specialists in areas such as architecture, acoustics and climatic will usually be required in order to obtain the most favorable answer. Nevertheless, knowledge incorporated in a expert system can cover the main design parameters and also make the designer aware of the multiplicity of factors entering into good workplace design.

METHODOLOGY

We envisage two levels of interaction and consultation with the expert system when solving a workplace design problem: (1) the ergonomic professional or his/her deputy; and (2) the semiprofessional.

(1) The ergonomic professional wishes to obtain in-depth advice about technical or professional factors which may affect his decision making process.
(2) The semi-professional is required to solve an engineering oriented problem such as workstation design or redesign in a real life framework. Such activities include: doctors dealing with a work-related trauma; safety officers checking out the acceptability of a work-related situation; and industrial engineers, personnel managers and work foremen (especially in a small organization) dealing with the design or implementation of a work station.

The system incorporates a flexible approach to evaluate parameters such as equipment configuration, thus allowing a designer freedom of choice in developing a suitable design. Moreover, medical personnel who are well aware of the relationships between incorrect postures and ill-health, can also contribute to the elimination of such problems as a result of the guidelines and critiques provided by the system. The ergonomic advisor has been developed so as to reach out to both expert and non-expert users, who can thereby take advantage of this novel approach to workplace design without requiring sophisticated computing equipment. In realizing the aims of "guidance" and "user-friendliness" we have gone by the principle that the expert system must be able to interface with both novice and expert users.

The expert has experience in workplace design, and is thus provided with a comprehensive set of questions to be answered and a large amount of ergonomic detail based on these answers. The novice, who is feeling his or her way around the idea of workplace design, is not required to interact so extensively with the advisor. Each user can decide, of course, into which category he or she falls; and during the same session the user can switch from one mode to the other.

The decision process is based upon the concept of an array of data (requirements, actual measurements), some of which are provided by the user. Not all data need to be furnished, however; the system uses default values if necessary, or computes values based upon stored ergonomic rules. The resultant total array can be seen as a consistent set of values which may have been input or derived—i.e. serving as both input and output.

In order that the design process be both logical and effective, the order in which each aspect is explored and determined has to be sequenced correctly. We work "top down", from general to detailed aspects, using a hierarchical series of displays. Most topics presented in each display are linked to one or more detailed displays at a lower level. For example, when developing a station configuration, the first screen asks for the working position—sitting, standing, kneeling, etc. When one of these postures is selected, the next display asks for equipment details: table, chair, computer, telephone, etc. When one of these items is selected, a subsequent display presents recommended dimensions for the item, such as seat height and breadth. Parallel displays provide a schematic layout of the work station element, with recommended measurements, and textual recommendations and critiques regarding the element, such as suggested materials of construction or colors, or the fact that dimensions are too small or too large.

LEVELS OF WORKPLACE DESIGN

The program envisage three levels of comprehensiveness at which workplace design and evaluation can be carried out: (1) The data category, which is supporting the basic workplace design. (2) The working category, to provide considerations regarding the working environment. (3) The supporting category, contains considerations for failure analysis aspects, references and biomechanical related evaluations, as seen in table 1. These three levels are arranged at the expert's operating engine as envelopes which are to be peeled at users request They are operated starting at the data category for basic workplace design.

Table 1 The general three program categories.

Category	Content
The data category	Anthropometric information on the worker to be accommodated (such as sex, weight, body measurements). Characteristics of actual posture involved, and desired workstation equipment which constitute the basic design parameters.
The working category	Information regarding actual or required working conditions: climate, light, noise and vibration.
The supporting category	Information regarding support for the system recommendations, Biomechanical sources, references and formulae's.

At the workplace design level, three traditional ergonomic design and evaluation factors are taken into account: anthropometry of the worker for whom the station is being designed, worker posture during activity at the work station, and equipment to be operated at the station.

Anthropometry: all design starts with anthropometric information, gender and body measurements of the worker, and classification of these measurements according to accepted percentile intervals. After supplying the actual anthropometric data of a subject, according a list supported by the system the posture screen is activated. Two levels of details are offered:

(1) Semi-professional users are provided with a list of basic anthropometric factors and values, based upon percentiles These are related to normal and maximum working areas and clearances.
(2) Professional users are provided with more extensive data covering all body components and regions such as finger, foot and waist dimensions, and clothing allowances.

Posture: here we deal with aspects of given working posture, we evaluate postural efforts, relate to postural discomfort and provide lists of possible reasoning for postural related problems. The system provide evaluations in two levels of expertise. At the semi-professional level, we consider unsuitable postures and the likely pain to be caused, an example is shown in Table 2. At the professional level we look at further factors and more detailed evaluation, here again we relate likely risks of pain as presented in Table 3.

Table 2 Posture screening at the semi-professional level.

Posture	Likely site of pain
Standing	Feet, lumbar region.
Sitting with lumbar support	Lumbar region.
Sitting w/out back support	Erector spine muscles.
Sitting w/out footrest support	Knees, legs, lumbar region.
Arms reaching upwards	Shoulders, upper arms.
Lifting heavy weights	Erector muscles, lumbar region.

Equipment: here we deal with several aspects of equipment (furniture, tools) to be provided for the worker. Matching equipment to workers and their capabilities is a difficult design problem, and must be based on considerations, at the two interactive levels, such as seen in Table 4.

In order to confirm and analyze the match between worker and workplace design the expert system will present a graphic (animated) picture of the work station and the worker. This enable the user to view the station from different angles, check how the worker fits into the furniture, and provide an animated simulation of the work situation.

Table 3 Posture screening at the professional level.

Posture	Likely risk of pain
Standing in one place	Feet, legs, varicose veins.
Sitting erect without back support	Extensor muscles of the back.
Seat too high	Knee and neck.
Seat too low	Shoulders and upper arms.
Head inclined forward	Neck, deterioration of discs.

Environmental factors: at this level three ergonomic design and evaluation factors are considered which influence the worker's performance safety and special needs (such as operating a battle tank). They encompass: vision and light; noise, sound and vibration; climate and heat; the depth of knowledge will be different at each user level.

Evaluation and failure analysis factors: one of the most significant changes in ergonomics practice that has taken place during the past two decades has been the expansion of the areas to which it has been applied. In particular, it is realized that the "system" component of a "man/machine system" embraces more than just interface displays and controls on the one hand, and the workplace and its environment on the other. In our opinion ergonomics, and a expert advisor in this area, should relate to organizational well-being as much as to individual well-being. This can be done most effectively by supporting and empowering the professional with the deeper knowledge required to enable a competent evaluation and failure analysis of a man-machine situation. The expert system tool implement and support decisions in the following areas: Biomechanics (back and lower/upper extremities), Methods and measurements, Cumulative trauma disorders and Data sources for detailed professional references.

The program is interactive and is composed of dialog windows linked together in a top-down way. The first (top) window leads to secondary more detailed ones, which in their turn lead to more specific ones up to the last: and most. detailed window on the course. It is possible to move from every window to another, more detailed one, or vice-versa-to the one we came from. In this way every window forms a 'crossroad' from which secondary windows stream out, and from where it is possible to to return to the previous crossroad, up to the starting point. To change a course it is necessary to reach the right crossroad from which point the wanted course may easily be selected and attained. Usually there is no short-cut from one course to another.

Table 4 Screening the equipment category at two professional levels.

Consideration	Semi-professional level	Professional level
Anthropometry	Basic	Detailed.
Furniture	Table, chair	Further extensions.
Tools	Simple tools, handles	Power tools.
Object to be handled	Weight	Shape, size.
Task	Frequency	Safety.
Editions		Stairs, ladders, Aisles, corridors, Containers, Material transfer and Controls.

The advisory program contains display screens, input and output information screens. The output screens are drafts of working station or equipment, relevant information etc. Input screens are windows enabling upward, downward and sometimes sideward motion as shown by arrow bars, for filling up of data. Where a data entry line appears, typing just 'enter' is allowed, thus reaching the window with the detailed subject on that line. Instructions regarding leaving of window and/or motion on course appear at end of frame, right corner. Lowest line in window describes place of orientation inside the three phase structure.

CONCLUSIONS

The methodology of an expert system as an advisory tool for workplace evaluation was developed in the frame of an ongoing project at the Technion's Research Center for Safety and Human Factors. Our intention, at this stage, has not been to necessarily find the "best formula" for determining each ergonomic factor; any such formula can always be replaced by a more reliable or effective version. Rather, we have demonstrated that it is possible to develop a systematic method for the design and/or critiquing of a workplace environment; that the method is user-friendly; that a wide range of factors can be included; and that these factors can be represented and presented in modular fashion. Thus the system, which is already more than just a prototype, can serve as the basis for the development of a far more extended system.

For each aspect at the proposed expert advisor for ergonomic evaluation, the user can go down the design hierarchy as deeply as he or she wishes; and can explore as many aspects as necessary. The outcomes (advice and criticism) are "optimal" in the sense that they reflect the extent to which information has been provided to the system, and the "optimality" of the rules and formulae incorporated. If actual data conflict with those out forward by the system, of provides comments on the "inadvisability" of the current station parameters and suggests, when it can, how to overcome them.

A unique feature of the advisor is the incorporation of an extensive battery of recommendations and comments. These cover physiological factors, such as worker capabilities and endurances; environmental factors, such as colors and noise levels; and psychological factors, such as effects and postures on attention spans and productivity. Some are specifically geared to the work station being designed or critiqued; others provide general advice on good design. Particular attention is paid to correct posture. The system points out back, leg and arm problems that are likely to occur if correct furnishings are not provided. Moreover, should the worker have a specific problem—such as pregnancy or obesity, or physiological or age-dependent disabilities—the system recommends devices, such as adjustable seats, footrests and working surfaces, which can be of help. We intend augmenting these comments by allowing complaints to be entered—on behalf of the worker—and possible causes to be displayed. More extended user support is provided when dealing with the working environment. The user may be unable or unwilling to determine noise, lighting or climate conditions. The system provides additional "reference information displays" which can be consulted in such cases: data tables and graphs listing typical parameter levels in given environments—such as noise conditions in offices, or when using certain types of tools, or temperatures during certain seasons. The user can select the relevant data from these sources to be included in his or her data array.

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ERGONOMIC EVALUATION OF PRODUCT FUNCTION AND WORKING ENVIRONMENT IN A COMPUTER-AIDED-ENGINERING SYSTEM

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The purpose of this communication is to report from a project, the aim of which is to develop methods and procedures for graphic simulation and ergonomic evaluation of product function and work (postures and movements). The intention is to enable designers and manufacturing engineers to perform this evaluation in a CAE environment. In this way the ergonomic consequences of a design concept as well as a work place layout can be made clear very early during the product development process when changes still are possible to make.

Introduction

Overload injuries are a serious problem in all industrialized countries. In Sweden these injuries have made up more than fifty percent of all reported occupational injuries for many years. Large efforts have been devoted to improving the working conditions, but obviously in vain, since the rate figures have not decreased. The reason for this is multifactorial, no doubt, as different demands from the society on the working life pull in different direction. For example, investments for increased productivity have to compete investments in the environment. Even when no such conflicts are at hand, the injury rates do not decrease, which is difficult to understand. One explanation can be that the working conditions are not improved in many companies, particularly in the mechanical engineering industry where the number of injury cases is high. To understand this it is necessary to look in to how working conditions are created. In a recent study Trygg (1) pointed out the fact that the better part of the production methods and also the production costs are determined already at the engineering design stage of product development. This also means that most of the working methods and conditions are determined at that stage and that little can be done to improve working conditions when the production is being planned. The situation could be much improved if the conditions of work in the production could be evaluated during engineering design. To accomplish this it is necessary to provide the engineers with a tool by means of which the work can be simulated and ergonomically evaluated. Computers with capabilities for modeling and animation can be used for this provided that the relevant software is available.

The purpose of the present paper is to report from a research project with the purpose to develop methods and procedures for simulation and ergonomic evaluation of work by means of graphical computers and software for modelling, animation and biomechanical evaluation.

Procedure

In the project a graphical workstation computer is used and a software environment consisting of a modeller and a multibody systems analysis module is built up. The modeller is used to build the environment and an anthropometric human body model. The multibody systems analysis module is used to calculate static and dynamic forces and torques, and to help the user to create an acceptable movement pattern. It is also used to visualize the resulting movements.

The anthropometric body model is used for evaluation of reach distances, space requirements, visual obstacles or constraints and comfort angles of joints. The body model is not only a geometric model in the CAE system but also a mathematical model in the multibody systems module. This means that the biomechanical calculations is made on the same model.

The manikin is created from a feature in the CAE system. The other objects are created from start, or if they have been used before, retrieved from a datastorage device, and positioned in proper locations. In case of a product function evaluation the geometric description of the object is retrieved from the ordinary CAD system. A feature creates a geometric model with specified relations from some input data. In the case with the manikin it could be that the user gives a percentile and some angular data as input. The user should also have the option to select different body constitutions, for example “thin” or “heavy”. The CAE-system would then create the manikin automatically with correct measures and constitution.

The movements of the operator model are planned and described sequentially. If an analysis of static postural stress is going to be performed, the relevant postures for analysis are identified. The manikin is placed in these postures and positional and angle data are used as input to the MBS program. For each joint a calculation of torques and resulting forces is done. The resulting values are compared with established reference values and if they are too high the working situation is changed until a satisfactory result is obtained. If a dynamic stress analysis is requested, the movements are described kinematically. This description is then used as input to drive the manikin and the inverse dynamics capability of the MBS program is used to drive the manikin kinematically and to calculate the forces and torques in the joints that are required to achieve the prescribed motion. The instantaneous magnitudes of the resulting forces and torques are then compared with reference values as before. In the dynamic case weighted time integrals of the forces and torques are also calculated as measures of the dose of load that a person doing the same task as the manikin would be exposed to. When suitable criteria are established, the load on the body can be optimized. An important result of the simulation procedure is the three dimensional graphical output which demonstrates what the work place and the work task would look like but which can be used also for evaluation by having experienced people make their judgements of the situation.

All the controling of the different degrees of freedom on the human model is made in the multibody systems module. Depending on what kind of analysis is made, different controls are used. In the kinematic case the user can guide the model interactively or by use of subroutines. The use of subroutines is useful if the user wants to guide some part of the human model along a movement path. The user could then draw a path in the CAE system with spline curves and create the subroutine to guide the model. The kinematic case can be used for evaluation of reach distances and space requirements. In the dynamic and the inverse dynamic case the model is guided by subroutines. In the dynamic case the user would prescribe the forces acting on the model, and in the inverse dynamic case the user would prescribe a motion pattern and the system would calculate the necessary forces and torques to obtain the prescribed movement. This means that it is possible to first guide the model interactively in a kinematic case, and then use the movements as input to a inverse dynamic case and have all internal forces and torques calculated. This data could then be used to evaluate the dose of load acting on the model.

Discussion

In manufacturing industry, products are often designed by use of CAD systems. As part of the design procedure engineers are checking material strength and safety margins of a particular product geometry. Strength calculations are made using so called finite element methods (FEM). To expediate this procedure, programs for FEM calculations are using the same geometrical representation as the CAD system. Also, CAD systems therefore include FEM software so that the calculations and the drawings can be made in the same computer. In some cases it is also possible to perform a kinematic or even a dynamic function analysis making use of multibody systems (MBS) analysis software (2). The output can be in the form of tables or diagrams, but modern software can also illustrate movements graphically on the display screen. Graphical illustration is also important in the styling phase of product development in which case software for modelling and animation is used (3). Such software permits the creation of photorealistic images of products as well as production environment including animation which can be used for evaluation based on judgements.

An early evaluation of product design against methods for manufacturing, especially in manual assembly, is an important means to accomplish effective production and safe working conditions as well as an ergonomically correct product. In a study of the feasibility of this approach both design engineers and occupational health and safety staff considered it to be effective and necessary in the future (4). However, details of the procedure for evaluation and the ways to handle the resulting data have still to be discussed. One question is how to chose between different possible working postures and movements.

Many computer models of the human body have been developed (5). Naturally different models are needed for different purposes. The number of segments required depends on the task, e.g. manipulation of small details versus gross body movements. Also a model used only for computation does not have to have as good appearance as a model used in visualization.

Much research is on-going in the field of motion control in computer animation. Depending on your model and your goal different techniques are useful. If the model have few degrees of freedom keyframe animation is a useful technique and quite straight forward. The model is placed in position for the first keyframe, then moved to the second, third and so on. The system calculates the movement paths to reach each keyframe position. The user specifies how many frames there should be between the keyframes. With a complex model such as a human body this technique is very tedious and time consuming. This is easy to understand when considering that a simple model with 19 joints have 37 degrees of freedom, and all degrees of freedom have to be positioned for each keyframe. Another technique that could be used in this case is scripted animation. This technique is often used in robotic applications. The user writes a script, similar to programming languages. Depending of how intelligent the system is, the script can be from low to high level. In a low level system the user would have to be much more precise and describe coordinates of points in space the different joints should pass through. In a high level system the user could give commands like “walk to the door”. The script control does not, however take benefit of the graphical display in the controling phase. After the script has been written the user can see the result, but it is a tedious work to design the movements. A combination of an interactive technique like keyframe animation or path specification, and scripted animation could be very useful. The interactive technique allows the user to view all movements of the model during the design of the movement pattern. To reduce the need of controling each degree of freedom in the model, techniques like inverse kinematic can be used. This means that if the user choose to move a distal limb, and the system will calculate the movements of the proximal limbs. In this case a kinematic model is used. If a dynamic model is used it has to be guided by a low level script, specifying forces and torques acting on the model over time. Such a model will behave more naturally since gravitational forces and friction forces would act on the model. In all this controlling techniques many things can be automated (6). This will take some of the burden of the user. An automatic collision detection is a good example of such an automation. In cases when a long sequence is planed or the movements are of a repetitive type algorithmic control can be used. An example of this is walking. Instead of creating new “walks” every time a preprogrammed sequence is used. A third method to control motion is based on behaviour (7). This method specifies the motions of the model in terms of how humans behave. The user control the model by giving high level directives to, for example, impose a degree of fatigue on the model.

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HUMAN ERROR: LESSON LEARNED FROM A FIELD STUDY FOR THE SPECIFICATION OF AN INTELLIGENT ERROR PREVENTION SYSTEM

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The safety and reliability of highly automated and risky industrial systems, such as power plants, chemical, petrochemical and space industries still greatly depends upon control room operators' decisions and actions. If operators have firstly to be considered as safety agents, they also sometimes contribute to systems' unsafety through human error. In this paper, the authors try to explain how the results provided by a field study on the nature of expertise and the analysis of one human error case reported from industry have motivated the development of an original computerized error prevention system.

INTRODUCTION

The behaviour of control room operators remains a central component of the safety and reliability of any complex socio-technical system, such as systems for electrical energy production, chemical or petrochemical industries and space. In those complex environments, where energies used are enormous and the effects of human decisions are often transmitted and amplified by chains of automatized control and supervision systems, human errors may have dramatic consequences.

Thus there is a need both for understanding the nature of human error, and for developing new generations of 'Intelligent Decision Support Systems' aimed at detecting, preventing or recovering human failures in a more flexible and comprehensive way (Hollnagel, Mancini & Woods, 1986), allowing to 'keep the man in the loop'.

Psychologists effectively underline the necessity of keeping human operators in complex systems, due to their unique capability of coping with situational unforeseen events and conflicts, of compensating informational and procedural deficiencies and of managing crisis situations.

The paper is divided into three parts.

In part 1, we present a field study that took place in a Conventional Power Plant over the last three years in Belgium, focalizing on the way operators manage the start-up process of a production unit, according to their level and type of expertise.

In part 2, a short reflexion on *human error* is proposed, on the basis of a very challenging error case reported from another Belgian industrial context.

Part 3 finally indicates how results provided by those two study cases have led to the development of an original support system called ‘Cognitive Execution Support System’, the objective of it is to prevent routine errors in environments characterized by high task regularity, low reversibilty and high potential risks.

THE FIELD STUDY: OBJECTIVES AND METHOD

The article starts with the presentation of a field study carried out by A.Housiaux, S.Lejoly and later on by M. Masson in a conventional Power Plant over the last three years in Belgium. The research is sponsored by the Belgian Politique Scientifique and belongs to a research framework aimed at favouring basic developments in Artificial Intelligence.

Object

The study focalizes on the way operators manage the start-up process of one production unit (Lejoly S., De Keyser V. and A. Housiaux, 1989; Masson M., 1991 a). Its main objective is to compare operators’ strategies, monitoring styles and background knowledge according to their level of educational and practical expertise. The study was also intended to contribute to that field of Artificial Intelligence and Cognitive Psychology research concerned with experts—novices differences (Chi, Glaser & Far, 1988; Smith, 1991).

The industrial context

A conventional power plant is an industrial system aimed at producing electrical energy by transforming the thermal energy brought by conventional combustibles (coal, gaz, oil). According to the particular Belgian context, where most of the electrical power is fournished by nuclear plants, the function of such a thermal plant is mainly limited at producing electrical power either when the demand of the network exceeds a certain threshold or when there is a lowering in the overall production capacity, due to power reduction or shutdown conditions in some other plant.

Information and control systems

More than two hundreds indicators and controls are present in the control room.

The information technology is a 70’s one, with various updatings.

The use of computer is rather limited, there is no multilevel automatization and the techonolgy of graphic imaging is oldfashioned. Strictly speaking, the operator's task consists more in manual control than in supervision.

Information and control systems suffer locally from various limitations: poor functional or structural integration, geographical dispersion, ergonomical deficiences and lack of pertinent information supports and visualisation means (Housiaux, 1989).

Several technical operations cannot be directly performed from the control room. This includes both maintenance, repair and replacement operations, and production operations—like a manual valve closing. In the same way, the set of informations instrumented in the control room don't cover the whole set of potentially useful indications. Some of them are instrumented in the production unit or are of the informal type: sounds and noises, odors, vibrations, moods, etc. Those indications can only be collected in the field.

Subjects and methodology

Start up processes are managed by a team of workers.

A team is constituted by a control room operator, a production engineer (acting as a team supervisor or as an operator), a foreman and several field operators.

The control room operator's task consists in process control, monitoring, and fault management. He is supervised and assisted by the production engineer.

Five subjects participated to the study: one *experienced electrical engineer,* three *experienced operators,* with more than ten years experience of autonomous process control and one *novice operator,* with less than one year of process expertise. All those subjects normally operate in the control room of the production unit.

The study had the particularity to combine two methods of investigation: *field observations,* carried out in the production unit's control room, and *knowledge elicitation,* performed in laboratory.

Task analysis

Investigation focalized on the start-up process. The start up is a process by which the turbine's rotating speed is progressively increased to reach a threshold value needed for connecting the unit to the electrical network. Start-up is typically a *transient* process. It lasts for about ten hours before a state of equilibrium, corresponding to nominal power, can be reached.

Within that time envelope, the process can be broken down or *discretized* in a set of phases and sub-phases. Task analysis reveals that this sequence of phases is a *fixed* one. Thus the control room operator's task is a rather rigid one: it consists in going through that succession of phases, adopting a progression speed that allows to achieve the process goal—supplying the network at the prescribed time—while respecting the process technical constraints.

Salient results

Section one presents selected results regarding the *knowledge elicitation* facet, while section two reviews a set of salient results regarding *field observation*. A more complete presentation can be found in (Masson, 1991a).

Knowledge elicitation

The analysis of the answers to the questionnaire indicates that all experienced operators, including non engineer operators, share a common representation of the process evolution profile. This result can be partially explained by the strong *objective* structuration level characterizing the start-up process (see the paragraph on task analysis in section one). The novice operator excepted, each of the elicited subjects encountered enough opportunities to interiorize the control procedure and to develop a corresponding valid knowledge base of "ready to access" structured temporal representations. Those process evolutions are verbalized in a way that make them easily amenable to schemata (Bartlett, 1932), *scripts* (Shank & Abelson, 1977) or *plans* (Neisser, 1976).

Descriptions are furthermore characterized by the presence of a considerable amount of *episodic* materials (Tulving, 1983), excepted for the experienced engineer.

Whatever their level of expertise, all subjects used to *discretize* the process, using a kind of *breakdown strategy*. According to De Keyser (1991), such a breakdown strategy contributes to enhance operators' mastering by lowering and thus keeping manageable the subjective complexity of the process.

Subjects were also asked to define a list of physical concepts characterizing the process—like pressure, heat or rate flow—and to set up causal links between them in relation to the control task. The definitions obtained do not generally fully correspond to any physical standard. Some are correct, some are *approximative* and some are simply *erroneous*. In particular, subjects with less educational background in thermodynamics own kinds of *pseudo-concepts*, i.e. concepts that are a blend of, or intermediaries between canonical physical concepts.

Despite those deficiencies, approximations and conceptual errors identified in their verbalizations, experienced operators efficiently control start-up processes. How can we anage to cope with that contradiction? Maybe by recognizing that this contradiction is only a spurious one. We are indeed invited to deduce that process control efficiency does not imply an extended and fully correct knowledge of the process physics. Process control skills are, at least partially, of a different nature: if this highly efficient know-how is not based on formal theory, it must have a *practical* or *factual* origin. The hypothesis we formulate is that operators are efficient because they resort to and benefit from numerous memorized process experiences acquired through practice. *The richness of their factual, episodic and procedural know-how allows them to compensate the inadequacy of their conceptual, semantic and declarative knowledge.*

Field observations

In order to facilitate comparisons and to structure analysis, we have defined two macroindicators, namely selectivity and economy.

Selectivity is defined as the ratio of the number of indicators and controls effectively used by an operator to the number—fifty—of indication and control supports that were chosen as observation units, while *economy* is defined as an inverse function of the total number of indication gatherings and actions effectively performed during an observation session.

The first noticeable result is that economy and selectivity are positively related. The second one is that both of them increase altogether with an increase in practice and in formal education.

We interpret this result pattern as follows.

1. By the effect of practice, operative relations are progressively discovered, inferred and refined between available information sources—both formal (like indicators) and informal ones (like sounds, smells, vibrations, lights and co-occurring external events), control means and hidden process variables.

Stated in a different way, episodic materials, facts and experiences encountered during practice have two basic outcomes:

– they constitute, as such, a kind of episodic knowledge base available for *pattern matching* (Reason, 1988), and

– they yield operational relations in the form of qualitative or simplified quantitative statements, available for *reasoning* (Moray, 1988).

This acquisition process is not limited to static materials, like instantaneous indicator values. Operative relations are also drawn between formal and informal indices on the basis of *temporal properties* (simultaneity, anteriority, overlapping, etc.). The temporal structure existing among process events, control actions and indicator values and tendencies is also accessible for learning, yielding a set of operational temporal relations. Those temporal relations that turn to be invariants can then be used as *'Temporal Reference Systems'* (Grosjean, V. and Javaux, D., 1991; De Keyser, 1991) to cope with temporal planning and scheduling problems. This set of acquired temporal relations favours selectivity, provides efficient hints for coherence testing, and supports anticipation. (Masson, 1991a).

2. Theoretical laws and principles acquired during formal training and qualification stages constitute another source of knowledge. Formal knowledge structures enhance, interact and sometimes conflict with, but never fully replace operative relations issued from practice.

Practice and formal education are thus the two main facets of expertise. *Both of them support selectivity and economy by providing efficient procedural and formal knowledge systems which allow to be less dependant upon the instrumentation.*

A HUMAN ERROR CASE

Being less dependant upon external information systems certainly brings advantages: when the operator works on the basis of an internal representation instead of repeatedly refreshing it by picking up indications in the environment, he turns to be less sensitive to environmental ergonomical limitations, informational noise and instrumentation failures. Working in that 'open loop' way also contributes to lower informational work-load (Bainbridge, 1989).

But this open loop mode can also uncouple the operator from reality and trigger incident cases in a soft, hard to notice and pernicious way (Woods, Roth & Embrey, 1986). This is precisely what occurred in the case of human error reported some years ago by De Keyser and Coll., (1981) from another Belgian industrial context (See also De Keyser and Woods, 1989; Masson, 1991b).

This incident involved one control room operator during a night session. The operator's task was to monitor the treatment of recoverable materials. The task was to control by manual operations the filling of three tanks in succession, corresponding to three stages of the recovery treatment. As such, manual switch-over does not present any particular difficulty. But a change was introduced into this simple scenario, as the usual filling rate was increased by about fifty percent by the supervision engineer just before the operator came on duty. The operator had the opportunity to inform himself about that change but he did not do it. After the time needed to fulfil the first tank according to the increased rate flow, level and pressure alarms began to indicate risk of tank overfilling. The operator noticed those warnings but instead of intervening right away, he waited till the usual time—corresponding to the standard rate flow—was elapsed before ordering tank shifting. The real challenging character of that case is that the standard procedure was also carried out for the second and the *third* tank, without the operator realizing that he was behaving unproperly. It lasted six hours before overfilling was noticed by other operators outside the control room.

From a cognitive point of view, this case is particularly revealing of one pernicious effect of expertise: *the operator's conviction was stronger that any warning signal provided by the environment.* Once the operator had selected the usual strategy—which he believed to be appropriate, he became resistant to any attempt at change and assumed that all alarms he received were due to instrumentation failures.

SPECIFICATION OF AN ERROR PREVENTION SYSTEM

Results provided both by the field study and the error case reported above confirm that, as stated by W. James (1890) and Reason (1988), successful practice of any type of activity results in the gradual devolution or *delegation of control* from a 'high level', closed loop and attention-driven control mode to a 'low level', open loop and schema-driven processing style.

Devolution of control results in the setting up of what could be called 'action demons' or *semi-autonomous cognitive processors*. Those processors progressively acquire a substantial amount of autonomy in the release and control of activity, and free attentional resources from the situation at hand, both in its spatial and temporal components.

The more an operator is skilled, the more his activity relies on those ready-to-access and ready-to-use low level knowledge and control structures. As highlighted by Reason (1988), there is however a 'price to pay' for becoming skilled, as those low level semi-autonomous processors can be used in an unappropriate way, in an unsuitable context or with a wrong timing simply because they were *successfully*, *frequently* or *recently* used in the past, or because they are—at least partially—*released by the environment.*

Preventing and/or correcting those 'low level', hardly noticeable errors is the objective of a research currently carried out in our laboratory inside the IA programme. This research aims at developing and experimenting an original assistance system called "Cognitive Execution Support System", the final objective of it is to prevent routine errors in environments characterized by high task regularity, low reversibilty and high potential risks.

A software prototype has recently been implemented in lisp on a SUN Workstation by M.Masson (1). Forthcoming laboratory experiments are expected to test its validity and efficiency and to provide precious hints for subsequent improvements.

(1) The original idea of designing such a system and a first mock up were elaborated when the author was employed by Aérospatiale Protection Systèmes, a Subsidiary of the French Aérospatiale Group (Rouhet & Masson, 1991).

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THE ASSESSMENT OF CONVENTIONAL AND COMPUTER-AIDED INDUSTRIAL WORKSTATION DESIGN METHODOLOGIES

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For evaluating human-machine interface in the industrial workstation design, the methods of integrating various anthropometry of the user population are presented. In the conventional method, the manner of implementing ergonomic principles and guidelines for such a design is discussed. The computerized human modelling programs used to evaluate and optimize the design process are described. The characteristics of five main stream programs: COMBIMAN, CREW CHIEF, JACK, PLAID and SAMMIE, are presented. The computerized method of evaluation is quick and economical but its use is restrictive due to non-availability of computer program documentation and application specificity.

INTRODUCTION

With the advent of sophisticated mechanical and electronic devices, most of the industrial workstations are characterized by light but repetitive type of work. The operators are seldom required to exert physically during such work. In majority of the cases, the physiological strain of the operators result from the working posture, which in turn depends on the layout of the various components of the workstation through which the operator interacts with the system. A poor design solution of the workstation is likely to lead to improper posture. The postural or static effort will eventually manifest in acute localized muscle fatigue and consequently decrease performance and productivity and enhance the possibility of operator-related safety and health hazards (Grandjean et al. 1983).

Physiological, psychological, environmental and dimensional factors have long been recognized to affect operators performance and well being. The principles of motion economy attempt to regulate these factors in workstation design. They are directed towards improvement of productivity by optimizing the operator's performance. Corlett (1988) has proposed an alternative set of workstation design principles that are essentially based on the ergonomic considerations. These principles emphasise the requirement of proper posture of the operator. Considerable epidemiological, biomechanical and physiological research work has been done to identify the occupational factors that effect the repetitive strain injury. Several harmful working postures of the upper body has been identified to be work related factors for repetitive strain injuries (Armstrong 1986).

In an industrial workstation design, the objective is to eliminate the harmful postures and to minimize the design imposed stresses on the users. This is primarily accomplished by considering the mutual effects of anthropometry and locations of the machine elements on posture, reach, vision, clearance, and interference of the body segments with the machine elements. All these individual design factors determine the postural requirements during work. Human variability in size and capability is the main obstacle in the implementation of these recommendations in a real world design situation. It is a challenge to the designers to come up with solutions which will optimally fit the diverse anthropometry of the worker population to the designed workstation.

Generally both for a modification of an existing industrial workstation and design of a new industrial workstation, the designer is often constrained by the financial and technological factors, such as, extent of modification, available space, environment, individual equipment size and their frequencies of use, work methods, and targeted population. However, within these constraints the designer has a considerable latitude for decision making in the layout of the workstations. The design is essentially a compromise between the operators biological needs, as determined by the ergonomic criteria, and the physical requirements of the workstation in terms of the size and functions of the individual equipment in the workstation. In the conventional design method, design aids such as scaled drawings, manikins, human subjects and mockup-workstations are employed to evaluate and optimize the alternative design solutions. Graphical anthropometric computerized human models, based on computer-aided design (CAD) technology have been developed as an aid in workstation design.

The objective of this paper is to examine the methods available to the designers of an industrial workstation, particularly in the context of complexity of such a design in integrating variable anthropometry of the human operators with the workstation layout, to ensure acceptable posture of the anticipated worker population during work. After presenting the conventional design method of dealing such problems, the paper describes a selected CAD anthropometric human models by giving an up-to-date account of the capabilities of such models and the benefits offered by this new technology over conventional industrial workstation design process.

CONVENTIONAL INDUSTRIAL WORKSTATION DESIGN METHOD

The industrial workstation design procedure commences with identification of the appropriate user population, that is based on such factors as, ethnic origin, gender, and age. The necessary anthropometric dimensions of the population are obtained or approximated from the results of the available anthropometric surveys that reasonably represent the user group. The anthropometric data are mostly linear dimensions between physiological landmarks in standard postures, which designate the length and size of the human body segments. Individual dimension of the body segments are given in statistical percentile form. As these dimensions are taken from nude subjects in erect posture and they need to be adjusted appropriately for the effect of clothing, shoe and normal slump posture during work. Das and Grady (1983a) showed the derivation of such adjustments and presented a corrected set of anthropometric dimensions for male and female subjects in a readily usable form for the industrial workstation design purpose.

A natural workstation design objective is to ensure that the majority of the population of the intended user group can be accommodated comfortably, without any harmful posture during the work. User compatibility can be improved by incorporating provision of adjustment in seat or work table or bench height in the workstation design. Height of the working surface should maintain a definite relationship with the operator’s elbow height depending upon the type of work (Ayoub 1973). The range of height adjustment, thigh clearance between the seat and the bottom of the working surface, and the foot rest height for a seated operator can be calculated from the adjusted anthropometric dimensions of seated elbow height, seat height, and thigh thickness. To accommodate diverse operator size, a well known approach is to design the reach requirements of the workstation corresponding to the measurements of the 5th percentile of the representative group and the clearance corresponding to the 95th. percentile measurements, so as to make the workstation compatible for both small and large persons.

The concept of normal and maximum working areas (Das and Grady 1983a, 1983b), describes the working area in front of the worker in a horizontal plane at the elbow level and the areas are expressed in the form of mathematical models. Once the work surface height is determined, 5th, 50th, and 95th percentile normal and maximum reach profiles can

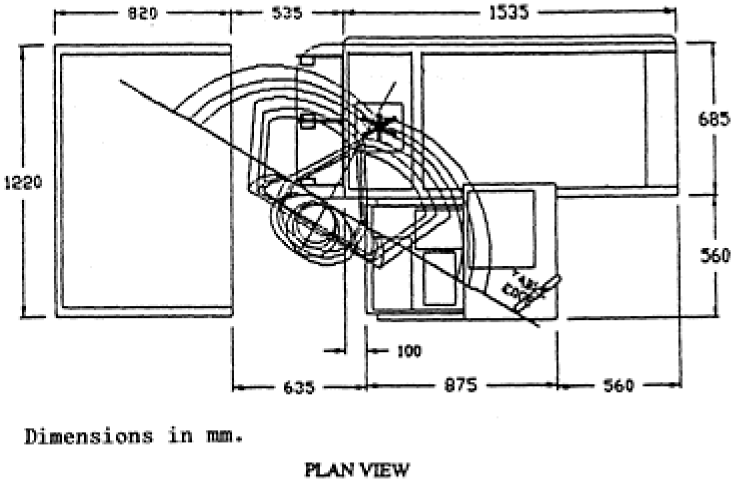

Figure 1. Normal and maximum reach ares superimposed on the plan view of a supermarket checkstand workstation.

be geometrically determined from the reach models. Such reach profiles can be superimposed on the scaled plan view of the workstation to analyze the compatibility of the operator's reach capability and the reach requirements during work. The most frequently used area of the workstation should preferably be within the normal reach of the operator and reach requirements should not exceed the maximum reach limit to avoid leaning forward and bad posture (Figure 1).

The above analysis can provide a better fit of the operators in designing a human-machine interface. However, the reach profiles are applicable only for the standard upright postures. They neither provide the interference of the body segments with the elements of the workstation, nor they can predict the resulting posture. The posture of the operator is largely determined by the geometric relationship between the length of appropriate body segments, body position and the layout of the various controls and displays in the workstation. Other than segment lengths of the human body, the interference of the workstation elements with the body segments, the visual requirements of the work also dictate the posture.

For applications where the operator has to assume a posture other than sitting in a horizontal seat or standing, use of stick figure models with variable stature is a convenient alternative to analyze the layout of the machine components. Dempster et al. (1964) expressed the mean dimension of each functional link length in terms of a regression equation of the external anthropometric dimension. Based on these link dimensions, a stick figure may represent the human operator geometrically and links can be manipulated around the joints to predict the different postures required for interaction with the elements of the workstation. Wisner and Rebiffe (1963) have described in detail how such stick figure models can be utilized to represent 5th and 95th percentile operators geometrically. They have demonstrated the method of finding the optimum location of the hand and foot controls in an automobile driver's cabin to ensure joint angles within specified limits.

Two dimensional scaled manikins representing variable anthropometry have been described by Kennedy (1982) as an aid to check operator compatibility to the workstation design on the drawing board. These card board dummies have an added advantage over the stick figure models that the breadths of the links are represented, which gives a better idea about the interference and clearances of body members within the workstation geometry. But the use of both stick figure and card board dummy are limited to the applications in two dimensional plane of the drawing board. The operator-workstation interactions in positions which do not lie in the two orthogonal planes, are difficult to predict. In the final stage of the design, it is customary to build a mock-up of the designed workstation and the operator-workstation fit is evaluated with selected live subjects. However such a procedure is subjective in nature. The selection of subjects that should represent a desired operator population often becomes very difficult Also the posture adopted by the different test subjects in such trials are not properly standardized. Nevertheless this type of evaluation is very useful before the construction of a prototype industrial workstation. However the tests are carried out in an adhoc manner and thus the test results may not be relevant

COMPUTER-AIDED INDUSTRIAL WORKSTATION DESIGN METHOD

The computerized human modelling programs for an industrial workstation design provide a convenient computer interface for the user to interactively generate and manipulate true-to-scale, three dimensional (3D) image of human and the workstation graphically on the video display terminal (VDT). Through the use of the programs, the designer can construct a large number of anthropometric combinations to represent the human. The programs give a complete control to the user over the development of the human model and provide a comprehensive package to evaluate human-machine interaction through easy to understand programmed commands. The users need not be a computer specialist to use such programs.

The human modelling programs are either developed through the use of a commercial CAD package, or written entirely in a third generation language, such as FORTRAN or C to perform similar CAD functions. Normally the user has various options to control the anthropometry of the human model. The human model is usually developed by means of interconnected links of appropriate dimensions to represent body limbs and each link endpoint represents an articulation with an adjacent segment. These links are enfleshed by developing surface patches to represent an outer silhouettes. Various programmed commands are available to bring in the human model in some user/system defined default postures, to a specified point within the workstation model. During analysis of human interaction with the workplace, programmed routines can be called through simple task oriented commands such as move, reach, and carry. These routines usually contain the joint movement range data of different body segments and prevent the human model from an unnatural body position and/or movement Thus employing different percentile values, and with such task oriented commands the posture, reach, clearance and interference can be visually evaluated in 3D for an industrial workstation design.

Other than the basic abilities to manipulate the human model, as described above, various programs have incorporated additional functions to improve upon human-machine interface analysis. Some of these are: rendering and colouring to augment computer generated drawing, multiple window to present more than one view at a time, visual field of the human model at a given posture, biomechanical forces and torques resulting from application of an external load, strength models to predict available strength to operate controls at different positions, effect of bulky clothing and implements on reach, feasibility of a posture from the viewpoint of body balance, automatic interference check, force guided motion in a gravity less environment, and animation of a human model. Human modelling programs are constantly being upgraded to incorporate additional features. The characteristic features of the selected five main stream programs are described below to illustrate the latest developments in the human modelling programming. The programs are selected on the bases of their current usage and availability of information regarding the programs in the published literature.

COMBIMAN (COMputerized Biomechanical MAN)

It models an aircraft pilot in a seated posture and can be used to evaluate the physical accommodation of the pilot in a crew station design in terms of reach, fit, visibility, and strength for operating controls (McDaniel 1990). The human model consists of 35 links and the user has flexible options to vary the link lengths of the human model. The user can select any of the six available anthropometric databases to size the model. The human model can be manipulated in a task oriented commands, such as reach to a point For the selected percentile of arm length dimension, type of clothing and type of harness, the reach algorithm repositions the model’s hand nearest to the specified reach point It can also compute the intersection of the reach envelope with horizontal surfaces of the crew station. The strength model contains a database for various percentile strengths for male and female to operate eight types of aircraft and helicopter controls at different positions, for either single or both handed or, foot operation. For a chosen set of conditions, the available strength in foot pound, are displayed in a box for 1st, 5th, 50th, 95th, and 99th percentiles for males or females. To analyze vision of the human model, the program can generate a visibility plot by mapping the visual field of a given workplace against the current head and eye position.

CREW CHIEF

It evaluates the maintainability of aircraft and other complex systems in terms of physical access for reaching into confined areas with hand tools and other devices, visual accessibility and strength requirements, for using hand tools and manual materials handling (McDaniel 1990). The structure of the human model in CREW CHIEF is simpler than COMBIMAN, and it can provide ten different sizes of human models, 1st, 5th, 50th, 95th, and 99th percentiles of males and females. There are twelve default postures, such as, standing, sitting, stooping, squatting, crawling etc., in which the model can be imported into a workplace model and then manipulated in task oriented commands. It has similar capability of reach to a point or visual ability analyses as that in COMBIMAN model. The strength requirements analysis is available for all appropriate combinations of tasks and posture. CREW CHIEF contains 105 types of tools in its database and each tool has its own tool envelope analysis functions. Using the tool envelope function the designer can verify the free range of movement of the tool and check interference with other objects. It also provides torque strength data for such operations.

JACK

It is a graphic program to model a generalized linked figure with 3 degrees of freedom of movement, where each link can contain various attributes such as segment length, segment volume, mass, centre of gravity, and inertial properties (Badler 1991). The anthropometric database, consisting of body attributes can be accessed through the Spreadsheet Anthropometric Scaling System (SASS) that enables the user to interactively change various parameters and attributes of the human model while it is displayed graphically, and to try out the effect of varying the individual anthropometry, population, percentile, gender, and joint limits. JACK provides multiple view, presentation of orthographic and perspective views, saving a view for future recalling, and animation based on a timed display of series of postures captured through saved views. In addition it has incorporated many advanced features, such as, on screen strength data display, animation through strength guided motion for gravity-less environment, provision of a hand grip which realistically grip an object by fingers using realtime collision detection technique, a polyhedral facial model capable of changing expression during animation, a seventeen segment vertebral column modelled with proper stiffness and joint mobility to represent torso movement realistically. JACK is intended to be a comprehensive system and can be used for building a general anthropometric human model, as well as, for dynamic simulation of motion, analysis of lifting task, and animation.

PLAID (Panel Layout Automated Interactive Design)

It is basically a versatile 3D CAD modelling software with advanced features like 3D surface modelling, hidden line removal, automatic interference check, shading and rendering with colour capabilities. PLAID has been used for analyzing situations that are unique in the weightless condition of outer space. The default posture of the human model is a zero-g neutral body posture (Woolford et al. 1989) with a lower effective height of the model. Figure 2 shows the PLAID human model wearing space suit opening a box with a tool. PLAID’s capability includes analysis of visual fields of view, ability to reach to a specified point, and spatial conflict (fit). It accesses an anthropometric database to generate appropriate human figure of any specified percentiles or absolute size.

SAMMIE (System for Aiding Man-Machine Interaction Evaluation)

It is used as a general purpose tool in designing human-machine interface for variety of workstations (Porter et al. 1990). The human model can be formed to represent an individual anthropometry or can be reconstructed from statistical population data. Appropriate body shape, such as thin, muscular, and fat, can also be selected. The joint range of motions of the model are constrained to the normal range of motions and the human model can be interacted with the workplace in a manner consistent with movements available to human beings. It can compute the position of the centre of gravity of the human model at any given posture. Additionally, the system alerts the user if joint angle is positioned beyond the comfort angle for the joint SAMMIE has all conventional viewing

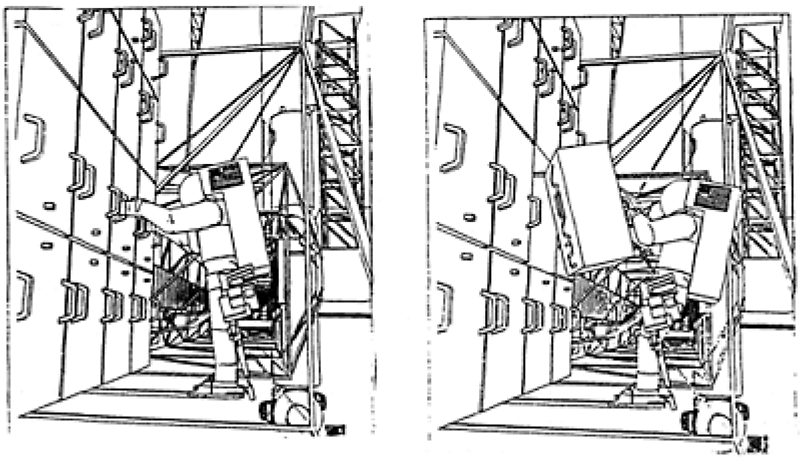

Figure 2. PLAID generated model of an astronaut manipulating an experimental module.

modes, such as viewing from any direction, orthogonal and perspective views, simultaneous multiple views of the objects, and hidden line removed views. It can present views of the environment seen by the model through mirrors placed at a certain position and orientation. This feature is conveniently used to design placement of rear view mirror in automobiles. SAMMIE has been used in a variety of design situations such as visibility study of fork lift trucks, interior design of a vehicle, and computer workstation design.

CONVENTIONAL VERSUS COMPUTER-AIDED INDUSTRIAL WORKSTATION DESIGN METHODS

The advantages and disadvantages of the computerized industrial workstation design method are assessed in the context of the conventional design process. Computerized workstation design method permits a convenient and low cost way of construction and/or modification of alternative workstation designs and evaluate many such iterations with the help of the variable anthropometry human model, quickly and economically. The method allows for three-dimensional evaluations of human-machine interface from the early stage of design. In the conventional workstation design process where this type of operator compatibility check is only possible at the later stage of the design, through a mock-up construction of the workstation. The computerized models with their ability to produce multitude of variable anthropometry human models in standard user defined postures, eliminate the difficulty of selection of representative personnel for fitting trials and thus, can provide a relevant, and standardized fitting trial.

The conventional design aids, such as, line drawings, manikins, 3D dummy human model and mock-up workstation, can virtually be replaced by the 3D computerized human workstation models. As the human attributes in terms of structural size, volume, joint movement ranges, strength, mass, and inertial properties are embedded within the computer program, the necessary calculations required to evaluate posture, clearance, spatial compatibility, visual requirements, biomechanical loads, and body balance can be handled by the programmed routines. However, contrary to the common belief, the computerized workstation design method does not act like an expert system. It cannot by itself generate an optimum workstation design from a set of given conditions. The designer must determine posture, working height, preferred line of sight, body clearances and other pertinent physiological factors. Thus for an effective use of such computer programs in workstation design the designer must be knowledgable of the relevant ergonomic principles and guidelines.

With all its virtues, computerized human models are seldom used for industrial workstation design. An estimated seven percent of the surveyed designers in the field use these CAD models, whereas nearly half of them build mockup (Kern and Bauer 1988). The CAD human modelling programs have been criticized in the past (Rothwell 1986) for the scarcity of documentation of these programs in the literature and are alleged for appraised by only their developers. Many of the programs have been developed for a specific application.

CONCLUSIONS

In summary, the conclusions reached by this investigation are:

1. The conventional industrial workstation design method is described in a systematic manner. To eliminate harmful postures in the workstation, work height, normal and maximum reach areas, visual requirements and clearances are determined for the intended user population through the use of relevant anthropometric data. Scaled drawings, manikins, human subjects and mock-up workstations are used to evaluate and optimize the design.
2. The operational characteristics of the computerized human modelling programs used for industrial workstation design are described. The computerized 3D human and workstation models are used to evaluate and optimize the design process from the early stage of the design. Five main stream human modelling programs are described: COMBIMAN, CREW CHIEF, JACK, PLAID and SAMMIE.

3. The computerized method of evaluating the design process is quick and economical. However the use of such a method is restrictive due to non-availability of computer program documentation and application specificity. The knowledge of ergonomic principles and guidelines is still needed in the computerized method in the same manner as the conventional method.

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SCHEDULING NURSE SHIFT VIA ERGONOMICS AND EXPERT SYSTEMS APPROACH

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In this article, we discuss the effect of nurse shift job on circadian rhythm, work stress, and some important ergonomics criteria. We also review and compare different nurse shift scheduling methodologies. A hybrid expert system, entitled NURSE-HELP, is developed with the emphasis on considering Ergonomics criteria. NURSE-HELP consists of a linear 0/1 goal programming module and an expert system module. The results shows that NURSE-HELP is superior than the head nurses in preparing schedules, both in terms of time and quality.

INTRODUCTION

The shortage of nurses has been a prevailing and cyclical problem for a long time. The Hospital Nursing Personnel Survey performed by the American Hospital Association in 1988 (Powills, 1989) showed that 13 percent of 813 hospitals nationwide were experiencing “severe” shortage of registered nurses. A similar survey performed in 1987 showed that the shortage was even higher—19 percent. Moreover, in the same survey, we found that about 60 percent had either “moderate” or “mild” shortage problem. As a result, only about 20 percent of the hospitals were free from the nurse shortage problem. The situation may be even worse if we consider the number of beds that have already been closed because of the lack of nurses. Another survey by the National Association for Health Care Recruitment in 1988 showed similar results. The majority of the respondents predicted a continuation of the nursing shortage. Moreover, it reported that the difficulty of recruiting nurses has returned to the situation of the early 80’s. Concerning turnover rate, the Hay Group reported that 31 percent of the registered nurses quit before they completed their first year (American Journal of Nursing, 1988). From these statistics, it may be easy to mislead the readers that there are not enough nurses available. Indeed, the real problem is that there are not enough qualified nurses who want to work as nurses. Dorsey Smith *et al.* (1988) reported that only 1 million out of 1.7 million registered nurses were actually practicing. Therefore, the focal point of the nurse shortage problem should be why so many qualified nurses have given up their profession.

The contributing factors to this acute problem are indeed many and varied. The irregular working schedules not only disturb the circadian rhythm, but also affect the family and social life. The stressful working environment is unhealthy to nurses both physically and psychologically. The uncompetitive salary and lack of positive image towards the career cause only a few nurses (only 34 percent) to be satisfied with their jobs (Wagner, 1988). The consequences of these problems are that not only do working nurses leave the career, but also students are discouraged to enroll in nursing schools. In order to alleviate the problem, hospital administrations have put a lot of effort in designing programs to retain and recruit nurses. Some of these programs include medical insurance, tuition reimbursement, maternity leave, child care, flexible scheduling, pension plan, increased salary etc. The survey done by National Association for Health Care Recruitment reveals that hospital administrators prefer the flexible scheduling program more than any others. The National Commission on Nursing also highlighted the importance of flexible scheduling (Elliot, 1989). This is very reasonable because all other programs require a considerable budget. While, on the other hand, the flexible scheduling program is much more cost effective in implementation ion.

EFFECT ON CIRCADIAN RHYTHM

In the hospital environment, patient care has to be provided 24 hours a day and 365 days a year. Consequently, nurses have to be on duty at night hours during which the body is not quite ready. The research results from Knauth et al. (1982) showed that the circadian system required many days (7 to 14 days) to adjust to a change in routine, there is a period of time when the circadian system is in a state of disharmony. Furthermore, they observed that the adjustment of circadian rhythm to night work always remains incomplete. Therefore, the research results support the fact that nurses working the night shift have their circadian rhythm upset by the irregular working hours. This not only affects nurses' health, but also induce impaired performance.

The effects due to the disturbance of circadian rhythm are very widespread. Dirken (1966) and Hakkinen (1969) used 18 items to measure the seriousness of circadian rhythm disturbance. Some of these items are stomach-ache, indigestion, lack of appetite, headaches, nervousness and dizziness. Also, the research from Akerstedt (1985) showed that the day sleep of the night shift workers were typically 1–4 hours shorter than normal sleep. The accumulation of "sleep-debt" is very unhealthy to the workers. Therefore, it is very important to consider the effect of circadian rhythm when designing the scheduling process. Knauth et al. (1982) recommended that no more than two consecutive night shifts should be scheduled.

EFFECT ON WORK STRESS

The nature of the job for nurses has a great psychological impact to the nurses. For example, the chronic exposure to pain, suffering, death (especially the death of youth), hopelessness, etc. bombard nurses every day. Moreover, the environment itself intensifies the stress. In a noisy, crowded, and busy hospital, there is no chance for the nurses to keep calm and relax. Another source of psychological stress is that nurses are dealing with human beings. There is no second chance if they make a mistake. Therefore, they have to be very cautious not to be careless even though they may be exhausted.

The physical stress for nurses is even worse because of the serious understaffed situation. Since more than 90 percent of nurses are female, every nurse has to share the physical workload. This exposes them to various types of physical injuries. For example, some patients are totally dependent for any movement. Thus a nurse may have to lift up the patient and put him/her on a bed or a hoist. A survey done by Takala *et al.* (1987) found that each nurse has to lift more than four patients in each shift. The result is that many nurses are affected by the low back pain. Klein *et al.*. (1984) reported that nursing aids and practical nurses are two of the ten occupations that suffer most strains/sprains of the back.

OTHER ERGONOMICS CRITERIA FOR SHIFT SCHEDULE DESIGN

From the above discussion, we should understand how important it is to design some ergonomic guidelines in order to avoid and minimize the bad effects of shift work. From a literature survey, we came up with the following guidelines.

Most of the research results suggest that a shift schedule should have few night shifts in succession. It is because the circadian rhythm is less disturbed and the accumulated fatigue effects will be less serious with less consecutive night shifts.

The morning shift should not begin too early. Research results showed that the accident rate is higher when the morning shift starts too early. It is because an early-starting morning shift is associated with less sleeping hours. Consequently, the body will be less recovered from fatigue. Therefore, it is recommended that the morning shift begin around seven o'clock.

The length of the shift should depend on the physical and mental load of the task. If work load is light, then a longer shift is acceptable, and vice versa. Based on this guideline, shorter shifts will be more appropriate for nurses because the nursing job is described as heavy by most nurses. However, if a nurse works for longer shift hours, then he/she should have more days off for personal activities (this includes family and social gatherings). Therefore, nurses should be allowed to choose the shift length by themselves.

At least once every few weeks, the two rest days given to each nurse per week should coincide with the weekend. This period of rest is absolutely essential in order to reduce sleep deficit and to meet family and social obligations.

The length of the shift should be designed taking into account the physical and mental loads imposed on the individual by the tasks comprising that shift. And, since the night is likely to be more stressful, it could be shorter than the other shifts.

Other guidelines suggested by researches are that the duration between shifts should be at least 16 hours, a work stretch should not exceed 7 days, and forward rotation is preferable over backward rotation in the continuous shift systems. Also, alternative weekends off is highly recommended.

REVIEW OF SHIFT SCHEDULING METHODOLOGIES

The problem of planning an appropriate shift schedule is a very complex one and is a truly difficult job for the nursing administrator. The successful resolution of the scheduling problem entails simultaneous consideration of many factors. Traditionally, the scheduling job is done manually by the head nurse of the unit. Every nurse submits his/her preferences for the coming scheduling period. Then, the head nurse will try to arrange the schedule for each nurse based on their preferences. There are many drawbacks with regard to this traditional method.

The combination of the nurse categories is already quite complicated even in a single unit. There are nurses at different skill levels, such as registered nurses, licensed practical nurses, and nurse aids. Also, nurses are not all working full time. Therefore, some of the nurses are not available at particular times or days. Moreover, the amount of staff required varies at different time periods. For example, more nurses are needed during the morning hours than at late night hours. As we have mentioned so far, there are indeed too many considerations to lay out the schedules for the nurses. In an interview with several head nurses in the winter of 1989, we found out that it took from one to more than twenty hours to make a 4-week schedule. Consequently, it is very inefficient and uneconomic for the head nurse to spend so much time and effort to arrange the schedules. Moreover, it is even more frustrating when the schedule has to be rearranged due to unpredictable events such as sickness.

Another drawback is about the fairness of the schedules. Since it is quite impossible to meet all the preferences, individual nurses may feel frustrated and disappointed if his/her preference is not met. This will affect the morale of the team when the nurses feel that the head nurse is not fair in designing the schedules. However, if the schedules are worked out by a mathematical model or computer program, the output will be free from personal bias. Even in the case of an unfulfilled preference, the nurse will complain about the program, and not the head nurse.

Last but not the least, the schedule arranged by the head nurse is usually subjective and uncertain, so it would be almost impossible for individual nurse to plan their own schedule in advance. For example, a nurse is usually unable to plan for a weekend off with the family. As a result, family and social life is badly affected.

As discussed so far, we may conclude that manual scheduling is really not practical. As a result, over the years a number of techniques and methods have been developed to do the scheduling job. During the 60's, experts in this area (Howell, 1966; Frances, 1966) developed the cyclical scheduling patterns concept· The methodology of this concept is to design a working pattern that may repeat for every scheduling period. Adopting this method will definitely improve the fairness and reduce the time spent on arranging the schedules. This is because every nurse has to follow the same working pattern, therefore, any unfavorable working pattern (e.g. long working stretch, night shift, weekend and holiday shift) will be equally shared. Also, since the working pattern is not going to be changed, the scheduling task is really easy. Furthermore, since the working pattern is fixed, nurses can predict their day off and hence plan for their personal activities.

While the cyclical scheduling patterns concept has its advantages, we should not overlook its limitations and drawbacks. The cyclical pattern is a very rigid pattern. However, the scheduling of nurses involves circumstances that cannot be confined in such a rigid pattern. For examples, a nurse may ask for several days off for vacation, or she may call for a sick leave suddenly, or a nurse may attend some night classes. In the rigid cyclical pattern, just a single day-off request may jeopardize everything. Moreover, the turnover rate of nursing is very high, which makes the cyclical pattern more difficult to apply. As a result, the inflexibility of this method limits its applicability.

In the 70's, the widespread use of computer applications gave experts new insight into tackling the problem. There are two main streams of new methodologies. The first group makes use of mathematical models (Arthur *et al.*, 1981; Miller *et al.*, 1976; and Musa *et al.*, 1984) to obtain an "optimal schedule". The second group uses heuristic model (Ahuja *et al.*, 1975 and Okada *et al.*, 1988) to find a good schedule.

A mathematical model uses a set of equations to represent the problem. It includes an objective function and a set of goals (or constraints). In the nurse scheduling problem, the goals may be to fulfill the work force requirement, to minimize the amount of staff, to allow the nurses to have an alternative weekend off, to have personal preferences, etc. Violation of, or deviation from, the goal causes some penalty cost. Hence the objective is to minimize the penalty cost.

With the use of a mathematical model, the flexibility of the schedules improves. It is because it is possible to change the model's parameters to satisfy particular needs in each scheduling period, and then compute a new solution. Warner (1976) and Musa *et al.* (1984) have claimed that the schedules obtained from the model is optimal. However, Okada *et al.* (1988) challenge the validity of the "optimal solution". "… [R]elative significance of various requirements may change depending on the situation during the periods concerned. Also some of the constraints are ambiguous and it is not clear to what extent they should be satisfied. There seem to be many allowable solutions for a given period, and it is difficult to define the concept of 'optimal schedule' in a strict sense."

In conclusion, just how good is the schedule obtained from the mathematical model depends upon how good is the model. Since the scheduling task has considerations that are not expressible in terms of quantities, we have reservations on the optimality of the model. Moreover, the mathematical models have difficulties in considering the ergonomics guidelines (such as forward rotation pattern) that we have recommended. Therefore, the claim of optimal schedule seems to be doubtful.

The second group that makes use of computer application builds heuristic models. A heuristic model is a set of rules that is constructed based on some sources of expertise. Comparing with the mathematical model, the heuristic model is more subjective because the source of expert may be a person's own experience and knowledge. Hence, a heuristic model does not guarantee an optimal solution. Nevertheless, heuristic model has its own advantages. It requires much less computational time. It requires a less sophisticated computer. Also, when the model is built carefully and covers all the important considerations, the solution will be a good one. Many experts have put effort to build heuristic models on nurse scheduling, and they obtained satisfactory results.

Before going to the next section, we would like to bring out an important consideration that so far has not been recognized. Up to the present time, the scheduling tasks has been done independently for each scheduling period. The drawback concerns the "fairness" issue. For example, nurse A may have 50% preference fulfilled and nurse B may have 85% fulfilled in the previous period. When scheduling for the next period, if credit is not given to nurse A, she may have the same chance to receive a less favorable schedule. Therefore, previous results should be considered so that "fairness" will be improved in the long run.

HYBRID EXPERT SYSTEM—A NEW APPROACH TO NURSE SCHEDULING

A hybrid expert system is a computer program that combines an expert system and some other methodologies. The hybrid expert system that we use to solve the nurse scheduling problem consists of zero-one linear goal programming and expert system.

As we have discussed in the previous section, both the mathematical programming and heuristic programming methodologies have their advantages and weakness. The best thing is to combine them skillfully so that we will retain their advantages and eliminate the weakness in each method. In the scheduling problem, constraints like minimum and desired staff levels, preferred days off, overtime work, and work stretch are appropriate to be quantified. Hence they are included in the zero-one linear goal programming formulation. The output of this part will be an optimal work pattern, i.e. a day on and day off working pattern without specifying particular shifts. In the second part, we construct an expert system that assigns specific shifts to the working pattern. In the expert system, we will consider constraints which are not effective or appropriate to be represented in the form of equations. These constraints include forward rotation, no double-back, and shift preferences. When we design the hybrid expert system in this manner, we have the advantages of obtaining an optimal working pattern from the zero-one linear goal programming. We also retain the advantage of the expert system which considers other constraints effectively. Moreover, we avoid the drawbacks of the two methodologies. Therefore, a hybrid expert system, entitled NURSE-HELP (NURSE scheduling by Hybrid Expert system/Linear zero-one goal Programming), is developed to facilitate the nurse scheduling process with the emphasize of considering Ergonomics criteria.

Structure of NURSE-HELP

NURSE-HELP consists of a linear zero-one goal programming (0/1-LGP) module and an expert system module. The 0/1-LGP module generates the working pattern (i.e., the day on and day off schedule). the data is then transferred to the expert system module and appropriate shifts are assigned. Eight guidelines and recommendations have been considered in the 0/1-LGP module: 1) minimum staff level for each day, 2) emergent day off request, 3) vacation request, 4) preferred day off request, 5) limiting overtime work, 6) assigning forty working hours for full time nurses, 7) controlling work stretch (no more than six working days consecutively, and 8) preventing 010 working pattern. These items are considered in the 0/1-LGP module because they are appropriate to be quantified and can be efficiently expressed in equation form. The BALAS algorithm has been modified and coded in the QuickBASIC environment in this module with a total of eight goals to be considered.

Six guidelines and recommendations via the Ergonomics viewpoint have been considered in the expert system module: 1) forward rotation, 2) limiting consecutive night shifts, 3) shift preferences, 4) desired staff level, 5) fairness in shift allocation, and

6) preventing inexperienced nurse to work alone. In contrary to the items considered in the 0/1-LGP moduel, these items are either inappropriate to be quantified or awkward to be expressed in equation form. This module is constructed in EXSYS. Two basic types of knowledge have been acquired and developed in the knowledge base. Deep knowledge is mainly from public domain, i.e., books and articles. Nevertheless, a series of interviews with six head nurses were arranged at the Veteran Administration Hospital in Houston to obtain shallow knowledge. The knowledge representation in NURSE-HELP adopts the rule-based system with the forward chaining mechanism.

System Verification and Validation

The 0/1-LGP module has been verified by comparing the results of NURSE-HELP with solved problems. Both “consistency” and “completeness” are checked to verified the expert system module.

The performance of NURSE-HELP is evaluated by comparing the scheduling system currently practiced in the Veteran Administration Hospital in Houston with the consideration of 1) meet the minimum staff level, 2) grant the day off request, 3) prevent backward rotation, 3) prevent long consecutive night shift. 36 two-week schedules for three different shifts in three different units over eight weeks period are used in the validation process. The results shows that NURSE-HELP is superior than the head nurses in preparing schedules, both in terms of time and quality. In estimate, at least 80% of time has been saved by using NURSE-HELP. Concerning the minimum staff level, there are a total of 20 versus 39 ocassions violated in the schedules generated by NURSE-HELP and by the head nurses. For the day off request, the total number of requests not granted has been reduced to 50% level. In conclusion, the system validation and performance verification do provide strong support that NURSE-HELP is a flexible and effective tool to generate schedules for nurses.

CONCLUSIONS

NURSE-HELP has successfully incorporated the Ergonomics guidelines into the hybrid expert system module. Moreover, these guidelines are skillfully and carefully allocated into either the linear O/1 goal programming or expert system module. Even NURSE-HELP has been shown to be a flexible and effective model to generate schedule for nurses in hospitals, several extensions are suggested for the future development of NURSE-HELP:

1) Provide an option for the users to choose the preferred shift duration.
2) Enhance the system so that both full time and part time nurses can be scheduled together.
3) Provide a network system so that information in each unit can be shared.

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AGING

Difficulties Encountered by Older Adults in the Performance of Everyday Activities

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Older adults frequently encounter difficulties while performing routine activities such as meal preparation and bathing (ADL activities). These difficulties often arise because environmental demands create barriers that hinder task performance. This paper will discuss how ergonomic methodologies can be used to analyze these problems. Data presented will include survey, and videotape data of older adults performing a sample of ADL tasks. Use of this data to develop design guidelines for supportive home environments and assistive technologies to enhance the safety and functional independence of older adults will be discussed.

INTRODUCTION

A common theme within the gerontological literature is the strong desire of older people to live at home despite personal impairments or declines in environmental quality. Data regarding the living arrangements of older adults shows that most older people live in a household either alone or with a spouse. In fact, about 85% of all older people live in ordinary homes in ordinary communities and 75% own their homes (Parmelee and Lawton, 1990). It is expected that the number of elderly occupied households will increase given the increased number of older people in the population and the rising cost of institutionalization. This growth in households maintained by older persons underscores the need to attend to the housing needs of this population.

It is well established that older people often have difficulty remaining at home because they encounter problems performing routine tasks such as cooking and cleaning. Current estimates suggest that of the elderly people living at home 2.3 million need some type of assistance performing daily living activities and 2.7 million need some assistance with instrumental activities (Dawson, Hendershot and Fulton, 1987). In addition, other estimates suggest that approximately 13% of older people living at home exhibit at least one major deficit in physical ability (Office of Policy and Development Research, 1983). These data indicate that a large number of older people are at risk for placement in institutional settings.

Further evidence for the lessened ability of older adults to remain at home is reflected in the high rate of home accidents among persons 65+ years. In fact, persons in this age group account for approximately 43 percent of all home fatalities (Czaja, 1990). The most common causes of accidental injury are: 1) falls on stairways, floors and bathtubs; 2) burns and scalds from cooking, hot water and 3) poisoning from medications (Sterns, Barrett and Alexander, 1985). Falls represent the most frequent non-transportation related accident occurring among older adults. They are the leading cause of all home fatalities.

The high rate of home accidents and the high number of accident related fatalities among older persons provide a compelling area for human factors research. To date, studies of the elderly in home environments have been largely descriptive. They offer some general knowledge regarding environmental features involved in home accident scenarios and some guidelines for home modifications and technological interventions. However, they do not provide information needed to develop effective design solutions. There is a large gap between the empirical knowledge available and the data needed for design applications. A prerequisite for the development of design interventions is detailed information on person and task characteristics, environmental features and demands and product features. This type of data will allow us to specifically target why home tasks are problematic for older adults.

To gather this type of data human factors task analytic techniques can be applied to the study of home activities. Using the technique of task analysis, the demands of daily living tasks can be quantified and compared to capability data for older adults. This analysis can identify the person and environment characteristics that affect the success of task transactions. Faletti (1984) successfully applied task analytic techniques to study meal preparation and identified the most important physiological demands associated with this activity. Similarly Czaja and Drury (1986) developed a task analysis of the six most hazardous consumers products for older persons and Alessi and Brill (1978) conducted a human factors analysis to assess the safety of the stair environment. More research of this type is needed as it provides not only a means of understanding person-environment transactions in home tasks but also data on the demands which must be satisfied to complete home activities.

The intent of this paper is to demonstrate how Human Factors methodologies can be used to analyze problems encountered by older adults in the course of performing daily activities (ADL and IADL’s). Data from a research project, concerned with identifying the instrumental demands associated with activities of daily living are presented to illustrate the utility of using this approach.

METHOD

The data for this project included survey data, videotape data for a sample of 60 older adults performing ADL and IADL tasks in their own environments and objective measurement data.

A 107 item survey concerned with ADL and IADL activities was administered to a sample of 244 older adults, ranging in age from 55–93 years, who were living independently in the community. The survey respondents were questioned about how frequently they performed each task, the amount of help received performing tasks, and prevalence and types of problems associated with task activities.

The videotape data was collected on a subset of the survey respondents. The sample included 11 single males, 30 single females, and 19 couples. The breakdown of housing types was 12 free standing homes, 40 condo/apartment, and 8 mobile homes. The participants were videotaped in their own home, at the laundromat, and in the grocery store.

The tasks which were videotaped included meal preparation and clean-up, grocery shopping, laundry, using appliances, personal care tasks such as bathing and dressing, housecleaning tasks and home management tasks such as banking. A total of 25 tasks were recorded; the taping was spread over two days in most cases. This data served as the basis for the task analysis (TA). The task analysis was accomplished using a VTR linked to an IBM PC through a BCD serial interface. Software was written to standardize the selection of tasks, actions, demands, objects and location.

The videotape data was supplemented with objective measurements of the participants homes and objects used during task performance. Environmental measures included reach distances, room and appliance dimensions, and force and grip requirements. Object measures included weight, circumference, height, depth, and handle dimensions.

RESULTS AND DISCUSSION

The survey data indicated that tasks of meal preparation, grocery shopping, house cleaning, and dressing were the most problematic. Common problems associated with these tasks were largely related to physical demands and included problems such as bending/reaching, carrying/lifting and stamina (Table 1). The analysis of the TA data included identifying the global demand inherent to all 25 tasks and analyzing each individual task in detail. The global analysis was conducted in order to identify performance criteria which are critical to ADL and IADL activities. The detailed analysis at the task level is useful for identifying sources of problems associated with individual tasks and targeting areas of needed intervention. The task analysis data is supplemented with object and environment data in order to understand the parameters of the performance demands (e.g., height of reach). These demands can then be compared to data regarding older adult capabilities to determine potential sources of mismatch between person and environment.

The most frequent actions associated with task performance are lifting/lowering and carrying objects such as food, cooking items or grocery bags; and pushing/pulling items such as grocery carts or environmental components such as doors. By examining the object and environment databases we can delineate the specific nature of these actions and understand the strength requirements inherent in routine activities. For example, the average weight of grocery bags is approximately 11 lbs, pots and pans 1/2 lbs, cleaning supplies 1/2 lbs, and vacuum cleaners 23 lbs. The average size of a kitchen is 8 by 6 ft. and the distance from a high self to the counter is about 40 inches. These data can be used to define transport distances for lifting/lowering and carrying objects of specific weights and compare them to data regarding strength and stamina.

Given age-related strength declines some of these actions may be difficult for an older person to complete. A recent study (Kovar & La Croix cited in Stoudt, 1987) found that of women aged 65 to 74 years 35% have difficulty lifting or carrying 25 lbs and 10% are unable to lift or carry that weight; likewise, lifting or carrying 10 lbs is difficult for over 10% and impossible for about 4%. In fact, self-report data indicates that carrying/lifting and fatigue are common problems associated with ADL tasks. Our sample reported that one reason for frequent trips to the grocery store was to carry lighter loads. Thus, these data suggest that one area of needed intervention is reducing the lifting/carrying demands associated with home tasks. This could be accomplished by designing lighter weight products, redesigning storage units, and/or providing some type of lifting aid.

With respect to postures, the most frequent include standing, leaning, reaching and bending. Bending and reaching may be problematic given the general loss in range of motion and agility that occurs with aging. Fourteen percent of the population in the Health Interview Survey (Harris, 1987) reported problems reaching overhead and 7% were unable to reach at all. Again, we can examine the environment data to define the range of reaches required by tasks performed in the home.

Table 1. Individuals Reporting at Least One Problem with Selected ADL Tasks

	Meal. Prep.	Groc. Shop.	Bathing	Dressing	Transfer Tasks	House Cleaning	Using Stairs
			Overall				
Percent	45.5%	53.3%	28.3%	32.4%	25.8%	30.7%	6.8%
Number	90	130	69	79	63	75	16
			Type of Problem*				
Bending/ Reaching	12.6%	3.8%	98.5%	87.3%	19%	42.7%	–
Carrying/ Lifting	4.5%	3.8%	–	–	4.8%	2.7%	–
Stamina/ Fatigue	21.6%	53.8%	13.2%	–	14.3%	30.7%	33.3%
Manipulative	22 5%	2.3%	–	65.8%	3.2%	12%	–
Cognitive	26.1%	23.8%	–	–	–	5.3%	–
Visual	1.8%	4.6%	–	–	–	1.3%	–
Dislikes/ Fears	28.9%	6.9%	–	–	1.6%	9.3%	3.3%
Other**	34.4%	12.3%	62.3%	–	14.3%	17.3%	56.3%

* Percentage based on those persons reporting problems with the particular task.
** Including unspecified problems.

For example, the height of high shelves in kitchens is approximately 73 inches and the middle shelf 65 inches; shelves in grocery stores range from 6 to 68 inches. The maximum overhead reach of older women is 73 inches which suggests that most reaches are within an acceptable range. However, the depth of most kitchen shelves is 12 inches and that of grocery store shelves is 16 inches. The maximum effective reach (displacement of 15 inches) of older women is only 63 inches which implies that in many cases a person would need to stand on tip toe or use step stool to retrieve items from storage. This can create a potential for a fall or accident. In fact, data indicates that falls from chairs or ladders are a common type of home accident among older people (Czaja & Drury, 1986). A simple solution is to lower the height of shelves and reduce their depth. A maximum shelf height 55 or 60 inches would alleviate the need for high reaches. Adjustable shelves which are mounted on railing and operated electronically are also available (Charness and Bosman, 1990). Another needed area of design intervention is related to the grip and manipulation demands of daily living tasks. Examining the force requirements of these tasks can further delineate potential sources of performance difficulties. For example, the average amount of force required to operate a sink control is about 5 lbs and tub or shower controls is about 8 lbs. This amount of force may be difficult for persons with reduced hand strength. In fact, Faletti’s work (1984) suggests that the optimal torque requirements for older females is in the range of 3–4 lbs.

The data presented are meant to illustrate the relevance of Human Factors task analytic techniques to understanding problems encountered by older adults in the performance of routine tasks. It should be pointed out that only summary data were presented to demonstrate the power of this approach. The actual database derived from a task analysis is extensive and can be analyzed in a variety of ways depending on the goal of the analysis. In general, however, by delineating task demands and comparing the data with capability data we can specify sources of difficulty and identify palliative interventions with respect to person, product, and environmental factors. The data clearly indicate the need for such interventions as many of the physiological demands inherent in routine activities tax the capabilities of older populations.

CONCLUSIONS

Clearly, more research of this type is warranted. For example, the data presented only focuses on the anthropometric and biomechanical demands of tasks. Obviously, data also are needed which identify sensory and cognitive demands of everyday tasks. In addition, more data are needed on the functional anthropometry and biomechanical characteristics of older adult populations. This will greatly enhance our ability to develop design guidelines for supportive home environments and to develop assistive technologies which can extend the ability of the elderly to live independently.

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AN OVERVIEW OF THE DRIVING CONCERNS OF THE ELDERLY

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It is anticipated that in the year 2024, 25% of the U.S. population will be 65 or older, resulting in more than 50 million older persons being eligible to drive. Currently an investigation at the University of Nebraska is examining the problems of older drivers and developing ways to improve their safety. This paper presents an overview of the accident analyses, survey phase, and pretest experimental phase of the investigations. The salient findings of the accident analyses were: a) the older age group had a higher involvement ratio as compared to other age groups, b) older drivers were involved in more multivehicle crashes, and c) crashes involving older drivers were more in urban roadways than in rural roadways. The results from survey indicated a large female population among the elderly, greater difficulties experienced by the female driver, and an interesting set of age by gender interactions. Left-turn lanes, left-turn signals, stop signs, and traffic signals were considered to be the most valuable safety improvements. The results of pretests were interesting and showed potential for development of models for predicting driving ability. Peripheral vision, spatial relation, visual memory, and trails A and B tests appeared to be good predictors of driving skills. The results of all these studies are discussed

in light of the driving concerns and research needs of the elderly drivers.

INTRODUCTION

The elderly represent the most rapidly growing segment of the driving population in our society, both in the total number of drivers on the road and the number of miles driven annually per driver (TRB, 1988). It is estimated that by the year 2024, one out of four drivers will be over the age of 65. Older drivers as a group have more traffic convictions and crashes and incur more fatalities per mile driven than any other adult group (FHA, 1989). Barr (1991) has reported between 1980 and 1989 there is an increase in total driver deaths possibly due to increase in the number of older drivers who are licensed to drive, and an increase in the likelihood of fatality following a motor vehicle crash. Given such a significant proportion of older people in the population, the importance their safety in driving, and that of others when they are driving, cannot be overstated. Driving can become a problem for the older drivers because with aging certain deficits occur in the sensory, perceptual, cognitive, and physical abilities, and these abilities have been associated with driving performance. As driving is a highly visual task, a high incidence of visual problems associated with the elderly may be expected to influence their driving ability. It is estimated that approximately 90% of total input to a driver is visual (Bailey and Sheedy, 1988). Age related changes in the eye alter vision. These include loss of lens elasticity, ability of the eye to accommodate or change focus, loss of transparency in the lens, and yellowing of the lens. The pupils of the eye become smaller causing numerous alterations in vision. Individual differences show a wide range, but common problems include impairment in peripheral vision, the ability to perceive and distinguish colors, visual acuity, ability to distinguish an object from its competing background, depth perception, dynamic visual acuity, ability to tolerate glare, and ability to see adequately in low levels of illumination. Older persons whose visual acuity is poor show improvement as light is increased. A 45 year old driver needs about four times the light that a 19 year old requires (Malfetti and Winter, 1987). Further decrements continue and it is estimated that between 70 and 90 years there is a ten-fold decrease in the absolute threshold for the dark adapted eye (McFarland et. al., 1960). Although such changes have resulted in reported unsafe driving practices, 1t has been difficult to determine the exact deficit(s) known to cause the most difficulty (Malfetti and Winter, 1987).

Considerable published evidence exists that suggests decline in cognitive functioning of aging individuals (Lewis, 1983; Panek et. al., 1978). What constitutes cognitive functioning is matter of controversy among the researchers. Basic elements are learning, intelligence, and memory (Hooyman and Kiyak, 1988). Numerous studies have shown that intact cognition is a necessary component of safe driving (Sivak et. al., 1983; Quigley and DeLisa, 1983; Snipes, 1982). Older individuals are considerably more prone to chronic illness and disease, especially cardiovascular and cerebrovascular diseases, diabetes mellitus, dementia and depression. These are among the most commonly treated conditions among older persons and along with the medications prescribed are important factors to cognitive functioning as it regards the driving task. Under these conditions there is potential for problems in driving for the elders, yet little research has been done to substantiate this fact.

Although much research has been done on physiological changes that occur as people age, very little of this has been related to driving task (Brainn, 1980). With aging, changes occur in the cardiovascular system, musculo-skeletal system, and in sensory systems. Human perception-reaction time is considerably important when dealing with events where time itself is a crucial factor. Specifically, as related to the driving task, such events include the sudden appearance of a road obstruction, the rapid deceleration of a lead vehicle, the change of a traffic signal indication, the search for a gap through a busy street, and sudden flow of cross wind. Age related changes in reaction time is an established fact (Birren and Renner, 1977; Welford, 1969). Physiological changes resulting from the normal aging process are estimated to affect three out of five people aged between 75 and older. A decrease in muscle strength, slowing of reflex action, and general bone deterioration will cause coordination and reaction abilities to be compromised, which in turn can affect certain driving abilities (Cox, 1988). Decrease in sensation, coordination, and reaction skills may result in less than adequate accelerating, braking, steering, general control of the vehicle.

Therefore driving can be expected to be a problem for the elderly because with aging certain deficits occur in the sensory, perceptual, cognitive, and physical abilities. Currently an investigation at the University of Nebraska is examining the problems of older drivers and developing ways to improve their safety. The objective of this paper is to present an overview of this investigation and to enumerate the research needs on this virgin, yet vitally important area.

ACCIDENT INVESTIGATION PHASE

The 1988 accident level and vehicle/driver level files maintained by the Nebraska Department of Roads were analyzed to identify accident situations in which elderly drivers were over involved. The drivers were grouped into five age categories: younger than 25, 25 to 54, 55 to 64, 65 to 74, and older than 74 years. These categories were chosen as they seem to correspond to driving behavior pattern of drivers.

Accident involvement: The number of accidents in each driver-age group which occurred in Nebraska during 1988 is shown in Table 1. The table also shows the number of licensed drivers, and the vehicle miles of travel in each age group. The vehicle miles of travel in each age group were estimated by multiplying the number of licensed drivers by the average annual vehicle miles of travel for the age group (FHA, 1984). Table 1 shows the respective percentages of total number of accidents, “licensed drivers, and vehicle miles of travel in each age group. The ratios of percentages of total accidents to the percentages of licensed drivers and vehicle miles of travel give an indication of an age group’s involvement in accidents. It is noted from Table 1 that among the five age groups the youngest and the oldest groups have involvement ratios of greater than 1.

Accident rate Statewide accident rates in terms of accidents per million vehicle-miles of travel were computed for the age groups using the data shown in Table 1. Figure 1 shows the plot of the respective accident rates. The rate of 15.3 for the youngest age group was significantly higher than those of the other driver age groups. The rate drops to a minimum of 3.9 for drivers between the ages 55 and 64. The rate then increases to 8.6 for drivers 75 years and older, which was significantly higher than the rates for the 25 to 54, 55 to 64, and 65 to 74 age groups.

Accident type The accidents for each group were categorized as multivehicle, single vehicle, and pedestrian accidents. Figure 2 shows the histogram of these for the various age groups. Drivers 55 and older had higher proportions of multivehicle accidents than drivers younger than 55. The percentage of multivehicle accidents for drivers 75 years and older was significantly higher than for the other age groups.

Type of collisions Elderly drivers were over involved in right-angle, left-turn, backing, parked-vehicle, and parking-maneuver collisions. Compared to middle aged drivers, they had significantly higher percentages of right-angle (31 versus 8 percent), left-turn (7 versus 3 percent), backing (6 versus 3 percent), parked-vehicle (6 versus 3 percent), and parking-maneuver (11 versus 3 percent) collisions. The accidents were more likely to be at intersections in urban roadways than on rural roadways.

Table 1. Accident involvement by age group.

Age Group	Number and Percentage of			Ratio of % of Total Accidents to % of	
	Total Accidents	Licensed Drivers	VMT[a] (Million)	Licensed Drivers	VMT[a] (Million)
16–24	23,428 (36.2%)	193, 894 (17.8%)	1,535 (14.2%)	2.0	2.6
25–54	31,756 (49.1%)	602,731 (55.4%)	7,312 (67.5%)	0.9	0.7
55–64	4,464 (6.9%)	127,336 (11.7%)	1,147 (10.6%)	0.6	0.7
65–74	3,062 (4.7%)	101,974 (9.4%)	600 (5.5%)	0.5	0.9
>74	2,018 (3.1%)	62,335 (5.7%)	233 (2.2%)	0.5	1.5
Total	64,728 (100%)	1,088,27 0(100%)	10,828 (100%)	1.0	1.0

[a] Vehicle miles of travel.

Table 2. Summary of All Regression Models

Model Description	R—Square
Knowledge Test	.0716
Knowledge Test, Reaction Time	.0775
All Raw Variables	.4469
All Raw Variables (LT)	.4102
Factors Scores	.6195
Factor Scores (LT)	.7373

In summary the salient findings of this investigation were: a) the older age group had a higher involvement ratio as compared to other age groups, b) older drivers were over-involved in multivehicle crashes, and c) crashes involving older drivers were more likely to be on urban roadways than on rural roadways (McCoy et. al., 1991).

SURVEY PHASE

In this phase of the investigation, a survey was administered to a sample of older drivers. The objective of the survey was to assess the extent of driving difficulties encountered by the older population (Bishu et. al., 1991). A questionnaire on the various attributes of driving was designed. In its final version the questionnaire had 78 questions as detailed below.

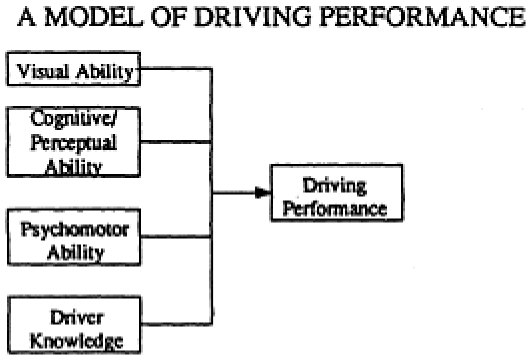

Figure 1

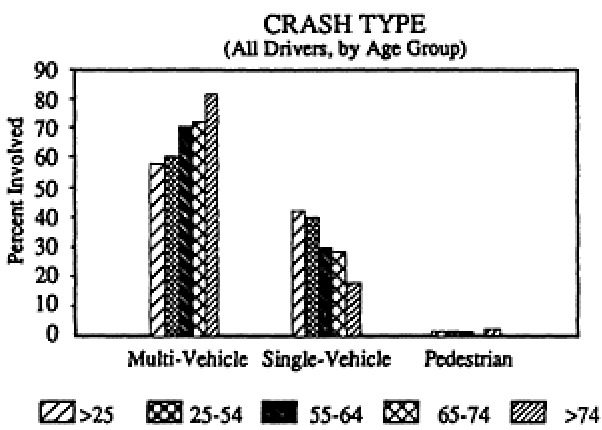

Figure 2

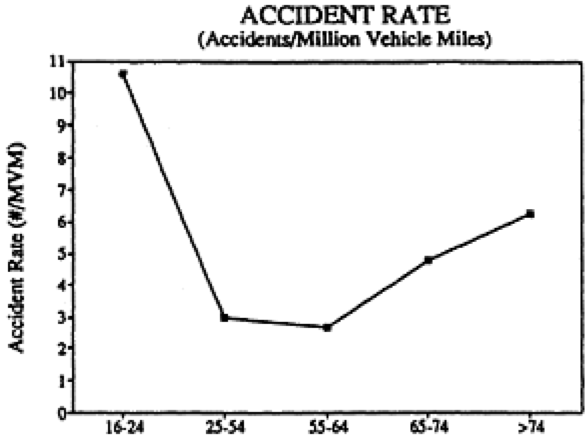

Figure 3

Demography	12 questions
Driving history	14 questions
Approach to	
Signals	6 questions
Stop sign	6 questions
Left turns	9 questions
Others	2 questions
Health/habit	16 questions
Safety issues	13 questions

The questionnaire was sent to 770 older drivers, of whom 425 (55 percent) responded. The mean age of the respondents was 79.5 years, with the range being 64 years to 91 years. Sixty percent of the respondents were females, and 80 percent of the respondents were still driving. The respondents had driven an average of about 7500 miles in the previous year.

The results indicated a larger female population among the elderly, greater difficulties experienced by the female driver, and an interesting set of age by gender interactions. The mean difficulty index as reported by the respondents peaked at 65–70 years for the female, and at 70–75 years for the male drivers. This was followed by a decrease in reported difficulty index for both genders, and then an increasing trend in difficulty. Females appeared to experience greater difficulties in negotiating common driving situations, especially after 75 years. Left-turn lanes, left-turn signals, stop signs, and traffic signals were considered by the respondents to be the most valuable safety improvements. Larger signs, lower speed limits, more stop signs and traffic signals, and wider parking spaces were also listed as needs.

EXPERIMENTAL PHASE

This phase of the study involved an assessment of the perceptual, cognitive, and functional abilities of the elderly to determine their relationship to driving performance. The logic for this study was based on a model of driving performance shown in Figure 3. According to Figure 3, driving performance is expected to be influenced by visual ability, cognitive ability, perceptual ability, psychomotor ability, and driver knowledge. Age was expected to impact driving in an indirect way by influencing the visual, cognitive, psychomotor, and perceptual abilities.

A battery of tests, some of which are known correlates of the task demands in driving, were chosen to be administered to the subjects in a controlled study. The tests were driving knowledge test, motor free visual perception test, trails A and B tests, visual sensory measures, range of motion measures, and on-the-road driving test. One hundred nine subjects, all over 65 years, participated in the experiment.

The main objective of this phase was to develop a predictive model for the elderly drivers on the basis of the model shown in Figure 3. To what extent did the findings validate the postulated model? Table 2 shows the R^2 summary of the various models tried. The modelling efforts started with the expectations that the knowledge test and the brake-reaction time would be the best correlate of the driving performance. A low R^2 of .07 indicates that the driving task is definitely more complex that what can be explained by just two variables. Inclusion of other variables in the model improved the explained variance considerably. Spatial relation, visual memory, stereoscopic vision, peripheral vision, and trails test were the best predictors. Finally, the models with factor scores showed the best R^2 values even though they were complex in the sense that 26 factors were included in the model for left-turn score and 17 factors were included in the corresponding model for overall driving score. Included in the factors were a variety of complex combinations of the raw variables.

The raw variables did not predict on-the-road performance adequately. This could have been due to the inadequacies of the model, or due to the inadequacies of the measures used in the study, or could have been due to the complexity of the driving task. However, the model with factor scores as independent measures is definitely too good to be ignored. As a predictive tool it looks promising. A validation study is definitely needed before any generalization can be made on the usefulness of this model. It is possible that the factors represent certain higher cognitive dimensions of driving than those that have been measured directly (Bishu et. al., 1992).

SUMMARY OF DRIVING CONCERNS AND RESEARCH NEEDS

What can be inferred from these all these results? The findings of the investigations reported here have been consistent with the others reported in the literature. Consider the following,

1. By the year 2024 one out of every four drivers will be over 65 years.
2. All the statistics indicate a larger proportion of females among the elderly.
3. Older females experience greater difficulties in negotiating common driving demands.
4. In terms of crashes per mile driven the elderly as a group are over represented.

5. Driving can be expected to be a problem for the elderly because with aging certain deficits occur in the sensory, perceptual, cognitive, and physical abilities.
6. Modelling efforts indicate that simple variables which can be easily measured do not predict driving performance adequately. This could have been due to the inadequacies of the measures used in the study, or due to the complexity of the driving task.

The evidence for the increasing number of elderly segment in the driving population, and their difficulties in driving is certainly overwhelming. Frequently such drivers may resort to compensatory behavior such as stopping driving at night, or in freeways, or in other more demanding circumstances. Restriction of exposure is definitely not a desirable solution (Waller, 1991). Research attention is needed on all the facets of this multi-facet issue, namely on the relative merits of the various therapeutic measures aimed to improve driving behavior, on the effectiveness of traffic engineering countermeasures such as improvement of sight distances, and on making automobile more intelligent and sensitive to the needs of the older driver.

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REDUCING THE POTENTIAL FOR FALL ACCIDENTS AMONG THE ELDERLY THROUGH PHYSICAL RESTORATION

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This study examined the response of elderly persons with chronic low back pain (CLBP) to an aggressive physical restoration approach. The study supports the contention that a well designed and administered physical restoration program can effectively increase strength and improve many human performance parameters in the elderly. Linking such improvement to reduced incidence of falls is recommended.

INTRODUCTION

In 1900, there were about 3 million people over age 65 in the US; in 1970 there were more than 20 million Americans over 65. Projections suggest that by 2000 there will be an estimated 29 million Americans who are 65 and over. As humans age, their anatomical, physiological, and functional abilities become affected. Muscles become weak (Whiple et al., 1987), and this may have an effect on the ability to perform activities of daily living (Lexell et al., 1992) and on the sense of independence in the older person. According to a survey in the United States (Jette and Branch, 1981), more than 67% of women of the age of 74 cannot lift objects weighing more than 4.5 Kg. In addition, joints become less flexible. Voluntary control on body joints is decreased, balance becomes disturbed, velocity of movement and gait may be impaired (Imms and Edholm, 1979), sharpness of vision is decreased, and reaction time is reduced. There are also other health problem due to malnutrition, diseases, and accidents such as falling and its associated disability.

Falls Among the Elderly. An estimated one in three adults age 65 years or older falls each year (Sattin et al., 1990). Falls are a health hazard and are a leading cause of fatal and nonfatal injuries among the elderly in the United States (DeVito et al., 1988). Annually, approximately 30% or more of elderly experience such a problem; 70% of deaths from falls occur in the elderly population (Duthie, 1989); and 62% of fractures result from tripping or losing balance (Dias, 1987). A major portion of the morbidity, mortality, and social cost due to fall injuries is associated with fractures (Melton and Riggs, 1985). The risk of falling and suffering serious injuries increases substantially up to the eighth decade of life (Kellogg, 1987). In addition to being a major health problem, falls and the fear of falls is the major deterrent of daily mobility (Winter et al., 1990). Falling can lead to both physical and psychological harm, causing some to place unwarranted restrictions on themselves based on their fear of falling again (Schulman and Acquaviva, 1987). Morbidity from falls includes fractures, broken bones, soft tissue trauma, hospitalization, confinement to wheel-chair, and anxiety and fear of walking. Even falls which result in no physical injury often have serious social and psychological consequences for the elderly, including loss of confidence, restriction of mobility, and fear.

Risk Factors. Falling among the older person is the result of many pathophysiological and aging processes, as well as possible behavioral, pharmacologic, and environmental factors (Sattin et al., 1990). Causes of falls are also different for persons of varying ages, health status, and levels of mobility (Kellogg, 1987). DeVito et al. (1988) indicated that most falls (97%) are accidental. Tack et al. (1987) reported 25.5% of the fall incidents in their sample to be related to neurologic conditions. Duthie (1989) related falls to environmental factors; neurologic illness; alcohol and drug use; orthostatics; cardiac arrhythmias; and acute illnesses such as infection, heart failure, and gastrointestinal bleeding. Overstall (1980) believes that, although environmental factors are sometimes to blame, the fundamental cause is a decline in postural control which is partly age-related and partly due to pathologic changes in the central nervous system. Schlapman (1990) identified factors such as weakness, environmental hazards, orthostatic hypotension, drug side effects, and gait dysfunction. Reactions and responsiveness are also important factors. When confronted with functionally inappropriate visual and/or somatosensory inputs, the elderly loose balance (Woolcott et al., 1986). Psychosocial factors can not be ignored. Elderly persons who attempt to “do for themselves” to maintain independence is a factor contributing to falls (Wright et al., 1990). Fear of falling contributes to the problem by causing inactivity and deconditioning, further increasing the danger of falls.

Prevention. A major problem in the prevention of falling is the identification of the cause. Many elderly persons who fall have multiple problems, which often present in a nonspecific manner (Barclay, 1988). Overstall (1980) suggested that falls may be prevented by maintenance of health, mobility and confidence, the avoidance of certain drugs, identification of specific health problems, and attention to environmental hazards. Schlapman (1990) recommended the use of a postfall assessment tool that include a detailed physical examination, environmental assessment, laboratory tests, and electrocardiograms to identify probable cause or causes for the falls, identify risk factors, and recommend intervention. Brummel-Smith (1989) stresses the importance of history of falls, the aggressive investigation to search for treatable causes, hazards of the patient's environment, the psychologic reactions to having fallen, and the use of functionally oriented interventions to decrease further falls. Wolf-Klein et al. (1988) recommended a team approach for successful management. Tack et al. (1987) used a comprehensive approach of data collection and assessment, education, and follow-up to decrease falls. Schulman and Acquaviva (1987) emphasized fall prevention education for all elderly, not only those who have a history of falling.

Many causes of falls are remediable (Schlapman, 1990). Elimination or redesign of steps and curbs and the provision of hand railings and walking aids are example of environmental approaches to preventing falls (Sorock, 1988). Dias (1987) suggested that more emphasis should be placed on safety in the home and in the provision of simple aids to those at risk. An approach that has been popular to guard against the risk of falls and physical injury, is the use of mechanical devices (such as side rails, vests, waist restraints) and alarm devices (Widder, 1985). The efficacy of these types of restraints are being challenged (Jagella et al., 1992).

In general, reducing fall and related injuries among the elderly can be accomplished through interventions addressing the various causes of fall accidents. These can be grouped as: pharmacplogic (drugs and medications), clinical (pathophysiological and psychological), ergonomic (environments and products), education (awareness), and rehabilitative (physical restoration and neuromuscular conditioning). The later strategy is the focus of this paper. Studies on efficacy of physical restoration in the elderly are scant and the use of objective, quantitative parameters to document improvements have not been widely used. This paper reports on one such study.

Physical and Functional Restoration in the Elderly

It is desirable to improve the quality of live for the aged, to provide them with the tools and support they need to remain independent and avoid accidents, and to preserve and improve their functional abilities, especially those of the muscloskeletal system. Proper conditioning of this system is essential for strong and healthy muscles, a balanced gait, stable and flexible joints, etc. More and more interest in the literature has been on the possibility of increasing muscle function in the elderly by physical activity. Several studies on the potential effects of exercise programs have shown positive results on improving functional capacity of elderly subjects (Overstall, 1980; Grimby, 1988; Rudd, 1989; Sorock, 1988; Foster et al., 1989; Lexell et al., 1992; Frontera et al., 1988).

The objective of this study was to examine the response of elderly persons with chronic low back pain (CLBP) to an aggressive physical restoration approach.

METHODS

The sample in this study consisted of 52 patients (26 males and 26 females) who are 65 years of age or older. All subjects were selected from the patients population of the University of Miami Comprehensive Pain and Rehabilitation Center (CPRC) at South Shore Hospital, Miami Beach, Florida. All patients were admitted with low back pain condition and received a diagnosis of myofascial pain syndrome. The CPRC utilizes a multidisciplinary comprehensive aggressive physical medicine approach to the management of chronic pain conditions. The components of this program are: neurosurgery, physiatry, physical therapy, occupational therapy, vocational counseling, nursing, psychology, psychiatry, biofeedback, muscle reeducation, and ergonomics. Treatment goals are: reduction/elimination of drug intake, physical restoration, vocational rehabilitation, behavioral modification, and return to a quality life style (Rospmoff et al., 1981; Rosomoff and Rosomoff, 1991). Specifically, the physical restoration program at the CPRC consisted of physical exercises of strengthening, stretching, endurance training, and balance exercises (Rosomoff & Rosomoff, 1987; 1991). The treatment approach at the CPRC comprises an individualized therapeutic program based on findings from the initial multidisciplinary clinical assessments made by multidisciplinary team. Even though treatment is individualized according to the specific needs of each patient, all therapies are derived from well documented, standardized treatment approaches made appropriate for the elderly. Throughout the 4-week inpatient/outpatient treatment program, patients attend 8 hours daily therapy. Muscle strengthening consists of progressive resistive exercise targeting key muscle groups. Resistance is applied through the use of manual techniques, free weights, and/or computerized exercise equipment. Flexibility exercises consist of low-impact movement therapy, active stretching and passive stretching, and joint mobilization. Postural exercises focus upon correcting muscular imbalance resulting from muscle weakness. Balance and gait training are provided according to the specific needs identified in the clinical evaluation.

The Ergonomics and Bioengineering Division (Khalil et al., 1988), evaluates patients performance and functional abilities upon admission to the Center and throughout rehabilitation in order to determine functional capacities, degree of functional loss, progress during rehabilitation, and treatment outcome. A battery of quantitative measures of human performance and functional capacities has been designed for this purpose (Khalil et al., 1987). For the purpose of this study, all patients underwent an initial evaluation (upon admission to the CPRC) and a final evaluation (prior to discharge from the 4-week program). The performance profile consisted of the following measures: psychomotor abilities, walking speed, squatting ability; trunk flexibility; grip strengths; isometric strength of the arms, shoulder, composite, and back; and right and left static knee extension strength. For the evaluation of static muscle strength, the concept of Acceptable Maximum Effort (AME) was used (Khalil et al., 1987).

RESULTS

Table 1 presents the means and standard deviations of the initial and final measures describing performance in the various categories for the male and female patients in the sample. In the repeated measures Analysis of Variance (ANOVA) design for data analysis, there was one grouping factor (Gender: males and females) and repeated observations on the within factor (Time: initial and final).

On the average, all patients demonstrated significant reduction in functional abilities prior to rehabilitation. Upon final evaluation, the change in performance was statistically significant for all mobility, flexibility, and strength measures. Exception was grip and shoulder strengths which showed improvement but not statistically significant. On the average, patients reported an overall decrease in pain level upon treatment. However, for this sample this change in pain level was not statistically significant.

TABLE 2. Means and Standard Deviations (SD) of the Measures of Functional Abilities for the Males and Females in the Sample of 52 Elderly Patients. An '*' Indicates that the Change from Initial to Final was Statistically Significant.

Variable	MALES		FEMALES	
	INITIAL	FINAL	INITIAL	FINAL
PAIN LEVEL (0 to 10)	4.7	3.3	5.2	4.9
WALKING SPEED, ft/sec	4.7	5.7	4.0	4.5*
SQUATTING ABILITY, in	6.9	4.2	17.8	10.8*
CHOICE REACTION TIME, sec	.66	.56	.79	.67*
TRUNK FLEXION, deg	88	112.2	94.2	120.4*
TRUNK EXTENSION, deg	22.6	32.1	23.1	30.6*
RIGHT LATERAL FLEX., deg	33.8	41.6	35.6	45.4*
LEFT LATERAL FLEX., deg	32.1	40.9	33.6	45.6*
GRIP STRENGTH, lb	64.9	74.4	33.4	37.9
ARM STRENGTH, lb	69.4	83.9	21.7	30.5*
SHOULDER STRENGTH, lb	74.3	86.1	23.2	29.3
BACK STRENGTH, lb	55.9	99.9	22.0	45.5*
COMPOSITE STRENGTH, lb	98.0	158.	18.7	58.7*
KNEE STRENGTH, lb	47.5	62.6	25.6	36.7*

Fig. 1. Initial and Final Strength of the Elderly Male Subejcts

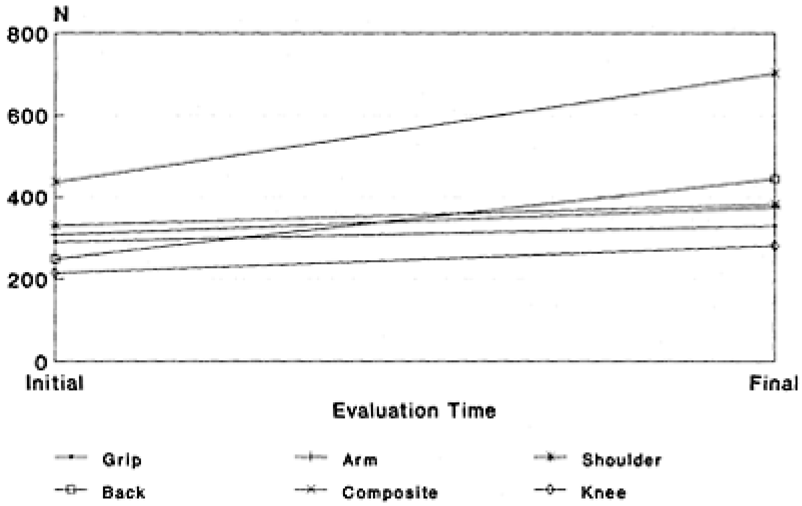
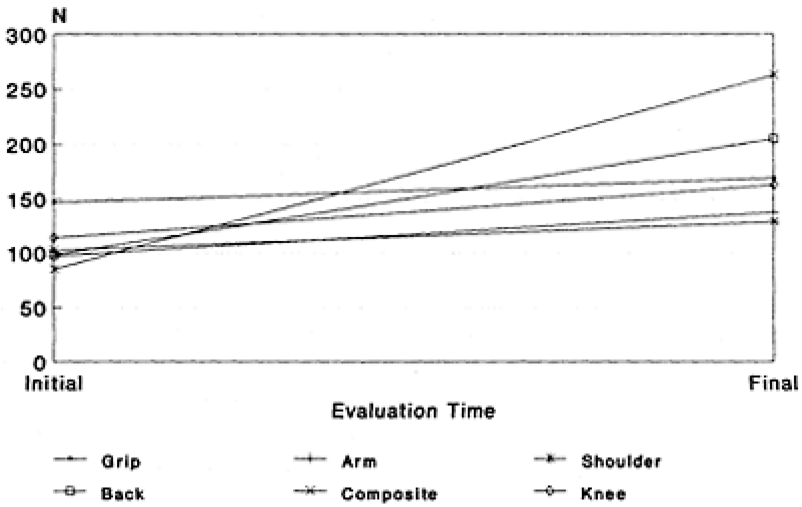


Fig. 2. Initial and Final Strength of the Elderly Female Subjects



DISCUSSION AND CONCLUSIONS

Most of the people who reach old age will experience some degree of disability. Disabilities among the elderly have many origins, forms, and degrees (levels). While some are considered to be a "natural" part of the aging process, other forms of disability can be avoided and even reversed. Disabilities resulting from falls constitute a major concern to elderly persons and their families and the health care system. Fall-related disabilities manifest themselves in different physical and psychosocial degrees. Physical disability include injuries, fractures and even death. Psychosocial ramifications include fear of falling, loss of confidence, and isolation. The management of fall-related disabilities requires a thorough understanding of their causes. Management is a process of assessment, treatment, as well as prevention of disability or further disability.

Exercise can improve the function of bodily systems and improve muscular and cardiovascular working capacity. Even though some studies have given conflicting accounts regarding the relationship between regular exercise and function, many attempts have been made to demonstrate the efficacy of exercise in improving functional capacity of the elderly. Because of the reported association between imbalance and falling, it has been suggested that exercise programs could improve stability and balance and thereby decrease falls (Overstall, 1980). Petrella et al. (1989) suggested that exercise may be useful in postural adaptation, and may be important in avoiding falls (Hindmarsh and Estes, 1989). Rudd (1989) advised clinicians to emphasize exercises to maintain range of motion and muscle strength; both to prevent flexion contractures and to maintain the ability to carry on activities of daily living. Sorock (1988) recommended recreational walking or physical therapy to improve deficits and lead to fewer falls.

At the CPRC, our experience with the frail and elderly patients have shown that a well designed and monitored physical exercise program can be effective in significantly increasing strength and endurance with minimal risk. This paper presented the efficacy of a functional restoration program on the abilities of a sample of elderly persons and their performance. All patients demonstrated low level of functional abilities upon admission for rehabilitation at the CPRC as can be seen from the performance profile obtained through ergonomics and clinical evaluations. Upon discharge from the Center, all patients showed significant increase in all measures of functional capacities. They graduated after 4 weeks of rehabilitation and returned to an active lifestyle. The findings of this study are in agreement with recent studies using strengthening training protocols (Lexell et al., 1992; Frontera et al., 1988) and our earlier findings (Abdel-Moty, et al., 1990). Our clinical experience support the fact that restoration of physical abilities is as effective in the elderly as it is for younger population. The elderly patients included in this study showed significant improvement in functional capacities upon the administration of appropriate exercise regimens. None of the patients experienced cardiopulmonary distress, musculoskeletal injury, or other significant medical complications as a result of a daily, relatively strenuous physical conditioning and rehabilitation program. The study supports the contention that a well designed and administered physical restoration program can effectively increase strength and improve many human performance parameters. Linking such improvement to reduced incidence of falls is yet to be firmly established. This requires a well designed epidemiologic prospective study to establish the relationship. It is strongly recommended that such a study be undertaken.

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CROSS-SECTIONAL DIFFERENCES IN WORK-PLACE SUBSTANCE ABUSE; A PRELIMINARY ANALYSIS OF THE CDS DATA SET AND ITS IMPLICATIONS FOR INJURY AND MUSCULOSKELETAL DISABILITY

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INTRODUCTION

Efforts to reduce morbidity and mortality in the workplace have focused on ergonomics (i.e., design or redesign of the workplace to fit the worker) or on administrative controls (i.e., pre-selection of the worker to match job demands). As Snook (1987) has pointed out, while ergonomic interventions appear to be the method of choice among professionals in the field, there are some jobs that do not lend themselves to ergonomic interventions (i.e., police, fire-fighters, military combat pilots, etc.). We intend to present data that suggests that ergonomic interventions can only be effective when used in conjunction with administrative controls. Administrative controls are required as an adjunct to ergonomics because of the changing demographics of the workplace (i.e., the average age of the work-force is increasing) and personal factors (i.e., prescription drugs, drug or alcohol use, etc.) which can circumvent the best efforts made to redesign a workspace. The fastest growing segment of the population in the United States are those individuals over 85 yrs of age. It has been suggested that this age group, referred to as the old-old, will continue to be the fastest growing age group in the future (Schneider & Guralnik, 1990). The increase in the size of the old-old cohort is predictive of the aging of the general population, and specifically of the working population. By the end of the current decade the median age of the work force will have increased from 36 to 39 years reflecting both an increase in the number of workers over 55 and the significant decrease in the number of workers between 16 and 24 years (McLaughlin, 1989).

An older work force will pose unusual challenges for the ergonomist trying to reduce mortality and morbidity in the work force. A recent study indicated that while younger workers (i.e., 20 to 34 years) experienced greater numbers of deaths, older workers (i.e., 55 and older) had higher fatality rates (Bell et al., 1990). This finding is consistent with data reported by Root (1981) who noted that, while older workers had fewer injuries than younger workers, the injuries that were reported accounted for more permanent disabilities and deaths. Root noted that all age groups had a higher proportion of job related injuries during the first year on a job than for any succeeding year on the job. This finding was replicated by Butani (1988) who noted that workers had twice the risk of injury during their first year on a job then for subsequent years, regardless of their age. While morbidity levels during the first year on a job may be due to inadequate training (Jensen & Sinkule, 1988), morbidity among older workers at all seniority levels may be due to the failure of cognitive strategies used to maintain overall competence in the face of age related declines (e.g., discussion by Salthouse, 1990).

Two problems that mitigate against providing a successful ergonomic solution for reducing work related morbidity in the older worker are 1.) the lack of an adequate knowledge base to redesign the workplace (Winn, 1991), and 2.) personal factors, such as alcohol or drug use, that can hamper cognitive functioning.

The cohort comprising the baby boom is the first generation to embrace drug use. This use cuts across race, religion, and SES lines. Drug use in this cohort has included LSD in the late 60s, heroin in the late 60s and early 70s, and cocaine in the 80s. The ease and familiarity with which this cohort adapts to drugs could progress to the widespread abuse of prescription drugs in senescence.

Radical demographic changes are occuring as the baby boomers age. These changes are partly the result of a smaller follow-on generation, referred to as the baby bust, which is creating a rapidly aging work force. The baby boom generation is taking both its strengths (i.e., well educated) as well as its shortcomings (i.e., substance abuse) into the workplace. This has resulted in substance abuse emerging as one of the more common problems encountered in industry (Wright 1989). The use of drugs in industry appears to not only increase the number of accidents, but to increase morbidity rates. For example, recent studies have indicated an increased risk for industrial injuries and accidents among individuals testing positive on a pre-employment drug screening at a Boston postal facility (Zwerling, Ryan, & Orav, 1990; U.S. Postal Service, 1991). Unfortunately, the studies did not determine if the accidents and injuries were a direct result of substance abuse or just associated with it.

An estimate of employer costs resulting from employee substance abuse can be determined from the work of Masi (1986). Masi estimates that 12% of the problems that affect job performance are related to substance abuse and that these problems result in a 25% decrease in productivity. Assuming a company pays an average salary of $25,000, and employs 1,000 workers, then the employer could experience a loss of three quarters of a million dollars (Masi, 1986). This loss does not include direct costs attributable to sick leave, health care, workmens compensation payments, or costs associated with engineering redesign. These costs provide a strong argument for the position that instituting ergonomic controls, without also instituting administrative controls for behavioral risks, could result in an expenditure of resources without a concomitant reduction in morbidity. For example, the ergonomic redesign of a workstation could effectively change task demands to such an extent that the older worker is put at the same risk for injury as a new employee. That risk could be compounded by a substance abuse problem.

Substance abuse (i.e., the abuse of either prescription or non-prescription drugs) has traditionally been considered a problem of the young, the homeless, and/or the unemployed. There has not been an attempt to determine if assumptions concerning personal risk factors in older workers are reflected in the data bases collected by the National Institute on Drug Abuse (NIDA). This report examines one of the NIDA data bases for insights into the drug use patterns of different age cohorts in industry. The current data is drawn from the Client Data System (CDS), a data base developed in response to requirements of the Anti-Drug Abuse Act of 1988. The CDS, which dates to August 1990, is not yet fully operational. Because of the preliminary nature of the data set, this report will provide descriptive information on referrals from Employee Assistance Programs to 646 drug treatment programs in six cities.

METHOD

Subjects

In 1990, the first year of data collection for the CDS, treatment programs submitted records on 17,993 cases. There were 73,280 cases submitted in 1991. The total number of cases for the two years was 91,273. Table 1 contains the referral sources for the population.

Table 1. Source of treatment referral noted on CDS for cases reported to NIDA

Source	Frequency	Percent
Individual	35,986	39.4
Alcohol or drug care provider	12,424	13.6
Other health provider	5, 359	5.9
School	758	0.8
Employer/EAP	1,562	1.7
Other community referral	7,877	8.6
Court or criminal justice referral	23,719	26.0
Unknown	3,029	3.3
Not collected	559	0.6

The current report is based on the 1,562 cases referred from either the employer, or Employee Assistance Program (EAP), to a public treatment facility. The six cities included in this report were Dallas, Houston, Detroit, Boston, New York, and Miami. This is a biased sample that under-represents the population. Most referrals from employers, or EAP programs, would probably be to private rather than public facilities. The current sample was composed of 1,308 males and 245 females. Sex differences are not reported because of the small number of females.

Method

The Minimum Client Data Set (CDS) is an attempt by NIDA, the National Institute of Alcohol Abuse and Alcoholism (NIAAA), and the States to work together in the collection of data which are useful for both policy decisions and program management at both the State and national levels. The success of CDS is dependent on three points: 1) The proficiency of the State alcohol and drug abuse agencies to collect and report data; 2) the consistency of the data both between and within testings; and, 3) the standardization of data content across State statistical systems. The CDS is based on information collected at admission from alcohol and drug clients admitted to State-supported treatment programs. The information contained in the CDS is based on approximately 40 questions asked of each individual who presents for admission. Each treatment center provides NIDA with a quarterly update. The current report, while limited to a small subset of the available questions, represents information collected through the last quarter of 1991.

Results

Table 2 provides data on the primary substance of abuse for each cohort. The primary substance of abuse for 10 subjects in the sample was recorded as 'unknown.' These 10 subjects are not included in the tables. The classification 'other' in Table 2 was used for the following drugs: Non-prescription methadone, PCP, other hallucinogens, methamphetamine, other amphetamines and stimulants, benzodiazepine, other tranquilizers, barbiturates, inhalants, etc.

Table 2. Age cohort by primary substance of abuse

DRUG AGE

FREQUENCY	UNDER 20	20 - 29	30 - 39	SUB TOTAL
ALCOHOL	2	62	163	227
COCAINE/CRACK	10	208	373	591
MARIJ/HASH	6	40	38	84
HEROIN	0	29	116	145
OTHER	1	11	30	42
TOTAL	19	350	720	1089

DRUG AGE

FREQUENCY	40 - 49	50 - 59	60 & OLDER	SUB TOTAL	TOTAL
ALCOHOL	109	44	18	171	398
COCAINE/CRACK	140	25	3	168	759
MARIJ/HASH	20	5	3	28	112
HEROIN	59	13	0	72	217
OTHER	19	5	0	24	66
TOTAL	347	92	24		1552

The row totals in Table 2 indicate that the most common drug of abuse for these referrals was cocaine/crack (49%) followed by alcohol (26%) and heroin (14%). What is surprising is that 7% of the sample was referred for treatment of a marijuana/hashish problem. Since hospital emergency rooms seldom report admissions for this class of drugs, this finding could be indicative of either an attempt by the treatment facility to protect the client (i.e., reporting this class of drugs as a primary problem rather than a class with more negative connotations such as heroin) or a change in employer attitude resulting in a zero tolerance for any substance of abuse.

More than 50% of this sample could be classified as baby boomers. We would have expected that the majority of drug users during the 1970s would have been under 30 years of age. In this sample 75% of the sample are older than 30 years and approximately 30% are 40 years or older. The Secretary of Labor classifies the older worker as those individuals over 40 years of age (McLaughlin, 1989).

CONCLUSIONS

If the assumption noted earlier is true (i.e., that this sample under-represents older workers who would tend to seek treatment in a private, rather than a public facility) then we may be prudent in speculating that physical and cognitive impairment, resulting from substance abuse in the workplace, is a significant problem. Using the assumptions by Masi (1986) that we discussed above, the number of employees represented in this sample constitute an employer cost in excess of a million dollars. This amount could prove to be significantly higher if indirect costs were included. For example, if it is shown that the abuse of prescription or street drugs facilitates demyelination of nerve sheaths, either through the action of the drug or through the action of the substances with which it is mixed, then we might expect a disability, and loss of time from the job; a drug induced impairement of cognitive functioning could increase the individuals risk of morbidity or mortality because of increased work load; or, the use of certain classes of drugs might act to decrease oxygen consumption resulting in an increased relative aerobic strain (RAS) on the worker. It has been suggested that an increase in RAS is associated with an increased probability of musculoskeletal disability for workers over 50 (Ilmarinen, 1991; Ilmarinen & Rutenfranz, 1980).

The effects of drug use on morbidity and mortality in the work place have not been well studied. This could pose a significant problem for the ergonomist who assumes that instituting engineering controls will reduce, or possibly eliminate, the risk of morbidity and or mortality. With an aging workforce, that has become comfortable with the use of both legal and illegal drugs, the ergonomist may need the assistance of a specialist in human psychopharmacology. This would provide the ergonomist with valuable information on whether job redesign, administrative controls, or both would be more effective in reducing the risk of morbidity and/or mortality. The integraton of human psychopharmacology into human factors has already begun in Europe (O'Hanlon, 1991); the importance of the field for the American workplace should soon be recognized.

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COLOR HUE IMPAIRMENT AS AN EARLY INDICATOR OF CNS PERFORMANCE DEFICITS

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Color vision impairment may be an early indicator of CNS deficits which could affect industrial safety and performance relying on visual stimuli. This study examined the effect of age and time of day on color vision among 89 chemically unexposed workers. Deficits in either eye increased significantly with age ($p<.01$). Although variation existed between individual pre- and post- shift scores, there was no significant difference between the averages of the two scores. The effects of gender, mood, and alcohol consumption were controlled for in the analysis. Mood correlated strongly with color confusion.

INTRODUCTION

Chronic low level exposures to workplace neurotoxins such as solvents and heavy metals are considered to be risk factors for accelerated central nervous system (CNS) degradation. However, most tests used to evaluate CNS status are subjective and effort dependent. Measurement of color vision deficits may offer a simple, yet more objective measurement of accelerated CNS degradation. Some studies suggest that these deficits could be a sensitive detector of pre-clinical CNS changes associated with workplace exposures (Mergler, 1987).

The Desaturated D-15 Hue (D-15) test uses colors of low purity to provide a sensitive measure of acquired color vision deficits (Lanthony, 1978). A number of studies have supported the test's ability to detect age related degradation of color vision (Pinickers, 1980, Helve and Krause, 1972, Bowman et al. 1984). We have attempted to replicate these findings in preparation for applying this test to occupationally exposed subjects. In addition, other confounding factors (such as alcohol consumption and subject's mood at the time of the test) have been considered.

METHODS

This cross-sectional study was designed to evaluate the effects of age and time of work day on color discrimination workers at two local institutions. Subjects were not regularly exposed to solvents or heavy metals in their work, and were tested pre- and post-standard work shift on the same day using the D-15 test. As acquired color discrimination can occur in a single eye (Mergler, 1987), the test was administered separately to each eye.

In order to evaluate each subject's motivation and affective state during the test period, the Profile of Mood States (POMS) test was administered preferably pre-shift, but post-shift if necessary (McNair et al., 1971). Information on age, gender, alcohol consumption and prior work experience was recorded during a brief interview with each subject. Subjects were paid $15.00 to compensate for their test time and effort. The Desaturated D-15 Hue test is comprised of 16 color caps from the Munsell book of color chosen to create approximately equal chromatic intervals between the caps. The Munsell 'chroma' (or purity) of each cap is 2 and the Munsell 'value' (or luminosity) is 8 (Lanthony, 1978). To standardize the test, we used illumination provided by a "daylight" GE fluorescent bulb (approximately 1150 Lux) at a distance of 30 centimeters over a black matte surface (Mergler, 1987). Both Bowman's (Bowman, 1982) and Vingrys' (Vingrys, 1988) color confusion index scores were used to quantify test results.

The Profile of Mood States test measures six identifiable moods (on affective states). These include tension-anxiety, depression-dejection, anger-hostility, vigor-activity, fatigue-inertia and confusion-bewilderment (McNair et al. 1971).

Analyses were conducted on a personal computer using the dBase STATS (Ashton-Tate Version 1.1) package for frequencies, cross tabulations and correlations, and EGRET (Statistics and Epidemiology Research Group, Version 0.26.5) for logistic regression.

RESULTS

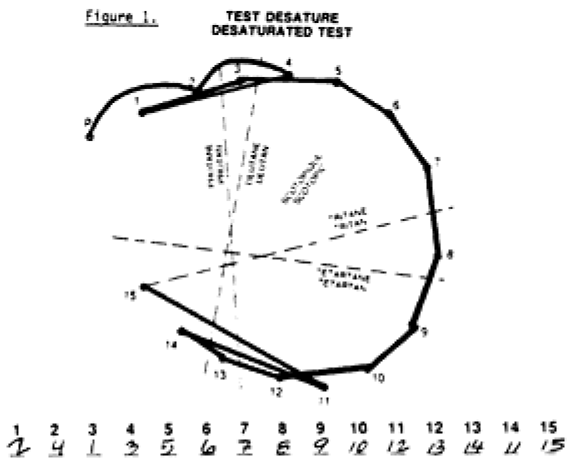
A heterogeneous group of 94 production workers from two local institutions were recruited for the study. Five subjects were excluded from analysis due to possible confounding factors (i.e. cataract, one glass eye, tinted glasses, or glasses not used for all test sessions). The 89 subjects accepted for analysis ranged from 18 to 69 years of age (see Table 1).

Table 1: Study Design, AM and PM Test Sessions

Age Category	Mean Age	Male	Female	N
<25	22.6	9	9	18
25–34	30.0	11	11	22
35–44	39.9	8	10	18
45–54	49.6	8	8	16
55+	62.4	2	13	15
Totals	39.5	38	51	89

Bowman's and Vingrys' color confusion index scores were compared to plots of the subjects' performance on a two dimensional color plane (Luneau Opthalmologie, 1990) to visually evaluate which score would best define unambiguous color vision deficits. While these scores are highly correlated and usually of similar magnitude, the average reliability of the right and left Vingrys scores was .88, exceeding .86 for the Bowman score. In addition, it was determined that the Vingrys score more accurately interpreted the visual plots. A Vingrys score of 1.60 or greater consistently indicated an impairment. This cut off point agrees with Vingrys' analysis of test scores using these plots (Vingrys, 1988). Figure 1 illustrates a plot of test results with a Vingrys score of 1.60 on the color plane. The Vingrys' continuous color confusion index, and a dichotomous color vision impairment variable based upon a cut point of 1.60 are used in the remainder of the analyses.

Figure 1.



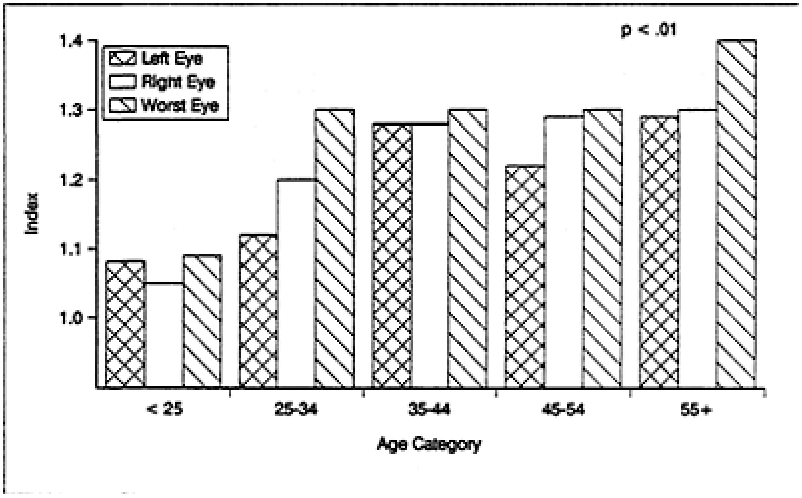
The mean difference between AM and PM Vingrys scores was 0.045 (p=0.15) for the right eye and 0.028 (p=0.33) for the left eye. The correlations between AM and PM were .78 for the right and .75 for the left eye. The small (PM-AM) difference scores represent a 3% and 2% right and left eye within-day variation which is easily detectable with as few as 9 or 17 subjects using the right or left eye (A=.05; B=.80). Thus the statistical power of this test is substantial (Vonesh, 1986).

Of equal importance, there were a number of subjects with large differences between the AM and PM test times. For the right eye, 25 subjects had AM-PM differences of 0.30 or greater, and 33 had differences of 0.20 or greater. For the left eye these numbers were 16 and 26. Approximately 60% of the subjects with these levels of AM-PM differences improved in their PM test. There were no consistent patterns of differences by age.

A comparison of AM and PM color vision impairment resulted in 13 subjects with discordant AM-PM categorization in the right eye, and 14 in the left eye. Because of these sizable variations, we decided that the best estimate of a true chronic deficit in each eye would be the best of the two scores for that eye.

Figure 2 shows how the Vingrys color confusion index increases with age (demonstrating deteriorating color discrimination) for both the left and right eye. In addition, because color vision deterioration may be monocular, we plotted the Vingrys index for the worst eye for each subject. This value also increases with age.

Figure 2: Vingrys Color Confusion index Versus Age Category



Recent alcohol consumption and subject mood appear to be important confounders in evaluating the relationship between color vision and age. The relationship between age and alcohol consumption shown in Figure 3. All the POMS mood scales were highly correlated with each other, and all but one were significantly correlated with age. Figure 4 shows the relationship between three of the POMS mood scales and age. “Depression” was the scale most highly correlated with the Vingrys color confusion index (r=.1748 with right eye, r=.2959 with left eye, r=−.2813 with age), and was chosen for use in the remaining analyses.

Figure 3. Proportion of Alcohol Use by Age Category

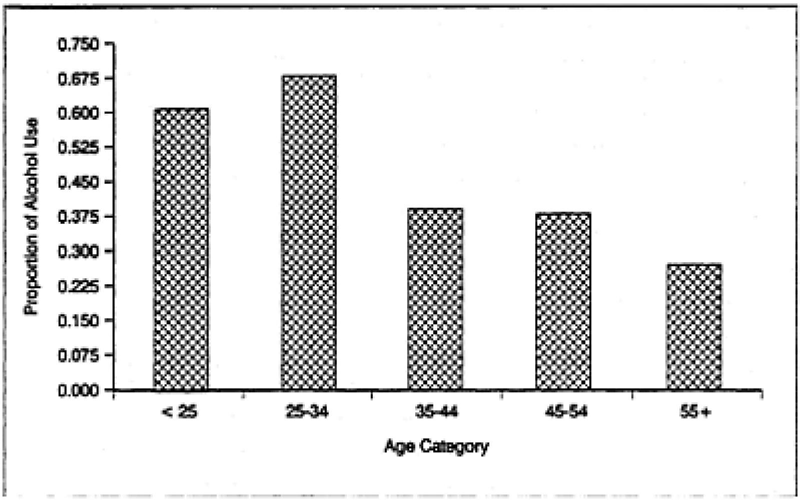
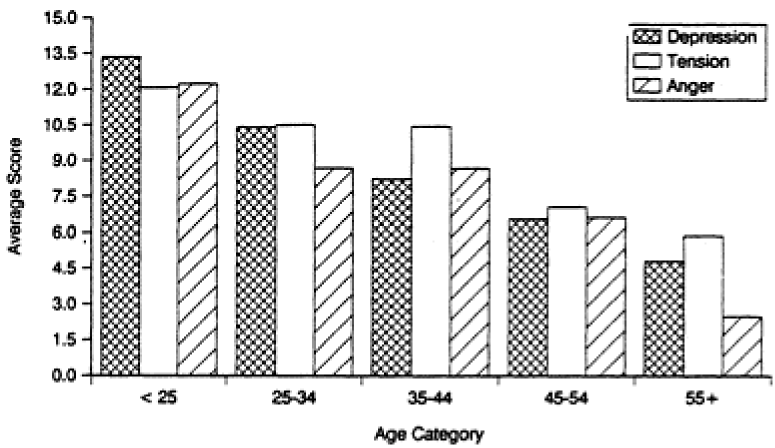


Figure 4: Mood Versus Age Category



Logistic regression was used for analyses of color vision impairment and control of possibly confounding variables. When age was stratified into five age categories, crude analysis demonstrated approximate linear trends in the odds ratios for color vision impairment in the right, left and either (or worst) eye. However, when adjusted for confounding factors, the trends became very linear. Thus, a continuous age variable was used in the remaining regression analysis. Age squared was introduced into the equation and was not an important or significant factor.

The results of the logistic regression are shown in Table 2. The effect of age is consistent for right, left and either eye. The adjusted odds ratio is consistently increased in magnitude by controlling for confounders. Mood, as measured by depression, is also a consistent factor. Gender is a non-significant but consistent factor showing less deterioration for females, while self reported alcohol use is both non-significant and highly variable in its effect.

Table 2: Results of Logistic Regression for Color Vision Deficit as Measured by the Vingrys Color Confusion Scale

Eye	Crude and Adjusted	Odds Ratio and Confidence Intervals			
		Age	Depression	Gender	Alcohol
Right	Crude	1.05 (1.01–1.10)			
	Adjusted	1.07 (1.02–1.13)	1.09 (1.02–1.17)	0.64 (0.14–2.83)	2.75 (0.59–12.9)
Left	Crude	1.06 (1.00–1.11)			
	Adjusted	1.09 (1.01–1.17)	1.15 (1.04–1.27)	0.41 (0.06–2.79)	44.8 (0.76–2653)
Either	Crude	1.06 (1.02–1.10)			
	Adjusted	1.07 (1.02–1.13)	1.08 (1.02–1.15)	0.55 (0.13–2.24)	4.07 (0.92–18.0)

Note: Score for each eye is best result of AM and PM effort.
Score for either eye is the result of the worst eye.
Color vision deficit is defined as a score of 1.6 or higher on the Vingrys Color Confusion Index.

DISCUSSION

There are a number of limitations on the interpretation of these results. First, visual acuity was not measured and is considered to be a confounder for color discrimination. In addition, while the intensity and color (temperature) of the light used for illuminating the test area was carefully controlled, surrounding light (room or daylight) may have been strong enough to effect the intensity and/or color of the actual light striking the color caps. Third, the right and left eye order was not rigorously controlled.

The first limitation, poor acuity, was controlled by eliminating those subjects who required corrected vision, but did not have glasses or contacts with them at the time of the testing, as well as those with special vision problems. However, we cannot be certain that this completely controlled for visual acuity. The possible effect of variation in light intensity and color would be minimized because most subjects were tested in one of two locations, and the age distribution for each location was wide. In addition, we used in our analyses the best of two efforts for each eye. Therefore, any introduction of variation by light source would not be expected to be correlated with age. Lastly, we recommend future studies balance the eye order to control for learning within a session. However, the effect of age and test session is likely to be far greater than the effect of testing the eye order on color discrimination.

It is difficult to explain the frequent large variation between subjects from pre- to post-shift testing. It may be associated with changes in mood (which was only measured once) or effort. It is quite clear, however, that there was no consistent improvement from AM to PM tests scores, and therefore no learning effect was apparent.

The observed increase in the average Vingrys color confusion index with increasing age category appears to demonstrate its ability to distinguish the effects of age. The fact that other researchers found age effects with the saturated and/or desaturated D-15 hue tests is reassuring. In particular, Bowman's results (Bowman et al., 1984) demonstrated an age effect using his color confusion index for the desaturated test that very closely matches the magnitude of the effect we have observed.

The average of Vingrys' color confusion test score for any age and/or gender subgroup may be overly influenced by a few people with extremely abnormal results (either acquired or inherited). This might make the test less sensitive to acquired, sub-clinical changes in color vision due to age and/or chronic workplace exposures. To avoid this possibility, we defined a color vision impairment as a value of 1.60 or greater on the Vingrys score. Using this dichotomous classification, we were able to show a highly significant linear increase in impairment with increasing age. The linearity of the increase improved as we controlled for possibly confounding factors. We believe that the consistency between the impairment results and the continuous color confusion index suggest that impairment may be useful in detecting sub-clinical color vision deficits within at risk populations.

In customary test-retest analysis of neuropsychologic tests, the within day variability of scores may be as great as the treatment effect (Echeverria, 1991). It may be that the color-hue Vingrys score measures more of a physiologic than psychologic parameter resulting in greater stability. This approach has promise in that physiologic tests may be quite sensitive to occupational exposures reducing the influence of common confounders such as education.

In conclusion, the D-15 test as scored by Vingrys appears to be a sensitive measure of color confusion related to age. If this is the case, it may also be a useful measure of CNS degradation related to chronic low level workplace exposure to neurotoxins such as solvents and heavy metals. However, this test seems to be more mood or effort dependent than we anticipated. To control effort dependence, we would recommend that multiple tests be given to a subject to determine a best, and hopefully reproducible, score. It also appears that the POMS mood score can correct for some of the variability that may be introduced by mood or effort.

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The relationship of field dependence, working memory, and visual search skill to driving decision at a left turn intersection

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Older drivers have particular difficulties at intersections, especially in their performance of left turns. The research is inconclusive regarding the individual characteristics that best predict such accidents. The following study will investigate the relationship of field dependence, visual search skills, and working memory to the decision of older drivers to perform a left turn at an intersection. Results will be presented and their implications for driving safety discussed.

INTRODUCTION

Older drivers' annual contribution to the total number of car accidents is low compared to that of their younger counterparts. However, although they drive 1/3 as many vehicle miles per year as persons under age 65, they are involved in twice as many accidents per mile driven than all other drivers except those 25 and younger (Retchin et al, 1988; Milone, 1985). In fact, drivers 75 and older have an accident rate per mile that is similar to that of drivers 25 years old and younger. Older drivers have a greater rate of accidents involving failure to yield the right of way; failure to obey traffic signs and signals, improperly negotiating intersections; making improper turns (especially left turns), careless or inaccurate lane changes, and careless backing and driving the wrong way on one-way streets (McKnight, 1988; Yaksich, 1985; Waller, 1967). In an analysis of the attribution of fault in different types of accidents (i.e., rear end, angled, left turn, sideswipe, backing into vehicle, right turn, head on) in the Florida 1989 accident data, Guerrier & Nair (1990) found older persons (65+) to be at fault more often than younger drivers in every type of accident except in rear end and head on collisions. As the baby boomers fill the ranks of persons 65 and older within the next three decades, the number of drivers 65 and older will greatly increase. Thus, there is a pressing need to understand the difficulties they encounter while driving so that effective intervention strategies can be developed.

As already indicated, older drivers have particular difficulties at intersections; especially in the performance of left turns. The demands imposed by left turns surpass those of other maneuvers at intersections (e.g., right turns, proceeding straight across the intersection). An analysis of maneuvers at an intersection, including crossing the intersection, making a right turn, and making a left turn from a standstill to about 30 miles per hour (Dulles, 1991) showed the following: 1) crossing an intersection takes about 4 seconds, thereby requiring a 5 second gap from traffic in both directions; 2) a right turn takes about six seconds, requiring a 7 to 8 seconds gap from a standstill, and 3) the left turn takes about nine seconds requiring a traffic gap greater than 9 seconds. The demands imposed by the intersection environment are evidently greater than the capacity of many older drivers as manifested not only by a greater percentage of roadway accidents (DHSMV Special Report, 1990) but also by the outcome of such accidents with respect to injuries and fatalities. Hauer (1988) reports that close to 40 percent of fatalities and 60 percent of injuries to drivers 64 years old and older occur at intersections. These data not only highlight the need for solutions to promote safe maneuvers at intersections, they also stress the need for understanding the factors that predict such accidents in the older driver.

It is recognized that the dynamic road environment imposes various psychomotor, perceptual, and cognitive demands upon the individual driver. These demands must be met by an individual for the safe performance of driving tasks. Various studies have reported specific deficits in the capabilities of older drivers that might impact upon their driving ability. For instance, Fell (1976) reported that 60% of accidents involving older drivers are due to information failures such as recognition and decision failures. Scialfa, Kline, Lyman, and Kosnik (1987) conducted an experiment where they found that older persons tended to overestimate the distance of vehicles compared to younger persons. Likewise, laboratory research by Hill and Mershorn (1985) has shown older persons to underestimate the separation distance between visual targets compared to younger individuals (cited in TRB Report 218, 1988). Such findings have implications for various driving maneuvers (e.g., performance of driving tasks at intersections) requiring assessment of vehicle distance. The recognition or decision failures reported by Fell (1976) may be related to declines in the driver’s perceptual/sensory capability. Other factors which may be related to failures at intersections may include personality characteristics such as locus of control (Laux and Breslford, 1990), field dependence/independence (Goodenough, 1976), perceived ability (Matthews, 1986), and perception of risk (Matthews, 1986; McMillen, Smith, and Wells-Parker, 1989).

The present study (in process) investigates the relationship of specific driver characteristics such as field dependence, visual search skills, and working memory to the decision to make a left turn. Also of interest is the relationship of demographic and other drivers’ characteristics such as driving experience to that decision.

METHOD

Invitations to participate in the study were sent to 180 older women age 62 and older who hold a valid drivers' license and currently drive. These women were selected from a pool of older persons who have participated in other studies conducted at the Stein Gerontological Institute. To date, data have been collected on eleven subjects. Upon consent to participate, the following were administered: 1) a visual acuity test (i.e., Snellen eye chart), 2) a demographic and driving experience questionnaire including a test to assess knowledge of common road signs, as well as questions about specific difficulties the older driver might encounter in operating her car; 3) a test of field dependence/independence involving the recognition of six embedded figures (i.e., embedded figures test) 4) a test of visual search capacity which consisted in determining the presence of a specific character from a cluster of other characters (no time limit), 5) a working memory test which consists in solving five sets of three simple additions mentally and relating the results to the experimenter upon completion of each set; 6) a simple reaction time test, 7) a choice reaction time test, 8) a spatial localization test.

The left turn decision task involved viewing fifteen film clips of oncoming traffic at an intersection presented on a black and white TV monitor. The film clips varied according to traffic density; they were selected from a film shot on a heavily traveled road. The participants were asked to indicate when they would choose to make a left turn at that intersection by pressing any key on the keyboard placed in front of them. This action would immediately stop the display. The participant initiated the next display when ready. This sequence of actions was repeated until all film clips were presented.

Two components of the participants' responses were analyzed: the decision time, namely, the time it takes the participant to decide on making a left turn from the initiation of the film clip and the vehicle gap time chosen by the participant. Vehicle gap for cars in the near and far oncoming lane were measured by the time elapsed from the initial position of the nearest oncoming car to its final position at a point near the intersection.

Equipment Used

A BCD device was used to control presentation of the film clips through a video cassette recorder (VCR) from an IBM PC compatible computer. This technique also enabled us to collect and analyze the driving decision data. The audio channels on the videotape were used to code frame numbers in order to locate the exact tape position where participants made a decision. A BASIC program was written to provide communication with the VCR and to select specific frames to be presented to the participant. The display consisted of a 13″ B/W monitor that was connected to the VCR through the BCD interface.

RESULTS

As mentioned earlier, data were collected on only eleven participants, consequently preliminary data are presented which are descriptive statistics as well as correlation analyses among the predictor measures. Analysis of the relationship between the predictor measures and criterion measures (i.e., gap chosen, decision time) will be presented at a later time.

The mean age of the eleven participants was 78.3 years (SD=6.1). Their age ranged from 61 to 84 years old. As might be expected, the older the participants the poorer their visual acuity (r=.68). Visual acuity was directly related to the visual search time of the participant (r= .81), it had a small negative relationship to their visual search score (r=−.16).

Performance on the embedded figures test (i.e, field dependence) was negatively related to visual search time (r= −.25) but had no relationship to visual search score. Age was negatively related to performance on the embedded figures test (r=−.43), a relationship that might have been contributed to by the older participants' poorer visual acuity as shown by the negative relationship between acuity and performance on the embedded figures test (r=−.31).

Performance on the working memory test had a low positive correlation with age (r=.19), and a moderate positive correlation with performance on the visual search score (r= .47) but no relationship to visual search time.

CONCLUSIONS

The preliminary trends between the predictor variables that are reported above show certain relationships that need to be studied on a larger sample. Furthermore, the relationship of these variables to the criterion variables related to left turn decision in this study has yet to be determined. Given the very small sample on which the above analyses were performed, it is not possible to explain the meaning of these relationships to each other nor prudent to speculate about their relationship to the criterion variables. For instance, what is the contribution of visual acuity to visual search performance compared to that of field dependence or age. More importantly, we need to determine how much of the variance of the components of left turn decisions these variables explain.

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REHABILITATION

ERGONOMICS IN REHABILITATION: A CONCEPTUAL MODEL

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The goals, content and methodology of rehabilitation has much in common with ergonomics. However, the clinical nature of the former along with its markedly different clientele creates a perception of exaggerated divergence. A comprehensive incorporation of ergonomic methodology can significantly enhance rehabilitation. A conceptual model and a framework for operationalizing such a strategy is briefly presented.

INTRODUCTION

The Disability Statistics Compendium of the United Nations (1990) reported that in some of the participating countries the disability ranged between 2.4% to 20.9% of the total population. However, it must be noted that due to a lack of standardization in process, criteria, and reporting, the number of people who fall under the disabled category may have been grossly underestimated. Furthermore, in many of the developing countries the economic factors may blur the distinction between the disease and disability. Such a factor is likely to create a greater degree of apathy and lack of motivation to report appropriately the extent of disability. As early as in 1979 Grall reported that in the United States alone the total number of people considered handicapped was 62.3 million—30% of the entire US population. He also stated that up to 49 million people were considered to be permanently disabled and handicapped. He indicated that this population was also 30% older than the non-handicapped and at least three times more likely to be unemployed. As clearly it appears that disability and aging have a significant degree of overlap. It is worthy of note that the projections for the North American continent that by the year 2010 up to 40% of the overall population would be in their golden years. Furthermore, this group also tends to be economically not so well off. With a dwindling normal population and an increasing group with a disability, it may become an economic necessity for nations at large to incorporate this group in the work force. Due to the economic hardship on people with disability, it also becomes an attractive proposition for them. The role of rehabilitation is to accomplish functional restoration to allow normal activities of daily living. Such normal activities then, merge with the working activities. The process of initial rehabilitation of people with disabilities to a normal living and subsequent vocational rehabilitation makes a systematic and comprehensive incorporation of ergonomics in rehabilitation attractive.

The purpose of this article is to highlight the commonality between the rehabilitation and ergonomics and draw the attention to complementary and parallel framework of these two disciplines. In addition, the scope of ergonomics within rehabilitation spectrum is presented.

The World Health Organization (1980), in its World Program of Action, has identified three goals. They are primary prevention, rehabilitation, and finally equalization of opportunity for handicapped people. To elaborate, the goal of prevention strives for preventing the onset of physical, mental, or sensory impairment. However, if an impairment has occurred, then efforts are made to minimize the negative consequences. The second goal is to launch a goal oriented and time limited process aimed at enabling an impaired person to reach an optimal functional level within the domain of disability. A necessary accompaniment of this goal is reduction and elimination of pain and suffering. The final goal is to minimize the effect of residual functional deficiencies by overcoming them through modification of physical environment, such as housing and transportation. Thus, this medical model of rehabilitation parallels the ergonomic model and its goals of ensuring worker comfort, health and safety, and enhancing his efficiency and effectiveness. Ergonomics thus, is not only complimentary to World Health Organization's model of disability management, but it can be an effective tool in the realization of WHO's goals. The disability prevention can be achieved to a large extent through elimination of hazards. The process of rehabilitation can also be significantly augmented by incorporation of ergonomic principles to optimize the outcome measures and increase the efficiency of management strategies. Furthermore, the role of ergonomics lies in generation of criteria for normal standards and development of appropriate testing and evaluation techniques. The latter will provide a means of determining the degree of impairment and subsequent recovery following rehabilitation procedures. It can also provide scientific enhancements of some of the treatment regimes by optimizing the processes and eliminating redundancies. Furthermore, the application of ergonomics will enhance WHO's third objective of equalizing the opportunity for people with disability. The latter can be achieved through modification of workplace, work process, and work environment in addition to living and recreational facilities. A conceptual integration of the role of ergonomics in the medical model of disability by WHO (1980) is presented in Figure 1.

Kumar (1989) defined rehabilitation as a science of systematic multidimensional study of disordered human

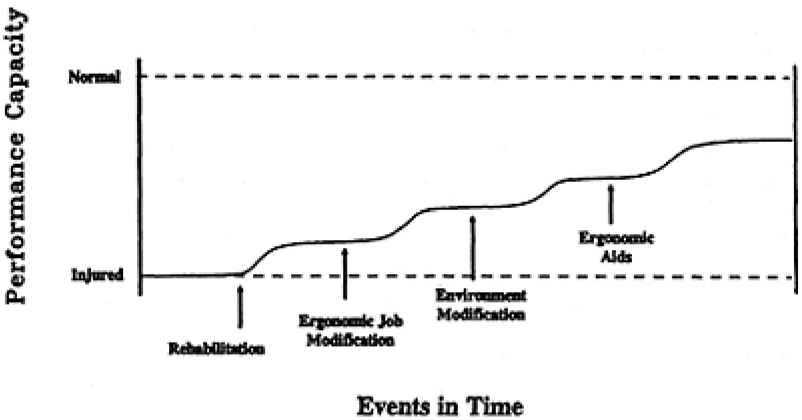

Figure 1. An integrated medical and ergonomic models

neuropsycho-social and/or musculoskeletal function(s) and its (their) remediation by physical, chemical, and psycho-social means. Ergonomics on the other hand, is defined as the natural laws governing work. If one were to discount the qualifier of disordered from the definition of the rehabilitation and consider activities of daily living as work, then the definition of ergonomics is entirely applicable to rehabilitation. From the previously mentioned tripartite goals of ergonomics and rehabilitation and the foregoing definitions, the overlap between the two disciplines is clear. One may deduce then than the central goal of both disciplines is to enable, enhance, and optimize function. The difference then lies in the context of application and the clientele to whom they are applied.

In spite of a significant overlap between rehabilitation and ergonomics, it will be misleading not to emphasize their essential differences. In addition to the context and clientele, their differences lie in the specific body of knowledge, rehabilitation being clinical and ergonomics non-clinical and applied. Furthermore, the ergonomists work toward to adjusting and optimizing factors external to workers to enhance comfort; well-being, efficiency, and effectiveness. The rehabilitation professionals on the other hand, work primarily toward enhancing the factors internal to workers for functional restoration. The remaining dysfunction is then dealt with through assistive devices and modification of the environment.

THE INTEGRATED CONCEPTUAL MODEL

To cover the spectrum of rehabilitation needs, it is essential to have functional divisions of this model covered separately. Some aspects will deal with people related issues, others with issues more pertinent to processes and yet others which will address aspects of products for use by people with disability.

People related aspects

In the field of functional assessment, a clear and unequivocal establishment of quantitative norms of multifaceted activities is an essential starting point. A transfer of information generated in unidimensional studies performed without accounting for other accompanying factors, may not be relevant. It is so because the influence of other variables not being measured in such a functional assessment cannot be accounted for quantitatively or qualitatively with considerable degree of reliability. It is essential that such database must come from normal, average population. Furthermore, such database must be generated from different age groups and both sexes in order to allow comparative versatility. Though time taking to develop, such a database will serve as a three dimensional framework to base the functional assessment of people with disability and more importantly, to quantify the nature of functional deficiencies and impairments associated with specific disabilities. Such a comparison will quantify the nature and degree of impairment and thereby establish the ideal goal for rehabilitation. In addition, this will provide a measure of the degree of multidimensional recovery in all relevant criteria. Commonly, patients are released only after partial rehabilitation and are not followed to their work places. One of the outcomes of such an incomplete follow-up is recurrence of injury and accentuation of subsequent disability. It is therefore, emphasized that rehabilitation is incomplete unless the patient is integrated in workforce and has assumed a normal, productive life. The independence of a patient is not limited only to a physical partial functioning, but also an economic independence and social adjustment. A disregard for such a holistic rehabilitation may incur significant cost to society, lost productivity to the economy and adverse social and psychological impact on the patient. Only a concurrent broadening scope of ergonomics and rehabilitation and their overlapping application can result in a holistic rehabilitation.

An injury results in preservation of physical homeostasis, which alters the interaction of different physical entities. Such an alteration, usually a deterrent in function, is categorized as an impairment. Such an impairment during the course of daily living or daily working will influence multitudes of activities involving numerous physical traits. Due to such an interdependence of physical traits and dependence of any physical or physiological function on more than one physical factor, the abberation in behaviour is likely to be variable in multiple dimensions. In order to maintain normal performance, one will have to have normal range of motion, strength, endurance, kinematics, kinetics, perception, and motor coordination. A physical injury causing pain may affect more than one variable in varying amounts resulting in a picture entirely different, compared to the pre-injury state. Therefore, it is essential that the physical work worthiness must be related multidimensionally, incorporating all relevant variables. In common practice, in many clinics, the assessment of impairment or rehabilitation is based on range of motion. This practice could be defended if the range of motion was the sole variable required for the function. No useful and productive function can be performed simply by moving the body parts. Frequently, application of force is also essential. Thus, the testing of motion for available range of motion must be augmented with testing of available strength in the motion concerned. Though characterization of available motion at the joint in question (Figure 2) is important, it must also be augmented with the incorporation of the strength data. Should this joint function be needed for repetitive work then establishment of availability of speed of repetition within the range of motion and with the desired force must also be depicted in order to get a comprehensive picture of the function of the joint. Finally, an overlap of the inventory of the available work capacity with the normal profile of the job requirement will be essential to yield a quantitative assessment of the functional decrement needed to be remedied for the person to be vocationally rehabilitated (Figure 3). It is important to point out here that such a comparison gives the functional deficiency only for one task cycle. The question of repetition of the productive cycle and the endurance; cardio-pulmonary fitness, aerobic capacity, dexterity, precision, tissue tolerance, characteristics, and status of pain must all be determined to assess the physical work worthiness of the patient. A similar multi dimensional assessment of psycho-social traits looking into perception, cognition, judgement, decision making, reaction time, fatigue, motivation, and other aspects must also be established to determine psychological work worthiness or otherwise of the patient. For a final assessment, the patient will have to be quantitatively tested on all affected relevant variables, including social variables as shown in Figure 4. The

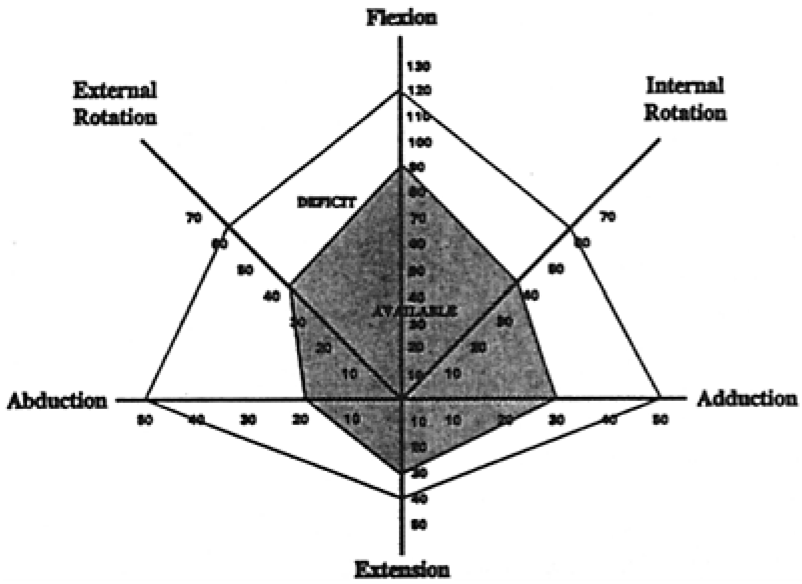

Figure 2. Range of motion of a joint

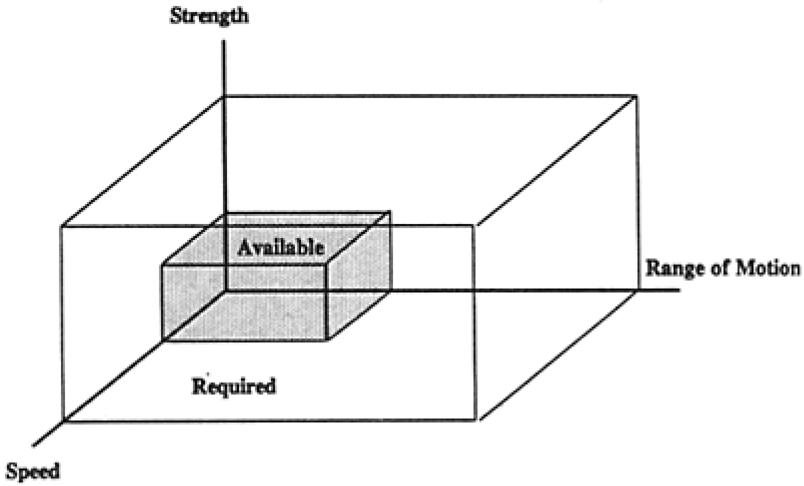

Figure 3. The inventory of available work capacity

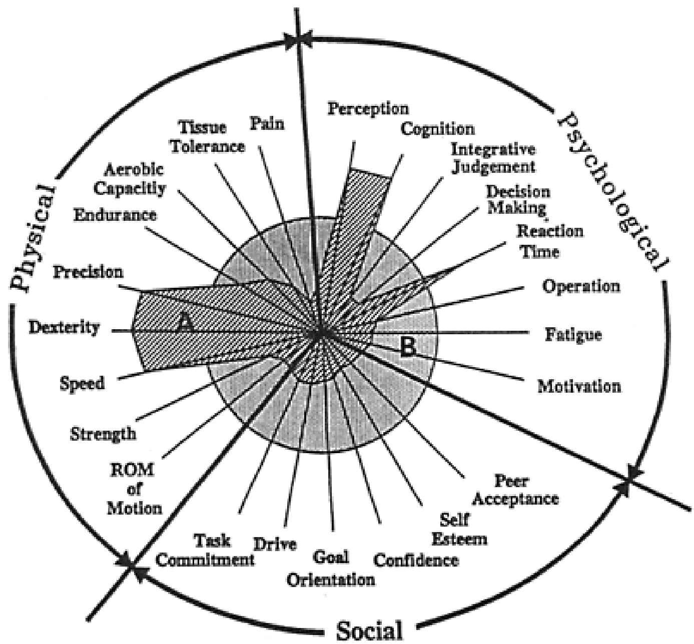

Figure 4. A conceptual model of comparison of worker with the task

decision of further treatment, training, or returning to work will significantly depend on the job demand. It will be only through preferably a quantitative overlap of the patient's physical and psycho-social capability over the job requirement that an ergonomically trained, rehabilitation professional will be able to determine the shortfall and select a strategy to manage. As depicted in Figure 4, an imaginary task exceeds the capabilities available in tissue tolerance, strength, range of motion, fatigue, and motivation. Therefore, such a patient is unable to go back to that job. A similar deficiency and hence, incompatibility could be found in psychological domain. These two conditions though require different management strategies as well as different rehabilitation procedures, yet indicate the unworthiness for being returned to the work. Incorporation of such methodology therefore, may allow a more holistic assessment of impairment and a better matching of the worker to the job for maintaining a long term physical and vocational rehabilitation.

PROCESS RELATED

Statistics Canada (1990) reported that almost one half (45.6%) of all disabled people required assistance in performing heavy household activities, while nearly one quarter required assistance to perform daily housework (22.4%), or to shop (23.2%). In many cases disability in fact is compounded due to people having more than one disability. Statistics Canada also reported that though mobility and agility are the most common disabilities, ranging between 55% to 65%, hearing, mental, and visual disabilities are also significant. It is worthy of note that only 40.3% of all disabled persons of working age were gainfully employed in Canada in contrast to over 66% of the general population. Many times, the transition from impaired to rehabilitated is gradual and at others even after full rehabilitation, there are residual functional impairments. Therefore, it is important to consider enablement of people with initial disabilities as well as residual disability. The role of ergonomics therefore, is foremost in job modification and environment adjustment to bring the job to the worker with reduced capability. Such job accommodation most frequently may require modification of hardware as well as the processes. For now, until the categories of generic disabilities along with their magnitudes of gradations are established, these may have to be dealt with individually. In some cases, job redesign may not be sufficient to enable a disabled worker. The process of enablement may require an augmentative device. Such a strategy may also have a place among workers with minor disability, where assistive devices may circumvent a need for expensive hardware modification. Such a strategy of flexible matching with varying extent of job modification and assistive device will not only give the disabled person a sense of self worth, but also increase the gross national product.

PRODUCT RELATED

Most of the consumer products on the market are designed for a normal population with full functional capacity. The disabled group which lacks in one of more functional capacity, generally has to struggle to use the same consumer products for their needs.

Though some special products have started appearing on the market, a systematic approach has been lacking. In fact, a lack of commonality in classification and description of impairment and disability may be a formidable impediment in widespread distributions. It may, therefore, be the necessary first step to develop a functional categorization regardless of cause and nature of disability. The discipline of ergonomics is equipped to commence the development of a generic functional classification applicable across conditions which result in similar functional impairments. These criteria can then be incorporated in design and development of products for use by disabled consumers. Existing products considered suitable for use by disabled consumers can also be tested against these criteria. Therefore, the scope of ergonomics can readily expand to include rehabilitation which in fact, is a legitimate, though relatively unexplored dimension. Thus, by a systematic and comprehensive applications of ergonomics in rehabilitation, one may comprehend development of rehabilitation ergonomics discipline. This discipline will then incorporate the aspects related to people, processes, and product. Such a conceptual model is advocated here and thought to be an essential and urgent need of the society.

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ERGONOMICS AND TITLE I OF THE AMERICANS WITH DISABILITIES ACT (ADA)

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Title I of the ADA requires non-discrimination in employment, and reasonable accommodations for potential and current disabled employees. Employers must make reasonable accommodations to the known limitations of an otherwise qualified disabled individual. Reasonable accommodation requires adaptation of the workplace, equipment or the job itself, which enables a disabled employee to perform the essential job functions for which he/she is qualified in training and abilities. Ergonomists will identify and analyze areas where reasonable accommodation is required for job placement.

BACKGROUND

The Americans with Disabilities Act (ADA) will impact nearly every employer, in both the private and public sector, in the United States by 1994. It has been called the single most powerful and far-reaching disability rights law ever passed (NCAU, 1991). Many laws have preceded the ADA, but none have had the enforcement needed to make them work.

People with disabilities have been fighting for legislation for nearly 20 years. The Architectural Barriers Act of 1968 was supposed to make all federal buildings accessible, but there was no enforcement. A study done from 1969–1972 showed that 33% of all federal buildings were still being built inaccessible to the disabled individual. In 1972, Mills vs. Board of Education and AARC vs. the State of Pennsylvania were two landmark cases that dealt with the rights of disabled children to have a public education (AARC vs. Commonwealth of Pennsylvania, 1972; Mills vs. Board of Education, 1972).

As a result of the Vietnam war, the Rehabilitation Act of 1973 was developed. The premise of this act was that disabled individuals have a fundamental right to no discrimination in employment. Title I (Section 504) of the Rehabilitation Act of 1973 was a step toward affirmative action mandating that disabled individuals be given the same consideration as non-disabled individuals in the hiring process. Section 504 originally applied only to discrimination in employment. Its coverage was extended by the Rehabilitation Act Amendments of 1974 to all areas of civil rights including education and training, employment, health, welfare, and other social service programs (Nickerson, 1978).

Title I of the ADA governs the employment of disabled individuals. Title I prohibits discrimination on the basis of disability in all aspects of employment including hiring, training, compensation, promotion, discharge, retirement, etc.. The law will enable men and women with disabilities an equal opportunity to take on jobs for which they are trained and qualified. The ADA defines an individual with a disability as someone who meets one or more of the following criteria: has a physical or mental impairment that substantially limits one or more major life activity; has a record of such impairment; is perceived or regarded as having such an impairment. The law takes the definition one step further to define a qualified individual with a disability as someone who possesses the requisite skill, experience, education, and other job-related requirements for the position in question (PL 101–336, 1990). Under the ADA, employers are not allowed to question applicants about their disability, but they can ask an individual to demonstrate how they would perform the essential functions of the job, with or without reasonable accommodation.

The term “essential function” refers to the fundamental duties of the job and does not include the marginal functions of the position. The term reasonable accommodation means modifications or adjustments to the job or job application process, the work environment, and the way a job is customarily performed. Reasonable accommodations include, but are not limited to job restructuring; part-time or modified work schedules; reassignment to a vacant position; acquisition or modification of equipment or devices; provision of readers, interpreters, or other assistance; modifications of training materials or practices; and making facilities readily accessible to and usable by persons with disabilities. (PL 101–336, 1990).

STATEMENT OF THE PROBLEM

Accommodation of the worker in the workplace is not a new idea. The first applications of machine guards and ventilating fans were job accommodations (NSC, 1988). What is new, however, is the accommodation of the disabled worker in the workplace.

Designing for people with disabilities is a normal function of the ergonomist. With the requirement to provide reasonable accommodation under Title I of the ADA, industry is going be mandated to address disabled individuals needs in the workplace.the ergonomist will be tasked to find ways to modify or redesign existing equipment, tools, work benches and even task sequences in order to accommodate a disabled employee. Accommodation of the disabled employee is usually no more costly than any other types of changes made to the work environment (NSC, 1988). It is also not unusual to find that changes made specifically to accommodate a disability will benefit the able-bodied workers as well.

DISCUSSION

A multi-disciplined approach to job placement and accommodation must be considered (see Figure 1). Ergono-

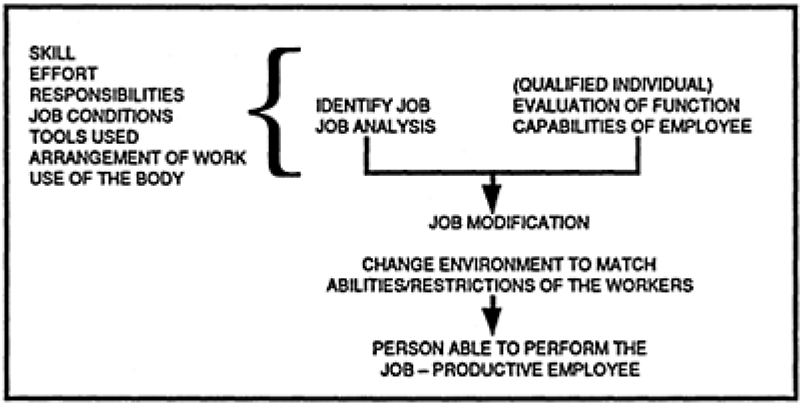

Figure 1: Job Accommodation Process

mists can specify task, equipment, and workstation modifications; Medical and Rehabilitation staff can determine the individuals functional capacities; Engineers can design actual equipment changes; and EEO/Personnel specialists can deal with personnel policies and benefits.

Many parts of the job accommodation process can be done by an ergonomist. Identification of the job and a subsequent job analysis will provide the employer with the essential functions of a particular job. This is very important when determining whether or not an individual is qualified for a particular job. Job modification and ad-aptation of the work environment is another aspect of the process that ergonomists can perform. Changing the environment to match the abilities and limitations of workers is a core function of the ergonomist. The ergonomist must try to satisfactorily solve the problem of allocation of functions between man and machine.

Job Identification and Analysis

Before it can be determined whether or not an individual is qualified for a job, essential functions of the job must be determined. This can be accomplished by doing a job and task analysis. A job analysis can be performed by doing a work-methods analysis to determine overall job functions. To maximize the human-machine interface, a clear understanding of the task is required for the human operator's role, and the functional specifications are required to maximize machine capability (Wade and Gold, 1978).

To perform a work-methods analysis, the ergonomist must have a complete task description which may include information derived from production records, direct observation, or interviewing employees who do the job on a regular basis. Each job is described by a set of tasks, and each task is broken down into a series of steps or elements (Putz-Anderson, 1988). The elements are described as fundamental movements or acts such as reaching, grasping, and moving required to perform a job.

Job Accommodation

Once it has been determined that a person is qualified for the job, i.e. has the basic skills and job knowledge, then assessment of the job requirements and the abilities of the person (reach, strength, and aerobic capacity) must be done. If there is a mismatch between job requirements and the persons abilities then a job accommodation is needed. This may include changes made to the facilities such as lowering water fountains or widening doors; changes to the work area and environment such as raising desk height for a person in a wheelchair, increasing lighting levels for a sight impaired individual, or having a Telecommunication Device for the Deaf (TDD) available to a hearing impaired employee to make phone calls; or changing the way a job is performed such as rearranging tasks, omitting difficult tasks, changing work methods and or procedures.

Once the need for accommodation is made known to an employer, information must be gathered to determine what accommodations are necessary to enable the individual to perform the job successfully. All accommodations should be evaluated for costs/benefits, the impact on productiv-ity, and the aid to other workers, both able-bodied and disabled.

CONCLUSION

The deadline for most companies to implement Title I of the ADA is July 26, 1992. Title III (Public accommodations and services operated by private entities) went into effect on January 26, 1992. Employers are encouraged to look at their businesses and come up with a plan of action to address each Title that affects them. We can no longer ignore the estimated 43 million Americans who are disabled. Disabled workers are a viable resource for American business, and employers should consider them as such. With the help of reasonable accommodations, many more people can be put to work, and others can return to work after injury as productive employees. The two key factors for employers to remember when trying to place disabled people in the workplace, is the need to identify the essential functions of the job through job analysis. This is an essential step for employers to take in order that they not discriminate in any area of employment. Secondly, the ergonomist must make sure that no mismatches occur between job requirements and the persons abilities. If a mismatch is present then the ergonomist must look at possible job accommodations to bridge the gap. Costs and savings for any reasonable accommodation proposed or implemented must be documented so that if any question should arise concerning the employers commitment to implementing the ADA they will have the necessary information available.

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FUNCTIONAL CAPACITY ASSESSMENT: A TEST BATTERY AND ITS USE IN REHABILITATION

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This paper describes a battery of tests specifically designed for the quantitative objective evaluation of physical, functional, and work capacities. The battery consists of 80 measures used to assess readings to return to work following back injury. The elements of this ergonomically-based assessment tool are presented. A case study is used to illustrate the value of establishing a composite profile of patient abilities during low back pain treatment. The test battery has great potential into becoming a standard Assessment tool in rehabilitation, work conditioning, employment screening, as well as with respect to the Americans with Disabilities Act (ADA) employment requirements.

INTRODUCTION

Methods of measuring functional capacity in low back pain (LBP) rehabilitation settings fall under three main categories: (1) patients self- report of functional levels (Rock et al., 19 84; Jette, 1980; Pincus et al., 1984) yielding information about the perception of how much a patient can or can not do; (2) medical examination (Spektor, 1990) attempting to provide estimate of medical impairment; and (3) quantitative assessment of abilities or limitations producing objective measures reflecting the level of performance which, in turn, can be compared to performance levels of healthy subjects (e.g. norms) or can be matched to job/task demands.

One form of quantitative evaluations that is of special interest to health care providers, third party payers, insurance agencies, and employers is Functional Capacity Assessment (FCA). The term FCA is generic, and is commonly used to describe a variety of assessment techniques.

The term FCA refers to an "assessment" process rather than being an "evaluation" or a "screening" method. An assessment is an investigation of the body function with reference to expected levels (e.g. norms or work demands). An evaluation is a mere measurement process to find values or amounts describing performance levels without regard to any expected demand. Screening is used to separate individuals according to skills based on interviews and tests. Screening serves in referring individuals to appropriate treatment, training programs, or for proper job placement.

For the purposes of this paper, FCA refers to *"an assessment process that translates findings of physical, physiological, and functional measures into performance potential for activities of daily living and/or work tasks"* (Abdel-Moty, et. al. 1991). Currently, there are many forms of FCA protocols and batteries of tests being used. Differences among the various approaches to FCA include variations in the number of measures comprising the battery and variety of measuring instruments. The lack of a unified acceptable definition combined with the variability of measuring protocols used have resulted in inconsistent utilization of FCA findings.

At the University of Miami Comprehensive Pain and Rehabilitation Center (Rosomoff and Rosomoff, 1991), FCA is a component of a Human Performance Testing Program (HPTP) specially designed to deal with the comprehensive evaluation and assessment of anatomical, physical, physiological, functional, and psychological characteristics, as well as vocational and work-related parameters. Evaluations in each category are carried-out by experts in the respective field. The FCA module and a case study describing its utility are presented here.

METHODS

Measurements used in the FCA battery were arbitrarily grouped under four main categories: physical, physiological, functional, and work-related measures. The rationale for grouping the measures into these categories stems from the fact that, while it may be desirable to measure one aspect of human <u>physical</u> abilities (e.g. muscle strength), this aspect may neither be accurate in reflecting <u>physiological</u> traits (e.g. endurance), nor does it describe the individual's ability to perform <u>functional</u> activities (e.g. lifting). In addition such description does not imply that the individual can perform an activity for an extended period of time at <u>work</u> (e.g. lifting for an 8-hour workday).

Within each of the above categories, relevant measures were included in order to obtain a comprehensive sub-battery describing human systems. The following is a description of each category and its elements:

1. Physical Measures:

In this category, the following measures can be obtained:

a. **Static muscular strength** of the fingers (tip pinch, palmar pinch, and keypinch), hands (grip), arms, shoulders, back, trunk (extension and flexion), and total body (composite). These testing postures simulate daily activities involving handling various objects. For testing static strength in patients with injury or pain, the concept of Acceptable Maximum Effort is used (Khalil et al., 1987a). In each of the tests, three attempts are performed and strength value is reported in terms of the average and peak values.

b. **Dynamic muscular strength** of the arms (curls/triceps), shoulders (press/ pull), trunk (flexion/extension), and knee (flexion/extension). Other measures such as squat strength and bench press can also be obtained. One type of dynamic strength measured is performed on an isokinetic machine. Results are reported in terms of: average force or torque, total work, range of motion, and power. A measure of consistency can also be obtained through analysis of force-time and force angle relationships. Also, average force curve, time to reach maximum contraction, duration of holding max contraction, and time of decline from max contraction, can also be obtained. In this category of physical measures a computerized exercise and evaluation system is used (Ariel Life Systems Inc., La Jolla, CA).

c. **Flexibility** of the trunk and neck during flexion, extension, and lateral movements. The American Medical Association Guidelines are followed (AMA, 1990) and electronic goniometer is used (Zaki et al., 1990).

d. **Psychomotor abilities** including simple visual and auditory reaction times, choice reaction time, and hand steadiness (tremor). The procedures described in Abdel-Moty et al., (1989) are used to measure psychomotor skills in this category.

e. **Walking pace** in terms of the time required to travel a predetermined distance. This is reported in ft/sec.

f. **Balance and sway** measured using a computerized balance assessment system. The anterioposterior and mediolateral displacement of the body's center of gravity are obtained while the subject is standing barefooted on a force platform in a comfortable, one-legged, or tandem stances under eyes opened and eyes closed conditions. The shift of the body's center of pressure is determined by measuring the changes in the x and y directions. The procedure followed to obtain these measures is described elsewhere in this book (Khalil et al., 1992).

g. **Static posture** in terms of body alignment and symmetry. Posture is scored relative to deviations from the horizontal and vertical lines on a posture chart.

2. Physiological Measures:

In this category the following measures can be obtained:

a. **Muscular endurance** measured in terms of fatigue curves, for a specific muscle group (e.g. Trunk extensors) using a computerized exercise and evaluation system.

b. **Cardiovascular endurance** is performed on a motorized treadmill to determine cardiovascular capacity in terms of heart rate and oxygen consumption. The Balke Protocol is followed (Balke, 1971).

3. Functional Measures:

In this category the following abilities are measured to tolerance and quantified in number, distance and/or time scales.

a. Sitting tolerance in minutes
b. Standing tolerance in minutes
c. Walking tolerance in distance and time
d. Kneeling e. Squatting in numbers
f. Stair climbing in number of steps
g. Lifting floor to table in kilograms
h. Carrying table to table in kilograms
i. Pushing and pulling in kilograms
j. Manual dexterity (Minnesota Pig Board)

4. Work-Related Measures:

In this very broad category, the objective is to assess the individual's ability to perform the physical work demands. The U.S. Department of Labor's (1981) guidelines are used. The Dictionary of Occupational Titles (DOT) describes 20 "physical demands" expressing both the "physical requirements" of the job and the "physical capacities" (traits) a worker must have to meet job demands. These factors are:

standing	walking	sitting	lifting	carrying	pushing
pulling	climbing	balancing	stooping	kneeling	talking
crouching	crawling	reaching	handling	fingering	feeling
hearing	seeing				

All of the above activities are evaluated under standardized protocols (Fishbain et. al., 1992). Performance in each of these activities is described either as score or in terms of the mere ability to perform. For the evaluation of weight handling abilities, the psychophysical approach is utilized (Khalil et al., 1987b).

In order to afford a holistic assessment, the HPTP at the CPRC also provides additional evaluations to supplement findings of FCA among these are Neuropsychiatric Evaluation, Psychological Evaluation, Musculoskeletal Evaluation. The following is a case study illustrating the utility of the above described FCA battery in evaluating and assessing a CLBP patient physical, functional, and work abilities. The profile also describes determination of limitations, behaviors, effort, consistency, and overall performance level.

CASE STUDY:

This is a 21 year old right handed male who was referred to the Ergonomics Division for an FCA evaluation. He weighed 86.2 kg, stood 190.5 cm. tall. In February 1989, he sustained a work-related back injury due to a slip and fall accident while he was working as a chef. Upon admission to the CPRC, he reported pain in the neck, lower back, and hips. Prior to initial testing, he reported an average pain level of 9 on the scale of 0 (no pain) to 10 (intolerable pain).

Table 1. FCA Profile of Case Study in the Various Categories (* indicates that average score is below expected "norm")

Measure	Initial	Final	Measure	Initial	Final
Pain level	9	7	Palmar Pinch:		
Balance:			Right	106.8	169.0
Sway [cm]:			Left	93.4	146.8
Eyes Opened:			Arms	*351.4	467.1
Anteriopositerior	2.25	1.68	Shoulders	*306.9	582.7
Mediolateral	1.58	0.85	Composite	*n/a	1227.7
Eyes Closed:			Back	*n/a	1298.9
Anteriopositerior	3.57	4.72	Knee Extension:		
Mediolateral	2.58	2.50	Right	*257.9	627.2
			Left	*244.7	556.0
Psychomotor Abilities:			Trunk Ext.	*235.7	725.1
Reaction Time [sec]:			Trunk Flx.	*257.9	867.4
Simple Visual	*0.66	0.24			
Simple Auditory	*0.63	0.17	*Dynamic Strength:*		
Choice Visual	*0.69	0.60	Force in [N], torque in [Nm], work in [J], power in [W], and range in [deg]		
Hand Steadiness [#]:					
Hand Tremor	*13	2	Curls:		
			Force	311.4	524.9
Mobility:			Power	146.6	545.5
Squatting Ability [cm]	0	0	Triceps:		
Kneeling	able	able	Force	*57.8	177.9
Crouching	*unable	able	Power	*17.6	208.9
Crawling	able	able	Curls/Triceps:		
Standing Balance	able	able	Work	*542.8	2697.1
Walking Balance	able	able	Range	*10	26
Crouching Balance	*unable	able	Shoulder Press:		
Walking Pace [m/sec]	*1.25	2.55	Force	*8.9	564.9
Stair Climbing	able	able	Power[W]	*1.8	755.8
			Shoulder Pull:		
Flexibility [deg]:			Force	*8.9	249.1
Trunk ROM			Power	*2.3	314.7
Flexion (Stooping)	*43	103	Shoulder Press/Pull:		
Extension	*26	34	Work	*40.7	2768.3
Right Lateral	*34	55	Range, deg	*21	23
Left Lateral	*27	55	Trunk Flexion:		
Neck ROM			Torque	*33.9	107.2
Flexion	*39	57	Power	*20.3	104.5
Extension	*28	77	Trunk Extension:		

Right Lateral	*44	64	Torque	*31.2	109.9
Left Lateral	*42	61	Power	*18.9	111.3
			Trunk Flexion/Extension:		
Static Strength [N]:			Work	*542.8	2183.4
Grip			Range, deg	*82	96
Right	*298.0	507.1	Legs Flexion:		
Left	*275.8	422.6	Torque	*44.8	333.8
Pinch Strength			Power	*38.0	343.3
Tip Pinch:			Legs Extension:		
Right	66.7	66.7	Torque	*42.1	301.3
Left	57.8	80.1	Power	*35.3	331.1
Key Pinch:			Legs Flexion/Extension:		
Right	66.7	88.9	Work	*464.1	3984.2
Left	66.7	75.6	Range, deg	*52	60

Measure	Initial	Final	Measure	Initial	Final
Isoinertial Strength [kg]			*Hand Function:*		
Lifting	*3.2	27.2	Feeling:		
Carrying	*6.4	36.3	Shapes	able	able
Pushing	*68.0	79.4	Sizes	able	able
Pulling	*68.0	79.4	Temperature	able	able
			Texture	able	able
Tolerances:			Handling:		
Sitting, min	*15	60	Holding	able	able
Standing, min	*16	30	Seizing	able	able
Walking, [km(min)]	*1.61(30)	1.61(<30)	Grasping	able	able
			Turning	able	able

The patient’s test battery consisted of the measures described above. Table 1 summarizes his performance in the respective measure at admission and discharge from treatment upon completion of a 4-week intensive rehabilitation program at the CPRC. The table also includes the results of comparing the patient performance in each category to a set of “norms” for healthy subjects in his age group.

During the initial evaluation, the patient demonstrated deficiencies in 50 of the 80 measures of performance. Performance levels in all of the 50 measures were below expected values of healthy males in a comparable age group. Physically, reactions to light and sound stimuli were slow; hand tremor was significant; walking speed was slow; trunk flexibility was limited; neck flexion was also limited; static strength of the hands, arms, shoulders, trunk, and legs were below average; measures of dynamic strength tested isokinetically for the arms, shoulders, trunk, and legs were also below expected values. In addition, the patient was unable to assume the postures required for static testing of squat and stoop strengths. Scores in the following categories were within acceptable ranges: sway, neck lateral bending, pinching strength, and isokinetic strength of elbow flexion.

Functionally, and in terms of work abilities, the patient had limited tolerances in sitting and standing (15 and 16 minutes respectively). Performance in 5 of the 20 job physical demands described by The DOT was not within the levels characterizing the requirements for his job. He was able to lift 3.2 kg and carry 6.4 lb, which are the below requirements for his job as a chef (lifting and carrying 11.3 kg frequently and 22.7 kg maximum). He was not able to crouch or balance while crouching. In terms of abilities, he was able to squat, kneel, crawl, balance while standing and walking, and climb stairs. Additionally, he walked 1.6 km in 30 minutes, pushed and pulled 68 kg on wheels. His manual feeling and handling functions were unaffected. In all tests, he was consistent in terms of test-retest as well as across tests, he seemed to exert good effort, was motivated, and there was no significant pain behavior observed.

After four weeks of rehabilitation, results of the final FCA evaluation showed significant improvement in all physical, functional, and work measures. There was over 100% increase in most measures of functional abilities. The patient's improved ability to perform all activities, not only of daily living, but also of physical job demands was reflected in all performance measures. He became more flexible, achieved functional tolerances (sitting 60 minutes, standing 30 minutes, walking 1.6 km in less than 30 minutes), and showed greater mobility. Static and dynamic strengths of all the muscle groups tested increased dramatically and were all above average. He was able to perform the stoop and squat strength tests at levels much higher than average. His lifting and carrying abilities exceeded job requirements for his job. His maximum acceptable weight in lifting was 27.2 kg and 36.3 kg in carrying. During this final evaluation, the patient performed enthusiastically, seemed to exert full effort, and showed consistency.

The FCA profile documented the physical and functional abilities, as well as readiness to return to work. Finding of evaluations supported medical indications of total functional restoration and success of rehabilitation.

DISCUSSION AND CONCLUSIONS

In the rehabilitation of LBP, quantitative methods of assessment vary considerably in complexity as well as purpose; ranging from simple measurement of ranges of motion to the more sophisticated computerized evaluations of work performance. Physicians, physical therapists, occupational therapists, ergonomists, vocational counselors, psychologists, and biofeedback specialists use their own assessment tools which serve specific purpose.

Quantitative assessment of human performance is becoming increasingly important in describing patients characteristics for the purpose of evaluating function/dysfunction. Results of this type of evaluation can be used to determine baseline level of performance from which improvement upon treatment can be assessed. Additionally, they can be utilized for evaluating functional status in relation to activities of daily living and job demands.

Interaction of Ergonomists with clinicians at the CPRC has allowed the development of practical, accurate, and comprehensive methods for evaluating patients' performance. The battery presented here is currently being utilized and shows great potential in becoming a standard assessment tool especially with respect to the Americans with Disabilities Act (ADA, 1991). At this time, more than 200 patients have undergone the evaluations outlined above. None of the patients tested experienced any medical complication as adverse effect to the tests used. The data obtained proved useful in describing, not only individual profiles, but also documenting the efficacy of rehabilitation in returning patients to work of compatible functional demands. Therefore, the safety of the methods and their applicability to the LBP population have been established.

In the growing field of FCA, and as a result of the increasing demand to perform quantitative evaluations, the following recommendations can be offered:

1. The measurement process should be labeled accurately to describe whether the objective is to evaluate (or screen, or assess) functional (or physical, or work) abilities (or capacities).
2. Multiple measures should be used. Reliance on single measures (e.g. static strength) can be misleading.
3. Measures included in an FCA battery should posses sufficient statistical power (Abdel-Moty et al., 1991) and scientific rigor.
4. Findings of physical evaluations do not necessarily translate into knowledge of the functional or work performance abilities of the patient. Non specific tests may not reflect the actual demands of repetitive job activities (Rodgers, 1988).
5. Behavioral factors and secondary gain issues should be considered post assessment so as not to bias the observation. During testing, all behaviors and observations should be documented. Moreover, evaluators should insure that the subject fully understands instructions and directions.
6. Patients may not exert themselves to a maximum, as pain may inhibit or produce fear when physical exertion is requested. Therefore, performance measures among LBP patients are the product of both physical and psychological factors.
7. Evaluators should incorporate data from other clinical, behavioral, and vocational assessment in order to establish a comprehensive view of the actual levels of function as well as factors interfering with performance.
8. Functional Capacity Assessment requires professional skills in designing, performing, and analyzing screening instruments. Reliance on computer- generated reports can be misleading and may have serious consequences.
9. No one evaluation machine is perfect for all patients, no one machine is ideal for all situations, no one machine can assess all aspects of human performance, no one system is foolproof, no one system provides the definitive answer regarding return to work, and there is no machine that can provide a composite picture of performance.
10. Findings of FCA should be cautiously interpreted when describing function, “impairment” “limitations”, “restrictions”, or “disability”. The following definitions are useful in judging performance based upon FCA findings. Impairment refers to “a stable and persisting defect in the individual at the organic level which stems from known or unknown molecular, cellular, physiological, or structural disorders (Susser, 1990). Impairment may lead to limitations of function and may decrease the capacity to adapt to the environment (Spektor, 1990). Limitations have been defined as “what the patient cannot do either because of mechanical/physiological problems or because the specified activity causes intolerable pain” (Battista, 1990). Restrictions are defined as “what the patient should not do because doing it will either aggravate the condition, delay healing or possibly constitute a risk to the health” (Battista, 1990). The delineation of impairment, limitations and restrictions by the physician leads to administrative decision about the disability status of the patient (Johns, 1990).

Disability refers to a stable and persisting physical or psychological dysfunction at the personal level, which stems from the limitations imposed by the impairment and by the individual's psychological reaction to it" (Susser, 1990).

11. Results of an FCA should not be interpreted by the evaluator alone. Input from vocational as well as medical experts should be included.
12. Findings of a comprehensive FCA can be very useful in describing performance levels at a point in time which, in turn, can serve as a baseline from which changes can be monitored. The utility of such information can be useful, not only in rehabilitation, but also for job screening.
13. For FCA to be meaningful assessment for social security or insurance purposes, it must be performed following a comprehensive rehabilitation program or when Maximum Medical Improvement (MMI) has been attained.

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PROFILE OF CHRONIC PAIN PATIENTS AND THEIR REHABILITATION OUTCOME

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This paper presents a profile of 204 patients suffering from chronic low-back and/or neck pain that were admitted to a 4-weeks rehabilitation program for evaluation and treatment. Treatment outcome was evaluated by comparing the ergonomics assessment measures upon admission and prior to discharge from the program. The paper presents the utilization of a Data-Base Management System that was created for the purposes of facilitating the process of data collection, retrieval, analysis, and report generation. Normative data for patients functional abilities were presented. Results showed that all post-treatment measures increased significantly than pre-treatment measures.

INTRODUCTION:

Back pain is one of the most prevalent medical problems in the United States. It is often associated with functional disability or limitations that can have serious economical, social, and psychological consequences. Pain centers have been recognized in recent years for the treatment and rehabilitation of pain patients. It is estimated that the number of pain clinics or pain centers in the United states are 2000 (Rosomoff and Rosomoff, 1991). Treatment goals vary from one pain program to another depending on its design, however goals for each program include at least one or a combination of the following:

reduce pain, reduce medication intake, improve psychological impairment, improve functional level, improve strength, enhance or restore avocational activities, and restore occupational role. Each of these goals or a combination of them can be used as a measure of success of treatment programs or as a determinant of rehabilitation outcome. To be able to evaluate and assess the outcome of treatment programs, reliable methods have to be used. These methods have to be standardized within each program and between programs to be able to establish grounds for comparison. An evaluation methodology and a database management system were developed as a step in the direction of facilitating and standardizing methods for patient evaluation and data collection. This system was custom developed to include standard evaluation methodology described in the ergonomics literature to assess human performance.

This paper presents and describe the functions and components of the data base management system used in conjunction with the human performance evaluation regimen. It is concerned with the evaluation of rehabilitation outcome for patients being treated at a multidisciplinary rehabilitation program. Finally, the paper presents some normative data to describe the functional abilities of the patients population upon admission (pre-treatment) to the treatment program and immediately prior to discharge (post-treatment). The post-treatment normative data can be used in addition to norms for healthy individuals to describe progress and to assess treatment outcome (Abdel-Moty et al, 1990).

DATABASE MANAGEMENT SYSTEM:

A data-base management system was custom developed to facilitate the processes of data collection, storage, retrieval, analysis, and report generation. The system is currently being used to input evaluation data and pertinent patient information through a user-friendly interface. This interface includes drop down menus, pop-up menus, entry forms, and selection lists. The system has two distinct functions, a clinical function and a research function.

Clinical Function: The system is used for storage, retrieval, and report generation of evaluation data. Reports from the system are generated on a regular basis and are incorporated in the patients chart as a final report. A mechanism was developed so that the data is entered shortly after an evaluation is conducted which allows for the immediate accessibility of data. The system provides a valuable feature that allows for identifying patients in the system and for displaying their admission, discharge, and evaluation status (admission date, discharge date, and date of individual evaluations). It also provides some error checking features to minimize data entry errors. The system accepts and distinguishes between three categories of patient admissions: one-time evaluation patients, reconditioning patients, and regular evaluation patients. Two types of patients are being admitted to the program for evaluation and treatment, regular patients, and reconditioning patients. The regular patients are the ones that are admitted to the program for the first time, reconditioning patients are the ones that completed the program at a previous time and return for reconditioning or for treatment on a readmission basis. The one-time evaluation patients are usually evaluated but they don’t get admitted to the program at the time of the evaluation.

Research function: The system provides a valuable research tool for data processing and analysis. Information stored in the system were carefully selected to form a complete data set that covers all the aspects needed for the purposes of data analysis (e.g. personal information, demographic information, information related to the causes of injury, information related to location of pain, evaluation information,.. etc.). Some of the data entry forms were designed to speed up the process of data entry and to ensure proper coding of data. This can be seen in the data entry forms for identifying the causes of injury and locations of pain where a list of preset choices are displayed for the user to choose from. Data can be easily imported by other software packages for further processing and analysis. The system's ability to accumulate evaluation data as they are collected provides up-to-date information that can be analyzed on a regular basis to determine changes and trends.

The system is composed of four modules: Input module, Retrieve module, File Management module, and Report Generation module (Figure 1).

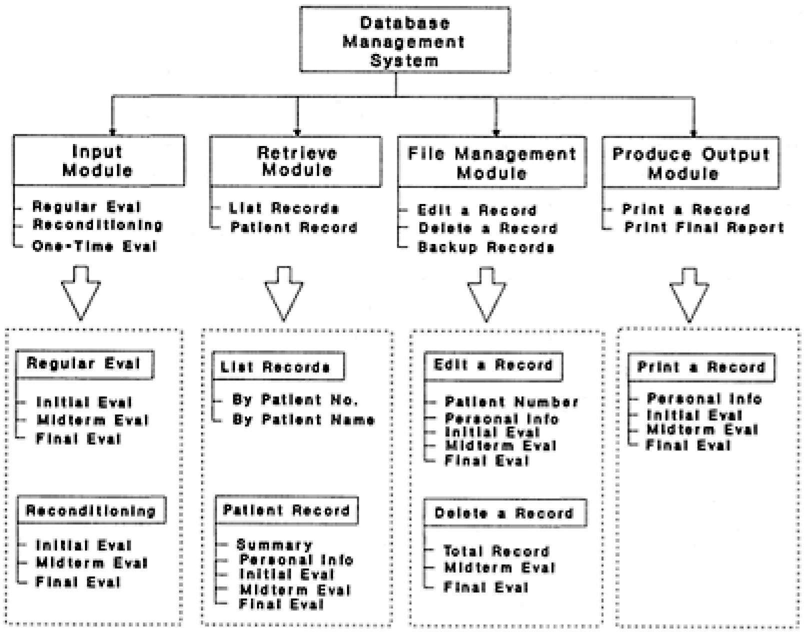


Figure 1

The Input module:

This module allows for entering evaluation information for the following three categories of patients:

1- Patients admitted to the program for the first-time.
2- Patients admitted to the program for reconditioning or readmission.
3- Patients admitted to the program for evaluation only (one-time evaluation).

The data entry component of the initial evaluation is different from that of the other two evaluations (midterm and final) in that it allows for entering personal information, precautions, and information related to causes of injury and locations of pain. Two lists of the most common causes of injury and locations of pain are displayed in entry forms that allows the user to choose from. The data entry components of the initial, midterm, and final evaluations are identical when measurements are being entered. Measurements for the session include pain level, gait, squatting ability, reaction time (visual and audible), range-of-motion for the cervical region, range-of-motion for the lumbar region, and static strength measurements. The static strength measurements include grip strength, arms strength, shoulders strength, back strength, composite strength, and knee extension strength. Up to three repetitions can be entered for each measurement. The average and maximum values of the three repetitions are calculated and stored.

The Retrieve module:

The retrieve module can be used for viewing a single patient record. It can also be used for producing a list of all the patients in the system.

The File Management module:

The file management module can be used for deleting patient records and for backing-up and restoring data from floppy disks.

The Produce Output module:

This module can be used to print a report for any of the three evaluations that the patient performed throughout the program (initial evaluation, midterm evaluation, or final evaluation). The report displays the value of the three repetitions for each of the measures, as well as the maximum and mean values of the repetitions. The module can also be used to produce a final report. The final report shows all the three evaluations parameters and the percentage change in all the parameters from the initial to the final evaluation. The report is generated for every patient upon discharge from the program and is included in the patient chart.

METHOD:

Subjects were selected from the patients population at the Comprehensive Pain and Rehabilitation Center (CPRC) of the University of Miami. The CPRC provides a multidisciplinary inpatient and outpatient rehabilitation program that typically lasts 4 weeks. Components and goals of the CPRC were described in Khalil et al (1983) and Rosomoff et al (1991). Two hundred and four subjects participated in this study. The 204 cases represent all full-time patients that were admitted to the program in a one-year period and that completed the rehabilitation program and performed both the initial and final evaluations administered by the Ergonomics division. The two evaluations are identical however, the initial evaluation is conducted upon admission to the program and the final evaluation prior to discharge.

Ergonomic evaluations include a battery of tests to assess mobility, psychomotor abilities, flexibility, and static strength (Khalil et al, 1988). Static strength measures were based on the Acceptable Maximum Effort (AME) concept (Khalil et al, 1987).

Data were analyzed using an Analysis of Variance (ANOVA) to determine rehabilitation outcome. ANOVA's were calculated for each of the functional measures. The dependent variable was the functional measure. Two independent variables were used, the gender (males and females) and the evaluation (admission and discharge). The means and the standard deviation for each of the functional measures were calculated upon admission and prior to discharge and was categorized by gender. The level of significance (at the 5% level) was calculated from the ANOVA table for the "evaluation" variable for each of the functional measures. This significance level was used to determine if the functional measures were different from admission to discharge.

RESULTS:

Descriptive information for the subjects sample included in the analysis are presented in Table 1.

Table 1. Description of the subjects sample upon admission to the CPRC.

Parameter	Description	
Average age	44.51±(13.87)	
Gender	Males 52% Females 48%	
Insurance category	Workers Compensation	58.8%
	Medicare	11.3%
	Private	29.9%

Means and standard deviations for the admission and discharge parameters are presented in Table 2. Bar graphs were created to visually display the results (10 figures were presented). The significance (at the 5% level) of each of the functional measures was displayed with the corresponding figure.

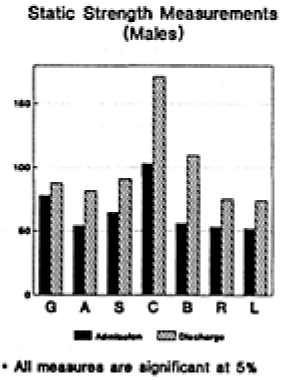
Table 2. Means and standard deviations for admission and discharge functional measures categorized by gender.

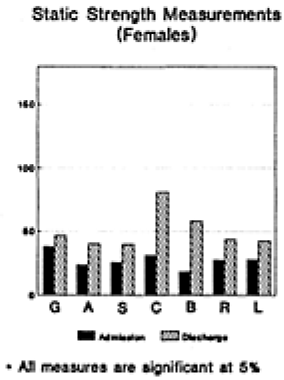
Parameter	Males		Females	
	Admission (mean±std)	Discharge (mean±std)	Admission (mean±std)	Discharge (mean±std)
Pain Level (1–10)	5.9±2.5	4.8±2.7	6.0±2.7	5.0±3.0
Mobility:				

	Squatting Ability (in)		9.9±8.4	3.7±5.7	14.4±7.9	6.4±7.2
	Walking Speed (ft/sec)		4.5±1.4	5.9±1.7	4.2±1.5	5.3±1.5
Psychomotor Abilities (dominant hand):						
	Reaction Time (sec):					
		Simple Visual	0.8±0.2	0.7±0.2	1.0±0.4	0.8±0.2
		Simple Auditory	0.6±0.2	0.5±0.2	0.8±0.4	0.6±0.2
		Choice Visual	1.7±0.4	1.5±0.3	2.0±0.6	1.7±0.4
Flexibility (degrees):						
Lumbar Range of Motion:						
	Flexion		76.4±31.9	110.3±25.9	82.2±36.0	120.5±26.8
	Extension		22.4±10.8	31.0±10.7	21.4±8.9	31.7±10.4
	Right Lateral Flexion		35.0±13.4	48.3±14.5	36.7±13.6	50.8±12.1
	Left Lateral Flexion		35.2±13.1	47.9±14.0	36.2±14.6	51.4±12.5
Cervical Range of Motion:						
	Flexion		43.0±13.5	57.5±12.7	42.9±15.7	57.3±10.8
	Extension		44.4±20.1	59.1±14.5	45.8±18.9	62.3±15.6
	Right Lateral Flexion		35.8±13.0	46.2±11.1	33.2±10.7	45.2±9.1
	Lef Lateral Flexion		36.9±13.1	46.4±9.7	31.9±9.8	45.7±10.6

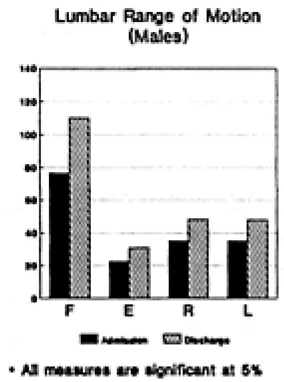
Parameter		Males		Females	
		Admission (mean±std)	Discharge (mean±std)	Admission (mean±std)	Discharge (mean±std)
Static Strength (lbs):					
	Grip (dominant hand)	77.6±31.0	87.5±29.6	37.8±17.4	46.8±17.9
	Arms (AME)	54.0±29.3	81.3±33.1	23.9±14.0	40.4±20.1
	Shoulders (AME)	64.3±36.7	91.1±36.7	25.8±15.9	40.1±17.3
	Composite (AME)	103.1±77.1	171.1±70.3	31.4±39.6	81.3±46.8
	Back (AME)	55.7±57.0	109.3±59.8	18.7±21.5	58.0±37.1
	Knee Extension				
	Right	53.0±25.4	75.0±27.9	27.6±13.7	43.7±18.2

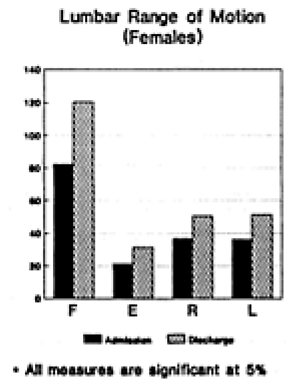
Left	51.7±27.1	73.9±26.6	27.8±21.2	42.8±16.0





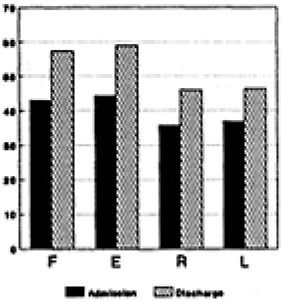
G= Grip, A= Arms, S= Shoulders, C= Composite, B= Back, R= Right Knee, L= Left Knee





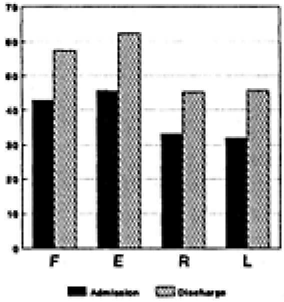
F= Flexion, E= Extension, R= Right Lateral Flexion, L= Left Lateral Flexion

Cervical Range of Motion (Males)



* All measures are significant at 5%

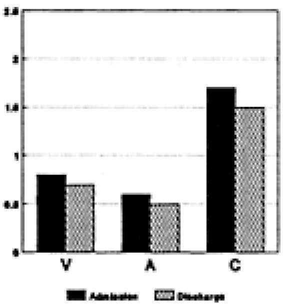
Cervical Range of Motion (Females)



* All measures significant at 5%

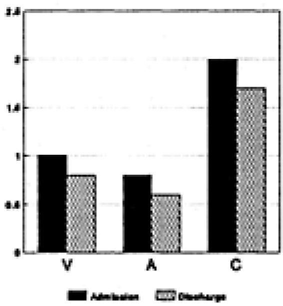
F= Flexion, E= Extension, R= Right Lateral Flexion, L= Left Lateral Flexion

Reaction Time (Males)



* All measures are significant at 5%

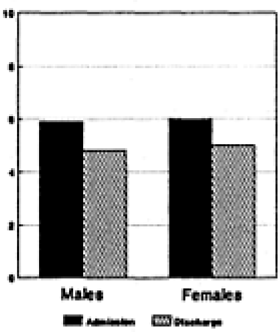
Reaction Time (Females)



* All measures are significant at 5%

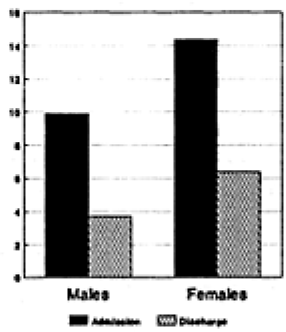
V= Simple Visual, A= Simple Auditory, C= Choice Visual

Pain Level



* All measures are significant at 5%

Squatting Ability



* All measures are significant at 5%

CONCLUSIONS:

The use of a database management system was found to be very effective in facilitating the process of data collection, processing, and analysis. It provides an indispensable clinical tool for organizing and retrieving patient records as well as for generating printed reports. It also contributes to the process of standardizing evaluation procedures,

Results showed that using a multidisciplinary rehabilitation approach was effective in reducing pain and in the functional restoration of chronic pain patients.

Normative data "patients norms" for functional abilities of chronic pain patients were presented in the results section. These norms can be used to assist in the evaluation of treatment outcome and functional restoration of patients that underwent the same or similar rehabilitation treatments. Patients progress during treatment programs can also be assessed using these norms. Post-treatment norms should not be used alone but should be used in combination with "healthy norms" to provide a more realistic guide for the assessment of functional restoration. Similarly, using healthy norms only can impose a constraint in the assessment of functional restoration due to the fact that most of the norms were collected for uninjured healthy individuals (mostly college students, athletes, military personnel, etc.).

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EFFECT OF “SECONDARY GAIN” ISSUES ON PERFORMANCE AND RESPONSE TO REHABILITATION OF WORKERS COMPENSATION CHRONIC LOW BACK PAIN PATIENTS

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This paper presents the results of a study on the relationship between “secondary gain” and functional abilities in two groups of patients with chronic low back pain (CLBP) and their response to a rehabilitation program. The first group consisted of patients collecting Workers Compensation benefits for work-related injuries and who have pending pain-related legal proceedings. The second group consisted of patients collecting Workers Compensation benefits for work-related injuries and not actively involved in litigation. The two Groups were compared on the basis of measures of strength, mobility, flexibility, psychomotor abilities, and walking speed. Findings supported the hypothesis that secondary gain issues may not be a factor in functional and physical restoration of workers compensation patients who receive effective rehabilitation.

INTRODUCTION

The majority of the men and women in industrialized societies will, at some point in their lives, suffer significant back pain. Back pain remains one of the most debilitating and prevalent medical, industrial, social, and economical problems in the United States. It is often associated with devastating functional disability leading to deleterious consequences for its sufferers. Moreover, back pain, when it results in disability, continues to have enormous burdensome effects upon industry and society in terms of loss of productivity and medical care expenditures.

The debilitating nature of back pain is seen clearly in its effects upon the work force. Two percent of the nation’s work force sustain back injuries each year, with back problems comprising at least 25% of the $35 billion paid out each year in workers compensation claims (Bell, 1991). It has been estimated that a worker with back pain, on the average, loses 10 days of productive work annually. Across all workers, estimates range from 170 million (Loeser, 1979) to 240 million (Bonica, 1981) lost work days per year as a result of back impairment. According to the National Safety Council on Compensation Insurance, average workers compensation claim costs have risen from $6,000 in 1981 to $9,225 in 1989. Lost workdays per 100 full-time workers rose from an average of 62 in 1981 to 80 in 1989. Another one of the many statements given on back pain was made by Bell (1991) who estimated that the cost of each disabling back injury can be as much as $18,000 with total direct and indirect costs ranging from $30 to $60 billion a year (Bell, 1991).

Therefore, vocational rehabilitation of workers following work-related back injuries is a desirable goal, though not easy to accomplish. Catchlove and Cohn (1982) indicate that workers compensation patients suffering CLBP are a challenge for pain relief and rehabilitation, possibly due to the complex nature of these patients’ disability. Workers compensation patients have been described as: unable to work; have long history of medical treatment; made repeated unsuccessful attempts to return to work; resist therapy; their work is affected as well as their relationships with family, friends, spouse, children, and employer; they are dissatisfied with the job; feel rejected; fear reinjury; depressed, regressed, dependent, emotionally dissatisfied; and angry with the employer, physician, spouse, family, friends, and with self. “Compensation neurosis”, “low back loser”, and “psychogenic pain” are terms often used to describe the compensation LBP patients who lacks identifiable physical cause for the pain (Walsh and Dumitru, 1988).

Returning a patients with such a profile to full functional capacities would be a valuable achievement that can reflect upon industry, economy, society, and the patients themselves. In the literature, back pain rehabilitation programs report varying degrees of success, or failure, in rehabilitating workers compensation patients (Ignelzi et al., 1977; Maruta et al., 1979; Newman et al., 1978; Painter et al., 1980). While some programs report poor results with workers compensation patients, the general pain population seems to respond well to the same treatment approach (Catcholve and Cohen, 1982; Greenough and Fraser, 1989). There is an apparent difficulty in comparing results from these studies. This is due to the fact that the approaches utilized to manage the pain problem appear to be different in terms of patients selection criteria, treatment modalities, rehabilitation goals, and outcome variables. In an earlier study (Khalil et al., 1991) we have shown that workers compensation patients who underwent the rehabilitation program at the Comprehensive Pain and Rehabilitation Center, on the average, respond in a similar fashion to non-compensation matched individuals. The issue that was not addressed then was whether "secondary gain" issues influence response to rehabilitation in workers compensation patients.

Secondary gains, financial incentives, and litigation have been thought to have negative effects on CLBP patients' treatment outcome (Block et al, 1980; Trief and Stein, 1985). Compensation/litigation issues appear to be important in returning a back injured individual to the same or different work. Most of the available studies comparing litigation and no-litigation patients emphasize psychological variables. This study aimed at investigating physical variables (strength, flexibility, etc.) in patients with secondary gain issues in terms of their display of functional abilities and response to rehabilitation. For this purpose, we used a battery of quantitative measures of human performance to analyze and compare patients upon admission and prior to discharge from a treatment program. The entire battery was used since we believe that none of the tests within the battery, taken individually, are enough for a composite performance measurement.

The objectives of this study were:

1. To evaluate and compare the functional abilities of two groups: workers compensation patients who have pending pain-related legal proceedings; and workers compensations patients who do not have pending pain-related legal proceedings. Groups were to be compared upon admission to an aggressive physical medicine rehabilitation program
2. To evaluate and compare the functional capacities of the two groups of patients prior to discharge from the rehabilitation program.
3. To compare the groups' relative responsiveness to the treatment program.

METHODS

Sixty-four patients with CLBP classified as Workers Compensation were included in this study. Only patients who **completed** the pain and rehabilitation program at the University of Miami Comprehensive Pain and Rehabilitation Center (CPRC) at South Shore Hospital, Miami Beach, Florida were sampled in this study. The CPRC utilizes a multidisciplinary comprehensive aggressive physical medicine approach to the management of chronic pain conditions. The components of this program are: neurosurgery, physiatry, physical therapy, occupational therapy, vocational counseling, nursing, psychology, psychiatry, biofeedback, muscle reeducation, and ergonomics. Treatment goals are: reduction/elimination of drug intake, physical restoration, vocational rehabilitation, behavioral modification, and return to work and productive life style (Rosomoff et al., 1981; Rosomoff and Rosomoff, 1991). The Ergonomics and Bioengineering Division, among its many contributions to pain management at the CPRC (Khalil et al., 1988), evaluates patients performance and functional abilities upon admission to the Center and throughout rehabilitation in order to determine functional capacities, degree of functional loss, progress during rehabilitation, and treatment outcome. A battery of quantitative measures of human performance and functional capacities has being designed for this purpose (Khalil et al, 1987).

The sample was divided into two, age-matched groups. The first group consisted of 32 patients (16 males and 16 females) who have a secondary gain issue (Group SG); e.g.

have a lawyer for the pain problem, involved in litigation and 3rd party suite. The second group consisted of 32 patients (16 males and 16 females) patients who sustained the back injury but did not have a secondary gain issue (Group NSG). For the purpose of this study, the two groups were compared on the basis of the following measures of functional abilities: psychomotor abilities, walking speed, squatting ability; trunk flexibility; grip strengths; isometric strength of the arms, shoulder, composite, and back; and right and left static knee extension strength. Evaluations were performed at three intervals: a) initial evaluation—upon patients admission to the CPRC; b) midterm evaluation—after two weeks into the program; and c) final evaluation—prior to discharge from the 4-week program. For the evaluation of static muscle strength, the concept of Acceptable Maximum Effort (AME) was used (Khalil et al., 1987). A repeated measures Analysis of Variance (ANOVA) design was used for data analysis. There was one grouping factor (secondary gain) with two levels (SG and NSG), two within factors: gender (males and females) and evaluation time (initial and final). Results were considered statistically significant at the 0.05 level.

RESULTS

Table 1 presents the means and standard deviations of the initial and final measures describing performance in the various categories for both groups; Secondary Gain (SG) and No Secondary Gain (NSG). Examination of the results showed that patients in both groups demonstrated significant reduction in functional abilities prior to rehabilitation when compared to available “norms”. Moreover, patients in the SG group showed greater limitations in trunk flexion range of motion and most static strength measures than patients in the NSG group. For this sample, this initial difference between performance of the SG and NSG groups was found to be statistically significant only in the measure of grip strength (Fig. 1). During the final evaluation (Fig. 2), the difference in performance levels between the SG and NSG groups was larger than that observed during the initial evaluation. This difference was not statistically significant at the 0.05 level (alpha in

Fig. 1. Initial Strength of Secondary
Gain and No Secondary Gain Groups

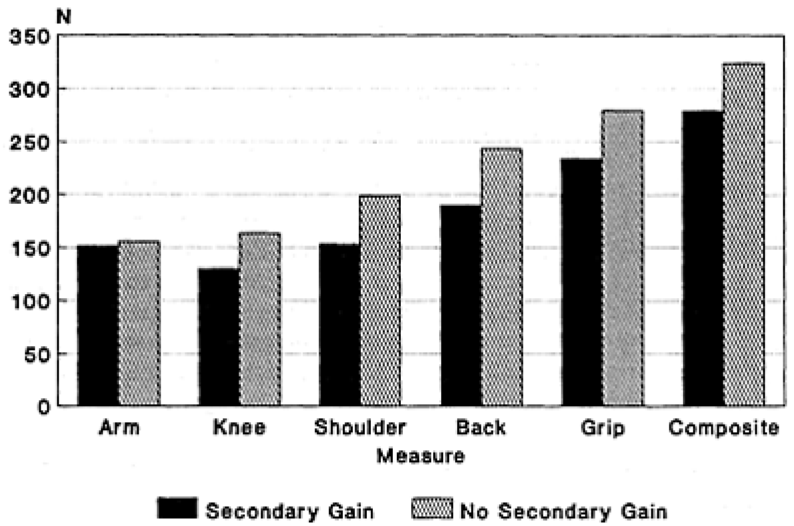

Fig. 2 Final Strength of Secondary-
Gain and No-Secondary-Gain Groups

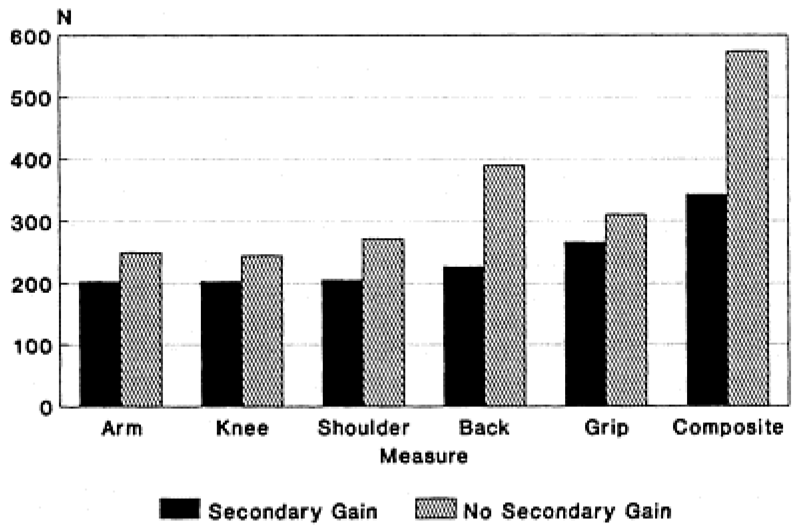

Table 1. Means and Standard Deviations(σ) of the Measures of Functional Abilities for Group SG (Secondary Gain) and NSG (No Secondary Gain). An '*' indicates that the Change from Initial to Final was Statistically Significant

VARIABLE	GROUP	INITIAL		FINAL	
		MEAN	σ	MEAN	σ
PAIN LEVEL	SG NSG	6.8 5.7	2.3 2.3	6.2 5.4	3.0 3.4
WALKING SPEED m/sec	SG NSG	1.74 1.56	1.22 1.01	1.13 1.01	0.88 0.52
SQUATTING ABILITY cm	SG NSG	32.3 36.1	26.2 23.1	18.0 16.8	20.3 20.6
VISUAL REACTION TIME sec	SG NSG	0.37 0.40	0.15 0.19	0.30 0.28	0.12 0.12
AUDITORY REACTION TIME sec	SG NSG	0.30 0.25	0.16 0.09	0.21 0.21	0.08 0.08
TRUNK FLEXION deg	SG NSG	61.6 72.3	31.4 39.6	97.0 110.0	27.6 38.2
TRUNK EXTENSION deg	SG NSG	18.1 17.2	12.5 7.6	26.1 27.2	13.1 11.7
RIGHT LATERAL FLEXION deg	SG NSG	36.7 31.2	14.9 11.4	46.4 45.2	12.8 11.9
LEFT LATERAL FLEXION deg	SG NSG	34.4 33.0	14.2 17.1	45.4 45.7	14.5 15.4
GRIP STRENGTH Newtons	SG NSG	234.1 279.6	111.7 154.1	266.7 311.6	123.3 144.7
ARM STRENGTH Newtons	SG NSG	151.8 156.7	119.8 117.9	202.6 250.2	162.9 171.8
SHOULDER STRENGTH Newtons	SG NSG	153.1 199.5	112.2 157.2	206.6 272.0	161.6 171.8
BACK STRENGTH Newtons	SG NSG	190.9 243.1	154.9 313.4	227.5 390.4	147.4 357.9
COMPOSITE STRENGTH Newtons	SG NSG	279.6 324.1	244.9 402.0	342.8 574.3	227.1 560.9
KNEE STRENGTH Newtons	SG NSG	130.4 163.8	84.1 102.4	203.1 244.9	132.7 124.7

the range of 0.094 for back strength to 0.723 for knee strength). Exception was for the trunk flexion range of motion. For both groups, the change in performance from initial to final was statistically significant for all mobility, flexibility, and strength measures. Additionally, change of score analysis (from initial to final) showed that there was not significant difference in the magnitude of change in abilities between both groups. During the initial and final evaluations, patients in the SG group reported, on the average, higher pain level than the NSG group. Upon final evaluation, both groups reported pain reduction, however, not statistically significant for this sample.

SUMMARY AND DISCUSSION

Medical treatment for CLBP in the United States varies considerably. Although certain treatment approaches have been associated with a high degree of success (Rosomoff et al., 1981; Cassisi et al., 1989), the overall outcome of medical management for back pain in the United States is relatively poor (Steinberg, 1982). As such, the rate of functional disability and accompanying economic and psychosocial consequences remain high among sufferers of chronic pain. Success during rehabilitation has been associated with many factors: individual, physical, psychological, vocational, legal, familial, social, and environmental. Of special interest to this study was the physical/legal issue; i.e. workers who sustain a work-related back injury and, as a result, seek some type of compensation.

Compensation status has been identified as a variable that may be predictive of returning a CLBP injured worker to work (Sheikn, 1987; Barnes et al., 1989; Frederickson et al., 1988; Lee et al., 1989; Deyo and Diehl, 1988). Financial compensation includes litigation, workers compensation, long-term disability, insurance, and social security (Walsh and Dumitru, 1988). Compensation status has been associated with poor CLBP patient treatment outcome (Turner and Leiding, 1985). Unfortunately, some low back treatment programs exclude patients seeking compensation (Painter et al., 1980). The differences between compensation and non-compensation patients have been attributed to litigation/secondary gain issues (Fishbain et al., 1988; Weighill and Buglass, 1989). We attempted to study this problem (Fishbain et al, 1988; Labbe et al., 1988; Khalil et al., 1991). The literature agrees on the conclusion that the relationship between compensation status and treatment outcome is very complex, especially in the presence of litigation and secondary gain issues. It has been assumed that it is likely that the greater the potential secondary gain of the litigation the less likely the individual would succeed during rehabilitation.

This study is one of a series of attempts to further analyze this assumption. The change in physical capacities upon rehabilitation was investigated for two groups of chronic low back patients classified as workers compensation: those who did and those who did not have a legal proceeding for their work-related injury. Prior to treatment, patients in both groups exhibited significant reduction in functional abilities as compared to healthy individuals. Patients in the “secondary gain” group seemed to demonstrate less levels of performance than the no-secondary-gain group. However, there was no statistically significant difference between both groups. With respect to self-report of pain level, patients in the secondary gain group reported higher pain. The difference between the groups’ report of pain level was not statistically significant. This is in agreement with other studies in which compensation/no compensation patients shown similar average pain intensities (e.g. Melzak et al, 1985). The physical restoration and rehabilitation at the CPRC enabled the patients to restore their physical capabilities following the 4-week program. Upon final evaluation, all patients showed significant improvement in all measures of functional abilities. Still, patients in the secondary-gain group performed at lower levels than the no-secondary-gain group, though the difference was not statistically significant for this sample. Also, findings indicate that all patients in this sample reported average reduction in pain level following 4 weeks of treatment, though not statistically significant. However, measures of functional abilities reflected significant improvement in performance. This supports our believe that function can be restored without immediate significant reduction in pain level.

In conclusion, for this sample of workers compensation patients, litigation status did not seem to be a critical factor in functional restoration, provided that the patient completes the multidisciplinary treatment program. It should be indicated here that only patients who completed the program at the CPRC were analyzed. Some other patients in the same category of workers compensation with or without litigation left the program before completion. Patients did so either on their own initiative or were terminated upon the recommendations of the medical staff. Some were advised that it would be more effective for their rehabilitation if they would settle their secondary gain issues before entering the program so it would not act as a distract to their rehabilitation.

Findings indicate that, whether patients were involved in a legal proceeding for a work-related injury or not, they follow similar pattern of improvement in functional restoration upon effective rehabilitation. For future research, it may be still necessary to delineate the different degrees of secondary gain involved, the degrees of disability, outcome of treatment in terms of return to same or different work, resolution of secondary gain issues, and the contribution of behavioral factors to outcome. Also, the issue of which patients complete rehabilitation needs to be addressed.

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ERGONOMIC JOB ANALYSIS FOR PATIENTS WITH CERVICAL TRAUMA DURING REHABILITATION

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This paper presents an ergonomic approach to the control and management of cervical trauma in patients who already have neck pain during their rehabilitation in order to prepare them to return to work while minimizing the potential of reinjury. The key element of the method is education and increased awareness of abilities, posture, body mechanics, and the human interaction with the environment. The component of this approach are outlined through a case study of a patient with head/neck pain. The importance of using electromyographic biofeedback and computer-aided workplace analysis and design methods is discussed.

INTRODUCTION

Statistics on work-related musckeloskeletal injuries are alarming with adverse effects not only on industry but also for individuals and families. In the United States, In 1987, 75 million workdays were lost because of job-related injuries, with a price tag of $42 billion spent on wage loss, insurance and medical costs, not including the cost of diminished productivity (Young, 1989). In Canada, during the same year, there were over one million compensable work injuries and illnesses, of which 59% resulted in the loss of 25 million work days and $3.5 billion in benefit payments and $17.5 billion in indirect costs (Labor Canada, 1990).

The head/neck/cervical area is a common target to work-related injuries and a source of pain and suffering. The neck is susceptible to pain and injury due to the constant demands placed on it throughout daily life. The cervical region is second only to the low back as a common source of tension and pain. Due to anatomical and physiological factors, cervical pain often involves the arms, shoulders, as well as the head. Therefore, any approach to reduce biomechanical stresses on the cervical region should account for the interaction of virtually all body parts (head, neck, trunk, upper and lower limbs) as well as external forces.

The potential sources of neck pain can be soft tissue injury and/or dysfunction/disorders of spinal structures; with the former being cited as the most common (Abdel-Moty et al., 1990). Soft tissue injury can develop as a result of tension, sprain, spasms, weakness, strain, contracture, and/or inflammation. It can also develop gradually as a result of the “wear and tear” that takes place when daily activities are carried put forcefully, awkwardly, or repetitively without considering human abilities and limitation.

Cervical pain has been always associated with desk-type tasks. However, it is well recognized that almost all activities of daily living can cause cervical distress if not carried-out correctly (Abdel-Moty, et al., 1992). Most of us have suffered from a “stiff neck” due to certain types of activities such as static work, such as holding the neck and head in a forward posture while sitting, laterally over-flexing the neck to hold the telephone receiver, holding the head to look at a computer terminal (Friedman et al., 1992), and awkward positioning of the head while sleeping. When a particular job necessitates excessive static activity, fatigue and strain are likely to occur. These two factors contribute to the discomfort and stiffness of the neck and shoulders.

In response to the problem of head and neck pain, continuous efforts are being made in: 1) improving safety at work (primary prevention); 2) rehabilitating the injured worker quickly (secondary prevention); and 3) preventing reinjury (tertiary prevention). These are the three stages of injury prevention. In the “primary” and “tertiary” prevention stages, the objectives are to increase the functional abilities of the worker to meet or exceed physical job demands; reduce the physical demands of the job to accommodate the functional limitations of the worker; modify the work environment to reduce physical stresses; and, in some cases, place the worker in a different job or occupation. In the “secondary prevention” stage, which is the focus of this paper, returning the injured worker to the same or different job in the competitive market becomes a desirable goal. This requires careful medical, physical, vocational, and ergonomic preparation during rehabilitation.

The basis of ergonomic interventions is the study of the human-machine system where emphasis is on human abilities (strength, anthropometry, posture, body mechanics), and the interaction with the environment, the workplace, and the tools. These constitute the basic elements of Ergonomic Job Analysis (EJA).

ERGONOMIC JOB ANALYSIS (EJA): EJA is the study of the relationship between: 1) job demands; 2) human characteristics; and 3) environmental conditions. Job demands are obtained from a detailed analysis of the various tasks comprising the job with the objective of matching task demands with human capacities required for successful performance of the job. The task demands are determined through direct observation and quantitative measurement of motion, time, forces, and sensory demands.

To gain further information about task demands, interviews with the worker and the supervisor or employer are necessary. The human characteristics relevant to job performance are described in anatomical and physiological terms as well as psychological aspects including aptitude, interest, temperament and educational level. Collectively, they establish a human performance profile which determines functional capacities. The environmental setting, stressors, and conditions in which the tasks are carried out are also assessed for their effect on task performance. The information obtained from the EJA is used to classify the job according to the demands of the work. The analysis is utilized to determine job duties that an injured worker can perform based on functional capacities in relation to job demands taking into consideration any environmental modification or other reasonable accommodations which the injured worker may require to perform the job.

The Ergonomics and Bioengineering Division of the University of Miami Comprehensive Pain and Rehabilitation Center (CPRC) has devised effective, multidisciplinary intervention methods for Job Simulation, Work Conditioning, and EJA that aid in preparing the injured worker to return to work following rehabilitation. The case presented below demonstrates the practical approaches used at the CPRC to implement EJA principles in order to reduce stresses on people who already have cervical injury during their rehabilitation.

EJA PROCEDURES. Generally, the EJA methods in rehabilitation consists of the following steps: data collection, an initial evaluation, an intervention phase, and a final evaluation.

1. Data Collection

The objective here is to obtain personal as well as job-related information such as: 1) physical characteristics and anthropometric dimensions of the person; 2) qualitative description of the physical environment within which the job is performed; and 3) patient’s description of a “typical” work-day including job tasks; with special emphasis on tasks causing more stress or discomfort. Information regarding general daily activities outside work are also gathered. In most instances, it may be helpful to obtain photographs or video records of the workplace if job site visits are not feasible.

2. Evaluation

The purpose of this evaluation is to establish a baseline of patient’s performance in critical job tasks. This baseline is described in terms of muscle electrical activity, body mechanics and motions, and postural changes and habits. This evaluation should be performed prior to intervention. For this purpose, and based on the information provided by the patient, a workstation that closely simulates the actual workplace is constructed in order to further analyze the patient’s patterns of movement within the simulated environment. Electromyographic activity (EMG) of cervical muscles is monitored using surface electrodes and is used to provide objective documentation. The evaluation protocol may consist of EMG recording for a period of 5 minutes while the patient is performing a selected number of simulated job tasks. In some cases, video taping of the simulation may be necessary for subsequent education and problem-solving. During this measurement period, no feedback or suggestions for modifications or adjustments should be given. While simulated tasks are being performed, patient's body mechanics are monitored and unsafe motion patterns are identified and documented.

This observation and monitoring session serves to identify the risk factors associated with performing the critical demands of the job. Activities that increase muscle tension, cause awkward body positions and extreme deviations from neutral postures are identified for further intervention. In general, the risk factors can grouped according to the origin of the stress. In other words, where increased muscle tension is noted to be the result of poor design of the work station, the risk factor is labeled as being related to "engineering" design of the workplace (e.g. work surface height). Other factors are grouped in relation to the manner by which job tasks are performed (postural and body mechanics habits such as over reaching).

3. Ergonomics Intervention

Following the identification of the risk factors, the intervention includes three concurrent procedures:

a) Re-engineering the workplace: where heights are adjusted based on computerized analysis using SWAD (Seated Workplace Analysis Design software). Also the layout of the workstation is modified so that all tools are located within functional reaches. Adjustments can include the chair, the seat, elbow rest, foot rest, and worksurface layout. The SWAD is an expert system that facilitates the individualized analysis and design of work stations (Abdel-Moty and Khalil, 1986, 1987, 1988). The rationale for modifications should be explained to the patient and supported through the use of EMG to demonstrate the extent of muscle tension reduction upon intervention.

b) Posture and body mechanics adjustment: Posture is corrected and awareness is increased through the use of audio and visual EMG feedback to demonstrate that corrections do indeed reduce muscular tension. The patient is instructed to lower EMG levels by utilizing the principals of maintaining the neutral position, avoiding excessive reaching and bending, and "thinking ahead". Patient is educated as to good posture and proper body mechanics while performing various job tasks. The importance of generalizing principles to all daily activities should be emphasized.

4. Final Evaluation

During this evaluation, the patient performs the same set of tasks as in the initial evaluation. EMG activity is recorded for a 5-minute interval without feedback.

CASE STUDY

This is a 32 year old right-handed female. She works as a computer graphics artist/type-setter. Her job involves setting type of letter patterns for printing articles, advertisements, and other printed matters using computer programs. The Dictionary of Occupational Titles (USDOL, 1986) classifies this job demands as "light". In 1989, she started complaining of neck and shoulder pain due to unspecific causes. By 1991, pain extended the upper and lower back areas. She described the pain as constant, dull, and is aggravated by driving, lifting, and using the computer “mouse”.

Upon admission to the rehabilitation program at the CPRC she received the diagnosis of multiple myofascial syndromes; specific or diffused aching musculo-skeletal pain associated with multiple discrete tender/trigger points. Her treatment consisted of: physical therapy, occupational therapy, vocational rehabilitation, behavioral modification, detoxification, and ergonomic interventions for Functional Capacity Assessment and Ergonomic Job Analysis (Rosomoff and Rosomoff, 1991; Khalil et al., 1985). Neurologic examination of the head and neck shows a decreased range of motion in lateral flexion and anterior flexion. She was tender over the right trapezius, both levator scapulae, right rhomboids, suprascapular notch and bicipital tendon.

The EJA procedures described above were used since it was recognized that the major cause of the neck condition was a result of job tasks related factors. Following data collection, an initial evaluation was performed followed by an intervention phase, and a final evaluation. During the initial evaluation session, the following risk factors were identified: sitting posture (slouching), radial deviation of the wrist when using the keyboard/mouse, lateral neck flexion when using the phone (resting between head and shoulder), chair height, computer monitor height (about 45 degrees below eyesight level), the layout of work tools (such as fax machine and phone), overreaching (to the sides and overhead), constant twisting and turning, frequent bending, lifting while twisting and in awkward postures, absence of foot support, and work/rest schedule. This session was video taped for further analysis.

During the intervention phase, results of the computerized analysis using SWAD was compared to the actual dimensions of the workplace provided by the patient. Main discrepancies between the actual dimensions and those obtained via SWAD were related to: seat height and depth and worksurface height, keyboard height, VDT height, and reaches. Recommendations for modifications were offered. The simulated environment was redesigned based upon the results of the computerized analysis. In addition to this quantitative approach, performance during the initial evaluation was discussed with the patient and awkward, repetitive movements and postures were pointed-out. In the simulated workstation, body mechanics and posture training consisted of teaching the patient to assume the positions that would permit lower muscle tension in the cervical area while maintaining neutral postures of other body segments. The audio and visual displays of the EMG device was used in order to assist the patient in reducing muscle tension levels associated with specific activities.

Results of the initial and final EMG assessment are summarized in Table 1. It can be seen that the final EMG levels (post EJA) were significantly lower than the initial ones (prior to EJA). Collectively, the engineering, body mechanics, and postural interventions contributed to lower muscle tension while performing the same tasks.

Posture was corrected by adjusting the seat height based on SWAD analysis so that body segments and joints were maintained in the neutral position (e.g with arms parallel to the worksurface, feet flat on a stool, knees slightly higher then the hips).

Table 1

EMG Levels During Initial and Final Evaluations of the Right and Left Sides (in units of uV*sec)

	Right	Left
INITIAL	3.075	2.033
FINAL	1.776	0.963

The height of the computer monitor was adjusted to fulfill the primary requirement in proper head-neck posture; i.e. not to exceed a 20–30 degree angle between the head and the neck (Grandjean, 1988; McCormick and Sanders, 1982). Head posture was adjusted in order to maintain the eye's line of sight within the comfortable range of eye movement (15 degrees below and above the normal line of sight). Support of the arms was recommended for long-term computer operation in order to counter-balance the effect of the upper extremity weight and allow to relax the shoulders and neck muscles. For avoiding continuous pressure and elevating the wrist, a soft wrist-rest was suggested. This allowed the wrist to remain in a neutral "keying" position and limiting ulnar flexion of the wrist. Relocation of items such as the fax machine and reference books was also recommended. Additionally, she was advised to use a head-set in order to replace the current hand-held receiver. This will allow working simultaneously with the computer, mouse, and documents while assuming proper posture of the neck.

SUMMARY AND CONCLUSIONS

The application of ergonomics job analysis methods is effective and valuable to the comprehensive rehabilitation of chronic pain patients. The case selected for presentation is a typical example of many cases that we encounter at the CPRC. Through proper education, increased awareness, and ergonomic interventions, patients are able to correct posture, learn to use proper body mechanics, and report less pain and discomfort while performing the same tasks. The development of realistic job simulations during rehabilitation permits the patients to perform job tasks under supervision. The use of electromyographic feedback is believed to be beneficial for the reduction of overall muscle tension levels (Qualls and Sheehan, 1981). It is important to use EMG feedback for educating the injured person and increasing his/her awareness of muscular function. The EMG levels at the start of the session become valuable indicators of sustained learning and ultimate success, for it is the sustained and maintained physiologic control between training sessions that indicates application of the learned behaviors to the patient's everyday activity schedule (Reich, 1992).

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MUSCLE STRENGTH IN CHRONIC BACK PAIN PATIENTS

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The present investigation was conducted to evaluate and review the literature related to the measurement of trunk strength in chronic low back pain (CLBP) patients. A standardized strength measurement in the area of chronic pain based on the Acceptable Maximum Effort (AME) is presented. The main objective of this study was to establish norms for the AME flexion and extension trunk strengths of back pain patients and study the relationship between these AME measures and the different characteristics of the back pain population. 131 patients suffering from CLBP disorders were evaluated on the first day of treatment and after two weeks of a rehabilitation program. The results obtained showed that flexion strength, on the average, was found to be higher than extension strength. The correlation between demographic characteristics and trunk strength were relatively low. For the sample used in this study the duration of pain symptoms and prior history of back pain related surgery did not affect the outcome measures used in the present study.

INTRODUCTION

Musculoskeletal injuries are among the most common problems in occupational medicine. These injuries have been listed under the ten leading work-related illnesses in the United States. The associated cost with these injuries in terms of disability, suffering, and economic loss is enormous. The National Institute for Occupational Health and Safety (NIOSH, 1981) reported that about 35% of all compensations claims in the United States are related to back injuries. The causes of chronic low back pain (CLBP) complaints are difficult to determine and are still undefined. Restoration of functional abilities has been one of the major concerns in the treatment of back pain disabled individuals. Muscular factors have been considered of some importance in relation to the symptoms of back pain. According to Flint (1958) it has been estimated that between 80 to 90 percent of all backaches may be attributed to faulty mechanical and postural habits which aggravate lumbar and sacral structures by placing stress and strain on these structures. Flint (1958) showed that by increasing the power of the back and abdominal muscles, symptomatic relief from chronic recurring low back pain may be obtained.

Several researchers studied the relationship between back pain and muscle strength. Nachemson and Lindh (1969) used the maximum instantaneous tension of abdominal and spinal muscles to compare normal pain free subjects and patients with low back pain. They found that strength values for male patients who had been incapacitated for less than one month were not significantly different from normal individuals. However, for those who have been inactive for more than one month, the strength of both trunk extensor and flexor muscles were significantly lower than normal subjects. They attributed these differences mainly to the prolonged inactivity or inability to work and to fear of pain. They concluded that the strength of the trunk is of doubtful importance for the prevention of low back syndrome. Also, Pedersen et al (1975) showed that the episodes of pain do not seem to influence the isometric muscle strength of the back. Addison and Schultz (1980) measured isometric trunk strengths of patients, admitted to a pain clinic, in the standing position during attempted flexion, extension, and lateral bending. These strengths values were compared with those of healthy subjects and with those of back pain patients treated as outpatients of a general orthopedic office practice. The absolute strengths for the two groups of patients were not significantly different, but were significantly lower than healthy subjects. Also, the intra-individual trunk strength ratios were compared to avoid the psychological factors and the problems of patients' general weakness. The comparison between the patients from the pain clinic and healthy individuals showed that these patients had significantly lower strengths during extension relative to their strengths during flexion and lateral bending. These results were in general agreement with the results reported by McNeill et al (1980). Hause et al (1980) used the Cybex machine to evaluate both isometric and isokinetic trunk strengths in normal and low back pain individuals. For the healthy individuals, the strength values in an isometric contraction were almost the same as those in an isokinetic contraction in both sexes. The strength values of low back pain patients were below the range of normal values. A similar study conducted by Thorstensson and Arvidson (1982) showed no significant differences between normal individuals and patients for trunk extension, lateral flexion or flexion when the center of rotation was at the L2-L3 level. However, significant differences were observed during the initial part of isokinetic trunk flexion with the pivot point at the hip joint. At the corresponding point of this position in the isometric measurements, no significant differences were found. Suzuki and Endo (1983) studied static and dynamic trunk strength in normals and back pain patients using an isokinetic dynamometer. The results of isometric strength showed that both trunk flexion and extension strengths in normals were significantly higher than back pain patients. This finding was true for patients with less than one month as well as those who had pain for more than one month. These results contradict the findings of Nachemson and Lindh (1969) and Pedersen et al (1975). Mayer et al (1985) compared the trunk strength of 125 normal subjects with 286 patients suffering from chronic low back pain. The minimum duration of pain symptoms were six months. In this study, extension and flexion strengths were measured using the Cybex at a speed of 120, 90, 60, 30, and 0 (static) degrees/second. The results of this study showed that CLBP patients had lower strength values for both extension and flexion than the control group and the variability among patients were higher. Also they found that extensor strength was affected more significantly than flexor strength.

This brief review of the literature illustrate the discrepancies regarding the relationship between the symptoms of back pain and trunk strengths. These discrepancies could be attributed to differences and limitations in selection of subjects and in the methodologies used for the measurement of muscle strength. Assessment of muscle strength, similar to any other measure of human function, is susceptible to many influences. Chaffin (1975) summarized some of the factors which could influence strength assessment. Smidt and Roger (1982) reviewed extensively the physiological, anatomical and biomechanical factors that contribute to the regulation of muscular strength. Some of these factors include, but not limited to, instructions given to the subject, duration of measurement periods, posture used during the measurement, rest period between trials, motivation, influence of body weight and gravity effect, measuring device used in the assessment of strength, type of contraction (eccentric, concentric, isometric, isokinetic,…), movement velocity and position of the center of rotation (pivot point) in dynamic measurements.

An extensive review of the trunk strength measurements reported in the literature showed that different researchers have utilized different techniques for the assessment of trunk strengths. Both static and dynamic (isokinetic) measurements have been utilized. Several testing positions have been used in different studies. Also, the measuring devices used included cable tensiometer, strain gauges, spring balance, hand dynamometer, cybex dynamometer,…etc. The number of trials and the rest period between the successive trials in many cases were not specified. In some studies the peak value was used to be the strength outcome while others considered the average of several trials to be their strength outcome. The instructions given during the testing sessions are not specified in many of these studies. Chaffin (1975) provided guides for the assessment and reporting of human static strength for healthy individuals.

Several postures have been used in the evaluation of trunk strengths in healthy individuals and patients suffering from back pain. Supine and prone position have been used in many studies for back strength measurements. In these positions, the weight of the upper body is a major component of the load. The effects of the gravitational forces in these positions can only be roughly estimated. The use of the torso lifting strength testing position has been recommended for the evaluation of back strength. The biomechanical evaluation of this posture conducted by Hansson et al (1984) showed that the compressive loads on the lumbar spine during the torso lifting test are close to a level at which structural failure of the spine could be expected even at a submaximal level of exertion while isometric extension and flexion tests in the upright standing position resulted in a considerably less load on the lumbar spine. Therefore, the standing erect position seems to be a more suitable posture for the measurement of trunk strengths for both extension and flexion.

The techniques currently in use for trunk strengths evaluation are based on either static or isokinetic measurement of the musculoskeletal capabilities of an individual. Static muscle strength testing measures a person’s ability to exert isometric muscle strength in a defined body posture. Isokinetic testing measures muscle strength capabilities while body segments move at a constant speed. Each technique has its merits and drawbacks. The main advantage of isokinetic techniques is that they measure the individuals' dynamic abilities. There is a general agreement that dynamic strength testing procedures produce values that are more realistic in predicting functional abilities. However, isokinetic testing is not very realistic since the human body does not move at a constant speed. Static techniques have the following advantages: (1) the test is easy to perform; (2) the risk of injury during the test is minimal; (3) the coefficient of variation is on the average 10% and test-retest values are highly correlated (r=0.9) (Chaffin, 1981 and Keyserling, 1979); (4) in static testing, an individual is capable of exercising better body control than in dynamic testing; and (5) static testing provides a better focusing on the output of defined muscle group(s). Based on these factors, it is concluded that static strength testing are more desirable for use with individuals suffering from low back pain. Also, Hause et al (1980) indicated that isometric measurement is more appropriate than isokinetic one for patients who have pain and fear of their pain aggravation with spinal motion.

Traditionally, static strength has been determined as the torque or force produced by a single isometric maximum voluntary contraction (MVC). The use of maximal function testing for CLBP patients would require these patients to exert themselves beyond their acceptable pain level. Addison and Schultz (1980) reported that during testing maximal isometric trunk strengths 33% of the patients reported pain during attempted flexion, 42% during attempted left lateral bending, 55% during attempted right lateral bending, and 64% during attempted extension. McNeill et al (1980) reported slightly lower percentages for patients experiencing pain during the testing. These were 20% for flexion, 40% for extension and left lateral bending, and 50% for right lateral bending. Khalil et al (1984) and Khalil et al (1987b) introduced the concept of submaximal isometric strength tests for the evaluation of the functional abilities of healthy individuals. These submaximal isometric strength tests are known as the "Acceptable Maximum Effort" (AME) which was defined as the level of exertion the individual is willing to maintain in a series of isometric muscle contractions. As such AME is based on the psychophysical approach for the determination of acceptable lifting capacity of individuals. The results of the studies reported by Khalil and his coworkers showed that AME is a reproducible measure with acceptable coefficient of variation values. AME was found to be a better indicator of the dynamic ability of individuals than MVC. Khalil et al (1987a) introduced the concept of AME as a standardized and reliable measure of the functional ability in the area of chronic pain. It is highly recommended to use this concept for the evaluation of the residual functional ability of individuals with neuromuscular deficiencies. A detailed description of the procedure used in the measurement of AME strength in CLBP patients can be found elsewhere (Khalil et al, 1987a).

Based on this discussion, it was decided to use the AME strength concept to evaluate the back strengths in CLBP patients statically in the upright position. In this study, a special frame, which required subjects to stand erect facing it with their pelvis stabilized, was used. A belt was placed around the torso of the subject and was attached to a chain linked to a force transducer. Subjects were asked to apply pressure to the belt by attempting back extension. They were instructed to continually exert effort smoothly until their AME level was reached and to maintain this effort for four seconds. AME concept was explained to the patients as a point of effort beyond which a person believes that pain would become intolerable (unacceptable). The measurement was repeated three times and the average value was considered the back extension strength AME score. One minute rest was allowed between trials. The AME strength of the back flexors was measured with the same method, except that the subjects attempted back flexion.

The main objective of this study was to establish norms for the AME flexion and extension trunk strengths of chronic low back pain patients. This relatively new approach for the evaluation of the functional ability measurement has not been well documented in the literature. More specifically, this study was designed to establish the relationships between AME trunk strengths of CLBP patients and the different demographic characteristics (age, height, weight,…etc). Also, this investigation was conducted to study the effect of history of back surgery on the AME trunk strengths, trunk ranges of motion, and pain level.

METHODS AND PROCEDURES

Subjects

One hundred and thirty one patients suffering from CLBP participated in this study. All subjects participating in this study received a diagnosis of myofascial syndrome as the etiology of their low back pain condition. Physical diagnosis related to the patients' pain condition were made independently by a neurosurgeon and a physiatrist. Patients receiving one of the following diagnoses were not included in the sample used: (1) no evidence of low back pain; (2) evidence of radiculopathy or other non-muscular related organic disorders; and (3) other interfering medical problems (e.g., cardiovascular disorders). The demographic characteristics of the CLBP population evaluated in the present study are presented in Table 1.

Table 1. Mean and standard deviation of the demographic characteristics.

Gender	Males		Females	
Surgery	Yes	No	Yes	No
No. patients	29	41	35	26
Age (years)	43.4 (12.5)	43.1 (13.2)	48.5 (13.4)	44.2 (12.8)
Height (inch)	69.9 (3.3)	70.1 (3.2)	64.9 (3.6)	63.8 (2.2)
Weight (lbs)	187.8 (28.0)	189.2 (31.4)	147.2 (25.5)	134.7 (25.8)
Pain history in months	100.1 (125.5)	34.4 (40.5)	166.0 (128.6)	25.0 (19.1)

Outcome measures

The outcome measures used were: 1) low back pain level; 2) AME strength of back extensors; 3) AME strength of back flexors; 4) back extension range of motion; and 5) back flexion range of motion. Measurement of the AME strength of back extensors and flexors were carried out statically in the upright position as descried earlier. Low back pain level was recorded on a scale from 0 to 10, where 0 represents pain free sensation and 10 represents excruciating pain. Ranges of motion of the back extensors and back flexors were measured using a hand held gravity goniometer.

All subjects who participated in the present study were initially evaluated on the first day of admission to the University of Miami CPRC. Final values of these measures were obtained after two weeks of the four-week treatment program.

Statistical analysis

The population of CLBP were subdivided into four subgroups based on gender and medical history of back surgery. The four subgroups were: (1) males with history of back surgery; (2) males without a history of back surgery; (3) females with history of back surgery; and (4) females without a history of back surgery. Analysis of variance (ANOVA) was utilized to compare the functional abilities of CLBP patients in these subgroups. A separate ANOVA was conducted for each outcome measure. Change of score analyses were utilized to compare between the improvement in functional abilities achieved by the four subgroups of the CLBP patients after the two weeks monitored in the present study. Post-Hoc analyses were performed as needed. Correlation coefficients were calculated to study the relationship between the outcome measures and the demographic characteristics of CLBP patients.

RESULTS

Means and standard deviations for the initial and final values of the outcome measures are presented in Table 2. The initial extension and flexion AME strengths for female patients, with a history of back surgery, were 53% and 58% respectively, that of male patients with similar history. The corresponding figures for patients who had no history of back surgery were 63% and 72%. These values are comparable to the results of McNeill et al (1980) based on MVC. McNeill et al reported that on the average, the strength of female patients was approximately 50% of male patients. Also, Addison and Schultz (1980) found the ratio between female patients and male patients in terms of maximum strength to be about 47% for flexion and 53% for extension. The final ratios between females and males were 63% for extension AME and 69% for flexion AME strengths for patients with history of back surgery. The corresponding figures for patients who had no history of back surgery were 60% and 61%. These ratios are similar to the values reported by Addison and Schultz (1980) and McNeill et al (1980) for healthy individuals (64% for flexion and 61% for extension). The intra-individual trunk AME strength ratios were compared to avoid the psychological factors and the problems of patients' overall weakness. On the average, the ratios between initial extension and flexion AME for male patients were 0.92 for the group with history of back surgery and 1.43 for the group with no history of back surgery. The corresponding values for female data were 0.97 and 0.99 respectively. The ratios of the final AMEs were 1.02 for males with history of back surgery, 1.14 for males without history of back surgery, 0.97 for females with history of back surgery, and 1.04 for females without history of back surgery. These ratios are similar to those reported by Addison and Schultz, 1980 and McNeill et al, 1980).

On the average, female initial ranges of motion of the trunk (both extension and flexion) were higher than male data as shown in Table 2. Also, the final ranges of motion of the trunk (both extension and flexion) showed similar trends. However, these differences did not reach statistical significance.

Table 2. Summary of the statistics of the outcome measures

		Male		Female	
Variable		Surgery	No Surgery	Surgery	No Surgery
Extension AME (lbs)	Initial Mean	62.3	64.8	33.1	40.9
	SD	45.9	40.0	18.2	15.7
	Final Mean	110.4	121.0	69.3	73.0
	SD	58.8	58.1	43.6	26.8
Flexion AME (lbs)	Initial Mean	71.1	62.3	38.9	44.8
	SD	45.5	48.2	21.5	20.5
	Final Mean	112.1	113.4	76.9	68.9
	SD	46.2	61.3	47.9	20.6
Extension ROM (°)	Initial Mean	18.5	19.6	21.1	20.9
	SD	8.4	8.9	10.3	10.9
	Final Mean	27.9	29.7	28.7	35.2
	SD	8.6	9.4	9.7	15.5
Flexion ROM (°)	Initial Mean	81.3	84.6	91.6	98.1
	SD	30.4	30.7	29.3	31.0
	Final Mean	120.0	124.1	125.9	129.1
	SD	19.6	22.8	21.6	21.4
Pain Level	Initial Mean	6.4	5.6	5.8	5.6
	SD	2.2	2.9	2.8	3.0
	Final Mean	5.4	4.2	5.6	4.7
	SD	2.4	2.7	2.4	2.1

The results of the analysis of variance for the initial outcome measures showed that the four subgroups were significantly different at the 0.01 level for both extension and flexion back AME strengths. Initial ranges of motion of the trunk (extension and flexion) and initial pain level did not show significant differences. The results of Tukey tests showed that for both extension and flexion AME strengths, male patients with a history of back surgery were not significantly higher than both female groups. However, extension strength of male patients with history of back surgery were only significantly different from females who had history of back surgery. For flexion strength, only the two groups who had history of back surgery were significantly different from each other.

The final outcome measures showed that the four subgroups were significantly different at the 0.01 level for only extension and flexion back AME strengths. The results of Tukey tests showed that for both extension AME strength, male patients with a history of back surgery were not significantly different from those who did not have history of back surgery. Also, female patients showed similar results. Extension AME strength of male patients with history of surgery were significantly higher than both female groups. However, extension strength of male patients with history of back surgery were only significantly different from females who had history of back surgery. For flexion AME strength, only the two groups who had no history of back surgery were significantly different from each other. Change of score analyses were conducted to study the effect of gender and history of back surgery on the outcome of the rehabilitation program used at the CPRC after two weeks only. The changes in all the outcome measures except pain level were not found to be significantly affected by the grouping of the patients according to their gender and history of back surgery. Only the change in pain level was found to be significant at the 0.05 level. The results of Tukey test showed that the change in pain level was only significantly different between male patients with no history of back surgery and female patients with history of back surgery.

The results of the correlation analysis showed a significant correlation between age and trunk flexion range of motion and pain level. These correlation coefficients were 0.293 and −0.218 respectively. Height and weight showed significant correlation with both flexion and extension back strengths. For height, the correlation coefficients were 0.367 for extension and 0.308 for flexion strengths. The corresponding correlation coefficients for weight were 0.382 and 0.356. Both history of back surgery and the duration of pain symptoms showed no significant correlation with any of the outcome measures. Extension and flexion trunk strengths were highly correlated. The correlation coefficient was 0.82 (significant at the 0.0001 level). The extension and flexion ranges of motion showed significant correlation at the 0.0001 level. This correlation coefficient was 0.455.

CONCLUSIONS

Measurements of trunk muscle strength can be influenced by several factors. A review of the literature indicated a lack of consistency in measuring methodologies, postures used. A standardized procedure is needed to assess and report trunk strength. The strength results reported in this study were performed in standing upright position and based on the AME measuring concept recommended for use with CLBP patients. The results of the present study showed that flexion strength, on the average, was found to be higher than extension strength for all the groups studied except male patients who had no history of back surgery. It is worth noting that extension and flexion trunk AME strengths were highly correlated. On the average, females have higher ranges of motion than males. The correlation between age, height, weight and trunk strengths and ranges of motion were relatively low. For the sample used in this study, the duration of pain symptoms and history of back surgery did not seem to have an effect on the outcome measures used.

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THE EFFECTIVENESS OF A WRIST BAND ON ACTIVITIES INVOLVING THE HAND AND WRIST

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The present study investigated the efficacy of a Double-Wrap wrist strap that could be used in tasks involving repetitive motions. Factors such as the effect on grip strength, pinch strength, EMG activity, and energy absorption were measured. Results showed that the use of the wrist strap reduced the muscle activity of the forearm muscles and assisted in the attenuation of transmission of vibration from the wrist to the forearm. No reduction of grip strength or pinch strength was observed when the strap was used.

INTRODUCTION

Cumulative trauma disorders (CTDs) of the hand/wrist structure has recently been reported widely in the workplace (NIOSH, 1989 and U.S. Dept. of HHS, 1989). The most frequently occurring types of CTDs include Tenosynovitis, DeQuervain's Disease, Trigger Finger, Tendinitis, Tennis Elbow, Carpal Tunnel Syndrome, Raynaud's Syndrome, Space Invader's Wrist (Lahey, 1984). Carpal Tunnel Syndrome is probably the most mentioned type of CTDs that affect the upper extremities. It is caused by compression of the median nerve in the Carpal Tunnel and is associated with tingling, numbness, pain, and can result in loss of some hand functions (Dionne, 1984 and Lahey, 1984). Major occupational risk factors that has been associated with CTDs include repetitive motion, wrist deviation, excessive forces, exposure to vibration, and improper design of tools and/or workplaces (NIOSH, 1981, Lahey, 1984, Dionne, 1984, Johnson, 1985, OTA, 1985, Silverstein, 1987, and NIOSH, 1989). Ergonomists and occupational health specialties have been searching for ways to reduce stresses associated with CTDs. These include redesign of work-stations and workpractices, proper design of tools in workplaces and/or the use of orthotic devices (Dionne, 1984, Johnson, 1985, OTA, 1985, and Schenck, 1988). Wrist straps are examples of such orthotic devices.

The effect of using orthotic devices have not been widely investigated in the literature, a study conducted by Guo et al (1991) showed that the use of wrist protective restraints reduced wrist discomfort while performing a manual handling task. Guo and his co-workers have relied on subjective rather than objective methods of assessing efficacy of the protective wrist restraint that they have used.

The objective of the current study was to investigate the efficacy of one type of wrist straps (Dynastrength) utilizing some quantitative methods for evaluation.

The strap is a double-wrap wrist band made of an elastic fabric (length=17″, Width=3″). It incorporates two velcro fasteners, the first fastener is used to secure the strap around the wrist and the second fastener is used to tighten the strap at the desired tension. This mechanism allows the user to easily and quickly adjust the strap tension to his/her comfort level.

The strap effects on the following parameters were investigated:

1- Grip strength.
2- Pinch strength.
3- EMG activity in the forearm.
4- Transmission of vibration in the forearm.

METHOD

Four independent experiments were conducted to test the effect of the wrist strap on each of the four factors.

First experiment: *To investigate the effect of the wrist band on grip strength.*

20 healthy subjects participated in this study. A digital grip dynamometer was used as the measuring device. The device stores the maximum value (lbs. force) for each measurement. Measurements were taken on two consecutive days. One day using the wrist-band, and the other day without the wrist-band. A random drawing was conducted for each subject to determine if the subject will use the wrist-band at the first day or not, if the drawing is in favor of the wristband, the subject will perform the measurements for the first day using the wristband and for the second day without.

Subjects were instructed to stand straight and flex the right arm 90 degrees. Subjects were asked to hold the dynamometer and squeeze maximally 20 times. A rest period of 10 seconds was allowed between repetitions.

Second Experiment; *To investigate the effect of the wrist band on pinch strength.*

13 healthy subjects participated in this study (9 males and 4 females, average age=25.61±6.3). A digital grip dynamometer with a pinch transducer was used as the measuring device. The device stores the maximum value reached (lbs. force) for each measurement. Each subject performed two measurements, one with the wrist-band and the other without. A random drawing was conducted to determine which would come first. If the drawing was such that the first measurement will use the wrist-band, the second measurement will be without the wrist-band and vise versa.

Subjects were instructed to stand straight and hold the pinch transducer between the index and thumb then to squeeze on the transducer maximally.

Third Experiment; *To investigate the effect of the wrist band on Electromyographic (EMG) activity of the wrist-flexor muscles when performing a lifting task.*

Electromyographic signal is the electrical manif estation of the neuromuscular activation associated with a contracting muscle. Studies conducted to identify the relationship between EMG signals and muscle contraction showed that a direct relationship exists (Khalil and Otero, 1973, Moty and Khalil, 1987). This relationship was found to be an indispensable research tool. Fields including injury prevention, equipment design and evaluation, and workplace design are among those that benefit from this tool.

15 healthy subjects participated in this study (8 males and 7 females, average age=26.86 26.86±4.7).

Data were collected using a PC-based EMG acquisition system which is composed of the following components:

1- EMG amplifier.
2- Analog-to-digital board installed on an IBM personal computer.
3- Data acquisition and analysis software program.

EMG surface electrodes were connected to the wrist-flexor muscles of the right arm and then to the PC through the A/D board. EMG was acquired at a rate of 5000 samples per second for a period of one second. Four measurements were taken for each subject, two with the wrist-band and two without it. The order of using the wrist-band for each of the four repetitions was randomized.

Subjects were instructed to stand straight with the arms beside the body. Male subjects were asked to hold a 12 lbs. dumbbell and female subjects were asked to hold a 10 lbs. dumbbell while standing. Subjects were instructed to perform an arm curl (elbow flexion) while keeping the elbow in position. EMG was recorded for a period of 1 second during the motion. A rest period of 10 seconds was allowed between repetitions.

EMG signals were stored on the personal computer then processed. Fullwave rectification was performed on the signals then the rectified signals were integrated. The slope of the integrated curves was calculated for a period of 0.5 second.

Fourth Experiment: *To investigate the effect of the wrist band on reducing the transmission of vibration through the forearm.*

10 healthy subjects participated in this study (7 males and 3 females, average age=29.2±3.7).

Vibration was generated and controlled using a sophisticated setup (Figure 1) consisting of the following components:

1- A signal generator producing a sinusoidal waveform at a frequency of 10 Hz.
2- A vibration sensor (accelerometer) which is connected to the handle that the subject holds. The sensor is connected to a conditioning amplifier which provides negative feedback to the amplifier.
3- Power amplifier which drives the shaker that produces the required vibration. The output from the amplifier is controlled through two inputs, the positive input from the signal generator, and the negative input from the conditioning amplifier.

Vibration was measured using an integration vibration meter with a Piezoelectric accelerometer. The device was used in the Leq (equivalent level) mode. In this mode of operation, the display builds up an indication of the 60 second Leq, computed by mathematical integration from all the mean square levels occurring since the measurement started. The display simultaneously indicates the maximum peak value.

Subjects were instructed to sit on a chair and rest their arms on the armrests. The vibration transducer of the vibration meter was strapped to the radius bone of the forearm in an upright position midway between the wrist and elbow joints. Subjects were asked to hold the handle maintaining uniform comfortable grip.

Two measurements were recorded for each subject, one with the wrist-band and one without. A random drawing was conducted to determine which would come first. If the drawing was such that the first measurement will use the wristband, the second measurement will be without the wrist-band and vise versa. The vibration parameters were maintained the same throughout the experimental period. The only variable changing was the use of the wrist strap.

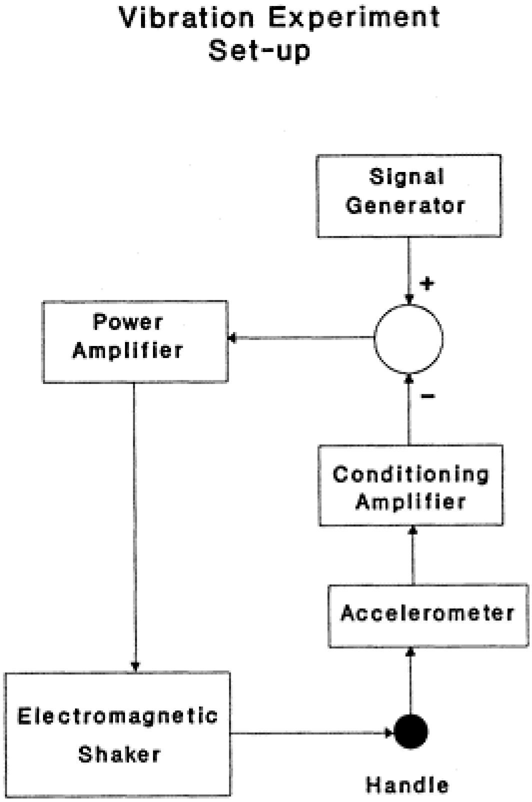

Figure 1

RESULTS

First Experiment (Grip Strength); Paired t-tests were conducted to compare between the grip strength values across subjects, once for the first measurement and another time for the last measurement (20th). Results are summarized in Table 1.

Table 1. Grip Strength results (lbs. force).

	Using Wrist-band		Not using Wrist-band		
	Mean	SD	Mean	SD	Significance @ 5%
First measurement	93.45	±31.6	94.30	±31.0	Not significant
Last measurement	70.95	±34.3	67.55	±26.6	Not significant

Results showed that the first measurement when the strap was used was not significantly different than the same measurement when the strap was not used. Similar results were obtained for the last measurement (Figure 2).

Second Experiment (Pinch Strength): Paired t-tests were conducted to compare between the pinch strength values across subjects. Results are summarized in Table 2.

Table 2. Pinch Strength results (lbs. force).

Using Wrist-band		Not using Wrist-band		
Mean	SD	Mean	SD	Significance @ 5%
13.61	±4.6	13.07	±4.5	Not significant

Results showed that the pinch strength when the strap was used was not significantly different than that when the strap was not used (Figure 3).

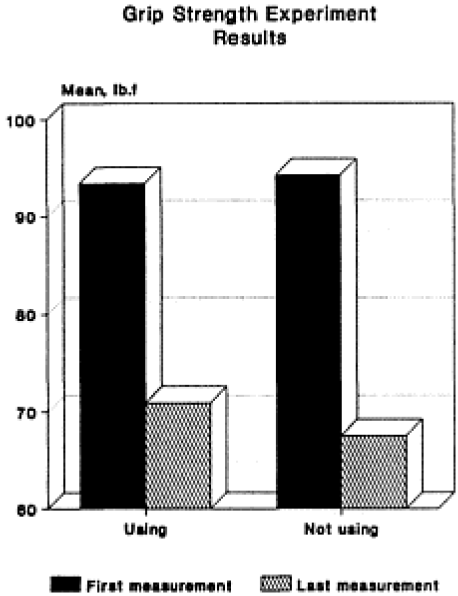

Figure 2

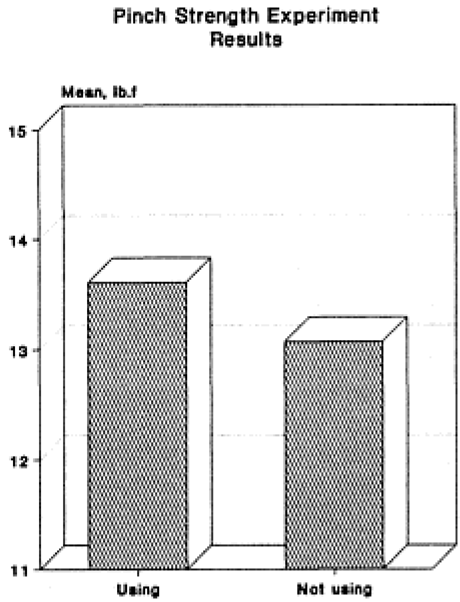

Figure 3

Third Experiment (EMG): Paired t-tests were conducted to compare between the slope of EMG curves (mvolts/msec) when using or not using the wrist-band. Results are summarized in Table 3.

Table 3. Slope of EMG curve (mvolts/msec).

Using Wrist-band		Not using Wrist-band		
Mean	SD	Mean	SD	Significance @ 5%
2.49	±0.73	2.72	±0.7	Significant

Results showed that the slope of the EMG curve when the strap was used was significantly lower than that when the strap was not used (Figure 4).

Fourth Experiment (Vibration): Paired t-tests were conducted to compare the peak and Leq between values obtained from using wrist-band and values obtained without its use. Results are summarized in Table 4.

Table 4. Vibration results (in/s).

	Using Wrist-band		Not using Wrist-band		
	Mean	SD	Mean	SD	Significance @ 5%
Peak	62.6	±17.5	72.8	±16.2	Significant
Leq	30.7	±13.3	37.1	±13.3	Significant

Results showed that the Peak and Leq values for transmitted vibration at the forearm were significantly lower when the strap was used (Figure 5).

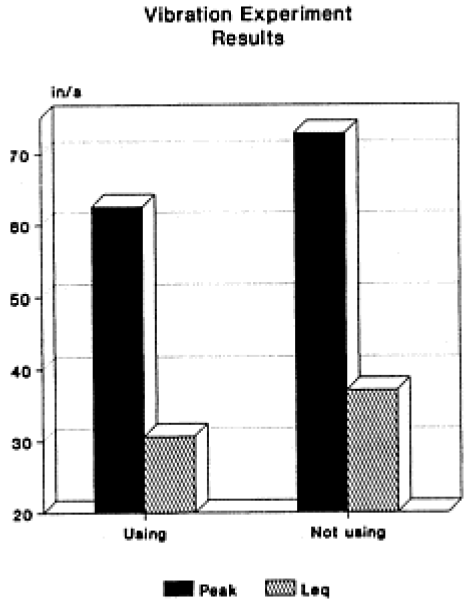

Figure 4

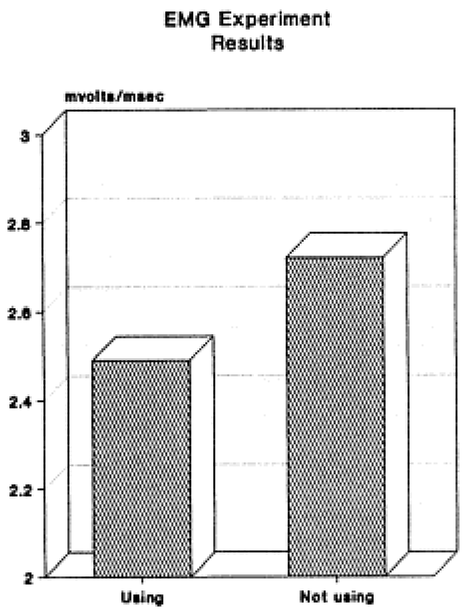

Figure 5

DISCUSSION

The wrist strap used in this study (Dynastrength) helps maintain the wrist in the neutral position. In this position, the least amount of stress is placed on the hand and soft tissue of the wrist. The flexibility of the wrist strap permitted hand movement yet favored the neutral position and restricted the hand from getting into positions of extreme deviation. Subjects were able to adjust the strap tension to their level of comfort. This helps reduce interf ference with blood flow that could accompany the use of fixed size wrist straps.

Use of the wrist strap did not show a reduction in grip strength or pinch strength for the sample used in this study. This implies that the wrist can be well supported without reduction of hand strength.

When performing a hand activity such as lifting a load, the wrist strap supports the hand-wrist joint. This support reduces the relative movement between the hand and forearm thus reducing the muscle activity at the forearm and the stress transmitted through the carpal tunnel. Reduction of muscle activity of muscles of the forearm upon introduction of the wrist strap also implies that it helps delaying the onset of fatigue. The less the stress on the muscle flexor tendons, the better the chance of injury prevention at the hand-wrist joint. If a micro-injury already exists, reduction of relative motion at the joints reduces the probability of further aggravation of the existing condition (such as inflammation, swelling,…etc.) and permits the human body to proceed with its natural healing abilities.

The wrist strap assisted in attenuating the vibration transmitted from the wrist to the forearm. Vibration has been known to contribute to a number of hand, wrist and elbow injuries. Attenuation of transmission is a positive contribution towards prevention of their occurrence. The absorption of energy by the strap has several connotation in reducing soft tissue injury (muscles tendons, ligaments, and fascia) of the wrist, f orearm, and elbow (cumulative trauma, tennis elbow,…etc.). Vibration and impact may be caused by hand tools such as drills, pneumatic or regular hammers, and hand-held power equipment.

No attempt was made in this study to evaluate different types of wrist supports. It is recommended that future studies be undertaken to compare the efficacy of different designs.

CONCLUSIONS

The results of the experiments conducted indicate that the use of the wrist strap (Dynastrength) has a general positive effect on reducing biomechanical stresses on the hand-wrist-arm structure while performing manual activities. The strap assists in attenuating vibration transmitted from the hand to the forearm. It helps maintain the wrist in the recommended neutral position as well as reduce the muscle activity in the wrist flexor muscles of the forearm. These factors can contribute to reduction of injury, discomfort or symptoms associated with Cumulative Trauma Disorders.

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DEVELOPMENT OF GROSS WEIGHT LIMIT FOR WHEELCHAIRS FOR INDIVIDUALS SUFFERING FROM A CARDIAC IMPAIRMENT

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Cardiac patients undergoing phase II and subsequent phases of rehabilitation are frequently advised to reduce physical exertion by using a powered wheelchair for movements around the workplace, around the plant/building, and to and from the parking lot. The wheelchair is generally removed from the trunk of car at the beginning of the work day and is put back inside the trunk at the end of the day. The weight of the wheelchair must be manageable for easy retrieval and storage. A review of wheelchair design literature did not provide any design data and, therefore, retrieval and storage of a folded wheelchair from the trunk of an average size American car was simulated. The simulation utilized both static and dynamic strengths. This paper discusses the results of the strength simulation.

INTRODUCTION

Wheelchairs are a primary device that provide mobility to individuals suffering from a wide variety of disabilities. As many as 3/4ths of a million Americans use wheelchairs as their primary mobility method (York, 1989). The typical user of wheelchairs may be classified as: (1) ambulatory but weak, with low exercise tolerance, painful arthritic joints, or poor coordination, (2) mobile, non-ambulatory (can walk very little and only with supervision), and (3) immobile (individuals with limited tolerance for walking due to lower limb amputations, respiratory disease, stroke, or severe heart problems) (Hoiden et al., 1988). The majority of the users are elderly (Stamp and McLaurin, 1981; Hunter, 1985) and a significant proportion may be labeled “wheelchair independent” (they can walk independently but must use a wheelchair because of low exercise tolerance-Hunter, 1987).

Wheelchairs may are classified as: (1) hand-driven and (2) battery operated (electrical). A third classification, hybrid (combination of manual and electrical power), has also been suggested recently (Cremers, 1989). The hand-driven, and even hybrid-powered, wheelchairs require significant arm force, arm movement, and cardiovascular endurance (aerobic capacity and circulatory capacity) of the user (Hunter, 1987; Cremers, 1989; Glaser et al., 1980; Gass and Camp, 1984; Goswami et al., 1986; Hilbers and White, 1987; Glaser, 1989; Samuelsson et al., 1989). As a matter of fact, the propulsion of wheelchairs may require well more than 50% of the aerobic capacity of the user (Goswami et al., 1986). This necessitates the use of self-propelled motor driven wheelchairs.

A number of researchers have provided design recommendations for wheelchairs (Hoiden et al., 1988; Purdy, 1986; Larkin and Martin, 1988). While the design recommendations include seat features, space under the seat, headrest, safety, mobility (casters, push bar), steering and manoeuvreability, ingress and egress, etc., little attention has been paid to designing for portability, particularly for self-propelled motorized wheelchairs. Portability of a wheelchair is a critical consideration for those who can walk independently but use it to reduce physical exertion of walking (ex., cardiac patients undergoing rehabilitation training). This was also recognized by wheelchair users who used the wheelchairs as a means of moving between the house and the car. The majority of these users found wheelchairs difficult to fold and too heavy to lift into the vehicle (Platts, 1974). Since such users constitute a significant proportion of the user population, portability is an important design consideration.

Even though the significance and importance of a wheelchair’s portability has been recognized, recommendations concerning this design parameter have been fleeting or qualitative (Hoiden et al., 1988; McLaurin et al., 1981; Blackman, 1983). This study presents design data on portability of wheelchairs and considers users who use the wheelchair in conjunction with their cars as a means of mobility between the house and the car, the car and the workplace, and for movement in and around the workplace. Users in this category would be such as patients suffering from coronary heart disease (CHD) and undergoing middle phases of cardiac rehabilitation. These individuals have greatly diminished cardiovascular functional capacity and routine work and activities during this period can be excessively demanding. In case of CHD patients, such activities are not recommended until proper and controlled exercise procedures restore the patients to a desirable exercise capacity appropriate to their clinical status, life style, and occupation.

In general, significant locomotion activities, other than those prescribed, are to be performed with the help of a motorized wheelchair. The patient would remove the wheelchair from the car, use it for a period of time, and then put it back inside the trunk of the car. The handling of the chair is, thus, infrequent and can be performed by the patient without requiring excessive endurance. The limiting factor for handling the folded wheelchair in such a situation would be individual’s body strength. The question that must be posed is “What is the maximum weight of a folded wheelchair that can be handled by an individual, comfortably and without excessive exertion?.” The answer to this question was sought in this study by simulating loading and unloading of a folded wheelchair from the trunk of a car. Both isometric (static) and psychophysical (dynamic) strength simulations were carried out. Comparison of these simulations was the secondary objective of this study.

METHODS

Experimental human strength simulations (static and dynamic) were carried out in order to determine the upper limit on the weight of a folded wheelchair that can be loaded and unloaded from the trunk of a car comfortably. Eight healthy male adults (mean age 25 yr, mean stature 174cm, mean body weight 68kg) participated in the study. Their anthropometric and isometric strength profiles were measured prior to their participation in the experiment.

Prior to carrying out the main experimental simulations, an informal study was conducted to observe how people, when given a choice, would load a folded wheelchair in the trunk of a car and how would they retrieve it from inside the car trunk. it was observed that nine out of ten individuals would lay the folded wheelchair flat on the ground (wheels horizontal) and then lift it, bring it as close to the car trunk as possible, lift it high enough to clear the trunk barrier, move closer to the car trunk until they touch the trunk gate, and then lower it to the base of the trunk. Two different lifting methods were observed almost equally frequently. In the first method, the individuals performed the lifting while standing facing the trunk (Figure 1). However, on several occasions individuals were observed to stand sideways prior to lifting the folded chair (Figure 2), lift the chair, and then turn 90° to put it inside the car trunk. When asked why they turned sideways, the answer almost always was “to come as close to the trunk as possible to reduce the stress”. Both methods were simulated in the experiment.

Since the task required only infrequent handling, strength capabilities of the individuals to carry out the task were measured. Both static and dynamic strengths were measured. A number of studies have reported success with the use of static (isometric) strength to predict task performance capability of an individual (Chaffin, 1973; Keyserling et al., 1980). For this reason, static strength capability of individuals to perform the task was recorded. However, since the task being simulated was dynamic in nature, dynamic strength exertion capability of individuals (really the psychophysically acceptable weight of lift) was also measured. The measurement of strengths was in accordance with the established procedures (Ayoub and Mital, 1989; Mital et al., 1986, 1992).

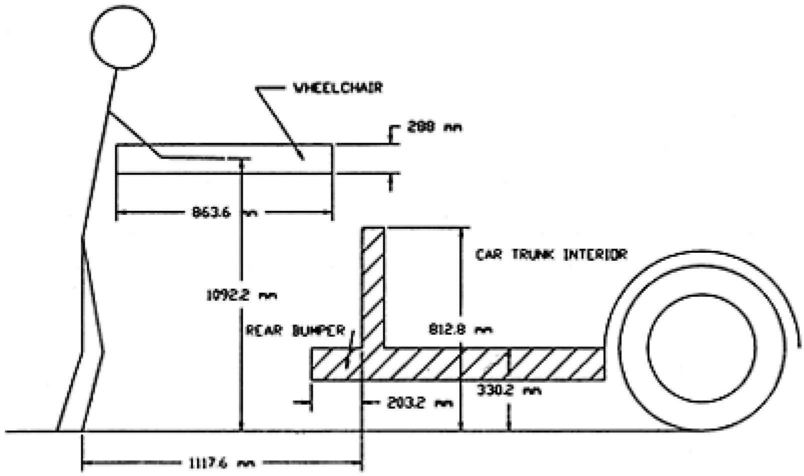

Figure 1. Wheelchair loading simulation—loading straight forward.

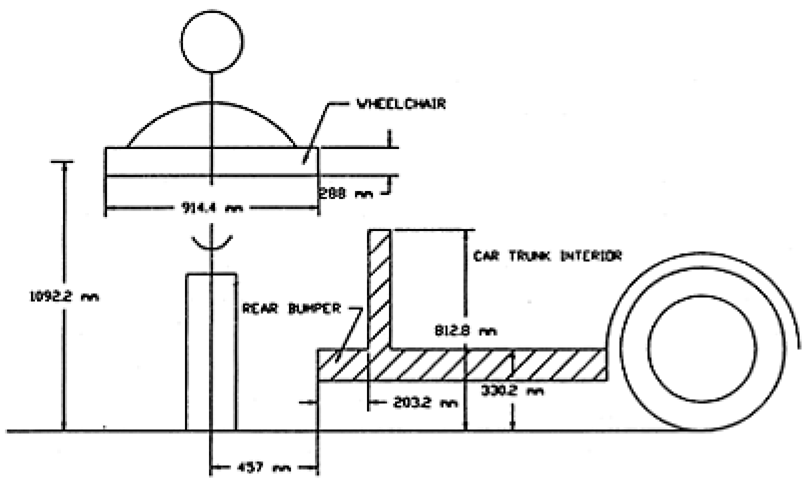

Figure 2. Wheelchair loading simulation—loading is asymmetrical.

<u>*Experimental simulation*</u>

The act of loading a folded wheelchair in the trunk of a car involves three distinct steps: (1) lift the folded wheelchair high enough to clear the trunk gate, (2) carry it forward until it is inside the trunk, and (3) lower it on to the bed of the car trunk. The retrieval of the wheelchair involves: (1) pulling it as close to the trunk gate as possible, (2) lifting it vertically until it clears the trunk gate, (3) carrying it backwards, and (4) lowering ‘it on the floor. From the isometric strength standpoint, three different strength capabilities are required: (1) strength exertion capabilities at different heights simulating lifting of the wheelchair from the floor to a height enough to clear the trunk gate, (2) ability to hold loads at different distances in the midsagittal plane simulating carrying the wheelchair forward, and (3) strength exertion capabilities at various heights simulating lifting of the wheelchair from the bed of the car trunk. It is important to measure the strength capability at different heights as height significantly influences an individual’s capability to exert (Martin and Chaffin, 1972).

Figure 1 shows the dimensions of a widely used commercial wheelchair in folded form, dimensions of the interior of an average size American car, and the dimensional relationship of the individual lifting the wheelchair with respect to both the car trunk and the wheelchair. The closest an individual can come to the trunk of the car before moving the chair horizontally (carrying) is equal to the width of the wheelchair (863.6 mm) plus car rear bumper width (203.3 mm) plus under-the-knee depth (average 104 mm). At this distance (1117.6 mm), the chair must be lifted clear of the obstruction (trunk gate) before carrying it forward. Once the chair has been lifted clear of the trunk gate (1092.2 mm height), the individual can move forward (carry the chair) until his knees touch the car’s rear bumper. The individual at this point must lean forward, with the chair, until the near end of the folded wheelchair (end closer to the individual) clears the trunk gate, and then lower the wheelchair until it touches the trunk floor. When retrieving, the wheelchair must be lifted from the trunk floor (330.2 mm high) until it clears the gate (1092.2 mm height), carry it backwards, and then lower it to the floor.

In order to carry out static strength simulation of these activities, static lifting strength of the individuals at various points in space were measured. The points were characterized by their height from the floor and distance from the individual’s ankles. To simulate the carrying activity, maximum weights an individual could hold in the bulk represented by the folded wheelchair at various distances from the ankles and at 1092.2mm height were determined. The static (isometric) strengths were measured at a horizontal distance of 660.4 mm (distance of the hands from the ankles) at 0mm, 228.6mm, 457.2mm, 685.8mm, 889mm, and 1143mm heights and at a horizontal distance of 889mm and at 533.4mm, 736.6mm, 939.8mm, and 1143mm heights. The maximum loads that could be held at a height of 1143mm and at horizontal distances of 736.6mm, 812.8mm, and 889mm were determined psychophysically (starting with a randomly selected light or heavy weight, the weight of the wheelchair bulk was increased or decreased until the individual reached a weight that could be held without excessive strain). The first sequence of strengths simulated lifting of the folded wheelchair from the floor to a height that would clear the obstruction; the second sequence of strength measurements simulated lifting of the folded wheelchair from the trunk of the car. The holding activity simulated carrying the folded wheelchair forward and backward during loading and unloading, respectively. Only lifting strengths were measured since lowering activities are less demanding than lifting activities. The least of the isometric strength capabilities in the 0mm-1143mm height range and 736.6mm-1143mm height range and/or maximum acceptable weights held at the 1143mm height would determine the individual’s isometric strength capability to load/unload the folded wheelchair.

The dynamic strength simulation is depicted in Figures 1 and 2. The bulk of the wheelchair is represented by a wooden box that permits weights to be added to it or removed from it. Figure 1 shows the situation when the individual lifts the wheelchair straight up. Figure 2 shows a situation when the individual the folded wheelchair asymmetrically. In order to determine the dynamic strength capability for wheelchair loading and unloading, the psychophysical methodology was employed (Ayoub and Mital, 1989).

Materials and equipment

The folded wheelchair was simulated by a wooden box (288mm high, 863.6mm wide, and 914.4mm long). The box was designed such that weight could be added to it or removed from it. The trunk of an average size American car was simulated with the help of a wooden structure (dimensions shown in Figures 1 and 2). Static strength was measured with the help of a handle attached to an unmoving load cell.

Measurements and procedure

The measurements made prior to experimental simulations included several anthropometric and isometric strength characteristics of the sample population (mean strengths—arm 38.5kg, back 60.5kg, composite 101.5kg, and shoulder 48.9kg). Experimental simulations involved measurements of: (1) two different sequences of isometric strengths, (2) one sequence of psychophysical load holding capability, and (3) two different dynamic (psychophysical) lifting capabilities. All these measurements were made in a random order and over several days. No individual participated in more than one set of activity on any given day. Data collection was followed by a 2-day rest period. Several individuals, however, participated on the same day.

The dynamic strength data were analyzed for the effect of technique (sagittal lifting versus asymmetrical lifting) while the static strength data sequences were analyzed for the effect of height. The holding capability data were analyzed for the effect of horizontal distance. A statistical comparison was also made between static strength and dynamic strength capabilities.

RESULTS

The effects of vertical height on isometric strength, horizontal distance on load handling capability, and technique on psychophysical strength were analyzed by carrying out several different analyses of variance (ANOVA).

Static (isometric) strengths

Two sequences of static strengths were measured. The first one was at a horizontal distance of 660.4mm and at 0mm, 228.6mm, 457.2mm, 685.8mm, 889mm, and 1143mm heights. The second one was at a horizontal distance of 889 mm and at 533.4mm, 736.6mm, 939.8mm, and 1143mm heights. The effect of vertical height on isometric strength capability was significant in both instances ($p < 0.05$).

The isometric strength capability at 660.4mm horizontal distance was least at 228.6mm height (19.92kg). It increased with height up to 685.8mm (23.83kg) and then declined. The decline was 1.47kg when the vertical height increased from 685.8mm to 1143mm. No significant difference was found in the isometric strength capabilities at 228.6mm height and 457.2mm height ($p \geq 0.10$). The average isometric strength exertion capability of individuals to lift a folded wheelchair, thus, was the average of isometric strength exertion capabilities at 228.6mm and 457.2 mm (=20.34kg).

At 889mm horizontal distance, the lifting capability increased with the vertical height. The isometric strength exertion capability was least at 533.4mm (14.19kg). The isometric strength exertion capability decreased with the horizontal distance. The decrease was highly significant ($p<0.01$). Thus, in context of the isometric strength simulation, the maximum weight of the folded wheelchair that could be handled during loading/unloading activities would be 14.19kg, on the average.

Load holding

The maximum load that could be held at 1143mm height declined significantly with the horizontal distance ($p<0.05$). The load holding capability was least (16.74 kg) at a horizontal distance of 889mm. This meant that the isometric lifting strength at the horizontal distance of 889mm and at 533.4mm vertical height (14.19kg) was the limiting factor.

Psychophysical (dynamic) strength

The dynamic strength was measured while using two different lifting techniques: (1) straightforward—sagittal lifting (Figure 1) and (2) sideways lifting—asymmetrical lifting (Figure 2). The effect of technique on dynamic strength was found to be insignificant ($p\geq0.10$). On an average, individuals accepted 21.00kg for lifting when lifting and moving straight forward. The maximum acceptable weight of lift increased only slightly (by 0.80kg) when the individual was able to come closer to the car trunk and lifted the simulated folded wheelchair asymmetrically (Figure 2). The maximum acceptable weight of the folded wheelchair for sagittal lifting, thus, would be the limiting value for dynamic strength. This value (21.00kg) is substantially lower than the limiting value provided by the isometric strength simulation (14.19 kg).

DISCUSSION

The results of this study indicated that healthy individuals are willing and capable of loading/unloading folded wheelchairs weighing up to 21kg from the trunk of a car. This weight is not only lower than the weight of commercially available powered wheelchairs, which generally weigh more than 40kg, it is also lower than manual powered wheelchairs which weigh approximately 23kg. Clearly, the weight of powered wheelchairs must be reduced drastically if they are to be portable and are loaded and unloaded from the trunk of a car by the user. Obviously, the question is "What can be done to reduce the weight?" The answer lies in the choice of materials and design of the battery. The heavy weight of motorized wheelchairs currently available on the market is the result of using steel in chair's construction and the lead battery. The weight can be reduced considerably by using composite materials.

As far as the weight of the battery is concerned, technological advances have been limited. In the absence of a lightweight battery, the choice is more or less limited to how the wheelchair is designed. One of the alternatives presently being investigated is modular battery pack designs that would permit them to be disconnected and removed from the wheelchair very quickly and with little effort. The mounting of the battery pack and its connection is also expected to be quick. Since the battery pack will weigh less than 21kg, loading and unloading it is not expected to be strenuous even though this means two separate loadings and unloadings (one for the wheelchair and one for the battery).

In this study, both static and dynamic simulations were carried out. The static simulation of loading/unloading indicated that the weight of the folded wheelchair should not exceed 14.19kg. The individuals who participated in the study, however, were able to handle heavier weights (on the average 21kg) when the activity was dynamically simulated. This tends to indicate that even though the simulated activity was infrequent, static simulation did not provide an accurate assessment of individuals' capability. This finding is not surprising. Several previous studies have pointed out the limitations of static strength simulation to assess an individual's capability to perform frequent dynamic task (Mital, 1987; Mital et al., 1986, 1992). It appears that for infrequently performed tasks also, isometric strengths do not provide an accurate assessment.

The age of the individuals who participated in this investigated ranged from 22 years to 30 years (average age 25 years). The maximum weight of wheelchairs acceptable to this group for loading in the trunk of a car and unloading from it was 21kg. In reality, the users of the wheelchair are expected to be much older (Stamp and McLaurin, 1981; Platts, 1974). Many of the users will be females and, therefore, somewhat weaker. This means the wheelchair weight recommendation must be modified for age and gender. The effect of age and gender on strength has been a subject of several previous investigations (Grimby and Saltin, 1983).

If the acceptable weight at age 25 years is 21kg, the acceptable weight for males at age 50 would be 17.43kg (83% of the weight at age 25). For female users, the acceptable weight at this age would be 9.66kg (46% of the weight acceptable to males at age 25). This means the need to reduce the wheelchair weight becomes far more critical as the users age. Newer materials and battery pack modules alone would not be sufficient to bring the weight of the self-propelled wheelchair under control. The equipment designer will have to look at sectional designs that can be assembled/dissembled without much effort or tools.

CONCLUSIONS

The results of this experimental strength simulation lead to the following conclusions:

1. The upper limit on the weight of a self-propelled folding wheelchair should not exceed 21kg.
2. Psychophysical (dynamic) strength simulation provides a more realistic estimate of users' capability to perform the actual task than the isometric (static) strength simulation.
3. The wheelchair weight limit must be revised downwards for elderly and female users.
4. Equipment designers must look at new light-weight materials, such as composites, and modular sectional designs that can be assembled and dissembled quickly and without the use of tools.

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TELEROBOTICS

HUMAN OPERATOR DISCOMFORT IN VIRTUAL REALITY SYSTEMS: SIMULATOR SICKNESS—CAUSES AND CURES

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Flight simulators are virtual reality systems which have been around for several years. Often these devices occasion a form of discomfort which resembles motion sickness, except that this simulator sickness exhibits more eye strain (33%) and less actual vomiting (<0.10%) than "true" motion sickness. Virtual reality systems of the future are likely to include more compelling realistic visual display systems, but if the operator does not move (as in physical reality), these systems too can be expected to produce symptoms of motion sickness. Implications of such untoward after-effects of exposure include safety and health, user acceptance, and adverse training/performance. Design criteria and other counter-measures are needed as well as a theory which has better predictive discrimination than the sensory conflict theory. The U.S. Navy has a database of greater than 7,000 human exposures from recently conducted simulator sickness surveys. Previous findings from this data base have shown: a) equipment features such as wide field-of-view, moving base platforms, and CRT infinity optics displays have the highest incidences of sickness; b) there are enormous individual differences showing that some people can get sick in the "good" simulator and others don't get sick in the "worst" simulators; c) a past history of motion sickness is predictive of susceptibility; d) different profiles of sickness are obtained in simulators with different

equipment configurations; e) adaptation to the sickness symptoms can occur in a few exposures, but post-effects such as disequilibrium can get worse as this adaptation occurs; and f) experienced pilots are at greater risk for some forms of simulator sickness than newly trained aviators.

INTRODUCTION

In the Navy, more than the Army or Air Force, simulator facilities have become adventitious laboratory for the study of simulator sickness. One reason for this is that the Navy, to a greater extent than the other services, tends to have multi-missions (fighter, attack, electronic warfare, search and rescue, etc.) along with rotary and fixed wing aircraft. Navy aviation platforms range from the large P-3C Orion to the light and fast F/A-18 Hornet and all of these now have simulators with wide field of view display systems. Nearly all Air Force simulators are fixed-base systems which simulate centerline thrust, fixed-wing aircraft. U.S. Army systems are largely moving-base platforms simulating rotary-wing aircraft. As a design philosophy, the Army and the Air Force, set out to obtain multiple copies of one type of simulator (U.S. Congress, 1984), while the Navy, as technological advances were made, went through a series of state-of-the-art approaches for different aircraft models. Through this period, the Navy began with point-source projection systems and since have employed model boards, domes, and multiple CRT systems utilizing computer generated imagery. The latter, which are most in use today, are probably most provocative of simulator sickness. As a consequence, the Navy has taken the lead in terms of problem definition and development of measurement and methodologies to study simulator sickness. Therefore as virtual environments are developed which are also expected to occasion user discomfort, the Navy experience may have the most to teach us about the nature of the problems as well as to identify solutions. Over the past few years various methods have been employed in surveying the incidence of sickness and one of these, spectral analysis of simulator sickness, is featured in this paper.

IMPLICATIONS OF SIMULATOR SICKNESS

The implications of simulator sickness are discussed below. We should add that this is not an exhaustive list, but representative of the types of problems which have been described by the Navy. We would warrant that to the extent that virtual worlds are used for training, they too will suffer from these problems. The breadth of these implications point out that no one agency within the military has the technology nor charter to address all the areas which are surfaced. It will require a multidisciplinary approach.

Safety and Health

Among the implications of simulator sickness for safety and health are the presence of locomotor ataxia, interference with higher-order motor control, physiological discomfort, and visual aftereffects or flashbacks. The aftereffects which are occasionally experienced following a simulator session are particularly like those observed in research with distorted or rearranged visual stimulation. The perceptual factors that trigger flashbacks, their duration, and their period of retention are all important issues for which there is meager information in the scientific literature. There is also little information in the simulator sickness literature concerning aftereffects other than that they occur and often outlast the stimulus for a considerable period of time. Their occurrence can, however, be presumed to pose a significant threat to pilots' safety immediately following use of the simulator, and in some cases mandatory grounding policies have been adopted following simulator training flights to guard against effects of disorientation in flight (FITRON 124, 1981). This is a major aeromedical management problem.

Compromised Training

The occurrence of simulator sickness may result in poor training and the development of adverse strategies to circumvent the problems occasioned by the training device. Symptomatology may interfere with learning in the simulator by various means, including distraction due to the presence of physiological disturbance. Moreover, it is known that pilots may develop strategies such as restricting head movements and "going on instruments" to reduce symptomatology. The plasticity of the human central nervous system makes it likely that trainees will eventually adapt to any unpleasant perceptual experiences in the simulator. However, the most critical problem is that behaviors learned in the simulator may not be similar to responses required in flight, potentially resulting in the acquisition of perceptual-motor behaviors inappropriate to flying.

Readiness and Operational Effectiveness

The occurrence of simulator sickness has implications for pilots' operational effectiveness, including down-time and the acquisition of habits inappropriate to control of operational systems, For example, to minimize pseudo-Coriolis effects (Dichgans & Brandt, 1973) pilots may restrict head movements in the simulator. Pseudo-Coriolis effects occur when an individual viewing a rotating visual stimulus makes head movements outside the axis of rotation. This situation often produces feelings of disorientation similar to those experienced when head movements are made outside the plane of actual physical rotation. Based on restrictions in force within the U.S. Navy and Marine Corps concerning flight activities subsequent to training in simulators with high sickness rates, pilots may be grounded for 12–24 hours following the simulated flight. Making the following simplifying assumptions: 1) that there is an enforced 24 hour down time after every hop for Navy pilots, and 2) that an average pilot receives two to three sets of simulator exposures in a 90 month "career;" as much as 5% of the available flying days could be lost. Therefore, any reduction of simulator sickness, or of the restrictions which result therefrom, may result in very high payoff in terms of improved pilot operational readiness for the Navy.

Corporate Image

When simulators develop a reputation for producing problems, there are at least two consequences: 1) persons using the system lose confidence in the training they are receiving; and 2) persons using the system may limit their exposures so that usage rates go down. This was a problem with the 2E6 during the early days of its installation (McGuiness, Bouwman, & Forbes, 1981).

Economics

The systems engineering of Navy simulators follows formal requirements with respect to the research, development, test, evaluation and acquisition of such devices. What this means is that a fielded simulator is "purchased" based on analyses of the systems' training requirements, and tempered by tradeoffs among costs, equipment features, software, available dollars, technological advances, pilot opinion and other factors. When possibly high cost equipment features that have been incorporated into simulators based on their training need turn out to be nauseogenic, instructors and students may turn that system off. Some simulators (e.g., TH-57C) do not use day available scenes because the interaction of flicker and luminance signifies that the system can only operate flicker-free at the dusk setting (Lilienthal, Fowlkes, Kennedy, Tabler, & Dutton, 1987). In these cases some are likely to argue, albeit on a post hoc basis, that the Navy was not a smart buyer.

SYMPTOMS, SIGNS, AND TIME COURSE OF SIMULATOR SICKNESS

Simulator sickness is comprised of a constellation of motion sickness-like symptoms and signs. With simulator sickness there are somewhat different patterns or profiles from "true" motion sickness. Some of the symptoms occur during simulator usage, and some for a period of time thereafter. The pathognomonic signs of vomiting and retching are rare in simulator sickness but do occur. The other overt signs such as pallor, sweating, and salivation (Colehour & Graybiel, 1966; Stern, Koch, Stewart, & Lindblad, 1987) are more common. Major reported symptoms include nausea, drowsiness, general discomfort, apathy, headache, stomach awareness, disorientation, fatigue, and incapacitation (Kennedy & Frank, 1986). Postural changes have also been observed directly after simulator flights (Crosby & Kennedy, 1982; Fowlkes, Kennedy, & Lilienthal, 1987; Gower, Lilienthal, Kennedy, & Fowlkes, 1987; Gower & Fowlkes, 1989; Kennedy, Allgood, Van Hoy, & Lilienthal, 1987). Among the more serious problems presented by this syndrome are residual aftereffects (Crosby & Kennedy, 1982; Baltzley, Gower, Kennedy, & Lilienthal, 1988; Ungs, 1987) including illusory sensations of climbing and turning, perceived inversions of the visual field, and disturbed motor control. Other signs include changes in cardiovascular, respiratory, gastrointestinal, biochemical and temperature regulation functions. Other symptoms include general discomfort, apathy, dejection, headache, stomach awareness, disorientation, lack of appetite, desire for fresh air, weakness, fatigue, confusion and, occasionally, incapacitation. The extreme drowsiness which is often found in connection with sea sickness (Graybiel & Knepton, 1976) is not as prevalent in simulator sickness and indeed entails a negative weighting in the empirically derived scoring system (Lane & Kennedy, 1988) which is described below. Visually-related disturbances are more prevalent in simulator sickness than are gastro-intestinal. Based on the profile of symptoms, simulator sickness bears a strong resemblance to disturbances experienced by individuals when wearing reversing, displacing, or inverting lenses (Dolezal, 1982), or when exposed to rotating (Graybiel, Guedry, Johnson, & Kennedy, 1961) or tilted rooms (Witkin, 1949). A prime candidate for research should be user tolerance for visual display distortions that occur in simulators.

In summary, simulator sickness resembles other forms of motion sickness except that: vomiting is rare; visual epiphenomena predominate; adaptation is rapid; and aftereffects far outlast the stimulus. Like the “classical” forms of motion sickness, the symptomatology of simulator sickness is diverse and is properly described as a syndrome. It is possible for some persons to exhibit all the signs and symptoms in connection with their exposure and others to only experience a few. Some may exhibit idiosyncratic sets of symptoms and others may be just as “sick” on two separate occasions but to report different sets of symptoms each time. No one symptom predominates in all persons. Some simulators may occasion more or less of some classes of symptoms although this is not well documented. Theoretically, it is possible that the types of symptoms reported may provide a clue as to the agent producing the sickness. Based on these factors, simulator sickness should be described as polysymptomatic (Kennedy & Frank, 1986).

Simulator sickness, like motion sickness, is polysymptomatic (any of a number of symptoms may be experienced by a given individual, and individuals differ both in susceptibility to sickness and in the types of symptoms they experience), and polygenic (a number of different aspects of the stimulus appear to “cause” the sickness) (Kennedy & Fowlkes, 1990). Moreover, the fact that each of these multiple agents appears to account for only limited amounts of outcome variance has strong implications for experimental design. Specifically, except in unusual circumstances, >50 subjects per treatment are required for adequate statistical power in experimental studies (Kennedy & Fowlkes, 1990). Because such rates of usage are generally encountered only in operationally employed training systems, we sought to develop a methodology to collect the required data in an operational situation. Following this line of reasoning the U.S. Navy and Army have sponsored a series of surveys of various simulators. Some of these have been reported previously (e.g,. Kennedy, Lilienthal, Berbaum, Baltzley & McCauley, 1989; Gower, Lilienthal, Kennedy & Fowlkes, 1987). The U.S. Navy has a database of greater than 7,000 human exposures. The analysis of the data should provide useful information both to guide future simulator sickness RDT&E as well as to provide design criteria for virtual environment systems.

These baseline data can be used for several systems engineering applications. Increased report of symptoms may be indicative of a simulator malfunction and the data may be used for troubleshooting purposes to diagnose the malfunction (e.g., system calibration that has exceeded the tolerance set forth in the device specification). Symptom profiles (e.g., excessive report of visual disturbance) may provide insight for the identification of specific simulator engineering features that should be targeted for engineering efforts to alleviate the problem. Finally, automated monitoring of simulator induced symptomatology can be used to assess the impact of engineering feature modifications as well as changes to the training syllabus (e.g., increased hop length).

The purpose of the present report is to introduce this method of data analysis and to suggest that this approach may prove useful for comparison to similar reports of discomfort which may emerge from usage of virtual environment systems.

METHOD

Self-reports are a useful method for capturing large amounts of data, inexpensively, from persons with expert knowledge or experiences (Cronbach, 1990). Recorded over time, self-reports can serve as a baseline against which future treatments can be compared, and they have been used in the past to study motion sickness (Alexander, Cotzin, Hill, Ricciuti, & Wendt, 1945). A Motion Sickness Questionnaire (MSQ) (Kennedy, Tolhurst, & Graybiel, 1965; Wiker, Kennedy, McCauley & Pepper, 1979) consisting of a severity rating scale for each of 32 symptoms, has been used for over 40 years to provide an aggregate score of motion sickness. However, a global discomfort score does not reveal information about the potentially separable dimensions of simulator sickness. Although motion sickness scientists have commented on the variety of symptoms in different environments (cf., Crampton, 1990), so far as we know there are no scoring keys for profile scoring. An exception may exist in one instance we know of where a factor analysis of seasickness was attempted (Bittner & Guignard, 1988) in 16 subjects using a much-abbreviated symptomatology checklist (e.g., salivation, among other symptoms, was omitted).

To address this lack, Lane and Kennedy (1988) factor analyzed over 1400 MSQ's from the survey of 10 Navy simulators (Kennedy, Lilienthal, Berbaum, Baltzley, & McCauley, 1989). The factor analysis produced an overall malaise score (or total score) and three specific symptom clusters: (1) oculomotor (e.g., eyestrain, visual flashbacks), (2) vestibular (e.g., disorientation, postural instability), and (3) neurovegetative (e.g., stomach awareness, nausea, vomiting). We opine these clusters represent subscales which can carry diagnostic meaning in terms of identifying specific components of the training device that contribute to the problem. An item analysis was conducted revealing 16 "best" items. These 16 items were used to rescore the Navy's data base which includes the original 10 simulators, two "newer" Navy simulators and three selected U.S. Coast Guard Simulators, and four U.S. Army helicopter simulators. This new data base also includes motion sickness "assessments" of persons exposed to rough weather at sea (sea sickness) as well as other land measures such as vection, experimentally induced alcohol intoxication, and other forms of ataxia.

The entire data base of >7000 separate exposures was rescored according to the newly developed scoring key. This permitted an analysis of: a) the incidence of sickness, which is shown proportionally in a series of pie shapes—the larger the pie the greater the incidence of sickness; and b) spectrum or profile of the symptomatology—which is shown as the relative contribution to the total score by the size of the pie wedge for each of the three clusters of symptoms.

RESULTS

In figures 1–4 we have shown four different examples from the data base, but nearly two dozen simulators have been examined by this technique to date. The first figure shows the 2F64C, simulating the SH-3H helicopter, to have a much higher rate of sickness than the "Fleet Average", but note that the distribution of symptoms is very similar. However, the 2F114, simulating the A-6E aircraft, is shown in figure 2. Note that here the incidence of sickness is high, nearly as high as in the 2F64C, but the disorientation symptoms are more prominent, and the eye strain related symptoms are less. The differences between these two simulators are that the former is a fixed base device, with a dome, and the latter is a moving base with multiple cathode ray tube displays. These different equipment features may be the cause of the different distribution of symptomatology. Figure 3 shows the 2B42, a simulator for undergraduate pilot training in helicopters (TH-57C). Here, the symptoms are less than in the other two devices, but the symptom cluster which is most prominent is nausea and other neurovegetative problems. It is possible in this device that the movement of the device in the vertical plane around the frequency of .2Hz may contribute to these problems, or perhaps there are lags or asynchronies between stick input and response of the visual and inertial device. Figure 4 illustrates a simulator (2F132) for the F/A-18 aircraft. This device has very low reports of sickness and what is reported is mostly due to eye strain or related oculomotor complaints. Note that the oculomotor complaints are more severe than in the other devices, implying that some characteristic of the device is causing this symptom complex to be reported somewhat frequently.

DISCUSSION

Previous findings from analyses of this data base have shown that: a) equipment features such

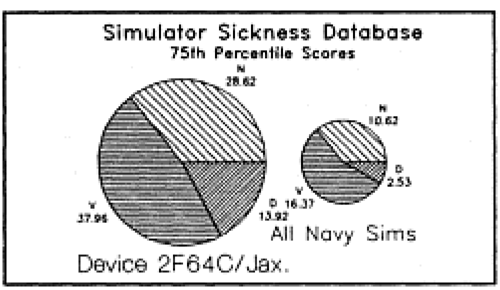

Figure 1. Device 2F64C by Symptomatology

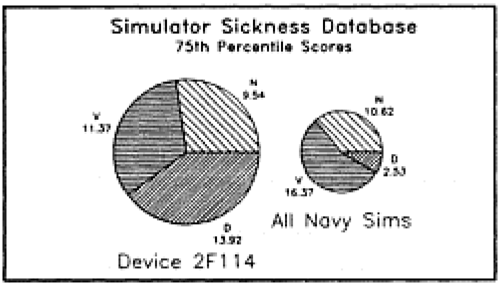

Figure 2. Device 2F114 by Symptomatology

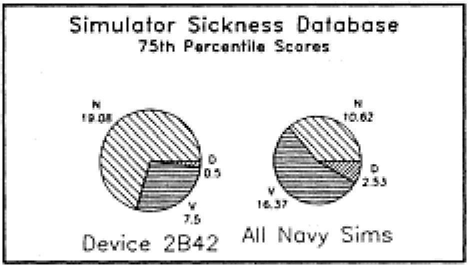

Figure 3. Device 2B42 by Symptomatology

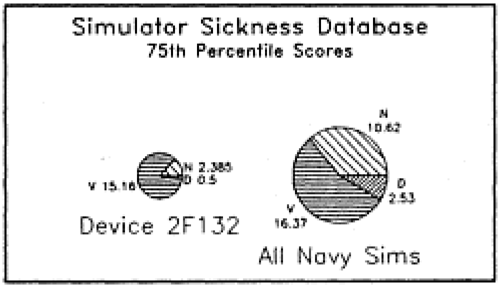

Figure 4. Device 2F132 by Symptomatology

as wide field-of-view, moving base platforms, and CRT infinity optics displays have the highest incidences of sickness; b) there are enormous individual differences showing that some people can get sick in the "good" simulator and others don't get sick in the "worst" simulators; c) a past history of motion sickness is predictive of susceptibility;; d) different profiles of sickness are obtained in simulators with different equipment configurations; e) adaptation to the sickness symptoms can occur in a few exposures, but post-effects such as disequilibrium can get worse as this adaptation occurs; and f) experienced pilots are at greater risk for some forms of simulator sickness than newly trained aviators. The present findings take our work on diagnosis and recommendation for cure of simulator sickness a step closer. We have shown that simulator sickness can vary along two dimensions (severity and symptom mixture) and we hypothesize that conclusions and inferences about how to fix the simulator can be made according to both outcomes. We propose that the process should work as follows: a) from survey data it should be possible to identify those simulators which should be addressed first based on incidence recordings; then b) the distribution of symptomatology should be examined and specific combinations of symptom clusters should be employed as a sort of spectral analysis to suggest specific characteristics of the simulator which may warrant change (either in the form of updates OR as something which may be tested by being shut off or modified); then c) after the change is made an additional survey is conducted to determine whether the change improves simulator sickness incidence or spectrum. These findings have implications for virtual environments which are presently being developed and in our judgment the conflict theory of motion sickness adaptation can provide a useful principle for organizing these findings.

Conflict theory

Motion sickness has long been viewed an adverse consequence of man's passive transportation in conveyances and vehicles. In all places where motion sickness is reported a common thread tends to appear: The perceptual worlds of vision, proprioception, or inertial forces are transformed somewhat from past experiences or reality or both. As new forms of vehicular transportation (e.g., aircraft, surface effect ships, spacecraft) have come into use, new forms of motion sickness have appeared as well. Therefore, it is not surprising that when the ability to simulate vehicular self motion was developed, a form of motion sickness unique to these conditions emerged. It has been referred to as simulator sickness.

Of the flight simulators developed over the past thirty years, the simulators which receive the best marks for realism from experienced pilots also score high on simulator sickness incidence although the correlation is not perfect. The express purpose in simulator design has always been to produce the illusion of realism by the use of virtual images. Since simulators are one kind of virtual environment, the question can be posed: "Will simulator-like sickness also occur during training in other virtual environments?".

Perceptual conflict theory is known by several names: mismatch, neural mismatch, cue conflict, incongruity and sensory rearrangement being the most common. The present authors believe that perceptual conflict is the most descriptive term and, consequently, recommend its use here.

In brief, the perceptual conflict theory posits a referencing function in which motion information, signaled by the eyes, vestibular apparatus or proprioception, may be in conflict with these inputs' expected values, based on a neural store (which reflects past experience) or with how the system circuitry is wired. Kennedy (1970) suggested, as have others (Held, 1965; Reason, 1970), that perceptual conflict theory is based on a lack of correlation between appearance and reality. Under ordinary circumstances, there is a correspondence between what is sensed and the physical representation of the stimulus.

The sensory systems report reality, and after periods of time, create a neural store of expectations. The expectations are also referenced to the sensory channel which delivered them, being stronger for more experiences and also in those ranges where the channel is most sensitive. The purpose of information processing and perception functions is to predict reality in order that one may interact with it, spatially and temporally. We believe that central nervous system integration could be represented by a linear model (Cohen, 1968). Our version of the sensory conflict theory is described in greater detail in Kennedy and Frank (1984) and Kennedy, Berbaum, and Frank (1984).

Computer-generated imagery and display systems to create virtual realities have been most widely applied to simulation training. Increasingly, this technology is being extended to other areas such as biochemical engineering, architecture, medical procedures, and teleoperation. Moreover, computer generated imaging is being extended beyond the visual sense to include auditory and proprioceptive domains. These emerging virtual reality applications may occasion the same kinds of problems that are being dealt with in Navy simulator sickness studies. Specific examples in each application area were provided. Finally, it is argued that the application of lessons learned from the military experience with simulator sickness may be a key factor in optimally interfacing humans with these virtual reality applications.

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OPTIMAL FORCE LEVEL AND ANTAGONISTIC MUSCLE EXERTION STRATEGIES FOR AN ISOMETRIC TRACKING TASK

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This paper briefly describes two experiments investigating isometric manual control during a pursuit tracking task. The first experiment investigates the effects of required force level and target speed on response accuracy. Results reveal that error as a proportion of the required force level increases linearly with the frequency of the forcing function and quadratically with the force required. The second experiment uses a similar task, but examines muscle control strategies using electromyography. Preliminary results from this experiment are briefly presented and discussed.

OVERVIEW

This paper provides a brief overview of research examining the manual control processes underlying the performance of a simple pursuit tracking task with an isometric joy-stick control. Results from an initial experiment are reported followed by some preliminary results from a second experiment.

EXPERIMENT I

Experiment I investigated the effects of control/response ratio (C/R ratio) and target speed on the magnitude of the tracking error. The C/R ratio was controlled by varying the required force level to track the target as a function of each individuals isometric elbow strength. Target speed was manipulated by changing the frequency characteristics of the forcing function. The task employed was a pursuit tracking task with a sinusoidal forcing function. The objective of this experiment was to determine the effects of force level and target speed on tracking performance and to identify those conditions associated with optimal performance. A more thorough description of the procedures and results for Experiment I can be found in Berkowitz (1990), Berkowitz and Woldstad (1991), and Woldstad, Berkowitz, and Rockwell (1992).

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Method

Twelve right-handed subjects (6 males, 6 females) were used in this experiment. Each subject completed 25 different tracking trials using a one-dimensional, zero-order (position), pursuit tracking task (Burke and Gibbs, 1965; Frost, 1972) with a sinusoidal forcing function. Trial conditions corresponded to all combinations of five levels of maximum required force (C/R ratio) and five frequency conditions. The maximum required force levels used were 10, 25, 50, 75, and 100 percent of each subject's isometric maximum voluntary contraction strength (MVC) for elbow extension. Strength values for both elbow flexion and extension were tested one day prior to the experiment using standard isometric strength testing procedures (Chaffin, 1975). The frequencies used for the sinusiodal forcing function were 1.0, 0.8, 0.6, 0.4, and 0.2 Hertz.

A laboratory computer system was used to record the data and provide feedback to the subject. During each trial, the subject's tracking force and the desired force levels were displayed using an attached cathode ray tube (CRT). For different maximum required force levels, the characteristics of the displayed forcing function remained constant while the gain level between the joystick input and the tracking force level was changed. Experimental trials were preceded by a warm-up period and were 20 seconds in duration. Subjects were given a minimum of three minutes rest in between each trial to minimize fatigue. Subject posture was controlled using a large chair with a fixture for the right arm. This system positioned the shoulder at 0° with respect to the transverse plane, and 90° with respect to the sagittal plane. The elbow was flexed to 90° with respect to the frontal plane (Kroemer, Marras, McGlothlin, McIntyre, and Nordin, 1990).

Results

Tracking error (E) was expressed as the average absolute error between the forcing function and the tracking response, divided by the maximum value of the forcing function for that trial:

$$\underline{E} = \frac{\sum \frac{\text{ABS(Forcing Function (N) - Actual Track (N))}}{\text{Max. Required Force Level for Trial (N)}}}{\text{Number of Observations}} \quad (1).$$

This measure represents the average absolute difference between the position of the cursor (desired position) and the subject's tracking position as displayed on the CRT.

Error values (averaged over subjects) as a function of maximum force level, and the frequency of the forcing function are shown below in Figure 1. These results can be described using a polynomial regression equation of the form:

$$\underline{E} = \beta_1 + \beta_2\text{Frequency} + \beta_3\text{Force} + \beta_4\text{Force}^2 \quad (2).$$

This model accounted for over 95% of the variance in the mean tracking errors, and predicts a zone of optimal control at moderate force levels. The predicted optimal force level was calculated by taking the derivative of this equation with respect to force and setting this result equal to zero. On the basis of this analysis, the model estimates the optimal force level for tracking to be approximately 66 percent of extension MVC.

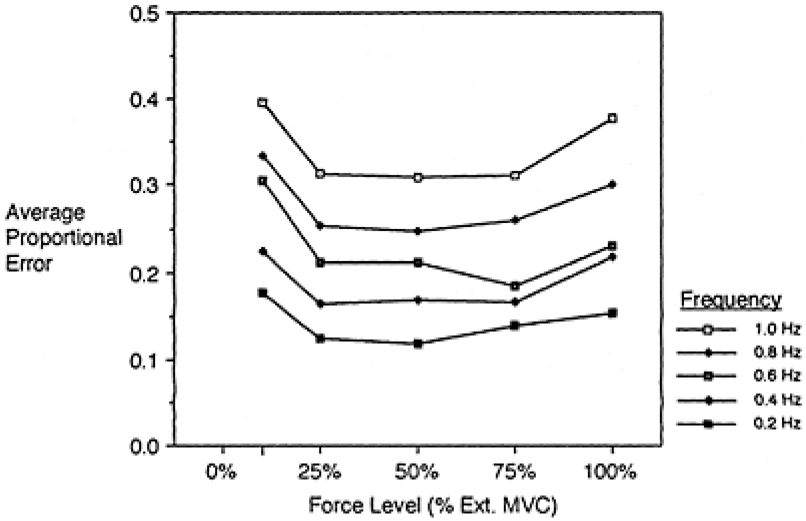

Figure 1. Two-way interaction between frequency of the forcing function (Hertz) and required force level (% extension MVC).

Discussion

The results demonstrate the existence of an "optimal zone" of manual control at moderate force levels. For this experiment, the optimal force level was approximately 66% of the subjects maximum isometric extension strength. These results are consistent with previous experiments which have reported similar results based upon subjective ratings of task difficulty (Hess, 1973; McRuer and Jex, 1967). One explanation of these results is that increased relative error at lower force levels may represent a constant minimum neuromotor noise level. This constant noise would increase in proportional magnitude as the control signal is decreased. At high force levels, the increase in relative error may be due to the well-known size-principle of motor-unit recruitment (Henneman, Somjen, and Carpenter, 1965). One difficulty in evaluating the results of Experiment I is that the force measured is actually the sum of the forces produced by the muscles flexing and extending the elbow. Previous work has demonstrated considerable co-activation of both the agonist and antagonist muscle groups for isometric elbow contractions of a sinusoidal nature (Woldstad, 1988). Experiment II addresses these problems by examining the individual muscle activities using electromyography (EMGs).

EXPERIMENT II

The purpose of Experiment II is to investigate the nature of muscle activity during the isometric tracking task. Of particular interest is the level of antagonistic muscle coactivation for different force levels and about the zone of optimal isometric control found in Experiment I. The experiment employs regression modeling techniques (Woldstad, 1988; Redfern, 1988) using integrated EMG to determine the level of co-active muscle force during the tracking task. These models will be used to further investigate the nature of performance error in the isometric tracking task under study. Work on Experiment II is currently in progress.

Methods

The procedures used for Experiment II are similar to those used for Experiment I. Ten subjects will perform the isometric tracking task under five required force conditions (20, 40, 60, 80, 100 percent MVC) and three frequency conditions (0.2, 0.6, 1.0 Hz.). One important difference is that the control/response (C/R) ratio is now manipulated in both the flexion and extension phases of the track. For the flexion phase, the required force is a percentage of the individual’s flexion MVC. For the extension phase, the required force is the same percentage of extension MVC. By using this symmetric scaling, a direct comparison of muscle activity and error performance between subjects can be made.

Electromyographic (EMG) measurements of the biceps and triceps muscle activity are collected with the force data for each tracking trial. The standard posture described in Experiment I allows isolation of the biceps flexor group and the triceps extensor group contributing to the isometric tracking exertion. For both muscle groups, the EMG signals are collected using 4-pair of Ag-AgCl electrodes. The electrode array is arranged across each muscle in order to reduce the spatial bias associated with electrode placement (Redfern, 1988). Custom preamplifiers mount directly onto the electrode array in order to minimize effects of external noise on the data. Integrated EMG (iEMG) signals are obtained by electrically integrating the raw EMG signal using an RMS estimator (time constant of 25 msec). Both the iEMG and isometric force data are sampled and stored in the microcomputer at 100 Hz. Data is collected for 10 seconds following a five second warm-up tracking period for each trial. The purpose of the shorter trial length and warm up period are to reduce the effects of fatigue during the experiment.

Preliminary Results

Results from two pilot subjects are available at this time. Tracking error is defined as in Experiment I (see Equation 1). A regression model relating tracking force to co-active iEMG is used to define the Force-iEMG relationship for all tracking conditions. Using the definition of equivalent muscle groups (Bozec, Maton, and Cnockaert, 1980), each muscle, the biceps or triceps, can be modeled as representing the activity in the entire flexor and extensor group respectively. The observed tracking force can then be modeled as:

$$Force=\beta_b*iEMG_{biceps}+\beta_t*iEMG_{triceps} \quad (3),$$

where ßb and βt are the coefficients describing the force contribution from the biceps and triceps respectively. In this form the coefficients will have opposite signs as they contribute oppositely to flexion and extension force.

Co-contraction is measured in terms of the absolute level of antagonist activity and the ratio of antagonist to agonist force at any time during the tracking trial. The agonist force is defined as the force contributing to the tracking movement, while antagonist is defined as force opposing the movement. Using this convention, co-contraction values were calculated and averaged for each phase of the tracking trial for all experimental conditions.

Figure 2 shows the tracking force and the iEMG data for a 10 second, 100% MVC, 0.2 Hz. tracking condition. The top graph shows the bicep and tricep force activity during the flexion and extension phases of the movement. The bottom graph shows the subject's actual tracking force and the modeled force using iEMG as described by Equation 3. The model accounts for much of the variance in tracking force (R^2=0.95). The model was fit for each force level at the 0.2 Hz. frequency condition to determine the co-active force at that condition. The iEMG data was able to fit each force condition with R^2 values ranging from 0.814 to 0.951.

Antagonistic co-activation (Figure 2, top graph) was present in both the flexion and extension phases of the movement with higher co-contraction in the biceps during the extension phase of the tracking exertion. This is in agreement with previous work of Woldstad (1988). This cocontraction was present in all trial conditions with the ratio of antagonist to agonist force exhibiting a general downward trend at higher required force levels. The absolute magnitude of antagonist muscle activity was shown to increase towards median values of required force level (Figure 3).

Discussion

The preliminary results indicate that co-active muscle activity is present in the performance of the isometric tracking task under all of the conditions studied. The concave shape function for antagonist muscle activity (Figure 3) indicates a possible optimal co-active force level associated with the optimal tracking force found in Experiment I (Figure 1). The presence of co-contractive muscle activity will alter the interpretation of the zone of optimal control found in Experiment I. This data indicates that co-active muscle strategies may be employed by humans to stabilize the joint in order to facilitate manual control. However, more data is needed to accurately quantify this effect.

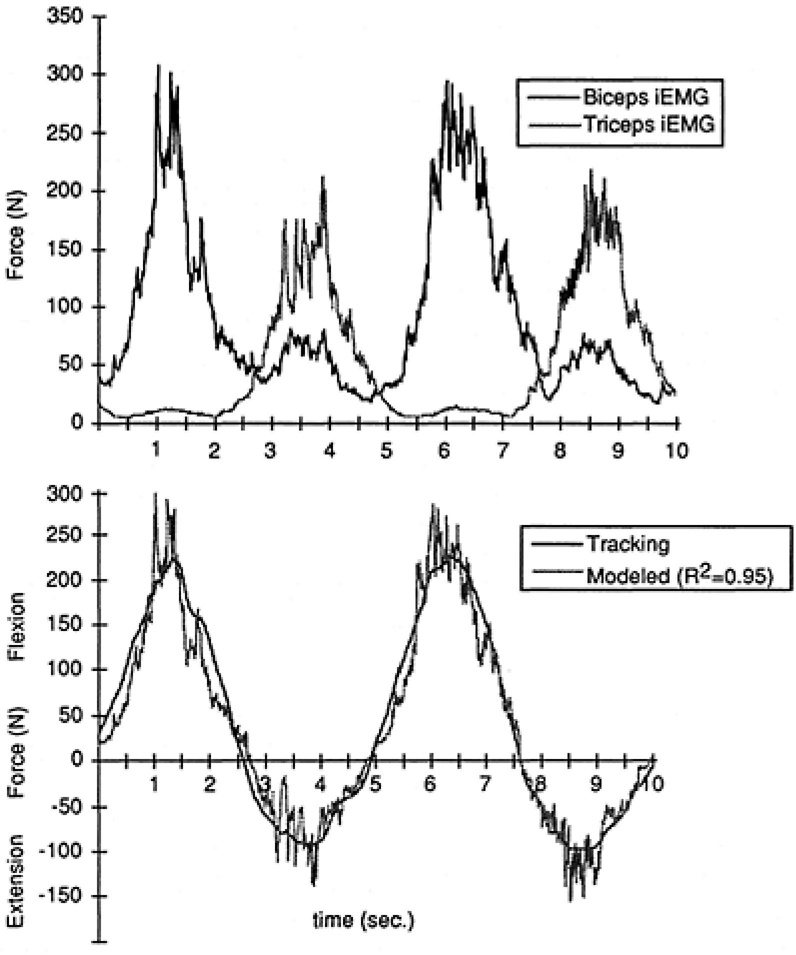

Figure 2. Data plot for a ten second sample sinusoidal tracking exertion (100% extension MVC at 0.2 Hz) showing bicep and triceps co-contraction force (top) and isometric

tracking force, and modeled force (bottom).

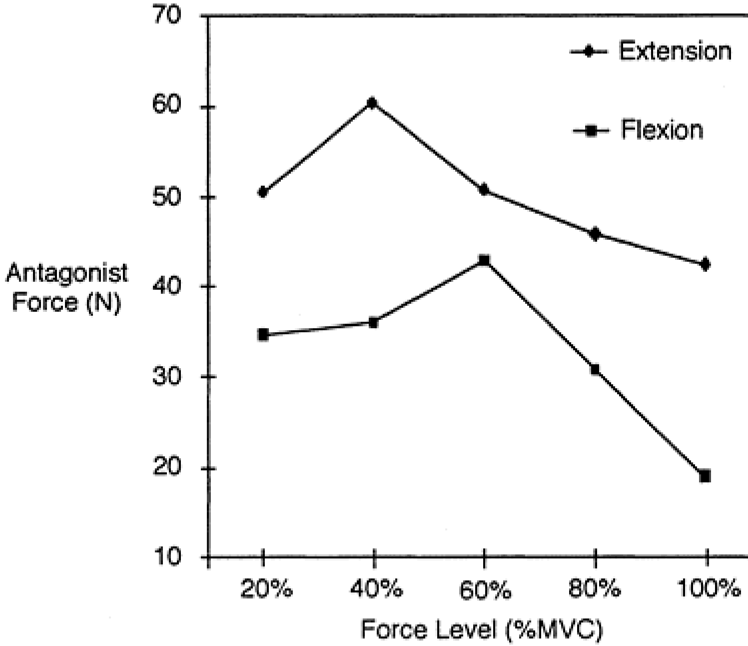

Figure 3. Antagonist co-contraction levels for the extension and flexion phases of the tracking exertion.

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CONTROL AND GAUGING GRASP FORCE IN TELEMANIPULATORS: A COMPARISON OF DIRECT FORCE AND ELECTROCUTANEOUS DISPLAY SYSTEMS

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This paper presents the findings of an experiment that was conducted to test the efficacy of using an electrocutaneous display, in lieu of direct force feedback display of equivalent gain, to guide control of remote grasp force in a telemanipulator.

INTRODUCTION

Operators of remote manipulators are usually provided with only visual feedback to guide the pose and grasp force of an end-effector. To avoid slippage, inadvertent realignment of objects held within the remote gripper, and ultimately loss of grasp, operators often overforce the master-controller. Unfortunately, sustained or very repetitious overforcing of the master controller can damage to objects held within the remote gripper, provoke localized muscle fatigue and discomfort (Wiker, Hershkowitz, and Zik 1989), degrade manual dexterity.

A solution to this problem is to provide bilateral, force-reflection between the master controller an remote endeffector. Once equipped, telemanipulators typically demonstrate much improved manipulative performance. Provision of force reflection is not, however, without its price. Bilateral force reflection: a) is usually quite expensive to build and then to maintain, and b) nearly precludes post hoc implementation with existing telemanipulators. In comparison with force feedback, current generation tactile displays: a) comparatively inexpensive to build, implement, and to maintain, and b) can provide sensory information that is consistent with that normally experienced during typical manual activities.

For these reasons, we have been interested in the efficacy of augmenting a telemanipulator with only tactile cues of grasp force (Wiker, 1988a, b). Previous investigators have examined the potential of tactile feedback in control of aircraft, to reduce operator visual demands, or for alternative communication systems (Geldard, 1961; Weissenberger and Sheridan, 1962; Hahn, 1965; Seeley and Bliss, 1966; Hirsch and Kadushin, 1964; Shori, 1970; Jagacinski, Miller, and Gilson, 1979). In sum, they have found that tactile feedback can compete with other sensory modalities if display gains are manipulated and if frequency response requirements and perceptual demands were not overtaxing. The studies performed were focused upon control of joysticks and other forms of controller that possess lower bandwidths and reduced positional control in comparison to that can be offered by the digits alone.

This paper presents the findings of an experiment that was conducted to test the efficacy of using an electrocutaneous display, in lieu of direct force feedback display of equivalent gain, to guide control of remote grasp force in a telemanipulator.

METHODS AND MATERIALS

Subjects. Six university students, five males and one female, participated in this experiment on a voluntary, paid, and informed consent basis. All subjects claimed and appeared to be in good health.

Apparatus. An electromechanical, single degree-offreedom, bilateral, master-slave telemanipulator, shown in Figure 1, was used this experiment. A microcomputer monitored and controlled direct-drive electric actuators that produced negligible friction and backlash (See Duffie, Wiker, and Zik (1989) and Duffie, Wiker, Zik, and Gale (1990) for a more detailed explanations of the master-slave apparatus employed in this experiment).

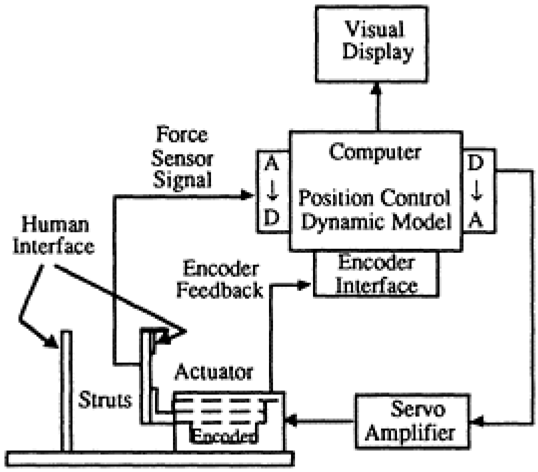

Figure 1. Diagram of the master-controller system used in the experiment.

A calibrated strain gauge was mounted on the master controller to measure forces exerted by the subject's fingers when squeezing the master controller's digits. A highresolution encoder monitored the actual position and velocity of the controller's digits. The microcomputer was used to command and to monitor the position of the master-controller, and to record: a) position commands sent to the mastercontroller, b) actual position of the master-controller, c) force or cutaneous stimulation presented to the subject, and d) time.

Direct feedback of remote grasp force was produced by monitoring commanded and actual position of the master-controller, and converting the position error into a reactive force using a spring constant of 0.833 N per mm.

When using the tactile display, the direct force feedback system was shut off. However, we maintained contact between the master-controller's "digits" and subject's fingers using a light servo-controlled contact force of 1.43 N. Errors in position, or grasp force, were computed as before. Error in grasp force was conveyed to the subject by stimulating groups of tactors on a custom-made 1×32 electrocutaneous array that was designed and built by UniTech, Inc., Madison, Wisconsin.

The display was coated with electrode paste and placed against the subject's abdomen. If grasp force was maintained at desired levels, then subjects received no cutaneous stimulation. If a right-handed subject overforced the master, then a linear group of tactors would become active on the left-half of the array. The magnitude of the error was signaled by the number of consecutive tactors that were activated. Activation of 16 tactors on the left-side of the array conveyed or signaled maximum overforcing error, while activation of 16 tactors on the right-side indicated maximum underforcing of the end-effector.

Perceived intensities of both the direct and electrocutaneous force feedback displays were matched psychophysically for each subject using a cross-modal matching technique (See Lodge (1981) for detailed procedures). Thus, any position error between the mastercontroller and its “end-effector,” signaling a deviation in the desired remote grasp force, produced equivalent perceived intensities of either grasp force or lengths of cutaneous “bars.” The current-varied intensity of electrocutaneous tactors was set to the mean between detection and pain thresholds established for each subject. In both cases, the subjects attempted to null the error encountered following a compensatory tracking task paradigm.

Procedures. Subjects were asked to perform a compensatory tracking task in which they attended either direct force feedback or electrocutaneous stimulation. The subject’s objective was to maintain a 5 N grasp force at a remote end-effector by varying their pulp-pinch grasp and, thereby the position, of a master-controller’s digits. The computer simulated a remote end-effector grasping an object or tool that was continuously challenging the end-effector’s grasp. The simulation resulted in a band-limited (0.1 to 1.0 Hz) white-noise variations in the position commands that were transmitted to the master controller. Each compensatory tracking trial was 30 s in duration.

The protocol used for direct force and electrocutaneous feedback differed slightly. When using the direct feedback display mode, subjects grasp the master-controller and applied force until a 5 N force was produced and a computer screen cursor was observed by the subject to move onto a visual target. Subjects were allowed to manipulate the master-controller at will until they ‘felt confident that they could recall and maintain the 5 N force. Once the subject verbally-acknowledged that they were ready for the trial to begin, the computer screen blanked, and variations in force feedback began after a randomly determined time interval falling between 2 and 5 s. The subject relied upon the initial set then to guide their relaxation or increased force of grasp in an attempt to maintain a constant 5 N grasp force on the master-controller.

When using the electrocutaneous display, subjects initially produced pinch grasp forces to raise the computer screen’s cursor onto the desired target force of 5 N. At that point, all “bar-like” stimuli to either side of the middle of the linear array disappeared. The procedures following were equal to those used in direct force feedback with the following difference. Subjects did not have to maintain a set for the 5 N force. If the array produced a bar stimulation to the subject’s right, then the subject simply countered the error by increasing the grasp to reduce and eliminate the bar. Thus, the force objective was clearly-maintained throughout the trial.

Subjects performed ten learning trials with both direct force and electrocutaneous feedback modes. Ten different band-limited white noise files were presented to a subject during the learning trials. A random-selection of the one of the ten band-limited noise files was used for the eleventh trial which served as the single experimental trial. Subjects rested for one minute between trials. This paradigm was repeated for each mode of display. The order of experiencing the mode of feedback was randomly assigned.

RESULTS

Inspection of the performance data showed that subjects were able to prevent baseline drifts in grasp forces during the 30 s when using the electrocutaneous display. Errors in grasp force were simply computed from command inputs.

However, we observed a negative drift in the baseline grasp forces when subjects used the direct force feedback display. Therefore, we subjected the data to a low-pass filter (<0.1 Hz), and fit the variations in the remaining baseline with a polynomial. The polynomial was used to represent the set used by the subject throughout the tracking period. Residuals about the polynomial, typically a 6 th order, were then used to characterize errors in grasp force.

Errors or adjusted errors in grasp force were subjected to an Analysis of Variance (ANOVA) in which subjects were used as a blocking factor. As Table 1 and Figures 2 and 3 show, the difference in grasp error during the 30 s trial was markedly lower when using the direct force feedback mode. On average, the RMS error in grasp force for the electrocutaneous display was about twice that found with the corrected direct force feedback display. See Figure 2.

As shown in Figure 3, electrocutaneous force feedback produced a stable baseline in grasp force with much greater variation. The variation produced with the electrocutaneous display would be sufficient to cause slippage, if not droppage, of an object that reacted against the end-effector with a comparable force-time history explored in this trial. Use of the direct force feedback mode markedly reduced the magnitude in grasp force errors.

Table 1. Summary of ANOVA of RMS Error in Grasp Force Recorded During 30 s trials.

Source of Variation	**df**	**Sum of Squares**	**Mean Square**	**F**	**p<**
Subjects	6	.359	.060		
Feedback Mode (M)	1	4.390	4.390	106	.0001
Error	6	.248	.041		

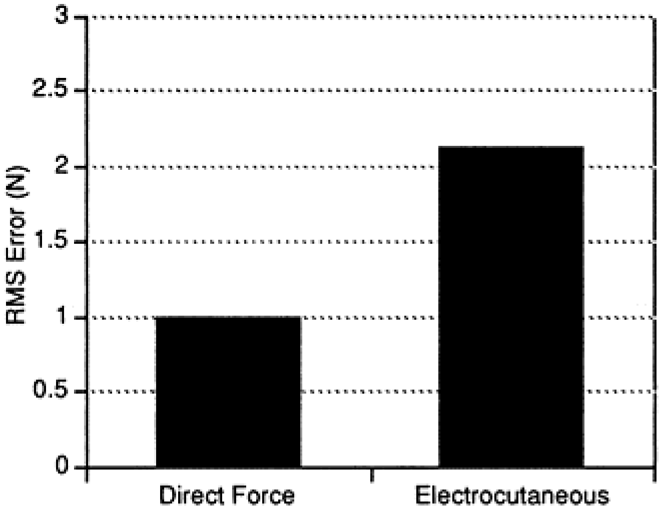

Figure 2. Average RMS error recorded with direct force feedback and electrocutaneous feedback.

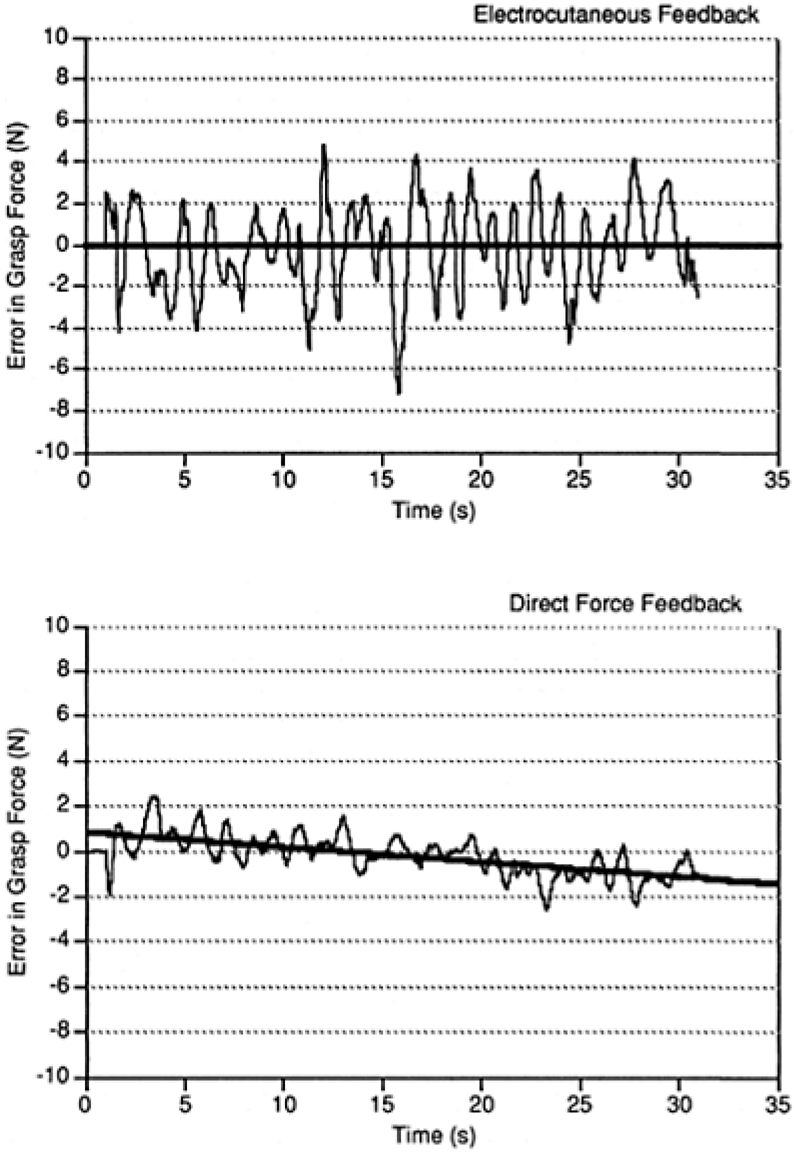

Figure 3. A representative plot of a subject's errors in grasp force observed with the electrocutaneous and direct force feedback display systems. Note that the heavy regression line shows that there was no change in the baseline grasp force for the tactile

display. However, subjects generally showed a decay in the baseline grasp force for the direct force feedback display.

DISCUSSION

Others have explored the efficacy of using tactile feedback systems in lieu of, or as adjuncts to, visual displays, to guide and control arm and hand movements. Collectively, their efforts have shown that the performance of tactile displays in aiding tracking or vehicular control is dependent upon: a) efforts to match the gains between display modalities, and b) bandwidths of the forcing function. In this study, we matched the perceptual magnitudes, or gains, of the force and tactile feedback systems, and insured that the bandwidths of the display systems were functionally-equivalent. Our results show that digit-control of end-effector grasp force, with composite forcing function frequencies ranging between 0.2 and 1 Hz, was aided by both tactile and direct force feedback. However, direct force feedback provided superior performance even with equivalent gains.

Though we matched magnitudes of perceived grasp force and electrocutaneous “bar” length, we were not able to also achieve accurate matching of the just noticeable differences (jnds) between display modes. Some subjects reported that they had greater difficulty gauging cutaneous bar length when deviations from the goal (i.e., zero length) were small; creating a broader “null” zone. This outcome would effectively decrease the subject’s performance because corrections would be initiated only when errors in grasp force exceeded some magnitude; producing larger errors and motivating a quasi-bang-bang control strategy.

In closing, this as well as past experiments with tactile displays demonstrate that use of tactile feedback can substitute or augment other forms of sensory feedback. However, considerable care has to be exercised in the design of the display and in application of such displays when operational bandwidths cannot be achieved by the display. We hope this, and ongoing research in our lab, will help to improve the efficacy of tactile feedback in telemanipulation.

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The Sense of Touch in Multisensory Interfaces

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INTRODUCTION

Tactile sensation, used in everyday life, is missing in computer interfaces. Miniature actuators of shape-memory alloy now enable us to employ tactile information in a variety of ways for man-machine communications, with potential benefits in virtual reality simulations, telepresence, medicine, and personal computer interfaces. Our tactile feedback systems use relatively few stimulators to produce tactile stimuli varying in amplitude and force, temporal and spatial frequency, spatial and temporal patterns, and areas of the skin stimulated. These variables can be combined to convey information about proximity, shape and texture of an object in virtual space, and about forcefulness or urgency of a signal. Tactile sense may thus be integrated with visual, proprioceptive, and auditory stimuli, to improve task performance in multisensory man-machine interfaces. Research in progress explores the potential benefits of a new channel for man-machine communication.

As we define it, tactile feedback is selective stimulation of the touch sense by time-varying patterns under control of a computer. Tactile and force sensations normally occur in combination in human perception, but force is detected by sensory organs in muscle and at the skeletal joints, while tactile sensors are embedded in the soft tissues and are especially concentrated in the fingertips.

One purpose of tactile feedback is to convey information about location and shape of a virtual or remote object. In the case of a real object, as in telerobotics, this information is generated by tactile sensors in contact with the surface of a solid object, converted to electrical signals, and transmitted via computer to an array of tactile stimulators. In case of virtual objects, information may be created by computer software to simulate the "feel" of entities represented by numerical description, e.g. CAD drawings, icons, images from scanning tunneling and atomic force microscopes, or video game sprites.

Tactile stimulation is used as a clinical means of diagnosis of neurological dysfunction. By enabling the clinician to perform more sophisticated tests including timing of stimulus and response, users of tactile feedback expect to extend understanding of disorders such as peripheral neuropathy and focal dystonia.

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Tactile feedback may be used to convey other kinds of information such as proximity, direction, alert to danger, or simulation of force. For example, tactile feedback applied to a control stick could convey a combination of signals as aids to flight and mission execution.

Sensory feedback involves hardware specific to each sense: visual feedback through real-time two- or three-dimensional television images, sound by binaural headsets. Touch sense is provided by tactual stimulators which press against the skin in time-varying patterns.

Except for embossed Braille and computer-driven refreshable Braille displays, mechanical means of tactile stimulation remain very limited. Available methods, including electrocutaneous stimulation, single point electromagnetic and pneumatic stimulators, and piezoelectric vibrotactile pattern generators, are of limited usefulness. One reason is that each of these methods targets a specific type of sensor in the skin. The programmable tactile array which we have implemented attempts to overcome the limitations of extant devices by providing controlled stimulation of several tactile sensor types.

THE TACTILE SENSE

There are four principal types of tactile receptors in the glabrous tissues, usually categorized as slowly adapting and rapidly adapting sensors, described by Nguyen (1988). Slowly-adapting sensors, under continuous pressure stimulation, partially adapt within 0.5 to 1 second, and maintain sensitivity for 25–30 seconds. Quickly adapting receptors, sensitive to transients, movements and vibratory stimuli, initially produce a strong response and completely adapt to the stimulus in 100 to 200 msec. Johnson (1981) reported that the peak of frequency response of certain types of corpuscles is at 200 hz. Densities of hand receptors are greatest at the fingertips and lowest in the palm. Inputs from several kinds of sensors are combined, by processes which are at best vaguely understood, to yield a perception of shape, speed, hardness, and texture of the touched object.

Kokjer (1987) and Kuc (1990) found in experiments with single and multiple tactors in vibration, and Johnson (1981) by means of raised patterns stroked against the skin, that one may infer some upper and lower bounds on the tactile channel of communication.

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Spacing of receptors in the fingertip, where density is greatest, limits spatial resolution to about one-half millimeter: higher resolution is accomplished by integration of signals from multiple sensors. An order-of-magnitude limit of 100 bits per second has been determined for temporal resolution of vibrotactile stimuli, compared to upper limits of capacity of the eye (10ˆ6 bits/sec), ear (10ˆ4). Recognition of patterns of vibrotactile tactile input to the finger tip are limited to a rate of about 10 hz., comparable to motor muscular response time.

Foulke (1982) reported that some people learn to read Braille at about 10 to 20 char/sec. Information can be conveyed accurately by means of the tactile sense, using a limited set of patterns. Time and effort are required to acquire the skill to translate Braille characters into meaningful percepts. Would it not be desirable to present the tactile system with more readily-interpreted stimuli? A person following a line on a CAD drawing or a wire in a circuit diagram will find it useful if the tactile stimulus resembles a ridge. In manipulation of three-dimensional virtual objects, collision is satisfactorily represented by a single tactile pulse, especially when it coincides with a visual cue, as has been shown by Tice (1991)

At one extreme, it would be desirable to present realistic effects such as textures, requiring subtleties of timing and spatial resolution which are beyond present technology. On the other hand, it is possible to convey a wide range of sensation by varying spatial patterns, temporal patterns, and force and frequency of stimuli by individual tactors. There is a middle ground between presentation of tactile images which resemble reality and the use of coded static information such as Braille. The limited objective of our tactile research is a compromise in which the human ability to recognize patterns is exploited using time- and spatially-varying patterns to augment the visual and auditory channels of communication with computers.

APPLICATIONS

Potential applications for tactile feedback are seen in a variety of disciplines including virtual reality, telerobotics, computer aided design, laparoscopic surgery, and data visualization.

We have selected the scanning tunneling microscope for study: it is a tool for investigation of surfaces, as is the sense of touch. An image from an STM scan is displayed on a visual screen, using different colors to convey

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information about depth. As a mouse-type device traverses these data, the pixels under the cursor are converted to on-off pulses which are transmitted to a tactile array under the fingertip via a port and control circuit. Visual input is thus augmented by proprioceptive feedback from hand position, and by tactile feedback representing three-dimensional features on the surface of the sample. The immediate goal is to enhance the utility of the STM by providing to the operator information about the surface through the sense of touch, in complementary addition to the visual presentation. This method of presentation should accelerate interpretation of steps, valleys, and anomalies such as sudden changes in surface roughness. R.L.Hollis (1990) et al interfaced a force-feedback ‘magic wrist’ to an STM, providing kinesthetic perception of the bumpiness by force feedback of a surface as it is scanned.

THE PROGRAMMABLE TACTILE ARRAY

For most applications it is desirable to have an array of several actuators on each fingertip so that patterns may be distinguished. The device should be small and light enough to fit inside a glove to be worn by the user, or on a wand or mouse or hand-held device and thus to move with hand gestures. The TAC programmable array meets these requirements.

The programmable tactile stimulation array comprises a multiplicity of levers, each actuated by an element of TiNi shape-memory alloy, under control of a computer. These tactors are capable of providing forceful steady-state or time-varying stimulation. Each cantilever has a TiNi wire attached at the distal end. The proximal end of the wire is attached to a fixed bridge so that when the TiNi wire contracts (due to heating by a current supplied by the power circuit) the cantilever is forced to bend upward. When current is stopped, the SMA wire cools to below its transition temperature, and the spring force of the cantilever is sufficient to elongate the wire to its original length, allowing the cantilever to return to its un-extended position.

The cantilever is brought to its ‘up’ position by a pulse of current. The speed with which actuation occurs depends upon the power delivered to the wire. When current density is high, heating is rapid so that very little heat is dissipated to the surrounding medium. Maximum cycle rate is governed by the rate of dissipation of heat, the practical maximum rate being about 10 cycles per second.

The Sense of Touch in Multisensory Interfaces

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IMPLEMENTING A TACTILE COMPUTER INTERFACE

In order to provide appropriate current levels and timing, movement of the individual tactor actuators is specified via signals generated by a dedicated microprocessor controller. This controller takes its commands from the host computer. Special software has been developed which translates the pixels under the cursor on the visual screen into a bit pattern which is sent to the RS232 port for interpretation by the controller. This special software runs as a background, so that tactile feedback may be combined with a variety of applications programs.

An array of tactors having nine elements (3 by 3) has been built into the top surface of a mouse device. As a user slides the mouse, patterns corresponding to lines and dots on the visual screen are felt under the fingertip. With this configuration, we have investigated reading of maps, circuit diagrams, and images of atomic surfaces generated by scanning tunneling microscope.

Tactile feedback has been successfully integrated into virtual reality software running on Silicon Graphics and Digital Equipment workstations. In addition to the mouse keypad array, tactors have been added to gloves, wands, and other input devices. Software permits the controller to be used as a stand-alone device or to respond to keystrokes on the host computer. A MIDI interface has been designed, which will allow tactile stimuli to be specified in musical notation.

IMPLEMENTING A TACTILE LANGUAGE

Experience with tactile interfaces makes it clear that we do not know how to use tactile feedback in an optimal manner. A tactile stimulus consists of a spatial pattern, exerted for some period of time at a predetermined force, then changed. The ability to vary force, frequency, and spatial arrangement of tactile stimuli provide a considerable range of versatility. Combining these elements into informational units which may be easily learned and unambiguously interpreted is analogous to invention of a language for tactile communication. This might be looked upon as a mapping of the information units available (spatial patterns, temporal patterns, force, location) onto the requirement for information (proximity, shape of icon, crossing of line or edge, severity or priority of signal.)

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This is complicated by the fact that tactile sense is used in conjunction with vision, sound, and force feedback. Effective use of tactile input will require an understanding of the inter-relationships of the senses. Experiments should not and probably cannot be conducted in isolation. Our goal is to use the sense of touch as an enhancement: we are less interested in the mechanisms than in the result, given the limitations of the various sensors.

As an example of such a mapping, we propose the following.

Receptor type	Tactile stimulus	Perception descriptor
Quickly-adapting	Temporal frequency	Proximity of Object
Slowly-Adapting	Spatial frequency	Shape of object

Combination	Amplitude of stimulus	Force applied to object
Slowly-Adapting	Spatial patterns	Texture
Combination	Temporal patterns	Hardness
Slowly-adapting	Areas stimulated	Urgency of signal

Research in progress will evaluate and improve on this language.

CONCLUSIONS

The use of visual devices was not obvious to early computer makers. They relied on printed copy exclusively for several years before the visual monitor was incorporated. At that time, only alphanumeric symbols were presented: now we have icons, graphical user interfaces which speed some operations significantly. But alphanumeric symbols were not replaced. Graphics enhanced the capability to communicate We believe that a similar evolution can take place by incorporating tactile stimulation into future interfaces. We are convinced that the benefits may be very large, and that the development costs will be repaid many times over.

Since the touch sense is so much used in everyday life, it seems that there are many places and many ways in which tactile feedback can be integrated into systems for man-machine communication. Even a small amount of tactile feedback may speed some operations.

The Sense of Touch in Multisensory Interfaces

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MILITARY OCCUPATIONAL ERGONOMICS

MAXIMAL LIFTING STRENGTH IN MILITARY PERSONNEL

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Heavy lifting is the most physically demanding task in 90% of all military job specialties. While there is a well used data base for their anthropometric measurements, there is little published information concerning the lifting strength of military personnel. The maximal lifting strength of a 2067 male and 1301 female soldiers was measured. Maximal lifting strength was the heaviest load lifted to 152 cm using a weight stack machine. This paper describes the maximal lifting strength of U.S. Army personnel as a function of gender, age, body composition and career status.

INTRODUCTION

Heavy lifting and lifting and carrying accounts for about 90% of the physically limiting tasks of Army jobs (Sharp et al., 1980). Unlike most industrial situations, soldiers in a field environment are unable to make use of automated lifting aids. While some task redesign is possible, the strength demands cannot be completely removed. For example, use of a shoulder harness may facilitate a soldier’s stretcher carrying ability, but will not aid in lifting the wounded soldier from the ground into the ambulance. With this in mind, it is important to know the lifting strength of the Army population to assist in the recruitment and placement of soldiers. The purpose of this paper is to describe the maximum lifting strength of a large sample of U.S. Army men and women, and to examine variations in strength with age, body composition and career status.

METHODS

The data contained herein are a compilation of 12 separate investigations conducted from 1981–1991, and are comprised of 2067 male and 1301 female soldiers. Soldiers were representative of three categories based upon their career status: 1) prior to basic training, 2) following basic and occupational training and 3) personnel permanently assigned to a unit (permanent staff). Basic training lasts approximately eight weeks and incorporates extensive physical training. Occupational specialty training lasts from one to nine months and includes physical training, but the emphasis is on skills development. Permanent staff are required to meet a body weight and physical fitness standard, but the amount of physical training they undergo varies from unit to unit.

Maximum lifting strength (MLS) was measured using an incremental dynamic weight stack machine (McDaniel et al., 1983). The initial load was 18.18 kg and was increased by 4.54 kg plates until the subject was no longer able to complete the lift. The handles of the weight stack machine were lifted from 30 cm to 152 cm above the floor (McDaniel et al., 1983; Teves et al., 1985). The 152 cm height was selected to simulate lifting a box with handles from floor level to the bed of a 2–1/2 ton truck. The subject was instructed to stand close to the weight stack, grasp the handles with an overhand grip and assume a starting position with the head up, the back and arms straight, and the knees bent. The lift was initiated with the legs and completed by pressing the load upward with the arms (military press) to reach the 152 cm mark. The test-retest reliability coefficient was $r=0.92$ ($p<.01$) for a group of 160 men and 30 women who were tested twice during a four day period.

Body composition was estimated using either hydrostatic weighing, the Army circumference method, or the Durnin and Womersley skinfold method (Vogel et al., 1988).

Analysis of variance with a $p<.05$ level of significance was used to assess group differences. Tukey's HSD was used to make post-hoc comparisons.

RESULTS

The physical characteristics of the subjects are listed in Table 1. Men were significantly different from women on all measures except age.

Table 1. Physical characteristics of subjects.

	men (n=2061) $\bar{X} \pm SD$(range)	women (n=1301) $\bar{X} \pm SD$(range)
age (yrs)	22.9±5.7(17–51)	21.3±3.9(17–40)
height (cm)	174.7±6.8 (153–198)	162.7+6.4 (144–184)
weight (kg)	74.5±11.2 (47–127)	59.1±7.2 (41–93)
body fat (%)	17.7±6.2 (4–42)	25.7±4.5 (12–50)
fat-free mass (kg)	60.9+7.3 (36–91)	43.7±4.5 (32–67)

The mean ± SD for MLS was 61.0±12.4 kg for men and 30.2 ±5.9 kg for women. The percentage distribution of MLS for men and women are listed in Table 2. There is very little overlap between men and women. In fact, less than 2% of the men scored 36 kg or less, which was equal to the 92nd percentile in women.

Lifting strength is affected by many factors. Age, body size and career status will be examined here. To determine the effect of age on MLS the subjects were grouped as follows: <25 yrs, 25–34 yrs, and >34 yrs. In males, MLS was inversely related to age group, as MLS was significantly lower with each increase in age group. There were no significant differences in MLS between the age groups in women. These data are listed in table 3.

Table 2. Maximal lifting strength frequency distribution.

	men			women		
load (kg)	frequency	%	cum %	frequency	%	cum %
18.18				29	2.2	2.2
22.72	2	0.1	0.1	186	14.3	16.5
27.27	5	0.2	0.3	427	32.8	49.3
31.80	7	0.3	0.7	385	29.6	78.9
36.36	23	1.1	1.8	176	13.5	92.5
40.91	57	2.8	4.6	66	5.1	97.5
45.45	177	8.6	13.1	22	1.7	99.2
50.00	236	11.4	24.6	4	0.3	99.5
54.55	309	15.0	39.6	2	0.2	99.7
59.10	334	16.2	55.8	2	0.2	99.8
63.64	270	13.1	68.9	1	0.1	99.9
68.18	207	10.0	78.9	1	0.1	100.0
72.72	177	8.6	87.5			
77.27	90	4.4	91.9			
81.82	69	3.3	95.2			
86.36	40	1.9	97.1			
90.91	46	2.2	99.4			
95.45	4	0.2	99.6			
100.00	5	0.2	99.8			
104.54	1	0.0	99.9			
109.09	1	0.0	99.9			
113.64	1	0.0	100.0			
118.18	1	0.0	100.0			

The effect of body size on MLS was examined by dividing the subjects into quartiles based on height, weight, percent body fat and fat-free mass. These results are illustrated in Figure 1. Height is positively correlated with muscle strength, because the cross sectional area of muscle is proportional to height (Assumussen and Heebol-Nielsen, 1961). When grouped by height quartiles, MLS was significantly greater with increasing height. MLS in the fourth height quartile in women was 3.8 kg greater than the first, however, no two adjacent quartiles were significantly different from one another. In men, the fourth quartile was 7.8 kg greater than the first for height, and all quartiles were significantly different from one another with the exception of quartiles two and three.

Table 3. Maximum lifting strength (kg) of men and women by age group,

Age (yrs)	Men		Women	
	n	Mean±SD	n	Mean±SD
<25	1462	62.9±12.3	1070	30.2±5.8
25–34	460	59.5±12.3	225	30.1±6.3
>34	139	54.4±10.9	6	28.0±6.7

When grouped by body weight quartiles, there were significant differences in MLS of 15.8 kg and 5.7 kg from the first to fourth quartile in men and women, respectively. When grouped by percent body fat, there was a significant difference in MLS of 2.3 kg from the first to the third quartile in men. There were no significant differences in MLS by body fat quartile in women. The soldiers were grouped pass or fail based on whether or not they met the current Army percent body fat standards for their gender and age group. There was no significant difference in the MLS of women who passed vs those who failed the body fat standard. The men who failed the body fat standard lifted significantly more (3.1 kg, $p<.01$) than those who passed. Analysis of the fat-free mass quartiles revealed that MLS was significantly greater from quartile one through four for both men and women, with the exception of quartiles two to three for women. The difference in MLS from the first quartile to the fourth was 20.3 kg in men and 6.7 kg in women.

Military basic and occupational training has been shown to improve the physical fitness of new recruits (Patton et al., 1980; Teves et al., 1985). How well these improvements are maintained throughout a military career is not known. The MLS for the different career status groups is listed in Table 4.

A sub-sample of soldiers who were tested before entry into basic training and following completion of occupational training increased MLS by about 4 kg ($p<.01$). There was no significant difference in MLS between pre-training and permanent staff soldiers, however, post-training soldiers were significantly stronger than permanent staff. Permanent staff soldiers were significantly heavier and had a higher percentage body fat than both pre- and post-training groups. Post-training soldiers had significantly more fat-free mass than the other status groups.

Table 4. Effects of career status on strength and body composition (mean and SD).

	Pre-Basic		Post-Training		Permanent Staff	
	men n=972	women n=988	men n=476	women n=495	men n=1078	women n=302
MLS (kg)	60.6	29.5	65.8	34.6	61.0	30.7
	10.7	5.4	10.8	5.8	13.6	6.8
weight (kg)	72.8	58.5	74.0	61.0	76.0	60.9
	10.8	6.7	8.6	6.9	11.3	8.6
body fat (%)	16.2	25.1	15.1	25.6	19.1	27.7
	5.2	3.9	3.8	3.9	6.7	5.7

fat-free	60.6	43.7	62.7	45.2	61.0	43.7
mass (kg)	6.7	4.2	6.4	4.5	7.7	5.2

DISCUSSION

The MLS frequency distribution is comparable to that reported for other military (McDaniel et al., 1983) and civilian (Stevenson et al., 1989) populations. It has been reported that men's isometric strength peaks at age 30, decreases slowly for 20 years and decreases rapidly thereafter (Asmussen and Heeboll-Nielsen, 1961). Women's isometric strength peaks at age 20, declines slowly, then more rapidly between 45 and 65 years of age (Black Sandler et al., 1991). Male strength loss with aging is associated with a decrease in fat-free mass and testosterone, while women's greatest strength loss occurs during the menopausal years. The male subjects in this study followed this general pattern, but women did not change. This may be the result of the small number of women in the oldest age group (n=6). In addition, women who remain on active duty may be more physically active than the average civilian, and therefore, not experience the slow decrease in strength.

Fitness for military duty is based on passing both a physical fitness test and a weight for height or body fat standard. Friedl et al. (1990) reported that overfat men and women had lower physical fitness test results than those within the Army body fat standards, and that this effect was more pronounced in men. He also found that women who were over the weight for height standard, but not overfat, were more likely to succeed in basic training. In the current sample a higher percentage of body fat did not adversely affect MLS. In fact, the men in the fail group lifted significantly more than those in the pass group. Soldiers who weighed more and had more fat-free mass were stronger, regardless of body fat.

Soldiers are expected to always be 'fit to fight'. It appears that the higher MLS achieved during basic and occupational training is lost when soldiers reach their assigned duty station. The fact that no difference existed in MLS between pre-training soldiers and permanent staff suggests a need for continued emphasis on strength training, particularly for occupations with heavy lifting demands.

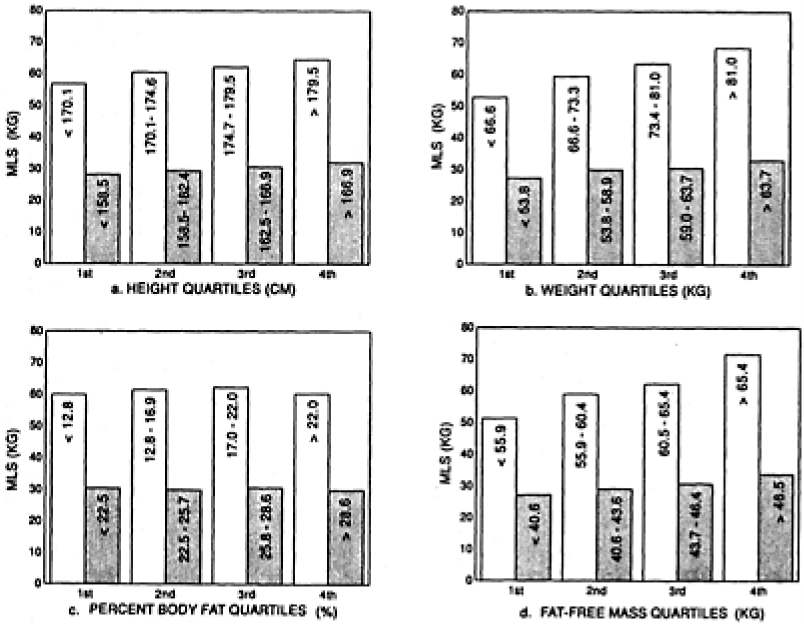

Figure 1. Maximum lifting strength (kg) for men (open bars) and women (shaded bars) by quartiles for height, weight, percent body fat and fat-free mass.

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DISCLAIMER

The views, opinions and findings contained in this report are those of the authors, and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other official documentation.

A USABILITY ASSESSMENT OF TWO HARNESSES FOR STRETCHER-CARRYING

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The purpose of this study was to compare the usability two harness systems in a field environment. Subjects carried and loaded as many patients as possible in 15 minutes. Three harness conditions were used: 1) no harness, 2) an H-cross design with aluminum “J-hooks” to secure the litter handles (HX-hook), and 3) an H-design with loops to secure the litter handles (H-loop). Results from indicate the H-cross design is superior to the H-design and that a harness is beneficial for female two-person teams during repeated short carries.

INTRODUCTION

Medical stretcher carrying is a physically demanding task in which sustained contractions induce muscular fatigue (Lind and McNicol, 1968). Soldiers often identify field expedient methods of accomplishing difficult physical tasks. For example, soldiers sometimes hook stretcher grips on the belt portion of their field gear to relieve the muscular fatigue in their hands and forearms and assist with stretcher carrying. However, new field gear is made with durable plastic buckles, which can not support the stretcher.

In the laboratory, we previously found that use of a shoulder harness improved stretcher-carrying ability and both post-carry fine-motor and marksmanship performance (Rice, et al., 1991). When carrying a stretcher for as long as possible (up to a half an hour), two-person teams carried the stretcher for 3.0 minutes without a harness and 21.9 minutes with a harness. Four-person teams carried the stretcher 9.1 minutes without and 24.8 minutes with a harness. While carrying as many patients as possible in a fifteen minute period, women benefitted from harness use in two and four-person teams and both genders perceived less exertion when using a harness in two-person teams (Rice, et al., 1991). The harnesses used were not compatible with field conditions, however.

Different harnesses were used for two-person and four-person carries creating an additional burden (two harnesses) to be taken to the battlefield (Figures 1 & 2). The two-person harness was too bulky to use with standard load bearing equipment (LBE). Both harnesses had loops of material in which the stretcher handles were placed, which made lifting the litter awkward. In addition, if the soldier carrying the litter tripped, the litter could fall

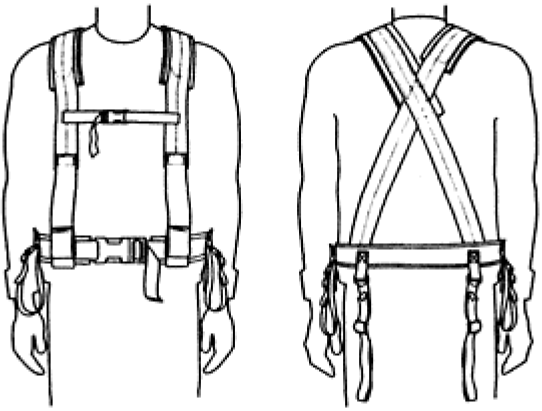

FIGURE 1. Two-person harness (H-loop design)

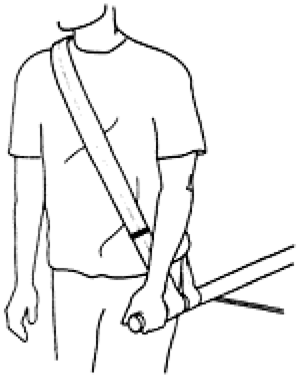

FIGURE 2. Four-person harness (loop design)

close to the soldier possibly injuring either the soldier carrying the stretcher or further injuring the patient. A new harness was designed to address these problems.

The purposes of this study were to ascertain the effectiveness and ease of use of two harness systems during a series of short carries (mass casualty situation) and to verify the usefulness of a harness in a field environment.

METHODS

Subjects

Four male and four female soldiers volunteered to participate. General descriptive statistics are included in Table 1. Percent body fat was measured by under water weighing and maximum VO_2 was measured by an interrupted, progressive treadmill test.

Harness

Three harness conditions were used for four-person teams: 1) no harness, 2) HX-hook harness, and 3) H-loop harness. The first two conditions were used for two-person teams, except during forced choice rankings, in which no

Table 1. Personal Data of Subjects

	Mean	SD	Range
Height (cm)			
Males	177.8	4.5	173.6–182.8
Females	159.4	4.6	154.0–165.2
Weight (kg)			
Males	77.6	8.9	65.7–87.3
Females	56.5	6.2	54.5–69.1
Age (yrs)			
Males	20.3	1.0	19–21
Females	22.2	4.5	19–30
Percent Body Fat			
Males	18.3	6.9	9.9–26.3
Females	28.8	5.6	22.2–33.8
VO_2 Max (ml/kg)			
Males	56.9	5.7	51.6–61.9
Females	46.2	7.8	40.1–51.9

harness, HX-hook harness, and the loop harness (Figure 2) were compared.

The HX-hook harness (Figure 3), designed for field use, was a modification of the single adjustable strap available in the military procurement system (Figure 2). Two straps were used. An aluminum “J-hook” was attached to one end and the other end was a loop. A “H-cross” design was used, that is, the front straps formed an H and the rear straps crossed. A small strap connected the two ends of the harness and acted as a guard to hold the harness in place (Figure 3). The HX-hook design was compared with the H-loop harness used for the laboratory study (Figure 1) and with no harness.

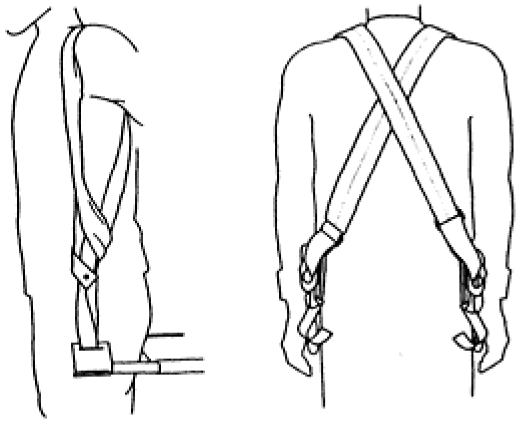

FIGURE 3. HX-hook design harness

Stretcher Carry Tasks

The task required subjects to carry and load as many casualties as possible onto a simulated emergency medical evacuation vehicle during a fifteen minute period. Teams consisted of two and four-person, male and female teams. First, each team carried the stretcher holding an 81.6 kg manikin (based on the weight of the 50th percentile male U.S. Army soldier, 78.5 kg±11 kg) for a distance of 50 m on level ground. The team then lifted the stretcher onto a truck bed 121.9 cm high to simulate loading an emergency vehicle. Finally, the team members ran 50 meters to pick up the next casualty, thus beginning the next cycle. The task was self-paced.

Subjects completed a fine-motor cord and cylinder task before and after each task. Heart rate was recorded for each team member in fifteen second intervals throughout litter carry testing using a $UNIQ_{tm}$ Heartwatch system. Oxygen uptake was measured for each team member using the Douglas Bag technique, during the carry portion of the fifth and ninth cycles. Stretcher motion was measured to assess patient comfort with an activity transducer, which was attached to the manikin's wrist. The accelerometric signal, due to the changing velocity of the transducer during stretcher movement, was recorded (passband=0.25–20 Hz, sampling rate=15 Hz). Number of carries completed, rest stops, and times for each portion of the carry cycle (i.e. mean times to carry the stretcher, lift the stretcher into the ambulance, return for the next stretcher, and pick up the stretcher) were recorded. Subjects rated their exertion level immediately following the task, using the Borg Perceived Exertion Scale (Borg, 1978). Forced choice rankings comparing no harness, HX-hook and H-loop harnesses were used, as well as Likert scale ratings of comfort, ease of use, ease of carry, and overall stability. Forced choice rankings for all three harness conditions were completed for both two-person and four-person teams.

RESULTS

A repeated measures design, counter-balanced for order, was used with an alpha level of 0.05. An ANOVA was used for evaluation of heart rate, oxygen consumption, and cord and cylinder timed data. The Friedman two-way analysis of variance and the Wilcoxon matched-pairs signed-ranks test were used for subjective evaluations. Descriptive statistics were used for stretcher movement and carry cycles, due to the small sample size resulting from team versus individual measurements.

Two-person Carry

The modified HX-hook design was ranked as the preferred carry method ($p<0.0001$) compared to the H-loop harness, and no harness. Oxygen uptake was greater while using the harness ($F=14.21$, $p=0.0130$). Subjects exercised at 72.4% of their maximum with a harness, which was significantly different from the 65.3% without a harness ($F=15.99$, $p=0.01$). Although subjects completed the carries faster with a harness, time to pick up the stretcher and lift the stretcher were slower (Table 2). Two-man teams completed more carries without a harness, but there was little difference for women (Table 3). However, women stopped to rest four times per fifteen minute period without a harness, but did not stop while using a harness.

Table 2. Mean values for two and four person carries*.

	No Harness	Loop	Hook
TWO-PERSON			
Number of carries	17.1		14.4
Actigraph	6.5		6.9
Carry time (sec)	32.3		26.9
Lift time (sec)	9.7		11.3
Return time (sec)	16.6		16.6
Pick-up litter (sec)	6.7		13.3
FOUR-PERSON			
Number of carries	18.7	14.6	17.1
Actigraph	8.9	8.4	7.1
Carry time (sec)	26.0	25.7	26.7
Lift time (sec)	5.4	8.7	6.6
Return time (sec)	15.4	17.3	16.5
Pick-up litter (sec)	6.6	12.7	6.2

*male and female values combined

Table 3. Mean values for male and female two-person teams.

	Male		Female	
	No Harness	Harness	No Harness	Harness

Number carries	18.0	16.8	11.7	12.0
Carry (sec)	24.9	23.8	39.8	30.1
Lift (sec)	7.1	10.2	12.3	12.5
Return (sec)	15.2	15.2	18.1	16.1
Pick-up (sec)	4.4	8.6	9.0	18.0

Four-person Carry

The HX-hook harness was ranked as the preferred carry method ($p=0.03$) and was rated easiest to use ($p=0.02$) compared with the laboratory loop harness and no harness. Oxygen uptake was lower with the HX-hook compared with the H-loop, and no harness ($p<0.05$). Subjects exercised at 59% of their maximum aerobic capacity with the HX-hook harness, which was significantly different from 69.5% with no harness and 71.3% with the H-loop harness ($p<0.01$). Time to pick-up the stretcher and to lift it into the 'ambulance' were slowest and fewer carries were completed with the H-loop harness (Table 2). Less movement was detected with the HX-hook harness. The cord and cylinder task was completed quicker post-carry with the HX-hook compared with the H-loop harness ($p<0.01$). No differences were found for ratings of comfort, stability, or perceived exertion, nor was heart rate significantly different for separate harness conditions.

During interviews the women indicated that they would prefer to use the HX-hook harness in a combat situation, while men qualified their reply as being situation dependent. The HX-hook harness was constructed such that the two parts could be taken apart and used separately in either a two or four-person configuration. The HX-hook harness was not bulky. During practice, the HX-hook harness was used with standard-load-bearing-equipment (LBE) and subjects reported the fit to be comfortable. One two-person team fell while carrying the litter. The stretcher handles came out of the J-Hook, the stretcher did not fall on the subject, nor did the subject fall onto the stretcher holding the manikin.

DISCUSSION

These results reveal that the HX-hook design is superior, compared to the H-loop design for stretcher-carrying as measured by user preference and performance. During two-person carries, oxygen up-take was greater while using the HX-hook harness, because subjects completed the carries faster and females did not take rest breaks. Compared with the X-loop harness, oxygen uptake was lower, delay and adjustment times were shorter, less stretcher movement was detected, and post-carry fine motor performance was quicker with the H-hook harness.

Findings were similar to those of the laboratory study (Rice, et al. 1991). Although subjects carried the stretcher quicker with a harness during the fifteen minute task, its use slowed four-person and two-man teams because of the time needed to attach and detach the harness from the litter handles. Remaining design issues need to be addressed (shoulder padding, ease and speed of assembly, use in various environmental conditions), however, the harness was shown to be beneficial for women in both two and four-person teams.

ACKNOWLEDGEMENTS

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THE STRENGTH OF WOMEN FOR ACTIVATION OF EJECTION SEAT CONTROLS

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One Hundred and four female volunteers performed static strength tests on side and center mount ejection seat controls with left, right, and both hands. Results indicated that all subjects were able to operate the side handles with one hand, with strength to spare. The minimum left hand torque was 25.3 Nm (224 in-lb), with 19.8 N m (175 in-lb) being the current requirement. When using the center handle, the minimum two-hand force was 274 N (61.5 lb), with 218 N (49 lb) being the requirement. Strength was not found to be meaningfully related to body size or mass.

INTRODUCTION

The ACES II ejection seat is now being used in the F-15, F-16, B-1, and A-10 combat aircraft as the standard escape system. These aircraft have side-mounted ejection handles, except the F-16, which uses the center-pull handle to avoid interference with the side-mounted flight control. In 1964, when the seat was developed, the Air Force had no female pilots; therefore, women were not considered as part of the user population. Because women can now fly all non-combat aircraft and are being considered as pilots of combat aircraft, the accommodation of female pilots must be addressed.

The issue of concern is whether small or weak women can operate the seat controls in all conditions. The design issue involves the need to have the largest resistance possible in the control handles to prevent inadvertent activation, a catastrophic consequence. To help answer some of these questions, the Air Force's Armstrong Laboratory (AL/CFHD) was asked to study the capabilities of women to operate an ejection seat of the ACES II configuration.

METHOD

One hundred four female subjects (19 to 40 years of age) performed a series of 26 strength tests for the ejection seat study. Of the 104 volunteer subjects, 51 were civilian and 53 were Air Force personnel at Wright-Patterson Air Force Base. Among the military subjects there were three Air Force pilots.

The test equipment consisted of a Pilot Strength Test Device, originally constructed to measure strengths for operating flight controls. The test device (see Figure 1) is a heavy steel framework with an adjustable seat, two foot pedals, and a control column with three grips configured to represent the flight controls in an aircraft cockpit.

The seat was modified to include both a center-pull and side-mount ejection handles. The handles were specially designed to have the size, shape, motion envelope, and force/displacement characteristics of the ACES II handles, but were more sturdy and had ball-bearings in all moving parts. As in the actual seat, the left and right side-handles were linked together so that a force applied to either caused both to move.

The handles had a limited-deflection spring mechanism in the linkage to allow the handles to move in response to the force applied, just as they do on the actual seat. The side handles, shown in Figure 2, had a breakout torque of 13.1 N m (116 in-lb) and stopped rotating after 21.5 degrees when a torque of 19.8 N m (175 in-lb) was applied. The center-pull handle, shown in Figure 3, had a breakout force of 93.4 N (21 lb), a displacement of 0.046 m (1.8 in) when 218 N (49 lb) of force were applied. These spring mechanisms were in series with the load cell, so the total force applied to the handles was measured, regardless of the handle displacement.

To assess the relationship between body size and the ability to operate ejection seat controls, and to compare this population to the larger Air Force population, the following anthropometric data were collected on each subject: age, handedness, stature, weight, sitting height, acromion-radiale length, radiale-stylion length, and hand length. Benchmark static strength measures were made on the stick and wheel controls to permit comparison of these subjects with earlier data gathered on a large sample of USAF pilots and pilot candidates. Additional benchmark tests included a dynamic weight lift to six feet and a static elbow height lift.

The data collection system consisted of a microcomputer, analog-to-digital converters, bridge amplifiers, electronic load cells, and a camera. Strength data were sampled at 20 Hz. The duration of the ejection forces was two seconds, initiated when the subjects exceeded a breakout force of 44 N (10 lb) on the center handle or 1.1 N m (10 in-lb) on the side handles. An auditory tone and a LED indicator signaled the end of the two second exertion.

To safely operate a real ejection seat, the operator must maintain an erect body posture against the seat back when the handles are pulled. Failure to do so can cause serious injury. The exertions were photographed to determine if the subject was able to maintain an erect posture against the seat back while operating the ejection handles. A computer-controlled 35mm camera with motorized film winder took two photos from a location about 3 m (9 ft) lateral to the subject's right elbow. The first photo was taken before exerting a force and the second at the end of the two second exertion.

The measures were grouped in four sets: strengths on the ejection controls, flight controls, benchmark tests, and finally the body size measures. Within each group, the sequence of exertions was randomized for each pair of subjects. For the two ejection controls, each of the exertions (right hand, left hand, and both hands simultaneously) was done twice, to check for sequence effects and repeatability.

For the ejection control and for aircraft control tests, the subjects wore Nomex flying gloves. The subjects were informed that they would achieve maximum torque on the side handles if they gripped the handles as far forward in the hand openings as possible. The effective moment arm of the side handle was about 0.102 m (4.0 in). For the two-hand exertions, the subjects were instructed to insert two fingers on each side of the center-pull handle and then pull in line with the axis of the handle.

Subjects were instructed to jerk on the handles as hard and fast as they were able. The exertions on the ejection handles were held for two seconds (starting at the initial application of force), followed by a two-minute rest period. Most subjects were tested in pairs, alternating exertions.

RESULTS

Maximum voluntary strengths for operating side and center mounted ejection handles with the right, left, and both hands is shown in Table 1. The minimum force required to operate the center handle of the ACES II is 218 N (49 lb). Six subjects were unable to operate the center-pull handle with one hand. Three of these subjects were unable to exert the required force on the center-pull handle with either the left or right hand, their scores ranging from 128 to 204 N (28.8 to 45.9 lb). The other three were unable to exceed the minimum

Table 1. 1st, 5th, 50th, 95th, 99th Percentile, Minimum and Maximum strength values for the Center-Pull (Newtons & pounds) and Side-Mount Ejection Handles (Newton-meters & inch-pounds).

<table>
<tr><th>Hand</th><th>1st</th><th>5th</th><th>50th</th><th>95th</th><th>99th</th><th>Min</th><th>Max</th></tr>
<tr><td colspan="8">CENTER HANDLE NEWTONS/POUNDS</td></tr>
<tr><td>Both</td><td>277.3</td><td>367.2</td><td>459.3</td><td>660.0</td><td>719.1</td><td>273.6</td><td>731.3</td></tr>
<tr><td></td><td>62.4</td><td>82.6</td><td>103.3</td><td>148.4</td><td>161.7</td><td>61.5</td><td>164.4</td></tr>
<tr><td>Left</td><td>131.1</td><td>219.1</td><td>284.7</td><td>417.0</td><td>451.9</td><td>128.1</td><td>452.8</td></tr>
<tr><td></td><td>29.5</td><td>49.3</td><td>64.0</td><td>93.8</td><td>101.6</td><td>28.8</td><td>101.8</td></tr>
<tr><td>Right</td><td>139.7</td><td>225.1</td><td>291.9</td><td>421.5</td><td>514.2</td><td>133.4</td><td>519.6</td></tr>
<tr><td></td><td>31.4</td><td>50.6</td><td>65.6</td><td>94.8</td><td>115.6</td><td>30.0</td><td>116.8</td></tr>
<tr><td colspan="8">SIDE HANDLE NEWTON-METERS/INCH-POUNDS</td></tr>
<tr><td>Both</td><td>44.4</td><td>51.3</td><td>64.8</td><td>93.6</td><td>105.9</td><td>42.4</td><td>106.5</td></tr>
<tr><td></td><td>393.2</td><td>454.2</td><td>573.9</td><td>828.1</td><td>937.1</td><td>375.2</td><td>942.5</td></tr>
<tr><td>Left</td><td>26.5</td><td>29.5</td><td>38.6</td><td>50.6</td><td>62.5</td><td>25.3</td><td>65.0</td></tr>
<tr><td></td><td>234.3</td><td>261.1</td><td>342.0</td><td>448.1</td><td>553.2</td><td>223.7</td><td>575.4</td></tr>
</table>

Right	25.0	29.9	39.0	48.3	62.4	25.4	62.9
	221.6	264.3	345.5	427.6	552.7	224.9	556.7

on the center-pull handle with the left hand, but were able to do so with the right hand, their left hand scores being 183, 212, and 215 N (41.1, 47.6, and 48.3 lb). These subjects could not be characterized as either the shortest or the lightest, with three of the six being above average and exceeding the minimum body size requirements for USAF pilots.

The minimum torque required to operate the side handles is 19.8 N m (175 in-lb). The side-mount ejection handles are more efficient than the center-pull handle. The average two-hand force of 663 N or 149.1 lb (67.4 Nm/0.102 m or 596 in-lb/4 inch moment arm) is about 40 percent larger than the two-hand forces exerted on the center handle. The one-hand forces averaged 30 percent, greater. This is probably due to the larger hand-grip surface and a force vector more in line with the shoulders. All subjects exceeded the required 19.8 N m (175 in-lb) of torque on the side handle with either hand or both hands. For the side handle, the weakest subject had a 28 percent reserve capability with the weaker hand.

In a comparative study of 101 male subjects, the men averaged 66 percent greater forces on the center handle [the minimum force was 249 N (56 lb) for the left hand] and 54 percent greater forces on the side handles.

One objective of this study was to determine if small women have sufficient strength to operate the ejection handles. To evaluate this, the sample was divided into sub-groups based on height (tall and short subgroups based on stature and sitting height), and weight (three subgroups). The two height groups were formed by designating as “tall” the 47 subjects whose stature was greater than 1.619 m (63.75 in) and sitting height was greater than 0.857 m (33.75 in). The remaining 57 subjects were designated as “short” subjects. Although the taller subjects averaged 4.4 percent greater forces, the difference was not significant.

The three weight subgroups were formed based of the sample’s weight distribution. Those subjects whose weight was in the upper quartile were designated as heavy; those whose weight was in the lower quartile were designated as light; and those whose weight fell in the middle two quartiles were designated medium. The means and standard deviations of the ejection handles for the three weight groups are presented in Table 2.

The analysis of variance only showed a significant difference between the weight groups for the center pull ejection handle exertion performed with the left hand. Post hoc analysis using Duncan’s Multiple Range test revealed that the mean for the heavy weight group was significantly larger than the mean for the light weight group. No other differences were significant.

To further investigate the relationship between the size of the subject and available strength for operating the ejection handles, Pearson product moment correlation coefficients were computed between each of the ejection handle exertions and the subjects’ anthropometry. There were no meaningful relationships between the size of the subject and the available strength for operating the ejection handles with coefficients ranging from 0.00 to 0.30. These low correlations mean that size cannot be used as an indicator of strength.

Table 2. Ejection Strength for Three Subgroups by Weight for the Center-Pull (Newtons & pounds) and Side-Mount Ejection Handles (Newton-meters & inch-pounds).

	Light (N=23) 43.5–53.5 kg 96–118 lb		Medium (N=57) 54.0–65.3 kg 119–144 lb		Heavy (N=24) 65.8–82.1 kg 145–181 lb	
Hand	Mean	SD	Mean	SD	Mean	SD
CENTER HANDLE			NEWTONS/POUNDS			
Both	445.0	71.0	467.2	82.5	509.9	91.8
	100.0	16.0	105.0	18.5	114.6	20.6
Left	272.6	55.2	294.7	51.6	324.5	68.3
	61.3	12.4	66.3	11.6	73.0	15.4
Right	293.4	65.3	291.4	54.9	331.3	56.3
	66.0	14.7	65.5	12.3	74.5	12.7
SIDE HANDLE NEWTON-METERS/INCH-POUNDS						
Both	63.5	9.7	66.5	14.5	73.8	13.8
	562.4	85.9	588.6	128.2	653.5	121.9
Left	37.3	4.9	39.0	6.8	41.8	7.1
	330.2	43.3	344.9	59.8	369.9	62.5
Right	39.3	5.5	38.9	7.6	43.2	7.1
	347.6	48.8	344.2	67.4	382.5	62.7

To determine the relationship between the aircraft control exertions, elbow height lift, and incremental weight lift, and the ejection handle exertions, Pearson product moment correlation coefficients were computed. The coefficients ranged from 0.32 to 0.67, with 56% of the coefficients being above 0.50.

This study intentionally included some small women which are below the minimum acceptable body size requirements for Air Force pilots to consider the impact of changing this standard. Air Force Regulation 160–43 requires pilots to be at least 1.626 m (64 in) in stature, 0.864 m (34 in) in sitting height, and 46.6 kg (103 lb) (if female) in mass. These body size criteria make the smaller half (approximately) of the otherwise qualified female population ineligible. Subjects in this study averaged 1.631 m (64.2 in) in stature, 0.862 m (34.0 in) in sitting height, and had a minimum mass of 43.5 kg (96 lb), which is about a 2nd percentile mass. Analysis of the photographs revealed a potential posture problem with small subjects and the side-mount handles. Three subjects were not able to lean firmly against the seat back when pulling both side handles. Note that none of these three subjects meet the current body size requirements for Air Force pilots, with statures ranging from 1st to 25 percentile, sitting height from 1st to 45th percentile, and arm lengths from 5th to 25 percentile. While three subjects were unable to pull the side handles and sit with the shoulders firmly against the seat back, the difference is small, and may not be significant. The photographs did not indicate that any of the small subjects failed to maintain contact with the seat back when using the center-pull handle.

Independent t-tests were used to compare the results of the strength exertions on the flight controls in this study with data from an earlier study, when a sample of 106 female students at the Air Force Officers Training School (OTS) performed the same 10 exertions on simulated aircraft controls. This comparison showed that the OTS students exerted more force (an average of 7.7 percent more) on all simulated aircraft controls compared to the subjects in the present study. The OTS students may have been slightly stronger because they have a rigorous physical fitness program, and, on average, were about 2 cm taller in stature.

CONCLUSIONS

All subjects were able to exceed 218 N (49 lb) on the center-pull handle with both hands, but six could not do so with one hand. All subjects were able to exceed 19.8 N m (175 in-lb) of torque on the side-mount handles with either hand or both hands, and with a considerable reserve capacity.

The weak subjects cannot be characterized as either the shortest or the lightest. Furthermore, three of the six which could not operate the center-pull handle with one hand were above the minimum size requirements for USAF pilots. The correlation between size and strength is very low. These data show that screening out the shorter or lighter subjects will not guarantee acceptable strength capability. In as much as all subjects were able to exceed the minimum force with both hands on the center-pull handle, there is no justification for excluding small subjects for strength reasons. There was, however, an indication that some small subjects may not be able to maintain the correct posture when operating the side-mount ejection handles.

These data were gathered in a benign environment. Before applying these data, some discount in available strength should be applied to account for environmental factors, such as acceleration (G-forces) and possibly suboptimal condition of the pilot, such as injury or disorientation. The low correlations between size and strength indicate that size cannot be used as an indicator of sufficient strength.

ACKNOWLEDGMENTS

This study was performed at the Armstrong Laboratory, formerly known as the Armstrong Aerospace Medical Research Laboratory (AAMRL), at Wright-Patterson Air Force Base, Ohio. The research seat was designed by Mr. Nilss Aume (AL/CFHD). The data were collected by Ms. Cheryl Lai and Ms. Jill Parks of the University of Dayton Research Institute (UDRI). The data acquisition computer was programmed by Mr. Van Thai (UDRI).

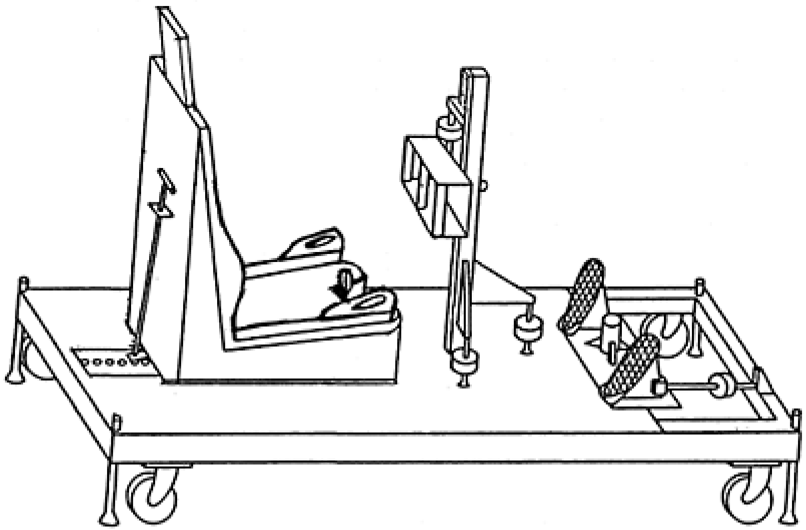

Figure 1. Pilot Strength Test Device for measuring static strength forces for operating aircraft controls. The device has adjustable seat, electronic load cells which sense static forces on stick- and wheel-type aileron and elevator controls, rudder pedal controls, and ejection controls. The ejection handles have a limited-deflection spring mechanism in the linkage to provide an accurate breakout force and force/ displacement, but the total force applied to the handles was measured, regardless of the handle displacement.

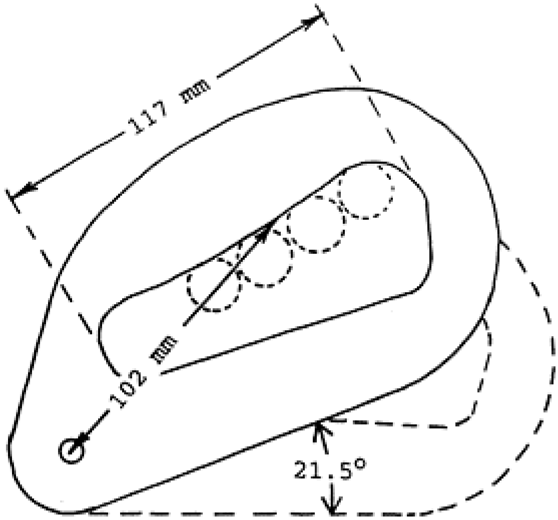

Figure 2. Simulated ACES II Side-pull Ejection Handles have a breakout torque of 13.1 N m (116 in-lb) and rotated 21.5 degrees when a torque of 19.8 N m (175 in-lb) was applied.

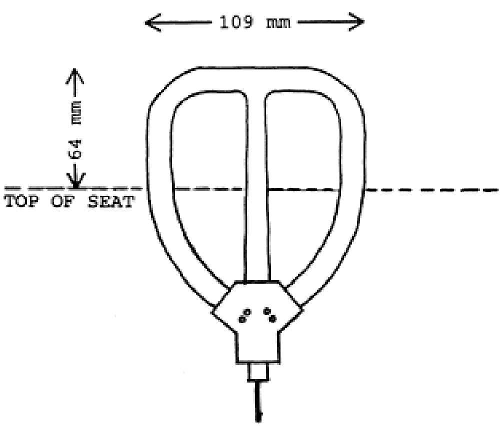

Figure 3. Simulated ACES II Center-pull Ejection Handle has a breakout force of 93.4 N (21 lb), a displacement of 0.046 m (1.8 in) when 218 N (49 lb) of force were applied.

INTERRELATIONSHIP BETWEEN STRENGTH, ENDURANCE, BODY COMPOSITION AND CATHEXIS, AND PERFORMANCE ON SELECTED ARMY TASKS BY WOMEN SOLDIERS.

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The purpose of this study was to determine the relationship between laboratory measures of strength and endurance, body composition, body cathexis and five field tasks considered by military experts as representative of an infantry soldier’s work, These tasks, unanimously approved of by the Forces Mobile Command of the Canadian Armed Forces, consisted of casualty evacuation, maximal effort jerry can task, ammunition box lift task, maximal effort slit trench digging task and weight load march. The subjects, 45 women (aged 19 to 36 years), were employed as combat support personnel at CAF, Calgary, Alberta. Results showed that these field tasks were significantly ($p \leq 0.05$) correlated to the laboratory strength and endurance, body composition and body cathexis tests.

INTRODUCTION

Women are entering nontraditional occupations in increasing numbers. With the reclassification of trades and occupations by the Human Rights Tribunal as of February, 1989, women in the Canadian military, theoretically can participate in all levels of combat- artillery, infantry and armoury. However, due to the common perception that women have insuf f icient strength, they continue to be discriminated against as suitable candidates for jobs that entail manual labour (Felton, 1990; Messite and Bond, 1988; Hunt, 1979). Hence this investigation elucidated some of the physiological parameters that characterized combat support personnel who participated in a variety of physically demanding tasks considered representative of an infantry soldier.

METHOD

Forty-five women volunteered to participate in a series of laboratory tests which included muscle strength and endurance and body composition and five field tests: casualty evacuation, slit trench digging, 16 km march, ammunition box lift task and maximal effort jerry can task. The subjects also responded to a questionnaire revealing satisfaction or dissatisfaction with various parts and processes of the body (Secord and Jourard, 1953).

The strength tests incorporated both static, including handgrip, trunk flexion and extension, arm flexion and dynamic components- arm flexion, trunk flexion and extension, leg extension, trapezius lift, bench press and knee flexion and extension. With the exception of handgrip strength which was determined using a Harpenden handgrip dynamometer and knee flexion and extension where the Cybex dynamometer at an angular velocity of 30° was implemented, the dynamic strength tests were conducted on the isokinetic electric dynamometer (Chahal, 1988; Singh, 1991) at a cable velocity of 13 cm/s (Okoro, 1987). The isometric endurance tests, performed on a weightloaded bar and using a Harpenden handgrip dynamometer, included both arm flexion and handgrip endurance. The dynamic muscular endurance tests (arm flexion, trapezius lift and trunk extension) were conducted on a free weight dynamometer. Wherever appropriate, carrying angle of the elbow was held at 110° and resistance encountered was 20 kg corresponding to the weight of a box loaded with ammunition.

Percent body fat, fat and lean weight were determined by hydrostatic weighing. To help mitigate error in this procedure, the subject sat in the tank on a chair suspended from a load cell. This load cell was attached to a computer. Following entry of the appropriate data, the computer calculated body composition based on the formula of Brozek et al. (1963). The Hologic QDR 1000 X-ray Bone Densitometer was used to scan bone density (g/cm^2) of the lumbar and femoral neck region.

Body image was discerned by using the Body Cathexis Scale (Secord and Jourard, 1953). This is a 40 item questionnaire which elucidates an individual's attitudes about their body parts and processes. Balogun (1986) stated that this scale not only reflects construct validity but also is a reliable psychological measure.

Demographic features including age, height, weight and girth measurements of the chest, waist and hips were recorded for each subject. Additionally, the subjects completed consent forms and questionnaires (including the health appraisal questionnaire, CF Express, 1989) which pertained to both the laboratory procedures and field tasks.

Field Tasks

a. Maximal Effort Slit Trench Digging Task

Subjects, using a standard issue shovel, were to dig gravel from one slit trench simulator into another as quickly and as efficiently as possible. The amount of gravel shifted was 0.5 cubic meters. The dimensions of the slit trench simulator were 1.8 m×0.6 m×0.45 m.

b. Maximal Effort Jerry Can Task

Subjects were to carry three full jerry cans weighing 35 Kg., one at a time, over three shuttles and empty each jerry can, in a controlled manner, into a funnel located at a height of 1.3 m. Distance covered was 35 m.

c. Ammunition Box Lift Task

Subjects were required to lift 48 boxes, one at a time, from the floor to a 1.3 m high counter (corresponding to the height of an army truck bed). The weight of each box was 20 kg. The subjects were instructed to moderate their effort so that they were working at a heart rate corresponding to 70% of their actual VO2 max. {Maximum oxygen uptake values were originally obtained from the laboratory treadmill test}.

d. Casualty Evacuation

Subjects were to evacuate another woman of her approximate body height and weight a distance of 100 m. They were to use the “fireman’s carry” technique and were instructed to exert maximum voluntary effort.

e. Weight Load March

Subjects marched at a pace of 5.33 km/h in full fighting order carrying a back pack weighing 24.5 kg. The maximal distance covered was 16 km or until the individual could no longer maintain the pace.

The statistical methods of Pearson moment correlations ($p \leq 0.05$) and multiple regression were implemented to discern the relationship between the physiological and psychological parameters measured in the laboratory and the subject’s level of performance while participating in the field tasks.

RESULTS

Maximal Effort Slit Trench Digging Task

Muscle strength testing revealed that the subjects who performed the maximal effort digging task with the most proficiency tended to reflect a significant relationship with both static and dynamic measures of trunk flexion and extension. The lower body strength measure, average knee flexion and upper body strength measures dynamic arm flexion, handgrip strength and bench press were significantly correlated to the performance of this task. Those measures of endurance significantly related to this task were trapezius lift, static arm flexion and handgrip endurance.

The body composition variables which were correlated to the maximal effort digging task included both lean weight ($r=-.4150$) and bone density of the femoral neck (trochanteric region) ($r=-.5306$).

Four body cathexis variables were significantly related to the performance of the maximal effort digging task. These included muscle strength, physical stamina level, energy level and body cathexes.

Maximal Effort Jerry Can Task

Alike the woman who excelled at the maximal effort slit trench digging task, those women who were adept at the maximal effort jerry can task showed significant correlations between this field task and static and dynamic trunk flexion and static arm flexion and trapezius lift endurance measures. The only demographic variable which was relevant to this task was chest girth where r=−.3386. The psychological parameter which was significantly correlated to the performance of this task was hip cathexis (r=−.3003).

Ammunition Box Lift Task

Analogous to both the slit trench digging and maximal effort jerry can tasks, those women who reflected superior performances in the ammunition box lift task were inclined to show higher force outputs for both static and dynamic trunk flexion. These subjects were distinguished from those who performed the other two tasks in that they also evinced a significant correlation with dynamic trunk extension. Multiple regression analysis showed that the relationship between trunk flexion and the ammunition box lift task was strong enough to be predictive of task performance. The lower body strength measures which were significantly correlated to this task were knee flexion (r=−.4403) and extension (r=−.3510). The only upper body strength measure which reflected a significant relationship was left handgrip strength (r=−.2821) and of the endurance measures, only handgrip endurance was significantly correlated to the ammunition box lift task.

Chest girth was significantly correlated to performance of this task. This characteristic also typified those women who best accomplished the maximal effort jerry can task. Other relevant demographic variables included waist girth, waist/hip ratio and age where (r=−.3644, r=−.3471 and r=− .3229 respectively) with the ammunition box lift task.

Of the relevant body composition indices, bone density of the femoral neck (Ward's triangle) was significantly correlated with the ammunition box lift task (r=−.3413). Body weight (r=−.3636) and lean weight (r=−.5188) were also significantly related to the performance of this task.

An analysis of the psychological parameters associated with the ammunition box lift task revealed that a significant relationship existed between physical stamina, posture and shoulder cathexes and performance of this task.

Casualty Evacuation Task

Those women who tended to evince a stronger performance in the casualty evacuation task also showed a greater force output of both static (r=−.4401) and dynamic (r=−.5813) trunk extension. In conjunction, they showed a significant correlation (r=−.4057) between dynamic leg extension and task performance.

Demographic variables indicated that height (r=−.4517), hip girth (r=−.3340) and BMI (r=.2939) were associated with the casualty evacuation task. A statistical analysis of body composition indices showed that those women characterized as having a higher fat/lean ratio tended to perform more poorly. This was reflected by percent body fat and fat weight where significant correlations with task performance were r=.4020 and r=.3919 respectively.

The psychological variables significantly correlated to the execution of this task were muscle strength and energy level cathexes.

Weight load March

Those women who demonstrated proficiency in the 16 km march tended to show strong trunk flexion force outputs. The only lower body strength measure significantly correlated with this task was left knee flexion where r=−.2710. No other demographic, body composition nor psychological variables were affiliated with performance of this task.

CONCLUSIONS

Trunk flexion and extension were significantly correlated to the performance of two out of the five field tasks, namely the slit trench digging and ammunition box lift tasks. Trunk flexion by itself was affiliated with two different tasks- the maximal effort jerry can task and the 16 km march. In contrast, trunk extension was associated with the casualty evacuation task.

Lower body strength measures were significantly associated with four out of the five tasks- the one exception was the maximal effort jerry can task. Upper body strength and endurance measures figured prominently in three of the tasks, namely the ammunition box lift, slit trench digging and maximal effort jerry can task.

Body composition analysis showed that whereas fat weight tended to be a deterrent in the execution of the casualty evacuation task, a preponderance of lean weight seemed to assist those individuals in the performance of the ammunition box lift and slit trench digging tasks. Interestingly, bone density of the femoral neck was significantly affiliated with the performance of both these tasks. This may be explained by the general recognition that there is a positive relationship between muscle mass and bone density (Doyle et al., 1970) and a somewhat less definitive association between muscle strength and bone density (Martin and McColloch, 1987; Sinaki et al. 1986; Lanyon and Rubin, 1984; Nilsson and Westlin, 1972).

When demographic features were evaluated it was found that those women characterized by larger chest girths tended to perform the maximal effort jerry can and ammunition box lift tasks more adroitly. Additionally, those subjects who were characterized by a larger waist girth, a higher waist/hip ratio and who were older inclined to be more successful at executing the ammunition box lift task.

The greatest number of cathexes variables were associated with the slit trench digging task where women reflected positive sentiments about their muscle strength, physical stamina level, energy level and overall satisfaction with body parts and processes. Alike those women who performed well on the slit trench digging task, those women who tended to excel at the ammunition box lift task also reflected a positive sentiment about their physical stamina levels. Also they expressed a positive attitude about their posture and shoulders.

The subjects who could best accomplish the casualty evacuation task tended to reflect positive feelings about their muscle strength and their energy level. Those who were better at executing the maximal effort jerry can task expressed satisfaction with their hips. No variables reflecting body image were affiliated with the 16 km march.

The two tasks exhibiting the greatest number of significant correlations with the laboratory measures were the slit trench digging task and the ammunition box lift task. These two tasks provided good measures of muscle strength and endurance. Hence, these were the best tasks overall to give an accurate impression of a woman's strength and endurance capabilities and thereby her ability to perform work of this nature. In contrast, the laboratory measures significantly correlated with the 16 km march were few in number denoting that performance on this particular task was not a very good indicator of strength and muscular endurance capacity.

An analysis of body composition indicated that lean weight seemed to be important in the performance of slit trench digging and the ammunition box lift task. Fat weight did not appear to be a handicap with the exception of the negative impact it appeared to have on the performance of casualty evacuation. In contrast larger women, at least larger in the sense of girth measurements seemed to excel at tasks such as the ammunition box lift task where those women with a larger chest and waist girth and waist/hip ratio tended to do better than others. Likewise, those subjects with a greater chest girth were inclined to perform better on the maximal effort jerry can task.

Those women who excelled at the slit trench digging were inclined to reflect a greater number of positive sentiments about their body parts and processes. The other group who appeared similarly positive about their physical stamina, posture and shoulders were those who tended to perform the ammunition box lift task in a superior manner. No cathexes variables were significantly associated with the 16 km march. Thus, from muscle strength, muscle endurance and psychological perspectives, performance on the slit trench digging and ammunition box lift tasks appears to be the best indicator of a female soldier's job proficiency.

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SOLDIERS' PERFORMANCE IN CHEMICAL PROTECTIVE GEAR

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Studies were conducted to investigate the impact of chemical protective clothing on soldiers' performance, aside from thermal stress effects. The clothing had a negative effect on such basic performance parameters as vision, speech intelligibility, body mobility, manual dexterity, and psychomotor coordination. It was also found that protective items that are functionally-comparable may vary in their impacts on performance.

INTRODUCTION

Clothing worn by industrial workers who must be protected against exposure to toxic chemicals commonly includes a respirator, a hood, an overgarment, overboots, and handwear (Schwope and Hoyle, 1985). Comparable chemical protective items have been developed for use by U.S. military personnel. The clothing encapsulates the body, isolating the wearer from toxic hazards. However, the materials used for this purpose have high thermal resistance and low moisture permeability. Therefore, the normal heat-dissipating mechanisms of the body are severely constrained, particularly sweat evaporation (Martin and Goldman, 1972). As a result, there is a risk of heat-induced illness even in temperate ambient environments (Paull and Rosenthal, 1987). Breathing resistance encountered when using a respirator can also be a physiological burden, especially during heavy work (Raven et al., 1979).

Much of the research associated with protection in a chemical environment has focused on alleviating the negative physiological consequences associated with use of the protective clothing (Goldman, 1988). Although physiological stress is a major concern, the findings from several studies suggest that the protective items themselves, independent of the thermal burden they represent, can interfere with an individual's performance. For example, Cox and Jeffers (1981) investigated the effects of protective clothing on U.S. Air Force ground crews who prepared planes for sorties. Considering only the time spent working, the authors found that the crews required an average of 72% longer to get a plane ready for a flight when wearing chemical protective outfits than they did when wearing normal duty uniforms. A study by Waugh and Kilduff (1984) also provided evidence of impaired performance attributable to chemical protective clothing. Waugh and Kilduff examined the effects of wearing a respirator and hood on performance of a short-duration (≤60 s), sedentary task that involved repairing a missile sighting device. Experienced repairmen took about 18% longer to complete the job when wearing a respirator than they did when bareheaded.

The findings from these investigations suggest that chemical protective clothing imposes not only a thermal burden, but a "mechanical" burden also. My colleagues and I conducted a series of laboratory studies to gain an understanding of the effects that chemical protective ensembles have on human performance, aside from those in the physiological realm. The studies were designed to minimize the contributions of physiologically-stressful factors, such as extreme temperatures, elevated activity levels, and extended work bouts. The research included testing of basic performance parameters: vision, speech intelligibility, body mobility, manual dexterity, and psychomotor coordination. Twelve subjects were selected for each study from a pool of U.S. Army enlisted men. Among the clothing components used were chemical protective items presently supplied to U.S. Army personnel and functionally-comparable items being considered for adoption. Some results of the studies are presented here along with plans for future research. Additional findings are in Bensel (1992), Bensel et al. (1987), and Bensel et al. (1992).

STUDY 1

These experiments were carried out with the Army's present chemical protective gear and with street clothes (i.e., the Army's normal duty uniform). The chemical protective items were tested individually and in various combinations in order to isolate the effects of each item and to determine the extent to which the items interact to impact performance.

Perimetric measurements of the visual field made monocularly indicated that the full-face respirator with its separate lens for each eye restricted the visual field substantially compared with the bare head. The difference was particularly evident in the nasal and the inferior portions of the visual field (Figure 1). Wear of the respirator and its hood, which covers the head and shoulders, also affected speech intelligibility, as assessed with the Modified Rhyme Test (House et al., 1965). In trying to identify the monosyllabic words, bareheaded listeners made almost three times more errors when the person speaking wore the respirator and hood than when the speaker was bareheaded. Use of the respirator and hood by listeners and the speaker further increased the number of errors.

Measurements with a gravity goniometer of the maximum extent of angular body movements indicated that limitations were imposed by one or more of the chemical protective items. Data from tests of head flexion and rotation while

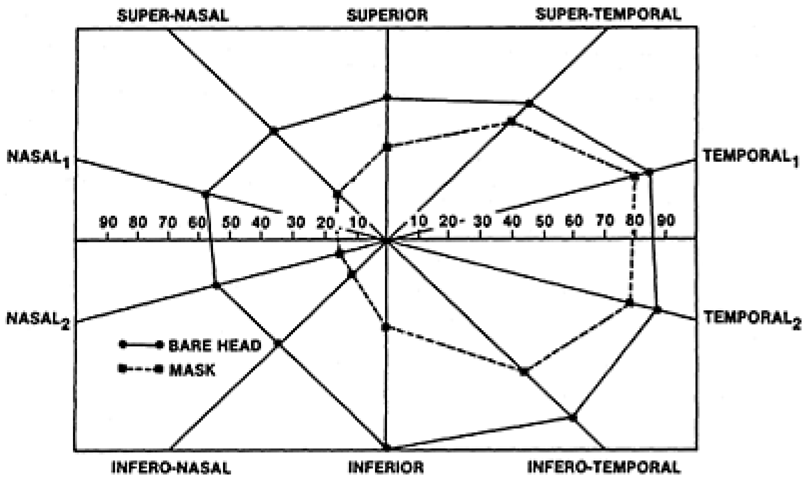

Figure 1. Mean visual field of both eyes combined (N=12).

Table 1. Mean scores on tests for three clothing conditions (N=12).

Test	Street Clothes	Chemical Overgarment	Complete Chem. Ensemble
Head Flexion (deg.)		141 139	120
Head Rotation (deg.)		156 148	106
O'Connor Finger Dexterity (s)		74 73	106
Pursuit Rotor ToT (s)		104 100	95
Railwalk (cm)		202 169	135

Note. Means connected by the same line were not significantly different (p>.05) in Newman-Keuls multiple comparison tests.

wearing street clothes, the protective overgarment alone, and the complete chemical protective ensemble are presented in Table 1. Both head flexion and rotation were restricted with the complete ensemble relative to the extent of the movements with street clothes or with the overgarment alone. Data from the other clothing conditions included in the study indicated that the respirator was the item that limited these movements. The facepiece of the respirator ends well below the wearer's chin, restricting the extent of head flexion; the prominent ventro-lateral surfaces of the facepiece restrict head rotation.

Time to complete a test of fine finger dexterity, the O'Connor Finger Dexterity Test (Hines and O'Connor, 1926), was also extended significantly when the complete protective ensemble was worn compared with times in street clothes or in the protective overgarment only (Table 1). Not surprisingly, the protective gear contributing most to the poor dexterity performance was the gloves. Relative to use of the overgarment alone, mean test completion time was increased by 47% when the gloves were worn as well.

The respirator also influenced the dexterity test, but not in a straight-forward fashion. Times with the respirator and the overgarment were slightly longer, by 5%, than those with the overgarment alone. However, use of both the respirator and the gloves increased times by 72% relative to use of the overgarment alone. Thus, the combined effect of the handwear and the headgear was greater than the sum of the effects when each was worn individually. There was a similar, but less extreme, finding for two visual-motor coordination tests, the Pursuit Rotor and the Railwalk (Table 1). In the case of the Pursuit Rotor, which involved tracking a moving target with a stylus held in the hand, time on target (ToT) decreased slightly when either the respirator or the gloves were used relative to use of the overgarment alone. Wear of both the respirator and the gloves resulted in a performance decrement greater than the sum of the decrements associated with each item alone. The Railwalk, a test of the distance travelled along a narrow rail in heel-to-toe fashion, reflected a similar interaction between the respirator and the overboots.

The results of this study provided evidence that chemical protective clothing has a negative effect on basic performance parameters, even in the absence of physiologically-stressful conditions. The data acquired also served to define the relative contributions that individual chemical protective components make to various types of performance processes. The question that was considered in the next study is whether or not chemical protective items that are functionally comparable, but differ in design or in use of materials, have equally negative impacts on performance.

STUDY 2

The testing protocol employed in Study 1 was also employed here. Data were acquired on the Army’s present chemical protective gear and on comparable items, prototypes from industry under consideration for future use. These particular “developmental” items did not differ from the “standard” items in a systematic fashion. They were used because they were available in sufficient quantities and sizes to outfit the test subjects.

Several of the experiments yielded differences between the standard and the developmental gear, and the better performance was associated with the developmental. Perimetric measurements revealed that the developmental respirator, which had lenses that were wider than those on

Table 2. Mean scores on tests for two chemical protective ensembles (N=12).

	Ensemble	
Test	Standard	Developmental
Head Flexion (deg.)	112	116
Head Rotation (deg.)	110	119
O’Connor Finger Dexterity (s)	136	141
Pursuit Rotor ToT (s)	95	94
Railwalk (cm)	133	147

Note. Means connected by the same line were not significantly different (p>.05) in correlated t tests.

the standard, offered a greater field of view in the temporal and the nasal regions. There were no differences between the standard and the developmental items on the test of speech intelligibility. However, on several of the body movements, the ranges of motion were greater when the developmental items were being worn. Among the movements was head rotation. It appeared that the superior performance with the developmental respirator was due to the fact that the ventro-lateral surfaces of the facepiece were not as prominent on the developmental respirator as on the standard. Data for the head rotation and head flexion movements are presented in Table 2, along with scores on the finger dexterity and the psychomotor coordination tests. It can be seen that Railwalk performance was better in the developmental than in the standard attire. This may be attributable to the greater field of view afforded by the developmental respirator. Also, the developmental overboots conformed to the shape of the underlying shoes and the standard overboots did not. Thus, the developmental overboots may have posed less of a tripping hazard than the standard.

The findings from this study revealed that protective items serving the same function are not necessarily equal in their deleterious effects on performance. However, because the functionally-comparable items did not differ in a systematic fashion, little was learned regarding the impact that particular material and design characteristics have on performance. Research has been initiated to address this issue, and the work done to date is reported in Study 3.

STUDY 3

Of all the chemical protective components, handwear is probably the item most often associated with inability to

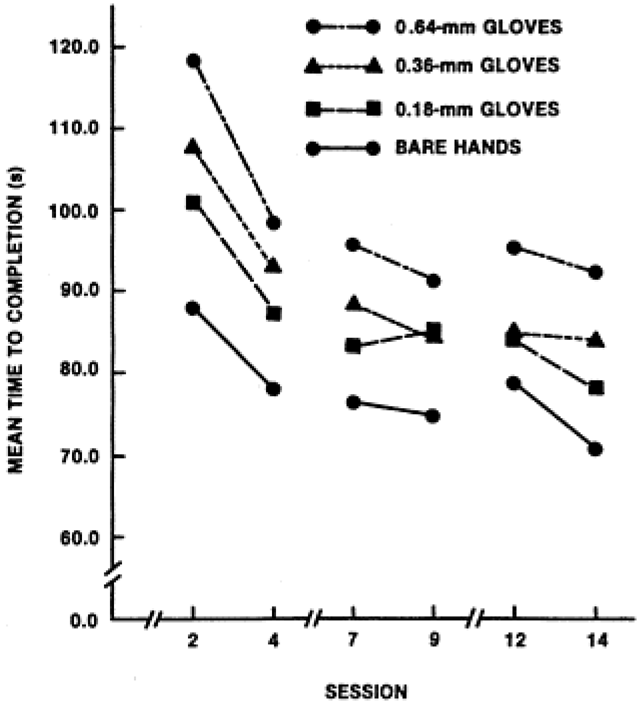

Figure 2. Mean times on the O'Connor Test (N=12).

work efficiently. Users complain that it is bulky and thick (Cox and Jeffers, 1981). The Army's present handwear, a five-finger glove, is made of butyl rubber with a nominal thickness of 0.64 mm. In this study, three types of butyl gloves were used, identical in all respects except thickness. In addition to the 0.64-mm gloves, gloves with nominal thicknesses of 0.18 mm and 0.36 mm were tested. Subjects performed the O'Connor Finger Dexterity Test and five other tests of manual dexterity once a day for 14 week-days while barehanded and while wearing each thickness of butyl glove. In order to assess the pure handwear effects, no other chemical protective items were used.

Analyses of times to completion yielded a significant ($p<.05$) main effect of handwear and of session on each manual test. The mean completion times for the O'Connor Test at the Tuesday and the Thursday sessions of each week of testing are presented in Figure 2. These data are representative of the relationships among handwear conditions over sessions on the other tests; mean times were shortest with the bare hands and increased with glove thickness. Performance on all tests improved over the early sessions for the bare hands and for the gloved-hand conditions. Scores with the gloves improved to the extent that they approached or surpassed the levels of performance achieved with the bare hands during the early sessions. Regression analyses carried out on the means for each subject across the last three sessions revealed a linear increase in times to test completion as a function of increases in handwear thickness.

This study established that there is an ordered relationship between thickness of the gloves and efficiency in completing manual tests. Thus, from the perspective of worker productivity in a toxic environment, thickness is an important characteristic on which to base handwear selection. Further research is planned to quantify the effects on performance of systematic changes in other items of chemical protective apparel.

DISCUSSION

In this series of studies, it has been seen that chemical protective clothing represents a mechanical burden to the wearer. Given this situation, attempts to enhance the functioning of users of this gear should not focus solely on alleviation of thermal stress. They should include as well alleviation of encumbrances on basic sensory processes vital to the successful performance of the user. Through the studies reported here, it has also been found that chemical protective clothing items serving the same function need not have equally deleterious impacts on basic performance processes. The task now at hand is to identify the particular clothing characteristics that affect performance and the manner in which performance varies as a function of systematic variations in these characteristics. A start was made in the investigation of the effects of handwear thickness on manual dexterity.

The studies to date have been conducted in a laboratory under controlled environmental conditions. The extent to which the findings may generalize to soldiers in military field situations is not known. Plans for future research entail collecting data in the field. The effects of chemical protective gear on walking and other locomotor activities will be investigated using a video- and computer-based system for motion analysis. Frame-by-frame analysis of the video images will reveal the extent to which chemical protective gear constrains a soldier's movements. Of particular interest is the impact of the somewhat bulky chemical protective overgarment on walking and marching gait. A second area to be addressed in the field research involves training in the use of protective gear, a particular concern for military operations. At the present time, few soldiers wear chemical protective attire in the course of their daily work. However, all soldiers are expected to be able to function effectively in the gear should the need arise. In the course of conducting the studies reported here, it was found that individuals can substantially improve their efficiency in performing manual manipulations, given practice performing in the chemical protective gloves. Field studies are planned to investigate the benefits, if any, to be derived from working daily in the chemical protective ensemble. Part-whole training will be studied in this research. It is possible that better performance levels can be achieved by building upon skills developed while wearing individual protective items than can be achieved by training only in a complete ensemble.

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DEVELOPMENT OF JOB PERFORMANCE STANDARDS FOR MUSCULARLY DEMANDING MILITARY TASKS

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Without objective standards, inadequate strength may contribute to losses during combat or casualties. Most military jobs involve a mix of technical and muscular tasks, thereby increasing the complexity of the problem. Methods to specify criterion tasks and performance standards were developed. Results of testing men and women are described. Issues of costs of nonimplementation, increased capablity from training, and notions of physical fitness are addressed.

INTRODUCTION

To reduce injuries and increase productivity, in jobs with substantial muscular demands, there are typically three approaches: (1) Selection (of most capable workers), (2) training, and (3) design (of job procedures, tools, or environment). This paper describes procedures that were developed to set performance standards as the basis of a selection approach. Weaker workers tend to have a higher risk of on-job injury than do stronger ones (Chaffin et al., 1977). Supposedly then, injuries could be minimized simply by selecting the strongest workers. But the problem of determining just how much strength is required for a particular job task is not so simple.

Although both military and civilian organizations have a common objective to minimize injuries from handling materials, certain differences in function may pose more complex problems in the military environment. In the field or aboard ship, availability of powered devices is limited. And, given a mix of technical and muscular tasks, the frequency and duration of performing the most muscularly demanding tasks is quite irregular. Further, as more women enter muscularly demanding jobs, the problem becomes increasingly complex, given the wide separation of strength scores between men and women.

METHOD

Performance standards were developed in a five-phase project: (1) Survey of all Navy muscularly demanding tasks, (2) field visits to

The opinions expressed in this paper are those of the author, are not official, and do not necessarily reflect the views of the Navy Department.

select criterion tasks and document standards of performance, (3) development of instrumentation to measure performance on the criterion tasks, (4) Development of a strength test battery (STB) to predict capability to perform the criterion tasks, and (5) validation of the STB's predictability. The survey identified carrying, lifting, and pulling efforts as the most common muscularly demanding tasks in the shipboard environment (Robertson and Trent, 1985).

Selection of Criterion Tasks

After survey results were reviewed, operational sites (ships and carrier-based squadrons) were visited to: (1) Identify the most relevant task for each occupation and for common shipboard tasks, (2) measure performance components of each of those tasks, and (3) document the minimum time to accomplish each task productively. The performance components measured were: Force (by dynamometer) to lift, carry, push, pull, or torque an object; distance and direction that the object was moved; and configuration of the grip points at which the object was handled. Incumbents identified and ranked the most demanding tasks for their job. It was not feasible, however, to select the most demanding task as the criterion, because most jobs had a mix of both technical and muscular requirements. Thus, effective use of available personnel technical resources would be reduced, if the most demanding tasks were used.

"Alpha" vs. "Bravo" Tasks

A distinction was made between two kinds of tasks, called alpha and bravo. An alpha task was defined as a task that all members entering a work group: (1) Were expected to perform it, and (2) must be capable of performing it. The criterion alpha task also represents the capability to perform all other alpha tasks for that specific occupation or shipboard job. A bravo task was defined as a task more demanding than alpha tasks, that some members of the work group, but not all, must perform. For example, in the Aviation Boatswain's Mate job of directing carrier-based aircraft from flight deck to elevators to hangar deck, some members must be capable of running, while wearing cumbersome protective suits, to a crashed, burning aircraft to extricate crew members. The task requires enormous strength; few members can or are needed to perform it; so it was defined as a bravo task, and not used as the criterion for that job.

Work Output (WKO) as Performance Standard Index

A WKO index was developed so that the performance standard for each type alpha criterion task could be simply specified. The WKO index was calculated from force times distance divided by time, or from only one or two of those variables if the other ones were constant. Table 1 shows WKO indexes for some of the tasks. For example, the WKO of 1.33 for aviation mechanic applies only two of the variables, feet per second, because the force (100 pounds) is constant. Most performance tests of team tasks were designed to measure the separate performance of one member of the team, such as one of a four-member bomb loading team. Performance of some shipboard tasks, however, was tested with 2-person teams (matched with similar strength scores), such as for stretcher carry. (See Robertson and Trent, 1985, for details of instrumentation and procedures.)

Table 1. Work Output (WKO) as Performance Standard Index for Criterion Tasks

Job	Task	Performance Standard WKO Index
Aviation mechanic	Carry fuel tank (TNKARY): Carry one end of aircraft external ("drop") tank (200 pounds empty, thus 100 per person), 200 feet in 150 seconds	1.33 ft/sec
Aviation fuels	Drag fuel hose (FUELHS): Drag refueling hose across flight deck (210 pound pull force by two persons), 80 feet in 80 seconds	1.00 ft/sec
Ordnance	Load bomb (BOMBLD): Lift one fourth of 555 pound from ground to attach to aircraft wing bomb rack	140 lbs
Ship electrician	Rig (RIGCBL) 3-inch diameter electrical power cable (per person, 80 pounds lift/ carry and 100 pounds pull force), carry/ pull 40 feet in 75 seconds.	.53 ft/sec
Shipboard	carry stretcher (STRECH): Carry stretcher (25 pounds) with victim (166 pounds) up and down ship ladder in 150 seconds.	150 sec (maximum)
Shipboard	Operate fire hose (FIREHS): Oscillate (through 90 degree arc) 2 1/2 inch nozzle for 40 right/left sweeps per minute.	60 sec

Performance Testing and Subjects

A basic strength test battery (STB) (Robertson, 1982) and the criterion tasks were administered to Navy recruits (259 women and 274 men) who were near the end of their recruit training.

RESULTS AND DISCUSSION

Performance scores for four of the criterion tasks and two of the STB static strength measures (armpull and armlift) are shown in Table 2. The scores reflect the typically wide separation (and thus small Tilton, 1937, percentage overlap) between women's and men's strength scores. The relatively large percentages of women below standard for these kinds of tasks appear to be consistent with other similar studies. For example, in tests of lifting tasks for military jobs (Celentano et al., 1984), 50 to 100 percent of the women were below performance requirements on 6 of 10 criterion tasks, compared with zero or small percentages of men. The Navy STB was found to be a good predictor of the criterion tasks—validities for separate gender groups in the .30s to .50s, and much greater for the combined group—in the .60s to .80s. For selection fairness, however, separate regression lines and cut-scores should be used for men and women (Robertson and Trent, 1985).

Although these methods to set standards have been demonstrated, they have not been implemented. Perhaps it is because (1) costs of injuries or nonperformance have not been adequately demonstrated, or (2) competing concerns for selection solely on technical abilities have predominated.

Table 2. Performance Scores for Navy Men and Women

	Men (M)		Women (W)		Means W/M	Tilton[a] %	% below WKO[b] Perf. std.	
Test	Mean	SD	Mean	SD	%	Overlap	Men	Women
Criterion[c]								
TNKARY	6.3	1.24	2.7	2.02	38	27	00	32
BOMBLD	132.7	25.73	66.2	15.12	50	10	50	100
FUELHS	4.3	1.70	0.7	0.52	15	10	01	77
RIGCBL	2.6	1.20	0.3	0.54	13	19	04	81
STB[d]								
Armpull	150.5	24.48	88.6	16.72	59	14		
Armlift	107.6	17.66	63.5	12.09	59	14		

Notes.

1. n=274 men and 259 women recruits.
2. Perf. std=performance standard, TNKARY=carry fuel tank, BOMBLD =load bomb, FUELHS=drag fuel hose, RIGCBL=rig power cable, STB =strength test battery, armpull and armlift=static strength by dynamometer.

[a]Tilton (1937) index of overlap.
[b]See WKO standards in Table 1.
[c]Scores are in WKO index measures.
[d]Scores are in pounds force.

Costs of Nonimplementiation

There is some preliminary evidence that costs related to strength differences may or could be substantial. For example, during the criterion task performance testing of Navy recruits (described above), injury data were recorded on 8 of the 15 test days. During those 8 days, 21 of 199 (10.6 percent) women and 2 of 223 (0.9 percent) men were injured. Most injuries occurred with equipment carry tasks on ship decks or ladders. These results are considered to be very conservative, because (1) safety lines were used, (2) safety monitors were positioned, and (3) there were no pitching or rolling decks.

There may also be hidden retraining costs from "occupational migration"—changing from one job type to another. In an Army study that compared migration out of jobs with light vs. heavy muscular demands, men's migration out of jobs with the heavy demands was nearly double (34 percent from light, 57 percent from heavy), and women's were more than triple (23 percent from light, 75 percent from heavy) (Kowal, 1983).

Technical vs. Muscular Abilities

Given the mix of both technical and muscular demands in many military jobs, the concern for selecting on technical requirements appears to predominate. In the demonstration of the WKO index to specify standards, varying percentages (across criterion tasks) of workers were below standard, particularly women, thereby preventing use of their technical abilities. None the less, the effects of inadequate strength resulting in rapid fatigue in sustained combat or casualty conditions, in turn contributing to additional losses of life, weapons, or battles—is a crucial concern.

There is evidence that increased muscular demands (of frequency or load) does decrease endurance (Genaidy and Asfour, 1989; Asfour et al., 1991). Further, in sustained combat, the relationship may not be linear (see hypothesized relationship in Figure 1). Personnel with marginal strength (i.e., near the performance standard) may fatigue at an accelerating rate. To address this concern, a prudent approach might be to combine: (1) Selection procedures, including judicious specification of alpha type tasks, with (2) endurance training to increase capability in sustained performance of specific alpha and bravo type tasks for a particular job.

There is also recent evidence that such specific training in manual materials handling can contribute to increased capability—nearly 100 percent increase (Genaidy et al., 1989; Genaidy, 1991). Such training could be incorporated into the curriculum of military basic technical schools (similar to present hands-on practice on technical tasks) thereby substantially reducing percentages below standard on criterion tasks.

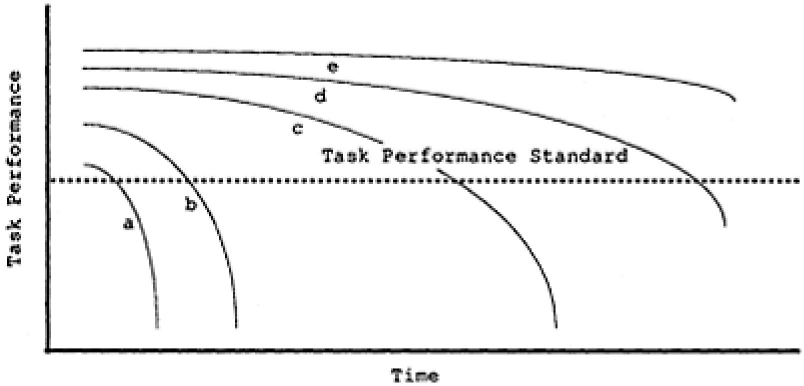

Figure 1. Hypothesized relation of strength to sustained effort. (Strength capability: a=low, …e=high.)

Notions of Fitness

Another competing concern is that of the notion of physical fitness, body fat, and health vs. muscular capability to perform actual job tasks. Fitness test scores, such as for the Navy physical readiness test (PRT), do not correlate with task performance scores (unless men's and women's scores are combined to spread variance). Likely, it is because the fitness test activities involve movement only of the body (dynamic measures such as running and calisthenics), rather than applying force to external objects (of the job task). The best predictor for the Navy criterion tasks was an upper torso static strength measure, armpull (Robertson and Trent, 1985). In a few unique Navy jobs, however, that involve rapid, vigorous movement of the body, such as underwater demolition team (UDT) tasks, dynamic measures were the better predictors (Robertson and Trent, 1983). As to body fat, although it tends to correlate negatively with running speed, it was found to correlate positively with three aptitude measures (math, electricity, and science) and education level, in a sample of 275 male recruits (Robertson, 1983)--the qualifications most needed for technical tasks.

CONCLUSION

Many useful methods have been demonstrated. Future research needs to demonstrate ways to incorporate the most useful or relevant aspects of each for task-relevant combat effectiveness.

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HUMAN FACTORS OF VISUAL DISPLAY SYSTEMS FOR THE INDIVIDUAL SOLDIER

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The Army is focusing on advanced technologies, such as helmet mounted displays (HMDs), to enhance soldier performance. Although there has been extensive research for aviators, little work has been done on HMDs for the dismounted soldier. The operational environment and tasks are quite different for the infantryman. There is a need to examine the information needs of the soldier and how HMDs might be effectively used in ground combat. This paper outlines cognitive and psychomotor performance issues to be addressed in preparation for human factors studies on information displays for the soldier.

INTRODUCTION

In the rapidly changing conditions of battle infantry commanders and their soldiers have an urgent need for information (Dunnigan, 1983). They need to know friendly and enemy locations and dispositions, operational orders, and how best to complete a particular action. They need to coordinate actions between themselves and other units. Consider the following example.

> "Tonight," [the lieutenant].. said quietly, "we are sending out an ambush."
>
> It was near dusk, and the lieutenant had his map spread out in the dirt in front of a foxhole. His squad leaders were grouped in a circle around him, watching where he drew X's, taking notes. [The lieutenant].. pointed at a spot on the map, circled it, and said, "We'll be bushing this trail junction. Headquarters has some pretty good intelligence that [the enemy's] in the neighborhood. Maybe we'll nail him this time."
>
> He drew two red lines on the map. "First squad will set up along this paddy dike. Make sure the together. Okay, Second Squad lines up along

> this hedgerow. That way we form an L. We get [‘em]coming either way. Third and Fourth squads stay here tonight. I’ll lead the ambush myself.”
>
> He asked if there were any questions, but the squad leaders were all experienced, and no one said anything.
>
> “Okay, good enough. We move out at midnight-maybe a little after. Make sure you bring enough Claymores. And for [heaven’s] sake, don’t forget the firing devices. Also, tell every man to carry a couple of grenades. No freeloading.” (O’Brien, 1973)

How assured is the lieutenant that each of his squad leaders fully understood, will remember, and accurately communicate the details of his plan? Will they remember the Claymore firing devices? Will they take enough? How well will the squads be able to form the L near the hedgerow at night? Will the platoon and squad leaders be able to monitor the positioning of squad members effectively? Will they all be able to identify friend from foe? Each of these questions raises some doubt in the mind of the platoon leader and indicates a situation where something can go wrong.

Consider the potential advantages if each soldier had a very small, lightweight helmet-mounted display (HMD) connected to a small lightweight computer, communications and special monitoring equipment. This HMD could present images that summarize the platoon leader’s plan while, at the same time, indicating the position of each squad member on an easy-to-read map using the latest intelligence on the enemy’s position. Imagine also that each soldier could call up check lists of items to take, the sequence of actions in the platoon leader’s plan, and other information critical to mission success. These added capabilities for managing mission information would give these soldiers an overwhelming advantage over a conventionally equipped enemy.

RESEARCH ISSUES

These and other capabilities are rapidly becoming possibilities as display and computer technologies advance (Binkin, 1986, Lewandowski, 1990). However, while a great deal of research and development have been directed toward HMDs, much of it has been for the aviator. This is largely because HMDs have been developed for aircraft, particularly helicopters. But it is also because the aviator has the advantage of being able to operate from a fixed sitting position, fully protected from the elements and with the availability of resources within the aircraft for carrying, powering and operating all the components of the system (Lewandowski, 1990). In contrast, there has been little to no research dedicated to the potential effects of this new technology on the performance of a dismounted combatant such as the infantryman. Until recently, there has been very little consideration given to the ground soldier. With the emphasis on the soldier as a system, this will soon change.

Research into the effects of HMDs on soldier performance is especially important because, in the case of the dismounted soldier, the relationship between man and machine (HMD) and the functional requirements of the combatant become more complex. First of all, the soldier must carry or wear the complete system as well as the power resources for operating it. The soldier has a greater exposure to the environment and must physically move about, assuming body positions from standing and marching to dropping prone to the ground, crawling, and moving through bushes, bogs, and rivers, and climbing over obstacles. He is required to operate in a wide range of lighting and visibility conditions from bright clear sun light to fog and smoke to dark moonless nights. The challenge for developing the system for the ground combat soldier is much greater than for any vehicle operator. Yet, the challenge is worth the investment to overcome it because there is potential for making the dismounted soldier tremendously more effective than he currently is.

Research on what information can be displayed to a mobile soldier and how to best display the information has yet to be done. Questions about which soldier performances can be enhanced by HMDs needs to be addressed. The list of questions can become almost endless as new hardware/software technologies emerge. Some initial research questions include: What type of information can be processed best through the visual mode? How much information can be attended to? What specific soldier tasks will information displays facilitate? What control over the display should the soldier have and how best can the soldier control or operate the display (voice, joystick)? What symbology works best? These and other human factor questions must be answered before the full potential of HMDs can be realized.

Studies will ultimately need to investigate the extent to which a soldier can perform the dual tasks of physically moving through unfamiliar terrain and, at the same time process display information related to the mission at hand. As the terrain becomes more complex or unpredictable (due to obstacles or divergent paths) how much attention can be given to different amounts or types of display information? Can certain display related cognitive tasks become automatic enough so as to reduce interference with movement performance? Could pre-exposure to patterns, presented on the display, facilitate the detection of enemy targets? Can map displays and real time orientation symbology facilitate land navigation? Can displays of distance information help when calling for artillery support? Is there display information, such as the terrain features of the immediate environment that would facilitate moving through a unfamiliar environment?

There is great potential for HMDs to enhance soldier performance by providing him with information essential to mission success. However, there is also a significant likelihood that the encumbrance of this new technology will complicate the infantryman’s mission to the extent that his performance could, at times, be degraded. This could occur as a result of information overload (Burkett, 1991, Gopher, 1986) or the mere presence of the HMD could distract him from detecting the presence of environmental obstacles or threats. However, if configured appropriately, the HMD could extend soldier capabilities to negotiate obstacles and threats during combat missions. By incorporating the means to anticipate terrain features and the location of obstacles, the HMD would aid the soldier in avoiding problems or allowing time to take corrective action.

PROPOSED APPROACH

Given the multitude of potential research issues, there is a need to proceed in a systematic fashion, in a way that will help optimize research efforts in this area. The following is an outline of a recommended approach for pursuing relevant research on information displays for design and ultimate application to the dismounted soldier.

Task Analysis

Initially, task analysis should be conducted to determine the performance, cognitive, and information requirements of infantry soldiers. This effort should determine essential information requirements of critical soldier tasks. The result should be a ranking of the relative categories of information and the functional tasks. Examples of critical tasks and cognitive/informational requirements of infantry soldiers include the following:

○ Visual detection/recognition of potential targets
○ Judgment of locations and estimation of distances
○ Choice of weapons and aiming/firing of weapons
○ Communication with team members: Listening/comprehension/memory/vocal performance
○ Listening to environment: Detection and recognition of relevant sounds

Analysis of Display Technology

Assessment should be done of the technical capabilities of lightweight computers and head mounted visual displays relative to critical soldier tasks. Within this analysis there should be efforts to configure display systems that are designed to provide support to selected combat tasks should be done on a one-at-a-time basis in order to evaluate the potential benefit of each function. Possible technical/functional capabilities include the following:

○ Visual display of target features to aid identification
○ Miniature video cameras and digitized images of field of view
○ Terrain map displays with GPS locations and automatic orientation information
○ Weapon sighting feedback to improve aiming accuracy and reduce reaction times
○ Computer code translation, message and note records keeping (visual)
○ Auditory sensing and visual pattern presentatio
○ Expert system decision making aids and information presentation

Initial Display/Performance Studies

Prior to conducting any of the above specialized investigations, some preliminary studies are needed to address the basic capability of soldiers to utilize information from a display while performing various psychomotor tasks. Thus, the first set of experiments should simply address the ability of the soldier to process display information while, at the same time, performing various mission related tasks (Schneider, 1985). Dimensions to be explored could include the degree of compatibility of the display information and the tasks to be performed and the level of attention required to process display information rapidly and effectively (Gopher, et al., 1986, Wickens, et al., 1983). Task difficulty may range from simply walking over flat terrain to more complex tasks such as moving over varied obstacles and/or operating a radio or weapon. Level of training and “automaticity” of performance tasks should also be included in these investigations. These initial experiments should help define the type of performances HMDs may be compatible with as well as help give direction to future studies.

CONCLUSIONS

The Army is currently establishing the management and organizational structures for the development of the soldier as a system. Focus is now being given to incorporating advanced technologies that have the potential to enhance individual soldier performance. One such thrust, as outlined above, is the development of helmet mounted displays for the dismounted soldier. Although there has been extensive research for applications of HMDs for aviators, little, if any, work has been done on systems for the ground soldier. The operational environment, conditions, and tasks are quite different for the infantryman. There is a growing urgency to examine the information needs of the soldier and how HMDs might be effectively used in combat.

The technology for HMDs and their attendant potential for enhancing performance are available today and are expanding very rapidly. Their insertion into the military inventory is inevitable. Thus, it is crucial that the important questions of how HMDs will affect soldier performance be addressed before hardware, software and policies for use are too firmly established.

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ENVIRONMENTAL FACTORS

ERGONOMICS AND OSHA: A CHRONOLOGICAL OVERVIEW OF ENFORCEMENT AND REGULATION DEVELOPMENT

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Despite the media, regulatory, and scientific attention that ergonomics has received recently in the United States, the events that influenced national occupational safety and health policy in this area are often overlooked. This paper provides a brief review of the impact that some of these events and the responses to them have had on national enforcement policy. U.S. Occupational Safety and Health Administration (OSHA) compliance efforts are highlighted. Included are perspectives on the use of the general duty clause and corporate-wide settlement agreements, the development of ergonomics guidelines for meatpacking, and recent activity on a national ergonomics standard.

INTRODUCTION

Ergonomics in general and cumulative trauma disorders specifically have received a great deal of attention in the United States over the last decade. From the period 1984 through 1990, the incidence rate for disorders associated with repeated trauma increased from 4.1 to 24.1 cases per 10,000 workers (BLS, 1991). During that same period, musculoskeletal disorders were identified as a leading work-related disease and included in a national strategic plan for combating these workplace problems (NIOSH, 1986). This paper provides reviews of the events that helped shape the present status of ergonomics regulation in the U.S.

POLICY DEVELOPMENT

While there is currently no occupational ergonomics standard in the U.S., Section 5(a) (1) of the Occupational Safety and Health Act of 1970, also known as "The General Duty Clause," has been utilized to support regulatory activity in ergonomics. To date, ergonomics violations are still cited under this clause. A NIOSH Health Hazard Evaluation performed at a photographic products plant in 1977 found 104 OSHA reportable cases of cumulative trauma disorders among 85 employees (Wisseman and Badger, 1977). Excessive ergonomic stresses were the basis for citations under the general duty clause in 1978 at Eastman Kodak, Windsor, CO (U.S. DOL, 1978) and at Samsonite Corp, Denver, CO (U.S. DOL, 1979). However, the real emergence of the ergonomics issue at the federal regulatory level did not occur until the increase of recordkeeping enforcement activity during the mid 1980's. For a chronology of events please see Table 1.

Table 1. Review of Ergonomics Compliance and Standards Activity

Date	Compliance Activity	OSHA Industry Guide/Standard
1978 1979	Eastman Kodak cited $4,300.00 ergonomic stresses. Samsonite cited $16,000..00 ergonomics violations.	
12–84 1–85	OSHA inspects plant at Institute, WV, records reviewed, no full inspection.	
4–85	John Morrell Co. records reviewed, no inspection.	
8–85	Institute plant experiences large toxic gas leak. OSHA inspects for 6 months, cites and fines $1.38 million, mostly for recordkeeping.	
1–86 6–86	OSHA responds to employee complaint at IBP. Review records, no inspection.	OSHA adds ergonomist Dr. R. Stephens to Office of Technical Support.
1–87 3–87	IBP inspected, fined $2.59 million for recordkeeping violations. Chrysler pays $295,000 settlement for recordkeeping.	
4–87 7–87	Morrell cited for 69 recordkeeping violations, fined $690,000. Ford Motor cited $476,000 for recordkeeping	Congressional testimony on exemptions, recordkeeping and ergonomics problems in meatpacking.
4–88	Morrell cited for ergonomic violations, fined $4.3 million.	
5–88	IBP cited for ergonomic violations, fined $3.1 million.	
11–	OSHA settlement with IBP and UFCW,	

88		
12–88	fines reduced to $970,000. Pepperidge Farm cited $1.4 million for ergonomics/records problems.	
10–89	OSHA cites U.S. Dept. of Agriculture	NIOSH issues call for
11–89	for ergonomic violations.	information on ergonomic hazards in the workplace. Recommendations to OSHA in 1992.
1–90	Pepperidge Farm cited $638,000 for	OSHA indicates General
3–90	recordkeeping and ergonomics hazards. Company contests.	Industry Ergonomics Guidelines may be available by July. OSHA begins ergonomics training for field offices.
7–90 12–90		OSHA- a general industry standard for ergonomics will be developed. Ergonomist Stephens- OSHA will assemble ergonomics advisory committee
7–91	OSHA cites U.S. Postal Service for	
9–91	ergonomics violations. Samsonite cited $1.6 million for ergonomics	
10–91	Testimony in Pepperidge Farm contest hearing for citations ends.	
Sources: BNA Occupational Safety and Health Reporter and other cited references.		

During the 1980’s, OSHA maintained a policy of records-based inspections. If a facility’s records indicated that it was below the national average for injury and illness incidence and/or severity, a walkthrough of the facility would not be conducted. It also exempted companies with records below the national average from the programmed targeting list (U.S. GAO, 1988). This emphasis on records was intended to allow OSHA to conserve its resources for facilities with the greatest problems (U.S. Congress, 1988).

The catastrophic release of methyl isocyanate from a chemical facility in Bhopahl, India in December of 1984 resulted in OSHA review of similar U.S. operations. OSHA conducted an investigation of a domestic methyl isocyanate production facility at Institute, West Virginia that same year (BNA, 1984). The facility’s records appeared in order, and only a limited inspection of the plant was made which resulted in no citations. However, five months following the inspection, the Institute facility suffered a gas leak which hospitalized six employees and required emergency treatment for 140 area residents (BNA, 1985a). OSHA returned to Institute and conducted a series of inspections which uncovered numerous health and safety violations and underreporting of injuries and illnesses.

During this time, OSHA introduced a new penalty structure which became known as the “egregious multiplier.” Under this structure, an employer could be fined for each instance of a violation (U.S. GAO, 1988). For example, as Union Carbide had 81 musculoskeletal incidents (strains, sprains, back injuries, hernias) which were not reported, they were penalized $10,000 per instance for $810,000 with a total proposed penalty of $1.38 million (BNA, 1986a).

ERGONOMICS ENFORCEMENT

In November, 1985, OSHA announced a change in inspection policy. All companies would be included in the inspection targeting list regardless of records and every tenth site visit to review records would include a full “wall to wall” inspection (BNA, 1985b). The agency also gradually dropped the exemption policy (U.S. GAO, 1988). During that period, several major meatpacking facilities, notably John Morrell and Iowa Beef Producers (IBP), which had been exempted from inspection under the previous system were reinspected. The reinspections lead to charges of underreporting of injuries and illnesses in these facilities as well. Many of these unreported cases were some form of cumulative trauma disorder such as carpal tunnel syndrome. These cases were also pursued using the egregious multiplier with IBP and John Morrell receiving proposed fines of $2.59 million and $690,000 respectively in 1987 (BNA, 1987a).

While these citations were later settled for reduced penalties, they established an important precedent and heightened federal awareness concerning ergonomics-related problems in industry. Use of the recordkeeping standard for these egregious cases was advantageous because employers had access to published BLS guidelines (BLS, 1986) and the basis for violation was previously established with the Institute and other compliance activity (BNA, 1987d). The fact that many of the illnesses not reported were of a cumulative or repeated trauma type indicated that these previously overlooked disorders should be targeted for correction.

Large recordkeeping citations in the automotive industry (BNA, 1987c) led to increased reporting of the disorders in those companies and further inspections (BNA, 1990a). Subsequently, general duty clause violations for ergonomics-related problems were identified and fines assessed on IBP ($3.1 million), Morrell ($4.3 million), and other meatpacking firms (BNA, 1990b).

This compliance activity generated a number of record fines and spurred the development of “corporate-wide settlements” with OSHA (BNA, 1990a). Originating in the recordkeeping cases (BNA, 1987d), these agreements differed from typical settlements because they applied across more of a company’s facilities than just the location cited. In general these agreements gave OSHA assurance of the company’s commitment to abatement in all its facilities in return for decreased compliance activity and reduced penalties. See Table 2.

In November 1988, IBP with the United Food and Commercial Workers Union (UFCW) reached the first of the ergonomics corporate-wide agreements. A year later, Chrysler Corporation and its unions became the first automotive company to reach an agreement with OSHA which covered five plants (Michigan Digest, 1989). The following March, Morrell reached an agreement with the UFCW and OSHA. Ford Motor Company along with the United Auto Workers union (UAW) completed a settlement that covered 81 plants- nearly 96% of all Ford facilities in July 1990 (BNA, 1990d). General Motors, the UAW, and OSHA reached a corporate-wide ergonomics agreement that covered approximately 138 plants that November (BNA, 1990e). These agreements represented a unique approach by OSHA. Rather than relying on the deterrent effect of the inspection/penalty system, these agreements established an ongoing agency-company relationship that would be monitored directly by OSHA. While the agreements targeted a specific workplace hazard—ergonomics, the enforcement system for other safety and health issues remained in effect.

While these compliance approaches were being tested, a number of criticisms were directed at this enforcement policy by organized labor. The UFCW outlined enforcement problems to the U.S. Congress in 1989 including insufficient numbers of experts and compliance staff trained in ergonomics, no national OSHA policy for inspections by area offices resulting in inconsistent approaches to inspection, problems with definition of appropriate abatement strategies, and the difficulties of policing corporate-wide agreements once they were established (UFCW, 1989).

OSHA began training its area field officers in ergonomics in late 1989 and early 1990 (BNA, 1989). Additional funds were appropriated to hire new personnel in ergonomics at regional, area, and national levels (BNA, 1989). Field policy was revised to allow coordination of resources for inspection through the regional offices and to improve uniformity of the assessment process (OSHA, 1990a).

FUTURE STANDARDS

In 1990, OSHA developed ergonomics program management guidelines targeted at meatpacking companies (OSHA, 1990b). The guidelines provided the first opportunity for companies in industry to view OSHA's perspective on ergonomics program content; the types of hazards to be addressed; the extent of involvement of medical, engineering, management, and labor sectors; and examples of the types of corrective actions OSHA found acceptable. The document also provided limited guidance on the qualifications of a professional ergonomist and specifically indicated which preventive and treatment methods were yet to be proven effective.

Coincident with the release of the guidelines, former Secretary of Labor Elizabeth Dole announced the beginning of two new thrusts in ergonomics (BNA, 1990c). The first, a special emphasis program in red meatpacking, concentrated both enforcement and consultation efforts in that industrial class.

Table 2. Review of Specific Hazard/Industry Regulation

Date	Corporate Wide Agreements/Industry Specific Hazards
4–87	Congressional testimony on exemptions, recordkeeping and ergonomics problems in meatpacking.
7–88	Suffolk County, New York, passes first VDT ordinance in U.S.
11–89	Draft Red Meat Guidelines receive positive, informal labor and industry (American Meat Institute) review.
12–89	Employers succeed in having Suffolk County, New York VDT ordinance struck down by New York State Supreme Court. Court cites lack of regulatory jurisdiction.
1–90	UFCW and Excel-Cargill (meatpacking) announce cooperative ergonomics program.
2–90	AMI states OSHA's draft guidelines are "needlessly complex" and a "[distortion] of the current state of ergonomics."
5–90	OSHA/Morrell settlement finalized, fines reduced to $990,000. Corporate wide agreement includes ergonomics program at all facilities.

7–90	Three California Newspapers reach agreement with Cal-OSHA for workers that use VDT's more than 2 hours per day.
8–90	OSHA Ergonomics Program Management Guidelines for Meatpacking released and mailed to all companies in red meat SIC code. Ford Motor Company settles citations in ergonomics/recordkeeping paying $1.2 million in fines and beginning corporate wide abatement program.
10–90	UFCW recommends to OSHA that companies entering into voluntary compliance agreements should be inspected every 6 months.
11–90	General Motors, UAW, and OSHA reach agreement covering 138 plants. Corporate-wide implementation of ergonomics program measures by 9/96. Plans for expansion to non-union facilities are included.
12–90	City of San Francisco passes first major metropolitan VDT ordinance in U.S. Legislation references Cal-OSHA/newspaper company agreement.
1–91	Intercontinental Branded Apparel enters into ergonomics agreement for 3 New York plants marking first corporate-wide settlement in apparel/textiles.
7–91	Draft ANPR released. 31 Unions petition OSHA for Ergonomics Emergency Temporary Standard. Cargill pays $400,000 reaches settlement with OSHA and unions covering 1800 employees
9–91	San Francisco VDT ordinance challenged by employers in California Superior Court.
10–91	Retailer J.C. Penney's reaches corporate ergonomics agreement covering 5000 employees in catalog and distribution warehouses throughout U.S.
11–91	City of Los Angeles begins drafting VDT bill similar to San Francisco law.
12–91	OSHA denies Sara Lee Corp. additional time to meet a project milestone in 1989 corporate-wide agreement. Cites lack of progress on corrective action. Submits petition to OSH Review Commission.
2–92	San Francisco VDT ordinance is struck down by California Supreme Court. Court cites only the state can issue health and safety standards.

Sources: BNA Occupational Safety and Health Reporter and other cited references.

The second, the development of a general industry standard in ergonomics, marked for the first time a potential departure from the use of the general duty clause in ergonomic citations.

As of February 1992, the general industry standard had not yet reached the initial public stage of a regulation—the Advanced Notice of Proposed Rulemaking (ANPR). A preliminary draft of the ANPR was released in July, 1991 (BNA, 1991a). This draft ANPR was comprised mainly of inquiries to employers for data and comments concerning their experience with ergonomics-related disorders and ergonomics programs. It also indicated that the standard could be similar in concept to the meatpacking guidelines. OSHA's general industry standard activity faces a number of obstacles. In particular, the issue of abatement control validity has yet to be resolved. Without the capability to demonstrate that there are proven solutions to the ergonomics problems in the workplace, OSHA faces resistance from industry, the Office of Management and Budget, and potentially even Congress. This concern may prove very difficult to overcome in the development of a standard.

In 1990, the National Safety Council formed a committee to develop a voluntary consensus standard for cumulative trauma disorder control under the American National Standards Institute (ANSI). The Control of Cumulative Trauma Disorders-ANSI Z-365 committee's scope is to develop "standards to control cumulative trauma disorders arising from manual lifting, assembly, manipulation of tools, machinery and other devices and other stresses to muscles, nerves, and tendons. Ergonomic considerations to be focused on include: work postures, work layout, strength requirements, vibration, work rates, tool design, and flexibility of work stations to accommodate individual variations" (ANSI, 1989). If this process is successful and a consensus standard is developed, OSHA would be able to adopt components of the standard under the provisions of the OSH Act of 1970, section 6 (b) (1).

If the general industry standard is not feasible, it is possible that OSHA might attempt to regulate industry or occupation-specific hazards using the corporate agreement or normal rulemaking approach. Precedent exists for occupation-specific regulation in ergonomics. The City of San Francisco legislated its own ergonomics standards for workers involved with video display terminals in December, 1990 (City of San Francisco, 1990). Although both San Francisco and a previous VDT ordinance in Suffolk County—New York, attempts were struck down by the courts, this type of legislation demonstrates public interest in these industry specific standards.

Pressure for action on ergonomics regulation is mounting. In August 1991, thirty-one labor unions including the AFL-CIO, UFCW, CWA, UAW, ACTW, SEI, and the American Postal Workers Union formally petitioned OSHA to issue an emergency temporary standard on ergonomic hazards in 1991 (BNA, 1991b). However, the executive moratorium on standards development initiated in January, 1992 could further delay release of the ANPR.

While the outcome is uncertain, the need to address ergonomics hazards is unquestionable. As OSHA gathers information on abatement methods and strategies and evaluates the success of the company-wide agreements, further delays in rulemaking are probable. Until that time it is likely that OSHA will continue to use the general duty clause and company-wide agreement approach.

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HEAT LOSS FROM MAN DURING DRYING OF PARTLY WET WORK CLOTHING

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INTRODUCTION

Occupational work in the cold is being performed for hours and often with an alternating activity level. It happens frequently that the clothing worn becomes wet from sweat during heavy work periods, and this is a major cause for consecutive periods of thermal discomfort. The wet clothing will dry on the human body using heat from the skin for the evaporation of the accumulated sweat. Garments should be selected so they minimize the resulting after-exercise chill. Therefore, it is important to know how different textile materials influence sweat accumulation in a clothing ensemble, and how the location of the accumulated sweat influence human heat loss during the period of drying out. The drying of the clothing and the corresponding energy exchange may in a work situation be influenced by the pumping effect resulting from working movements, thus complicating the process of heat exchange.

The main purpose of this study was to investigate how various textile materials in a clothing ensemble and the location of the accumulated sweat influenced evaporation rate and heat loss from a thermal manikin during drying of a partly wet clothing ensemble. In addition, the effect of walking movements and increased air velocity was studied.

METHODS

A 3-layered clothing system was used. The textiles were selected so the influence of the fibre type material could be studied. The underwear was manufactured in either wool (W) or polypropylene (P), the middle layer in either wool (W) or polyester (P), and the outer layer in either cotton (C) or polyester/cotton (65%/35%) (P). The combinations PPP and WWC were tested. Some physical characteristics of the textile samples are shown in Table 1, together with the thermal resistances of the individual garments measured on a thermal manikin (Madsen, 1976). The thermal resistance of the two clothing ensembles was 0.31 m2·K·W-1 (~2 clo).

Humidification of the garments took place by inserting top and bottom of a layer in separate plastic bags before adding 100 g and 75 g gram, respectively, sealing the bags and placing them in an oven at 50 °C for at least eight hours before the experiment.

Table 1. Physical characteristics of the textile materials and basic insulation (l_{cl}) of the individual garments

	Textile material		Textile construction	Thickness (mm)	Weight (g/m^2)	Thermal resistance (m^2−K/W)	Air permeability ($1/m^2$ s)	Water vapour resistance (mm)	l_{cl} garment(m^2−K/W)
underwater	Polypropylene (P)	(100%)	1-by-1 rib knit	1.62/1.18	148	0.034	1786	2.0	0.039
	Wool (W)	(100%)		2.2/1.5	185	0.044	1507	2.3	0.052
Middle layer	Polyester (P)	(100%)	plated structure with a fleecy back surface	2.80/2.10	280	0.051	1292	3.7	0.099
	Wool (W)	(100%)		2.30/2.50	325	0.065	758	4.0	0.111
Outer layer	Polyester/cotton (P)	(65/35%)	woven	0.73/0.54	280	0.016	82	1.4	0.092
	Cotton (C)	(100%)		1.67/1.14	375	0.023	26	1.4	0.096

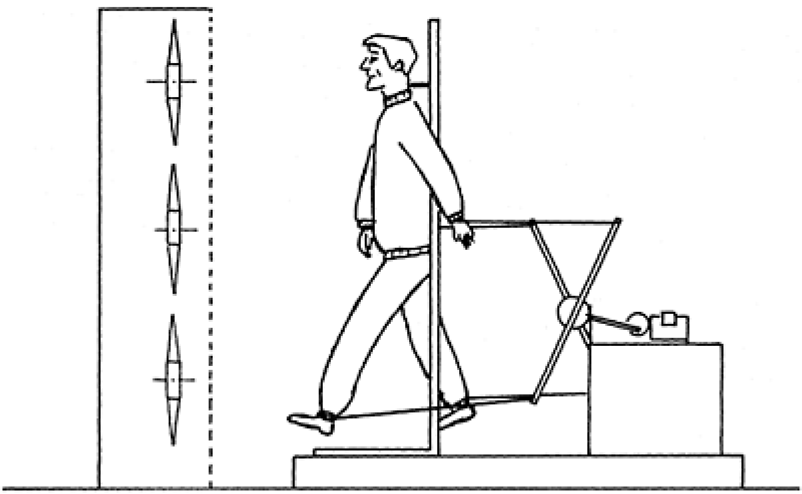

Figure 1. Set-up with the thermal manikin placed on a balance. A wind box with 3 ventilators was placed in front of the manikin.

All experiments were conducted in a climatic chamber (T_a= 10°C; r.h.=70%; V_a<0.1 $m \cdot s^{-1}$). A thermal manikin (TM) was placed in a standing position on a balance, and dressed in a clothing ensemble identical to the test clothing. Recording of heat loss from

TM began and a thermal steady-state was obtained prior to the beginning of the actual experiment.

The humidified clothing layer of the test clothing was now taken from the oven and together with the other garments weighed individually on a balance. The pre-experimental clothing was removed from the manikin as fast as possible, and TM was dressed in the experimental clothing ensemble. Walking movements or the wind box were started immediately after completing the dressing procedure of the manikin, when applicable. Recording of weight loss from the dressed TM started just after this. The procedure of changing the clothing on the manikin was standardized as much as possible, and durated approximately 20 minutes. Recordings of weight and heat loss continued until the heat dissipation from TM was back at a steady-state level. At the end of the test each garment was weighed again. Experiments were done with the manikin in a standing position with or without being exposed to an increased air velocity of 1 $m \cdot s^{-1}$, or the manikin was brought to simulate walking movements with 60 step per minute (Figure 1). Separate experiments were done with change of dry clothing on the manikin in order to measure the heat loss exclusively due to the change of clothing. This “dry” value was subtracted from the “wet” values.

Table 2. Dry weight, steady-state heat loss, evaporation rate initially and percentage of evaporation energy delivered from the thermal manikin in the various tests. The number codes refer to the location of the water (1=inner layer, 2= middle layer, 3=outer layer), the activity (0=standing, 2 =walking), and the air velocity (0=still air, 3=1 m/s).

Ensemble	Dry weight (g)	Heat loss in steady-state ($m^2 \cdot K \cdot W^{-1}$)	Evaporation rate ($g \cdot min^{-1}$)	Percentage of energy taken from manikin (%)
PPP100	2236	85	1.61	64
PPP200	2236	85	1.35	50
PPP300	2236	87	1.49	23
PPP120	2267	98	1.86	58
PPP220	2267	99	1.78	50
PPP320	2267	99	1.49	35
PPP103	2236	99	1.81	82
PPP203	2267	101	1.66	45
PPP303	2236	103	2.18	27
WWC100	2612	76	0.63	51
WWC200	2613	78	0.68	28
WWC300	2613	79	0.56	13
WWC120	2603	94	0.76	63
WWC220	2603	95	0.88	34
WWC320	2612	94	0.83	24

WWC103	2571	93	0.64	87
WWC203	2613	93	0.74	42
WWC303	2603	90	0.72	24

RESULTS

Evaporation of water from the clothing took place in two phases: an initial fast phase with a linear evaporation rate followed by a slower curved drying out phase (Figure 2c). An evaporation rate was calculated for the linear “130 to 70 gram” water content period (Table 2). Heat loss from the thermal manikin increased abruptly to a new level during the change of clothing and the first phase of drying. Then it slowly decreased to the steady-state level for the combination of clothing insulation worn, body movements, and air velocity under study (Figures 2 and 3). Only a part of the drying energy was contributed from TM.

Fiber type material had a significant influence on evaporation from the clothing and on the percentage of drying energy consumed from TM. Evaporation took place at a much faster rate from the ensemble manufactured from man-made materials compared to the ensemble manufactured from natural fibers (Figure 2c, Table 2). As a consequence drying time was much longer with WWC than with PPP. The differences in evaporation were ref lected in the time course of heat loss from the thermal manikin during drying (Figures 2a and 2b).

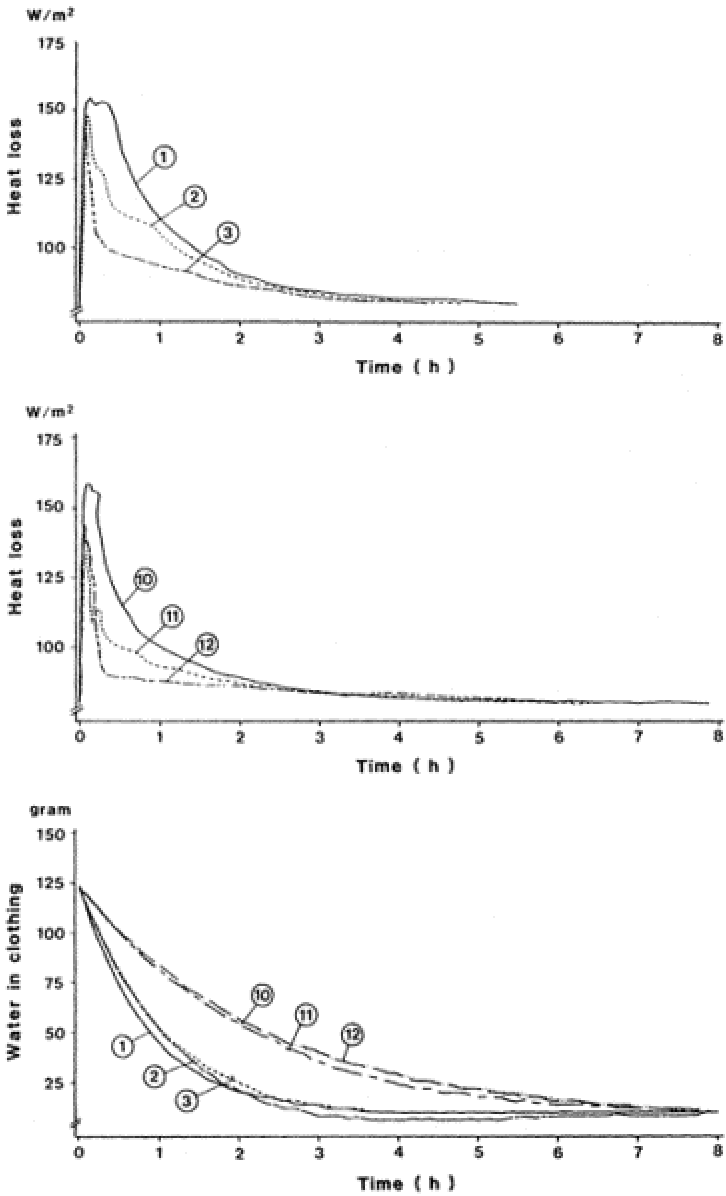

Figure 2. Additional heat loss from the standing TM and the rest water in the clothing as a function of time. The numbers refer to the following experiments: 1=PPP100; 2=PPP200; 3

=PPP300; 10=WWC100; 11=WWC200; 12=WWC300.

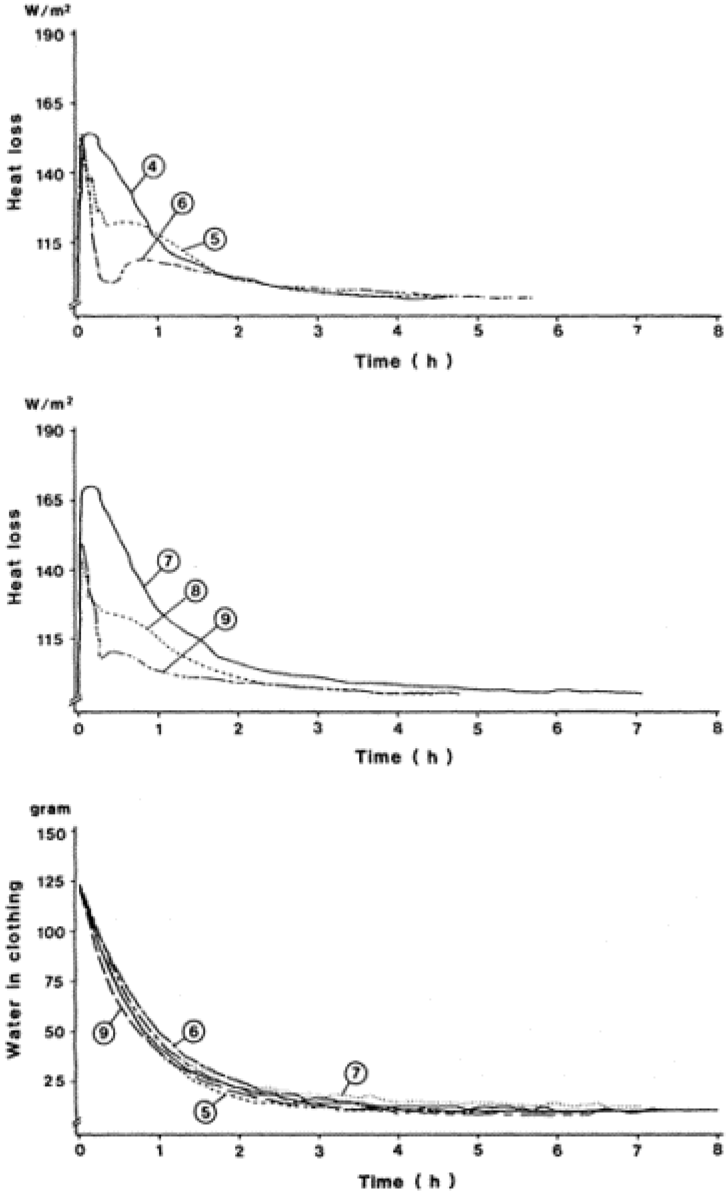

Figure 3. Additional heat loss from the TM when simulating walking (upper)

and when standing in the wind (middle) as a function of time, together with the corresponding curves of rest water in the clothing. Number references are 4=PPP120; 5=PPP220; 6=PPP320; 7=PPP103; 8=PPP203; 9=PPP303.

With PPP heat loss was considerably higher the first two hours compared with WWC. However, heat loss remained slightly increased for a much longer period of time with WWC. Totally, drying of PPP on the standing thermal manikin in still air consumed significantly more energy than drying of WWC.

The location of the water in the clothing did not have a major influence on evaporation rate, although evaporation seemed to be slower the further away from the manikin surface water had been placed. With water placed in the cotton outer layer of WWC, drying time was extended considerably. The location of the water in the clothing had a significant influence on the percentage of drying energy taken from the thermal manikin. Both with natural and man-made textile materials energy consumption from the thermal manikin during drying of the wetted clothing was significantly higher the closer to the manikin surface, the water was localized (Table 2). When the outer clothing layer dried out, less than 25% of the energy used for evaporation was consumed from the manikin.

When the thermal manikin was brought to simulate walking steady-state heat loss increased from 78 and 86 $W \cdot m^{-2}$ to 94 and 99 $W \cdot m^{-2}$ with WWC and PPP, respectively. The movements of the limbs slightly increased the evaporation rate from the clothing regardless of where the water had been placed. The energy contribution from the thermal manikin to drying of the outer clothing layer was increased by more than 10% due to the walking movements. With woolen clothing a similar increase in energy contribution from TM was seen when water evaporated from the inner and middle layers; however, with man-made materials in the clothing no such increase in the manikin's share of evaporation energy could be observed in this study.

With an increased air velocity of 1.0 $m \cdot s^{-1}$, steady-state heat loss from TM increased to 92 and 101 $W \cdot m^{-2}$ with WWC and PPP, respectively. Evaporation was much faster from the clothing manufactured from synthetic textile materials in the wind, and more the further out in the clothing the water had been placed. With the ensemble of natural fibers, the wind effect on evaporation was only significant when the water had been placed in the outer layer. The manikin's share of the evaporation energy was significantly increased during drying of the inner layer. For drying of the middle and outer clothing layer, wind increased the energy consumed from the manikin when the clothing was made from wool/cotton, whereas no significant effect was observed when the garments were made from synthetic materials.

In summary, this study showed that during drying of wet clothing differences in the evaporation rate (drying rate), the time course of heat loss and the amount of extra heat loss from the manikin were significantly determined by the locations of the water in the clothing. Although, the textile materials used in the clothing ensemble were far less important for energy consumption from the skin, they were they major determinant of drying rate and time. Both an increased air velocity and walking movements influenced heat loss from the manikin significantly during drying.

It can be concluded that for colder work places textile materials should be selected so that sweat accumulation will take place as far away from the skin as possible.

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SELECTING PERSONAL COOLING SYSTEMS:

Evaluation of Design Features

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The use of personal cooling systems is becoming increasingly popular in hot industries. There are three general types personal cooling systems. Each type of cooling has its advantages and shortcomings. Even within each type there are features which make one be preferred over another. This article demonstrate the use of a subjective, comparative method for evaluation of personal cooling systems.

INTRODUCTION

In many occupations, physical activities are often performed in hot environments. Heat stress associated with working in such environments is a serious problem to which the attention of many governmental agencies and numerous investigators has been attracted. Mining, highway and building construction, glass and ceramics manufacturing are examples of occupations in which workers may be exposed to high heat loads (both environmental and metabolic).

Advances in science and technology have made great contributions to the design of workplaces to improve workers safety, comfort and productivity. However, the issue of heat stress in many industrial occupations has not been completely resolved yet. The problem in some occupations, such as mining, is more critical than others.

Researchers have been investigating the effects of work in hot environments on man for some time. As a result, these efforts have provided rational bases for the prevention of health impairment and physiological damages to workers due to heat stress (Stephenson et al., 1974). Consequently, many industries have become involved in exploring methods for safeguarding their workers against heat stress, and to comply with governmental standards for working in hot environments. Minimization of the inverse effects of hot environments on work quality and quantity has been another motivation for their participation.

To be able to work safely and effectively in hot environments, the worker must maintain a body thermal equilibrium. The maintenance of this equilibrium depends upon the body's ability to dissipate some of its internally generated metabolic heat into the surrounding environment. In the absence of cooling, in hot environments, metabolic heat dissipation is restricted.

Performing physical activities in hot environments is often associated with high physiological costs. Discomfort is not the only problem associated with working in hot-humid environments. The major problem is heat stress, which occurs whenever heat input to the body exceeds its heat dissipation. The limitation in heat dissipation shrinks the safe time-temperature-workload envelope. An example of such an envelope is the permissible heat exposure threshold limit values (TLV's) adopted by ACGIH (1991). The risk of heat collapse or heat stroke increases rapidly at deep body temperatures above 39° C (Van Graan, 1975). Both WHO (1969) and ACGIH recommend that workers should not be permitted to continue work when their deep body temperature exceeds 38° C. But, as environmental temperature and metabolic work load increase, the body is less able to maintain its thermal equilibrium with the surrounding environment and deep body temperature may rise beyond the acceptable level.

In addition to physiological effects, the ambient temperature has shown to have a significant effect on the unsafe work behavior. For instance, Ramsey et al. (1982, 1983) in their study of the effects of temperature on workers behavior found a U-shaped curve for the unsafe behavior rate with a minimum in the preferred temperature zone of 17° to 23° C WBGT. These investigators also found that an increase in work intensity is associated with an increase in the unsafe work behavior rate. Åstrand and Rodahl (1977) observed the deterioration of mental or intellectual work capacity during exposure to temperatures exceeding 30° to 35° C, even though the individual may have been heat acclimatized.

Personnel working in hot environments have consistently shown an inability to perform prolonged, physically strenuous activities (Terrian and Nunneley, 1983). For example, in disastrous explosion and fire at the Belle Isle salt mine, the Crane Creek potash mine, and the Somerset coal mine, the rescue and recovery teams were forced to drastically shorten their missions because of severe exhaustion due to heat stress (De Rosa and Stein, 1976; Webbon et al, 1978).

The effects of heat on productivity and performance are also well documented. Edholm (1967) has argued that the slow work pace which is usually noticed in hot climates is not due to laziness, it rather is due to physiological causes. Fanger (1972) concluded that work capacity and performance seem to be substantially impaired in hot environments. Ramsey (1983) is supporting the mental effects of heat exposure. He states that the physical work capacity in hot environments is affected by physical fitness, general health, age, sex, status of nutrition, and the mental willingness to perform under physical workloads and heat. He argues that physical strength is minimally affected by increasing levels of temperature, but localized or general feelings of fatigue due to exposure to high heat intensity and/or long exposure will affect performance.

Modern technology has developed various types of electro-mechanical ventilation systems for use in many environments, including mines, which are characterized as hot and, in many cases, extremely humid. However, during disastrous accidents such ventilation systems usually fail to operate adequately. In addition, in many situations, such as farm and construction work, it is impractical or not economical to install ventilation systems.

If a worker is to maintain thermo-neutrality, minimize his body heat gain and the risk of heat collapse or heat stroke, or be able to work for a reasonable time period before reaching an allowable level of heat storage, he must be provided with protective devices. As McCullough et al. (1982) expressed, a worker will suffer from heat stress problems in hot environments depending on the degree to which the clothing ensemble alters heat transfer between the body and environment by convection, conduction, radiation, and/or evaporation. High ambient temperature and/or high radiant temperature would increase heat gain in body tissues. The problem arises when environmental temperature approaches skin temperature, and heat loss by means of convection and radiation gradually ends. At temperatures beyond skin temperature the only remaining means of heat loss is evaporation. Under such conditions, convection and radiation reverse directions and increase the heat content of body. When the humidity increases, the amount of heat loss by evaporation will decrease significantly. This is when the application of micro-climate cooling systems can significantly be appreciated. Focussing on a system which can provide complete or partial body cooling to workers in hostile environments seems to be a promising solution to the problem.

TYPES OF MICROCLIMATE COOLING S SYSTEMS

There are three general types of personal cooling systems with potential industrial application. They are air-cooled, liquid-cooled and ice-cooled systems. Each type of these cooling systems, however, has its own advantages and disadvantages. Even within each type there are features which make one be preferred over another. The restrictions associated with each type of the cooling systems have caused serious drawbacks in their application in industry.

Air-Cooled Suits

An air- or gas-ventilated suit which uses convective and/or evaporative modes of heat exchange is basically made of a garment with several tubes, for air distribution. This system requires an air conditioner and a hose to deliver cold. Some types of this suit use ambient air circulated by blowers (air-ventilated jackets). The air-ventilated jacket assembly was first used in the steel industry for protecting workers against heat stress at low levels (Crockford and Lee, 1967). Veghte (1970) commented that air ventilated systems are normally used under circumstances in which heat is confined by an impermeable shell surrounding the person.

Liquid-Cooled Suits

A liquid cooled suit is a relatively tight fitting garment with a network of thin tubes. Cold liquid, usually water, flows through the tubes and removes the metabolic heat from the skin surface by conduction. Except for its cost and trailing hoses, this method of cooling is highly efficient in hot-humid environments where sweat evaporation is not effective.

Shapiro et al. (1982) compared the performance of air-cooled and water-cooled vests. They concluded that the two types of cooling vests had similar efficiency, particularly with mild work performed in moderate to hot environments. They commented that the air-ventilated vest is less effective in moderate heat and can be harmful to the skin in very hot environments.

Many researchers observed the inferiority of air-cooled suits to water cooled suits because: (1) the high heat capacity of water allows a water cooling suit to be much more efficient and flexible (e.g., Shvartz, 1975); (2) the control of cooling rate in air cooling suits is poor as compared with water cooling systems (e.g., Harrison and Belyavin, 1978); (3) air cooled garments have limitations in heat transfer due to evaporation (e.g., Webb and Annis, 1967; Waligora and Michel, 1968; Shapiro et al., 1982); (4) cost of pumping water in water cooled clothing is much less than the cost of pumping adequate amounts of air in air cooled suits (Webb and Annis, 1967); and (5) air-ventilated garments have limitations with respect to environmental temperatures (Shapiro et al., 1982).

Ice-Cooled Suits

To overcome the restriction of mobility of the person wearing a cooling system while working, Van Rensburg et al. (1972) developed a phase change (ice cooling) garment. Their designed garment was similar to the Webb Associates' passive cooling system (PCS) described by Blockey (1970) with considerable simplifications in its construction. This PCS consisted of a garment with many small pockets sewn onto it Each pocket contained an ice bag. The garment was worn over an insulation garment with variable thermal conductivity. This conductivity controlled by the worker for prevention of over-cooling to achieve a thermal comfort.

Among the three cooling systems, that is, air-cooled, liquid-cooled, and ice-cooled systems, the latter seems to be most suitable in the design of a self-contained system which does not require the use of trailing hoses and other restrictive devices. For example, in water-cooled garments, the moving parts and the need for a power source to circulate cool water are quite restrictive. Hence the advantage of ice cooling system, that is, the lack of need for any moving parts makes it an economical and simple method of body heat removal while the wearer's mobility is not restricted.

Strydom et al. (1973, 1974) investigated the advantages and disadvantages associated with using loose bags. They reported that loose bags are easier to replace in the case leakage, replacement can easily be made for those that develop leaks. However, the disadvantages of using loose bags overshadow their advantages. First, additional time and effort are required to place the bags into their holding pockets. This would not only increase the cost of use and wear and tear, but would also decrease the cooling efficiency. Secondly, the bags could be easily lost. They also rejected the opinion that smaller freezers would be needed for freezing loose bags than those used for freezing whole garments because special racks would have to be provided to allow circulation of air around each bag. Although this argument remains questionable, freezing the whole garment provide a faster service.

Blockey (1970) found that the physiological protection provided by an ice-cooled suit (passive cooled system, PCS) is very similar to that provided by a liquid-cooled garment He also found that skin temperatures under the PCS were comparable to those under liquid-cooled garments at the same work level.

EVALUATON OF DESIGN FEATURES OF PERSONAL COOLING SYSTEMS

Design Features of some Selected Ice-Cooled Garments

To demonstrate the method for evaluation of the design features of personal cooling systems, some ice-cooled garments, commercially available and/or tested in laboratories, were selected. The design features of these ICGs are summarized in Table 1.

Table 1: Design features of microclimate cooling systems selected for evaluation.

CRITERION	OSA	PSA	RSA	BOM	DCO	EPR
Type of System (Garment)	Poncho	Poncho & an Outer Vest	Poncho	Poncho	Poncho & an Outer Vest	Vest & an Outer Vest
Inner Shell Material	Canvas	Plastic	Canvas	None	Neoprene	Nylon
Outer Shell Material	Canvas	Plastic	Plastic	Rubberized Dacron	Neoprene	Nylon
Insulation Filling Material	Plastic foam	Plastic foam	Plastic foam	Plastic foam	N/A	N/A
Thickness of Insulation Filling (mm)	12.5	10.0	12.5	6.25	N/A	N/A
Number of Pieces	1	2	1	5	3	2
Number of Pockets	18	26	28	14	N/A	54
Attachment of Ice Bags	Permanently sealed	Permanently seated	Replaceable bags	Velcro fastened	1-piece honeycomb	Replaceable bags
Size of Each Pocket (mm×mm)	N/A	115×120	110×120	150×100	1 piece	83×100
Size of Each Ice Bag (mm×mm)	N/A	110×120	100×110	150×100	1 piece	75×100

Ice Contact Area on Body (m^2)	0.24	0.34	0.31	0.21	0.41+	0.41
Coolant Material	Water	Water	Water	Water	Water	Water
Weight of each Ice Bag (g)	250	110	160	285	N/A	70
Weight of Coolant (Kg)	4.500	2.860	4.500	4.000	3.000	3.800
Heat Absorption Capacity (to 35° C)	603 W-h	383 W-h	603 W-h	535 W-h	400 W-h	506 W-h
Weight of System w/o Coolant (Kg)	1.220	1.260	1.220	1.360	3.000	N/A
Weight of System w/ Coolant (Kg)	5.720	4.120	5.720	5.340	6.000	N/A

Notes: OSA: Original South African garments (Van Rensburg, 1972).
PSA: Current S.A. garments with permanently sealed ice bags.
RSA: Current S.A. garments with replaceable ice bags.
BOM: Bureau of Mines' garments (De Rosa and Stein, 1976).
DCO: Drager COOL-over vest (Drager's Brochure, 1982).
EPR: EPRI's vests (Kamon, 1983).

Evaluation of the Selected Ice-Cooled Garments

There are various types and brands of personal cooling systems commercially available. Each system has its own advantages and disadvantages. The management may wonder what system would best fit its needs. A set of twenty-five design criteria for evaluation of the features of personal cooling systems was prepared and published by Tayyari et al. (1989) to be used as a checklist for selecting a cooling system (see Table 2).

In this paper, these design criteria were used to develop a new subjective, comparative method for evaluation of personal cooling systems. Each criterion should be assigned a desirability weight to be multiplied by (+1) if the criterion is satisfied, by (0) if moderately satisfied, or by (−1) if it is not satisfied. Then, the sum of the resulted products for each cooling system is calculated as the "overall score". The cooling system with the highest overall score can be considered as the most desirable system.

To demonstrate this proposed method, the selected ice-cooled garments, whose design features are given in Table 1, were simultaneously evaluated in terms of satisfying these design criteria. The result of this evaluation is presented in Table 2.

The evaluation can be performed on a personal computer using a spread-sheet package, such as "Microsoft Excel" on Macintosh computers or "Lotus 1–2–3" on IBM compatibles. The evaluation of the selected personal cooling systems in this paper was performed using the "Microsoft Excel" on a Macintosh computer. The results show that the EPR systems was best in satisfying the expectations of the authors. However, it should be noted that each criterion was given a subjective weight, while the weights can vary from one evaluator to another.

Table 2. Evaluation of microclimate cooling systems using desig n criteria.

CRITERION	Des. Wt.	OSA	PSA	RSA	BOM	DCO	EPR
Efficiency of Fabrication	10	10	−16	10	10	−10	−10
Resistance to External Environments	10	−10	10	−10	10	−10	−10
Resistance to Chemical Environments	5	−5	5	−5	5	−5	0
Economical Material	10	10	10	10	0	−10	−10
Low Number of Pieces	5	5	0	5	−5	−5	0
Durability of Ice Bags	10	0	0	0	0	0	0
Ease of System Maintenance	10	10	−10	10	10	−10	−10
Secured Attachments and Ice Bags	10	−10	10	−10	−10	10	10
Ease of Donning	5	−5	−5	−5	0	0	5
Close Contact of Ice with Body	10	−10	10	−10	10	10	10
Prevention of Cooling Discomfort	5	5	5	5	5	5	5
Compatibility with Work Clothing	10	10	10	10	10	10	10
No Interference with Mobility & Work	5	5	5	5	5	5	5
Freedom from Supportive Systems	10	10	10	10	10	10	10
Large Ice Contact Area on the Torso	10	−10	0	0	−10	10	10
Safe Coolant Material	10	−10	0	0	−10	10	10
Flexibility of Size	10	0	−10	0	−10	−10	−10
Prevention of Air Flow Around Coolant	10	−10	10	−10	−10	10	10
Prolong Effective Time	10	0	0	0	0	−10	0
High Heat Absorption Capacity	10	0	−10	0	0	−10	0
Low Weight	10	0	0	0	0	−10	10
Short Required Preparation Time	5	−5	−5	0	5	5	5
Low Storage/Freezer Occupancy	5	0	5	0	5	5	0
Wearing Comfort	10	10	10	10	10	0	10
Lack of Loose Attachments	5	−5	−5	−5	5	−5	5
Ease of Cleaning	5	−5	5	−5	5	−5	−5
Overall Score		**−10**	**50**	**15**	**50**	**−10**	**60**

Des. Wt.: Desirability weight.
OSA: Original South African garments (Van Rensburg, 1972).
PSA: Current S.A. garments with permanently sealed ice bags.
RSA: Current S.A. garments with replaceable ice bags.
BOM: Bureau of Mines' garments (De Rosa and Stein, 1976).
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Music Style, Age and Gender Relationships to Preferred Noise Levels for Headset Cassette Players

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One hundred subjects varying in age and gender participated in an experiment to determine music style and preferred noise levels for headset cassette players. Males preferred noise levels of 91.4 dbA which was significantly higher than that of females (86.5 dbA). Fifteen to nineteen year olds preferred the loudest levels (95.3 dbA). The over 60 year group preferred the lowest level (77.1 dbA). Since requiring designs with lower noise level control is impractical, education appears to be the only solution to reduce hearing loss risk when using this type of audio equipment.

BACKGROUND

Allayne, et. al. (1989) reported that one of the top ten causes of occupational injuries was hearing loss. However, workers may tend to blame hearing loss on excessive noise in the workplace without realizing the potential effects of noisy leisure activities. Yearout and Brown (1991) found, that for workers in a Western North Carolina manufacturing industry, leisure noise levels were significantly higher (approximately 10 dbA) than those measured at their workplace. Though these findings were for a specific population group, they tend to support Cohen and Anticaglia's (1970) recommendations that more stringent guidelines be imposed on non-occupational noise level limits (Table 1).

Calvert and Clark (1983) explained young adults' preference for very loud noise levels as a "social noise phenomenon." Codennec, Azzooz, Bassoom, and Ferrm (1986) surveyed 52,000 young males to determine if listening to stereophonic headphones for more than seven hours weekly will cause hearing loss sufficient to be exempt from National Service. Two other studies (Mori, 1985) and (Hellstrom and Axelsson, 1988) examined workers and teenagers who listened to music on portable radio and cassette players. Both studies concluded that the noise levels were excessive. In neither study were subjects observed using headsets that would provide amplification for the "walkman" type of tape recorders.

Catalano and Leoin (1985) surveyed NYC college students regarding their preferred volume settings and their estimated weekly exposure. Based upon testing of three brands of portable audio equipment set at the volume setting mean, this study concluded that audio equipment with headsets may be capable of placing 50 percent of those surveyed at permanent hearing loss risk.

The purpose of this study was to determine if the factors of music preference, age and gender have a relationship to high noise levels for this specific type of audio equipment.

Table 1: OSHA Permissible Noise Exposure Limits Versus Recommended Non-Occupational Limits

Maximum Exposure (Hours per Day)		
Noise (dbA)	OSHA (Occupational)	Non Occupational
70	–	16–24
75	–	8
80	–	4
85	16	2
90	8	1
95	4	0.5
100	2	0.25
105	1	0.13
110	0.5	0.07
115	0.25	0.03
Greater than 115 dbA is unacceptable		

METHOD

Data was collected for this study by both a short survey and noise level readings. Music preference was scored according to a subject's individual ranking. Age, type of activity (exercise or pleasure), number of exposures per week, duration of exposure, perceived hearing loss and type of headset data was also obtained. One hundred volunteer subjects were solicited from Western North Carolina High Schools, health organizations and from popular jogging and walking paths. A Gen Rad 1565-B Sound Level Meter was first calibrated and then coupled to the subjects headset. Minimum, mean and maximum readings were then observed every 30 seconds for three minutes.

RESULTS

Prior to conducting each statistical comparison, the Levine's test for homogeneity of variances was used. The standard analysis of variance and Least Significant Difference (LSD) test was used where variances were found to be homogeneous. Even though those who stated that they may have a hearing loss preferred a lower noise level than those who did not, 86.1 dbA to 88.7 dbA, this difference was insignificant at the 0.05 significance level. Two types of headsets were observed. The most common type rests on the outside of the ear while the other rests in the ear. The preferred level for the regular type headset was significantly higher than the levels for the type that rested in the ear. Table 2 shows these differences.

Table 2: Preferred dbA by Type Headset

Grouping	Means (dbA)	Headset Resting
A	89.7	on ear
B	79.7	in ear

Means with different letters are significantly different at a 0.05 significant level.

Since the variances for male subjects were unequal to those of female subjects, Satterthwaite's approximation (Millikin and Johnson, 1984) was used to determine that there was a significant difference between gender preferences (see Table 3). Males preferred noise levels of 91.4 dbA, standard deviation of 9.6 dbA, over 86.5 dbA, standard deviation of 11.2 dbA, for females.

Table 3: Preferred dbA by Gender

Grouping	Mean (dbA)	Gender
A	91.4	Male
B	86.5	Female

Means with different letters are significantly different at a 0.05 significance level.

Satterthwaite's pairwise comparison technique for heterogenous variances was again applied to determine age preference differences. The 15–19 year group preferred the loudest levels of 95.3 dbA, with a standard deviation of 8.1 dbA where the 60 and over year group preferred the lowest levels of 77.1 dbA, with a standard deviation of 5 dbA. Figure 1 graphically illustrates a trend with age group preference and Table 4 depicts the significant differences between age groupings. A significance level of 0.01 was chosen in order to obtain a 94% confidence level that the means were truly different (Bonferroni's adjustment).

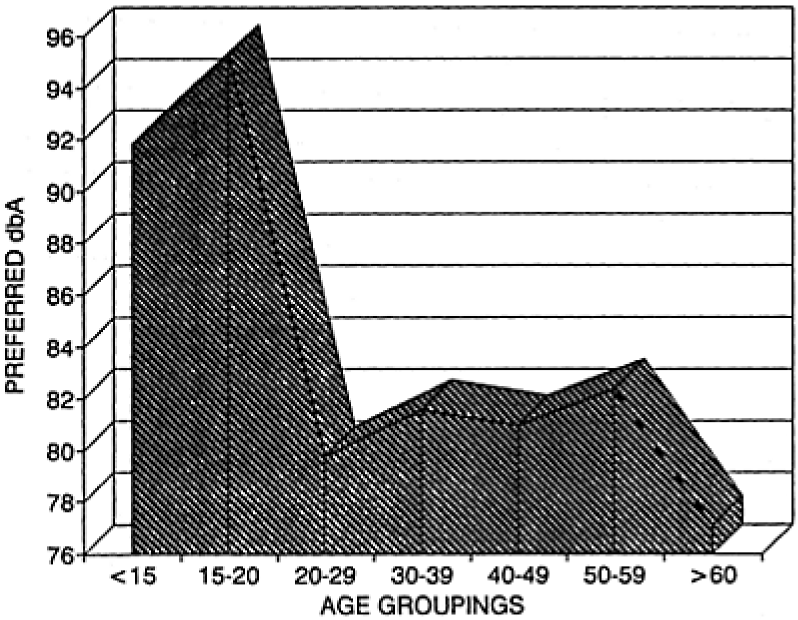

Figure 1: Age Group Noise Level Preferences

Table 4: Preferred dbA by Age Groups

Grouping		Means (dbA)	Age Groups (Years)
A		95.3	15–19
B		91.8	<15
C		82.4	50–59
C		81.6	30–39
C		81.0	40–49
C	D	79.8	20–29
	D	77.1	>60

Means with different letters are significantly different at a 0.01 significance level.

A comparison of music styles to noise level preferences also required a non-parametric procedure. Again the 0.01 significance level was chosen in order to obtain the 93% confidence level. Rap music levels were the highest level with 96.3 dbA, standard deviation 5.0 dbA, and classical at 78.8 dbA, standard deviation 7.0 dbA, was the lowest level. Rock music with a preferred noise level of 88.3 dbA, standard deviation of 12.6 dbA, was the next loudest music style. The fourth grouping which consisted of country and western, jazz, new age, pop or other music styles consisted of preferred noise levels from a high of 86.8 dbA to a low of 83.1 dbA. Within this fourth group of music styles there were no significant differences for noise level preferences Table 5 shows the results of this analysis.

Table 5: Preferred dbA by Music Style

Groupings	Mean (dbA)	Music Style
A	96.3	Rap
B	88.3	Rock
C	86.8	Country & Western
C	85.5	Jazz
C	84.8	New Age
C	83.1	Other
C	83.1	Pop
D	78.8	Classical

Means with different letters are significantly different at a 0.01 significant level.

CONCLUSIONS

The excessive noise levels preferred by many users for portable audio equipment with headsets recorded in this study are consistent with those obtained in similar studies. Males did prefer higher levels than females. It appears that louder noise levels are preferred for more primitive styles of music. Those who listen to more complex music, i.e. classical, prefer lower levels.

Since the current volume control allows users to listen at higher than recommended levels, it would be highly desirable to require manufacturers to redesign volume controls. Such a redesign would limit the user from exceeding the recommended noise levels. However, legislating and enforcing such lower audio levels in an international market place may be infeasible. Educating the user is the only practical solution to reduce the risk of permanent hearing loss. Requiring warning labels, stating that prolonged exposure at loud levels may result in permanent hearing impairment, is appropriate for both audio equipment and recording labels for certain music styles such as rap and rock.

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A REGRESSION APPROACH FOR EFFICIENT PREDICTION OF BROADBAND HEARING PROTECTOR ATTENUATION IN THE FIELD*

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A field study was conducted to collect third-octave spectral attenuation data using 40 industrial workers wearing 1 of 4 hearing protectors under each of 2 protector fitting conditions while on the job, and single-number Noise Reduction Ratings per subject (NRRps) were calculated. Simple linear regression was then applied to estimate the A-weighted broadband NRR_{ps} using only a single test band attenuation measurement at 500 Hz. The results suggest that the single-band attenuation data provide a reasonably accurate reflection of the broadband attenuation in the field.

INTRODUCTION

Background

Hearing protection devices (HPDs) are a popular and practical countermeasure against the insidious and often-tragic effects of occupational noise-induced hearing loss. According to the current regulation (EPA, 1990), all HPDs sold in the United States are required to be labeled for both frequency band-specific attenuation and single-number Noise Reduction Rating (NRR) data. For HPD labelling purposes, third-octave attenuation over nine bands with centers ranging from 125 to 8000 Hz must first be determined using a psychophysical realear test under optimal laboratory conditions (ANSI, 1974). Then, the NRR can be calculated (as a weighted single-number composite rating) to provide a simple means to estimate the overall dB (A) protection level with the HPD for a given C-weighted noise measurement (OSHA, 1988).

However, the procedure for determining broadband NRR attenuation is rather complex and time-consuming, i.e., 3 trial measurements of individual band attenuation across the spectral range may typically take more than 1 hour per subject on a single HPD. For practical purposes such as obtaining a quick estimate of the overall protection afforded by an HPD in the

* Research conducted in the Auditory Systems Laboratory at Virginia Tech

field, it may not be necessary to have all of the information currently needed for HPD labelling. Rather, single third-octave band (or single-frequency) attenuation measurements may be used to predict the broadband noise protection afforded by the HPD in the field, as suggested in prior research (Fleming, 1980; Padilla, 1976). The assumption behind this approach, as stated by Padilla (1976), is that if attenuation of a conventional HPD (most industrial HPDs) is acceptable at low frequencies (e.g., 500 Hz), then the attenuation at higher frequencies will probably also be as acceptable. Preliminary results from these studies have indicated that single band data measured at 500 Hz (Padilla, 1976) or 1000 Hz (Fleming, 1980) are most promising in this regard.

Research objective

The empirical approach of using only one test band for attenuation measurements could eventually save considerable amounts of time (perhaps each test may take less than 10 minutes of measurement time rather as compared to more than 1 hour) in field HPD testing. This also provides a much simpler testing procedure. However, to obtain a reasonably good prediction of the broadband HPD attenuation in the field, this practical method needs to be used along with a sound statistical approach for prediction. Although one prior study has used probabilistic limits, such as “confidence limits” (Fleming, 1980), for prediction purposes, none applied “prediction intervals” to estimate an *individual’s* minimum and/or maximum expected attenuation from a single band attenuation measurement. With this in mind, a field study was conducted to develop and evaluate a viable prediction method using a regression-prediction interval approach which would be applicable to attenuation data collected in the field. As a choice of a single test band for attenuation measurement, both a 500 and a 1000 Hz band were used for the regression approach, based on the results of the aforementioned studies. Neither frequency showed a prediction advantage; only results associated with 500 Hz data are presented in this paper due to space limitations. Complete results appear elsewhere (Park, 1991).

METHOD

Design

Forty male industrial workers, aged 20 to 59 years, who were required to use HPDs on the job, participated as paid volunteer subjects. Audiometric criteria for subject selection were pure-tone hearing threshold levels of 40 dB or less at any test frequency in at least one ear and left/right ear threshold differences of 20 dB or less. All work sites, whose measured 8-hour time-weighted average noise levels ranged from 86.5 dB (A) to 98.1 dB (A), were within a 5-min driving distance to the test laboratory so that the workers could promptly be escorted to the facility for testing.

The 4 HPDs under study, with which all workers were unfamiliar, were a Bilsom UF-1 foam cushion earmuff, an E-A-R foam earplug, an UltraFit premolded earplug, and a Willson Sound-Ban 20 ear canal cap. Since HPD was a between-subjects variable, a group of 10 workers was randomly assigned to 1 of the 4 HPDs which they used at work for 6 weeks. HPD fitting procedure, a within-subjects variable, consisted of naive "subject-fit" using only manufacturer's on-package instructions, and "trained-fit" with experimenter-guided verbal instructions and 70 dB (A) pink-noise feedback to aid fitting. The subject-fit condition was applied during the first 3 weeks of HPD usage, followed by the trained-fit procedure which was used for the second 3 weeks of the 6-week period. Another within-subjects variable was time period of use, which included 3 levels: week 1, 2, and 3. That is, subjects were pulled from their work (without prior knowledge of when they were to be tested) at an unannounced time once during each of the 3 weeks under each fitting condition (a total of 6 times) with their HPDs and attenuation-tested.

Protocol

All attenuation data were collected using real-ear attenuation at threshold (REAT) procedures in accordance with ANSI S12.6–1984. The tests were performed in a diffuse sound field within a sound-treated chamber, with stimuli consisting of 9 1/3 octave bands of noise centered at 125 through 8000 Hz. Using automatic audiometry, the subject tracked his thresholds for these stimuli which were presented (and responses scored) with an IBM PS-2/70 computer-controlled audio signal system with Norwegian-Electronics 828 hardware. More detail on the HPD test facility, which is accredited by the National Institute of Standards and Technology, can be found in Casali (1988).

During the 3-week field usage period under each fitting condition wherein the HPDs were first distributed, each subject was picked up on an unannounced basis and transported to the laboratory. Once pulled from the workplace, the subject was continuously monitored by the experimenter and not allowed to touch the HPD until after the occluded threshold tests. Even after the subject entered the test chamber, he was monitored using a closed-circuit TV system to ensure that no HPD adjustment occurred. With the HPD fit as found in the workplace, 2 occluded-ear threshold tests were first conducted at each of the 9 test frequency bands. Next, the HPD was doffed, and 2 unoccluded thresholds were then obtained at each test band. Each of the 3 attenuation data collection sessions (under each fitting condition) lasted approximately 1 hour, and there was about 1 week separation between each attenuation test session for each subject.

RESULTS

Attenuation data reduction

Based on the nonsignificant (p>0.05) differences yielded by paired t-tests between the 2 occluded trials and also between the 2 unoccluded trials at all test bands, the thresholds of the 2 occluded trials were averaged as were those of the unoccluded trials, resulting in a single pair of mean occluded and unoccluded thresholds for each subject in each experimental session. Then, attenuation, as a single dependent measure in each experimental condition, was computed as the arithmetic difference between the mean occluded and unoccluded thresholds. For complete attenuation data (means and standard deviations) for each experimental cell and the results of analysis of variance (ANOVA) procedures, the reader is referred to Park and Casali (1991).

With frequency-specific attenuation data in hand, a regression analysis was first performed to determine the linear relationship between the single test band attenuation and broadband (NRR) attenuation for different HPDs under different fitting conditions. Secondly, statistical prediction intervals were developed to provide a means for predicting an individual subject's probabilistic bounds of broadband protection from his single frequency band data.

Regression models

The typical NRR labeled on each HPD is a weighted single-number composite rating based on a logarithmic mathematical combination of the 9 individual frequency (125–8000 Hz) band-specific attenuation values (obtained from a minimum of 10 subjects), reduced by 2 standard deviations of attenuation (EPA, 1990). The NRR also includes a 3 dB spectral uncertainty correction. It constitutes a theoretical estimate of protection for 98% of the user population (EPA, 1990). To establish an effective regression approach, i.e., a one-to-one relationship between single frequency (500 Hz) band attenuation and broadband attenuation, a modified NRR was calculated for a single subject, namely the NRR per subject (hereafter NRR_{ps}), in this study. The NRR_{ps} does not reflect a 2 standard deviation correction (due to computation based on only 1 subject) but does include a 3 dB spectral uncertainty correction. Simple linear regression was then applied to predict the NRR_{ps} from the attenuation measurement at single frequency (500 Hz) band for a given HPD and for each fitting condition. Partitioning of data for regression (for each of the four protectors under each fitting condition) was based on the significant (p<0.05) interaction effect of HPD and fitting condition at most frequencies in the ANOVA procedures (Park and Casali, 1991). The regression results (slope *a*, intercept *b*, and Pearson coefficient *r*) are presented in Table 1.

Table 1. Single third-octave band prediction of NRR_{ps} at 500 Hz: linear regressions* using

attenuation data for each HPD and each fitting procedure.

HPD	FITTING CONDITION	*a*	*b*	*r*
Foam Plug	Subject-Fit	0.92	2.40	0.98
Foam Plug	Trained-Fit	0.52	10.56	0.65
Premolded Plug	Subject-Fit	0.90	2.35	0.96
Premolded Plug	Trained-Fit	0.69	7.40	0.93
Earmuff	Subject-Fit	0.85	4.26	0.96
Earmuff	Trained-Fit	0.68	8.03	0.77
Canal Cap	Subject-Fit	0.92	2.52	0.92
Canal Cap	Trained-Fit	0.79	5.08	0.89

$NRRp_s$=*(a)* (single band attenuation at 500 Hz in dB)+*b*

Based strictly on the descriptive regression results, it can be shown that the 500 Hz single band data (particularly the subject-fit data) provide a reasonably accurate reflection of the A-weighted attenuation for all HPDs sampled, as evidenced by the slopes near 1.0, intercepts close to 0, and high correlations ranging from 0.92 to 0.98 across protectors. This is a promising result because the main objective of the study was to predict the broadband attenuation in the field where the majority of workers quite likely fit HPDs in a similar manner to the subject-fit condition.

Prediction intervals

With regression models developed for a given HPD and fitting condition, the next research interest was to develop probabilistic bounds of predicted broadband attenuation on an *individual* (single) user's performance, *not* the *average* person's. For this purpose, 95% "prediction intervals" (Myers, 1986) were constructed around each regression line to predict an individual's minimum expected and/or maximum attainable broadband attenuation (NRR_{ps}) with 95% probability, from a single (500 Hz) attenuation measurement. Note that these intervals are different from typical "confidence intervals" which provide upper/lower bounds within which the predicted *average* value is expected to fall, with a given confidence level. The resultant 95% prediction intervals (which contain the true NRR_{ps} based on single subject's measured 500 Hz attenuation) for each HPD under the *subject-fit* procedure are depicted in Figure 1. [Complete figures for the trained-fit data appear in Park (1991).] In each panel of Figure 1, a dotted reference line (with slope=1 and intercept=0) which represents a perfect one-to-one correspondence of single test band and NRR_{ps} values is included for comparison purposes.

The prediction intervals presented in Figure 1 are best used to predict an individual worker's *minimum* expected protection in the field (lower bound). Suppose an employee is unfamiliar with the E-A-R foam plug and is relatively naive in proper fitting technique, then a minimum NRR_{ps} of 20 dB (see lower bound of the E-A-R foam plug panel in Figure 1) is expected with 95% certainty from a measured 500 Hz attenuation of 25 dB. Another way of using the prediction interval is perhaps for motivating improvement in protection. In this case, the maximum attainable attenuation is the target which can be defined by upper bound. For the same example using Figure 1, the maximum broadband protection attainable by the E-A-R foam plug is 30 dB, with 95% certainty, from a measured 500 Hz attenuation of 25 dB.

From Figure 1, it can be seen that the intervals with 95% certainty are consistently tight over the single test band attenuation range, particularly in the practical range (10–30 dB) for field applications, ranging from ±2.7 to ±6.5 dB. In summary, the results from prediction intervals again demonstrate that predicting broadband protection, NRR_{ps}, from a single test band attenuation measurement is potentially very useful in field applications.

DISCUSSION AND CONCLUSIONS

Using complete ANSI S3.19–1984 procedures to predict workers' in-field noise protection levels may be unwieldy, time-consuming, and impractical as discussed earlier.

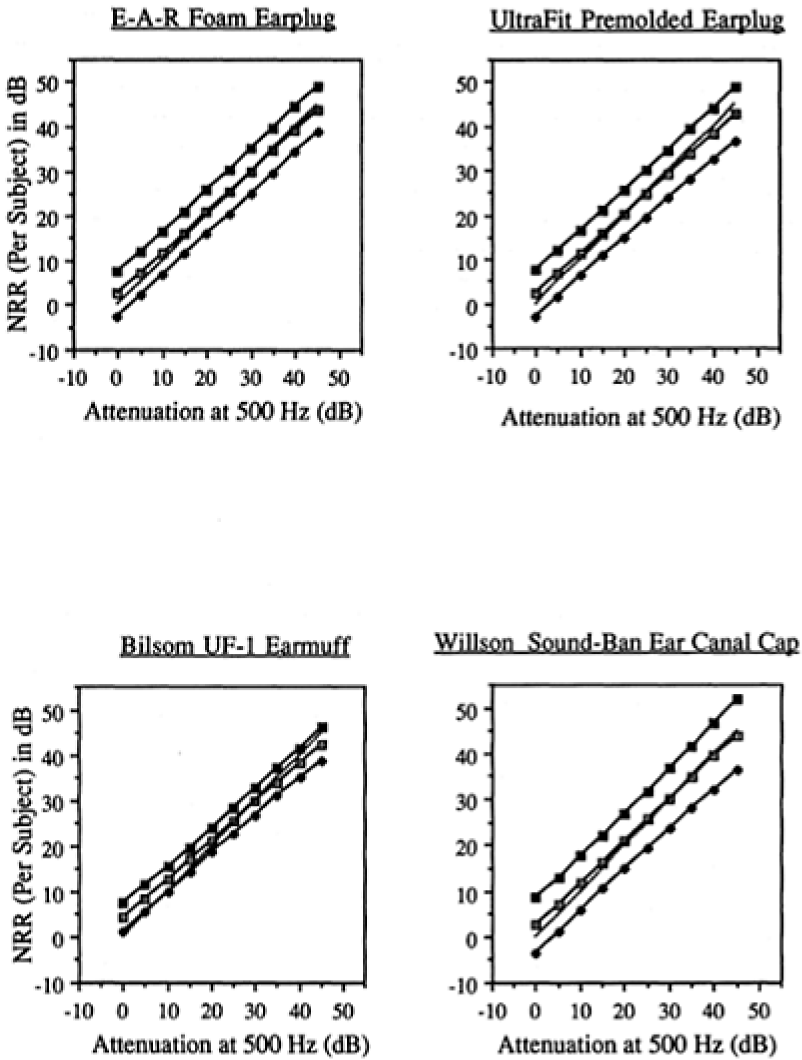

Figure 1. Prediction of the NRR_{ps} from single test band attenuation results at 500 Hz for each HPD under subject-fit condition. (Open squares=Regression line; solid squares= 95% upper and lower Prediction Intervals; dotted line= reference line with slope of 1 and intercept 0.)

The results of this study suggest that field attenuation measurements could be limited to only one test band (e.g., at 500 or 1000 Hz), so that a simple and quick procedure is established in a short test period to provide a reasonable prediction of broadband HPD attenuation achieved by workers. In this way, an individual worker's protection level can easily be verified at the time of a worker's annual audiogram. Such data may help improve the company's industrial hearing conservation program. The speed and practicality of single test band testing may compensate for the benefits in accuracy that are achieved via a 9 frequency test. This is because, in a practical sense, using only one test band for protection estimation purposes saves a considerable amount of testing time in the long run and enables individual workers' protection levels to be acoustically verified. Another benefit is that repeat testing may be done at low cost to improve the precision of test results.

The prediction methodology developed and tested in this study has many potential applications. For instance, in addition to the use of prediction intervals as discussed in the previous section, these intervals can also be used for checking certain situations (e.g., determining if a protector provides OSHA compliance), allowing for a quick, empirical verification of protector adequacy and compliance for an individual worker.

Although there is no distinct clear-cut advantage of one test band (500 or 1000 Hz) over the other for prediction performance, the 500 Hz data provided slightly better prediction under subject-fit, as shown by regression statistics in Table 1. Since the subject-fit condition used in this study (which represents the typical HPD fitting situation in many industrial workplaces) accurately predicted the broadband field attenuation, reliable estimation of overall protection for each individual can easily be made in the field on the basis of a quick, single-band test.

In conclusion, predicting overall field noise protection from single test band data is practical, reasonably accurate, and feasible. Such REAT measurements (as per ANSI S12.6–1984) may be obtained in the typical industrial audiometric booth. The booth may be outfitted with loudspeakers, and audiometers (which are readily available in the field) can be used in conjunction with signal conditioners, amplifiers, and pre-recorded third-octave test signals which will be presented for the attenuation test. An alternative approach may be to apply the regression-prediction intervals technique for estimating broadband attenuation from single-frequency (500 or 1000 Hz) pure-tone attenuation data. Pure-tones are available on all industrial audiometers. More work is needed to determine the equipment configurations and test signals which are amenable to field use.

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HEIGHT CHANGE MEASUREMENT OF THE SPINE DURING WHOLE BODY VIBRATION.

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Height loss was used as a measure of spinal load in comparing seated vibration with static sitting. Unsupported upright sitting was compared with sitting against backwardly inclined back supports. The seated posture always caused height loss and vibration during unsupported sitting caused significantly more height loss than static sitting. Supported sitting resulted in less height loss than unsupported but the backrests did not significantly eliminate the effect of vibration.

INTRODUCTION

Back pain and other musculo-skeletal disorders are the most common cause for work absenteeism among men and women over the age of thirty years. Prolonged sitting appears to be positively related to the development of low back pain (Hult, 1954; Magora, 1972; Lawrence, 1977). According to Kelsey (1975) there is an increased risk for the development of a herniated disc in sedentary workers, and the relative risk increases in people older than 35 years. Seated whole body vibration is the most common vibratory exposure in occupational life. A large number of studies have found an obvious linkage between seated whole body vibration and increased incidence of low back pain (Kelsey, 1975; Pope et al., 1980; Frymoyer et al., 1983; Wilder et al., 1985; Sandover, 1983; Heliövaara, 1987). People, whose profession is driving or operating motor vehicles, are often exposed to other activities believed to be harmful to the spine as well. Such activities include loading and unloading and prolonged sitting with limited options to adjust posture. Even with these factors considered, there seems to be a significant risk for back problems from vibration alone (Troup, 1978; Frymoyer et al., 1980; Kelsey and White, 1980). Kelsey and Hardy (1975) found that truck drivers were over four times more likely to develop a herniated lumbar disc than men who were not truck drivers. Also, those driving a car outside the job were about twice as likely to develop a herniated lumbar disc compared to those not driving.

Premature radiographically confirmed degenerative changes in the vertebral column were found in tractor drivers and were interpreted as indicators of an evident relatonship between whole body vibration and back problems (Rosegger and Rosegger, 1960). Increased prevalence of spinal disorders was also found in experienced bus drivers and truck drivers (Gruber and Zipermann, 1974; Gruber, 1977).

The harmful effects on the spine from whole body vibrations are not fully clarified. Some pathophysiological effects have been demonstrated through animal experiments and through human tests. Holm et al. (1985, 1986) showed that whole body vibrations lead to poorer nutrition in the intervertebral discs and consequently to an intradiscal accumulation of metabolites. Accumulation of metabolites is believed to stimulate the degenerative process of the disc. Other animal studies (Fassbender, 1979) showed that long term exposure to whole body vibrations stimulated the generation of mitochondria and growth of giant cells in musculature as well as cartilage cell degeneration. Jankovich (1971) showed in animal experiments that bone exposed to whole body vibration became fragile and brittle due to component changes of the calcium content, changes similar to the normal aging process of bones.

It has been suggested that seated whole body vibrations could cause fatigue injuries due to the frequent repetition of loading (Lafferty et al., 1977; Liu et al., 1983; Sandover, 1983; Brinkmann et al., 1987, 1988; Hansson et al., 1987). This could mean that a low load, such as from vibration, if repeated many times can be as hazardous as a high load that is applied only a few times. In fatigue experiments on human specimens it was shown that the occurred injuries were disc injuries combined with fractures of the vertebral endplate and in the adjacent spongy bone (Hansson et al., 1988). It seems likely that the risk of an injury increases considerably when a large number of loading cycles are accumulated even if each load is very small.

The spine behaves in a visco-elastic manner, meaning that the motion segment will deform when a static load is applied until an equilibrium is obtained and regain its original height immediately when the load is removed. The visco-elastic behavior is due to the mechanical properties of the spine, which are influenced by the magnitude, the duration and the frequency of the applied load. If the applied load is kept constant for an extended period of time, the motion segment will undergo creep, i.e. continue to deform asymptotically after equilibrium. Creep is, thus, defined as deformation under constant load as a function of time. This is well documented by a large number of researchers. The creep rate for a constant load decreases with time. The rate is dependent of the load applied, i.e. the higher the load the faster the creep. The creep rate for discs is influenced by the degenerated state (Kazarian, 1975; Keller et al., 1987).

The deformation of the spine, resulting from an applied load *in vivo* has been measured as a change in stature. The amount and rate of change has been assumed to reflect the amount of load on the spine.

MATERIALS AND METHODS

Spinal height change was measured by means of a linear voltage displacement transducer M.V., connected to a chart recorder. The transducer registered height changes continuously during the period of time that was chosen for the exposure. The device is equipped with means for posture control. Figure 1

The subjects were twelve women with an average age of 22 years. Their average height was 166 cm and their average weight 61 kg. Table I. They were all hospital workers with no history of low back pain.

Throughout the experiments, the subjects were seated on a wooden platform which was fixed to a vibration simulator. The simulator can elicit vibrations with varied frequencies between 2 and 15 Hz. An accelerometer placed on the platform monitored the vertical acceleration input to the seated subject. For these experiments the frequency of 5 Hz and the acceleration of 0.1 g RMS were chosen.

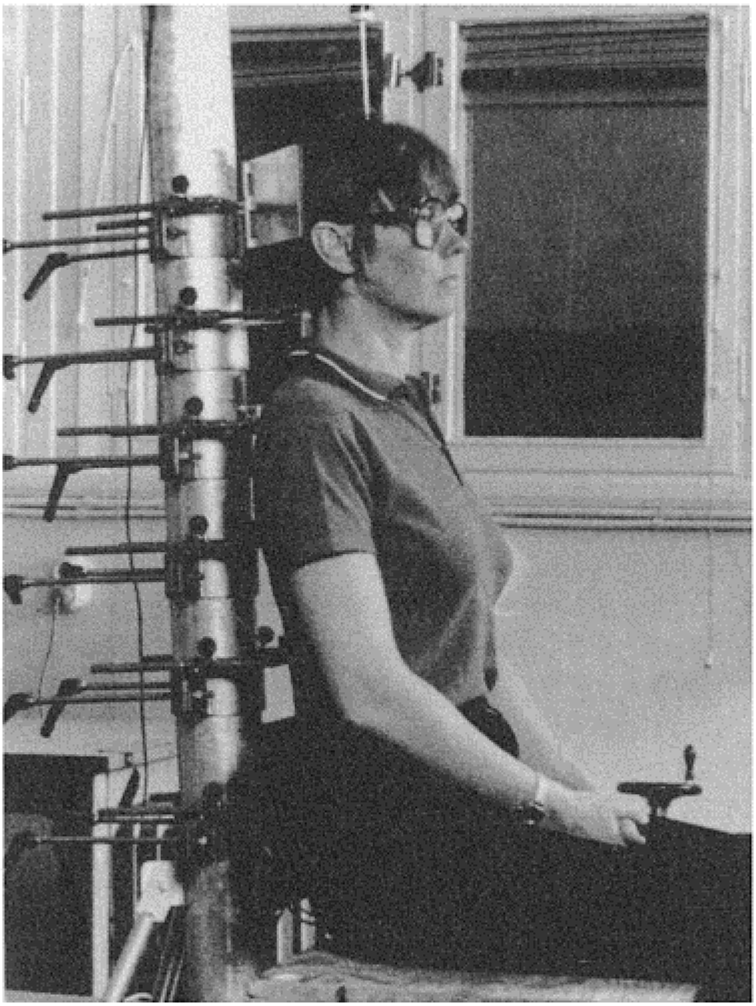

Figure 1: The adopted test posture which was controlled by the pressure sensitive switches, the arrangement of special glasses and a mirror.

Three different postures were studied. These were erect sitting with no back support and 110° and 120° supported sitting. The postures were carefully worked out prior to the experiments and the adopted posture was well controlled. The frequency and acceleration level of the vibrations were set for each subject after which she was asked to rest supine for thirty minutes in order to minimize the effects of preloadings, caused by preceding activities.

The height measurements started with a maximum stretch up after which the exposure posture was readopted and maintained for five minutes followed by another stretch up and readoption of the posture.

A serie of exposure consisted of six runs of which every second was with vibration and the other without vibration. Each run was followed by twenty minutes rest in a supine position. All the measurements took place during morning hours.

Table 1. Age, standing and sitting body heights and body weight in the twelve test subjects.

Subject	Age	Height	Sitting height	Weight
1	20	165.5	89.5	53.0
2	24	168.5	91.0	60.0
3	23	156.5	83.5	46.0
4	22	161.0	83.5	62.0
5	20	166.0	93.0	80.0
6	19	164.5	84.0	57.0
7	24	159.0	86.5	48.0
8	25	175.0	92.0	67.0
9	22	166.0	92.0	68.0
10	26	170.5	89.0	71.5
11	20	172.0	94.0	64.0
12	19	170.0	93.0	59.0

RESULTS

The seated posture with or without vibration always caused height loss. In erect unsupported sitting there was a larger height loss when the subject were vibrated than when not ($p<0.01$). This difference was significant also when posture change was corrected for ($p<0.05$). The height loss from supported sitting was less than from the unsupported ones with or without vibration. The difference was significant between erect unsupported sitting and supported sitting at 110° both during vibration and during static sitting, but only during vibration when the 120° backrest inclination was used. There was no significant difference of height loss between the two backrest inclinations with or without vibration. Table II

Table 2. The mean shrinkage and the standard errors of the mean (SEM) of the exposure to vibration and no vibration in the three different positions.

	Vibration	No Vibration	Signific.
	Mean (SEM)	Mean (SEM)	
90° no backrest	5.94 (0.59) mm	4.52 (0.54) mm	($P<0.01$)
110° backrest	3.59 (0.76) mm	2.82 (0.56) mm	N S

120° backrest	2.88 (0.58) mm	3.79 (0.96) mm	N S

DISCUSSION

In the erect unsupported seated positions, a significantly larger height loss was demonstrated in subjects having been vibrated than not vibrated. This difference was proven to be consistent even after correction for posture changes. The results are in agreement with those of Klingenstierna and Pope (1987), but in contradiction to those of Bonney (1988). These two cited studies did however, differ in many ways. One important difference was the time for exposure 30 minutes and 60 minutes respectively, compared to our 5 minutes exposure. Since we used a continuous measuring technique we had to choose a short measuring time in order to control for posture changes. The differences in methods and exposures in the study of Bonney and ours makes a direct comparison more or less meaningless. It should be mentioned, however, that no other study to our knowledge have confirmed their results, i.e. that whole body vibrations made the subjects grow in height.

The height loss in backwards inclined supported postures was always less as compared to the upright unsupported posture. The differences were in most cases significant. With techniques for measurement of disc pressure and muscular activity it has been demonstrated that the spinal load is increased in the seated posture compared to standing (Andersson et al., 1974). Andersson et al. (1975) also demonstrated that the increased load in sitting was reduced through the use of an inclined backrest. We have used height loss as a measurement of spinal load. Thus, the smaller amount of height loss, that was found when the back was supported and backwardly inclined, compared to the amount of height loss during unsupported sitting, indicates that changes in loads are measurable with this technique. As vibration significantly accentuated the height loss in the unsupported upright sitting position and providing that spinal shrinkage does reflect the compressive load on the spine, vibration consequently appeared to cause a greater load on the spine compared to static sitting. This assumption is also supported by the studies on muscular response to whole body vibration (Serroussi et al., 1989; Wilder et al., 1985).

The difference in height loss that was seen between vibration and no vibration during unsupported upright sitting was not significantly proven during the supported sitting postures, Thus, the inclined supported posture did not have a significant attenuating effect on the vibrations. Neither had the degree of inclination any significant effect on decreasing the height loss in any of the exposures. This is in agreement with recent results of the effect of backrest inclination on the dynamic response of the human spine to vertical vibration (Magnusson et al., 1992). They used the same inclination degrees of the backrest and found only a slight decrease in natural frequency and in the peak gain and concluded that the inclination of the backrest had only a minor effect in attenuating the vibrations.

It should be noted, though, that an inclined supported sitting posture is less loading to the spine than an unsupported one as proven through discometry and electromyography, and that our conclusion merely is that the backrest does not eliminate the effect of vibration on spinal loading.

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INTERNATIONAL ERGONOMICS

An Evaluation of Visual Search Strategy Under Different Product Characteristics

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The study is to determine how search strategy and product characteristics can affect inspection performance. The mean of the probability of target detection in a single fixation was taken as an objective measure of target conspicuity.

An experiment was designed. Sixty subjects participated in the experiment. The ANOVA results indicate that search field size, target conspicuity, fault number, and search strategy all have significant influences on search time performance. The results suggest that the systematic—random search which combines the merits of the systematic and random searches is a promising strategy for the inspection of soldering points on IC board or similar products.

INTRODUCTION

Recently, with the trend toward automation, many non—dimensional type of inspections still rely on human operators to make quality control (Drury and Sinclair, 1983). There are two major subtasks in inspection: one is visual search, to locate the flaw target; and the other is decision making, that is to determine whether the located flaw target violates the specified quality standard (Drury, 1975).

Search strategy is a generic term which involves several eye movement parameters, e.g. direction of eye saccade, sequential index, and interfixation distance (Megaw and Bellamy, 1979). In general, it has been classified into two categories (Morawski, et al., 1980; Kraiss and Knaeuper, 1982):

(1) random search: It means that the location of successive fixation is independent of each other and hence can be regarded as sampling with replacement.

(2) systematic search: It means that search field will be covered systematically without overlapping of fixations and hence can be regarded as sampling without replacement. This strategy is also called an exhaustive search.

In systematic search, the interfixation distance is an important eye movement parameter for determining search performance. It will affect the number of fixations needed to exhaust the search field. However, a greater interfixation distance can not guarantee a more effective search performance. It seems that there is a need to evaluate the relationships among them. In here, the systematic search assumes that the search field is subdivided into many small regions. The inspectors scan through these regions systematically.

Further, random search with overlapping of fixations results in more search time. An improved strategy called systematic—random search is proposed in this study. In systematic—random search, the inspectors scan through the search field region by region systematically, and randomly search within each region.

Many factors that are related to product characteristics have been reported to have an effect on visual search performance. Examples are search field size, target conspicuity, and fault numbers (Bloomfield, 1975; Kraiss and Knaeuper, 1982). For target conspicuity, it has been defined as the combination of properties of a target (e.g. size, shape, texture, surface luminance, and color) on the search field by which it can "attract attention" via the visual system (Engel, 1971). There is no agreed—upon method of measuring "attraction of attention". Various measurement paradigms have been suggested, for example, subjective ranking scales (Forbes, et al., 1967, 1968), recall (Johansson and Backlund, 1970), search and reaction time (Baker, et al., 1960), visual lobe (Cole and Jenkins, 1980; Engel, 1971, 1974) and the probability of seeing at a given visual eccentricity (Cole and Jenkins, 1980).

The main objective of the experiment is to determine how eye movement parameters and product characteristics can affect search performance. The results can be applied to determine the best search strategy under different product characteristics.

METHOD

Subjects

A total of 60 subjects, 48 males and 12 females, took part in the experiment. All subjects had normal corrected visual acuity, and normal color vision. Again, all were undergraduates of the National Tsing Hua University. Their ages ranged from 18 to 26 years.

Stimuli

The stimulus designed in this experiment was to simulate the inspection of soldering points of IC board. In other words, the task was to inspect the backside of an inserted IC board. The stimulus which simulates the pattern of soldering points on a IC board was generated by a personal computer. For the target and nontarget symbols, the color was darkgrey and the luminance was 2.797 cd/m^2. And the background color of the board was green, and the luminance was 7.115 cd/m^2.

Three size of boards were specified, they were in matrixes of 18×66 symbols, 15× 55 symbols and 12×39 symbols respectively. In order to maintain the same density of 65%, the actual number of symbols were about 772 (18×66×65%) for the large size board, 536 (15×55×65%) for the medium size board, and 304 (12×39×65%) for the small size board.

Search strategy

Search strategy involves both search pattern and interfixation distance. Four search strategies were specified which included a random search, two systematic searches (systematic-1, and systematic-2) and a systematic—random search. For systematic searches, the stimulus field was assumed to be subdivided into many regions. But this assumption is not applicable for random search, because it tends to have overlapping random fixations. In systematic search, only one eye fixation per region was allowed. The systematic-1 search has small interfixation distance and it specifies that the radius of the visual lobe is about 3 deg. And the systematic-2 search has large interfixation distance, and the radius of the visual lobe is about 4 deg. In systematic—random search, the subject scans through the search field region by region systematically, meanwhile randomly search within each region. Thus, the systematic—random search has the smallest number of regions than those of the two systematic searches. The 60 subjects were assigned randomly to four equal groups. The first group, including 14 males and 1 female with the mean age of 20.33 years (range 19–26), was trained to use random search strategy. The second group, including 10 males and 5 females with the mean age of 20.67 years (range 19–22), was trained to use systematic-1 search strategy. The third group, including 12 males and 3 females with the mean age of 21.07 years (range 19–23), was trained to use systematic-2 search strategy. And the fourth group, including 12 males and 3 females with the mean age of 20.87 years (range 19–26), was trained to use systematic—random search strategy.

Experiment design

Four factors were considered in the experiment design: search field size, target conspicuity, fault number, and search strategy. Both search field size and target conspicuity have three levels, fault number have two levels and search strategy have four levels. The specification of each level is listed in Table 1. In order to have valid randomization for target location, three replications were considered. In addition to the faulty stimuli, 18 perfect stimuli were added. Thus, a total of 72 (3×3×2×3+18) stimuli with a fault rate of 75% was performed by each subject.

Procedure

A 20 minute training session was given prior to the experiment. In the training session, the subject practiced at least 18 trials to learn the assigned search strategy and the three target types. If the subject requested, 5 additional stimuli were given each time until he/she was able to perform the task. A ten—minute rest was scheduled before the experiment.

During the experiment, the subject was requested to inspect the soldering points on the screen. If a correct decision is made by pressing the corresponding response key, then the next stimulus will be displayed. But if an incorrect response is made, a feedback sound is given. Then the subject has to continue searching for the target. This is to ensure that the subject is doing the task without guessing. A maximum of two warning feedback will be given per stimulus. If the subject still can not make correct detection after two warning feedback, the next stimulus will automatically be displayed.

After finishing the 72 test trials, each subject's performance data in search time, stopping time and the number of feedback warnings were automatically recorded on a personal data file.

RESULTS

The distribution of the number of warnings provided from 0 to 2 for all the subjects is listed in Table 2.

The warning feedback=0 indicates that the subject detects fault in the first search. The warning feedback=1 indicates that the subject fails to detect fault in the first search, but successfully detects the fault in the second search after hearing the first feedback sound. The warning number=2 indicates that the subject fails to detect faults in the second search and stops searching after hearing the second feedback sound. The reason may be that the search time is too long and the subject is impatient to the task due to eye fatigue.

Since the performance for trials under warning number=2 may be affected by motivation and fatigue factors, only search time performance for trials under warning number=0 and 1 was used. As it can be seen in Table 2, the cumulative frequency distribution under warning number=0 and 1 is 95.8%. Namely, at this time period, less than 4.2% of the targets remain undetected. Another performance measure was stopping time which is the response time of making correct decision for a good board. Analysis of variance on search time performance was performed and the results are shown in Table 3. All the main effects ($p<0.001$) and the interaction effects are significant. The significant main effects indicate that search field size, target conspicuity level, fault number, and search strategy all have strong influences on search time performance. Also, it is interesting to note that there are significant interactions between search strategy and product characteristics (i.e. search field size, target conspicuity level, and fault number). Table 4 also depicts the mean search time for different search strategies under various product characteristics.

From Table 4, it is logical that the low conspicuity targets involve the longest search time followed by medium and high conspicuity targets. Also the large size board involves the longest search time followed by medium and small size boards. In addition, it is not surprising that the boards having double faults result in less search time than that of single fault. This is consistent for all the four search strategies. Comparing the four stategies, it is interesting to note that the three systematic searches have better search time performance than that of random search in low conspicuity condition, and the random search has the worst search time performance among the four search strategies for low and medium conspicuity targets under all product conditions except in small size board with double faults case. This is because in small size board, the search. field can be exhausted in few fixations, and with double faults, the chance of target detection by random search is increased. Thus the difference between random search and systematic searches is not obvious. But in high target conspicuity condition, both systematic—random search and random search have demonstrated superior performance. The systematic—random search tends to have better performance in single fault case. But the random search tends to have better performance in double fault case. The findings suggest that if a soldering board or similar type of products involving only one easy detecting defect, then the systematic—random search is the best strategy. On the other hand, if the products have multiple easy detecting defects, then the random search is best used. But for low target conspicuity condition, the random search is not recommended. Further for the effect of interfixation distance on search time performance, no systematic relation is found. It implies that from this study there is no ground to say that systematic search with small interfixation distance is always better than that of using large interfixation distance or vice versa regardless of the conspicuity level or the size of the board.

Comparing the mean search time for the four strategies, as shown in Table 4, the systematic—random search which combines the merits of systematic search and random search is found to be the most efficient strategy in about two third (11 out of 18) of the product conditions. It seems to be a superior strategy to be used to inspect faults on the backside of IC board, especially in low target conspicuity and single fault condition.

CONCLUSION

For search time performance, all the main effects ($p<0.001$) and interaction effects are significant. The significant main effects indicate that search field size, target conspicuity level, fault number, and search strategy all have strong influences on search time performance.

Random search is more efficient than systematic search when the search field is small, fault number is high, and target conspicuity is high. But in low and medium conspicuity conditions, the random search becomes the least efficient one. The systematic—random search is found to have the best search time performance among the four search strategies in most of the product conditions.

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Table 1 The specification of the four factors in the experiment.

Independent Variables	Level 1	Level 2	Level 3	Level 4
Search field size(S) (Visual angle)	24.5°×35°	20.4°×29.9°	16.1°×21.7°	—
Conspicuity(C)	Low	Medium	High	—
Fault number(F)	Single	Double	—	—
Search strategy (St)	Random	Systematic-1	Systematic-2	Systematic-Random

Table 2 The distribution of the number of feedback warnings.

Warning number	0	1	2
Frequency	2288 (70.6%)	815 (25.2%)	137 (4.2%)
Cumulative frequency	2288 (70.6%)	3103 (95.8%)	3240 (100%)

Table 3 Analysis of variance for search time

Source of variation	Df	SS	F Value	Prob. of significance
Search field size (S)	2	58914.21	116.91	***
Target conspicuity (C)	2	209703.91	416.15	***
Fault number	1	23317.67	92.55	***
Search strategy (ST)	3	10222.04	13.52	***
S*C	4	19412.02	19.26	***
S*ST	6	4496.73	2.97	**
S*F	2	1554.01	3.08	*

C*ST	6	8501.41	5.62	***
C*F	2	3122.71	6.20	**
ST*F	3	2978.63	3.94	**
Model	31	342223.33	43.81	
Error	3071	773761.26		
Total	3102	1115984.59		

* p<0.05 ** p<0.01 *** p<0.001

Table 4 Mean search time (sec) in (A) single fault case (B) double fault case.

(A)

	S1*C1	S1*C2	S1*C3	S2*C1	S2*C2	S2*C3	S3*C1	S3*C2	S3*C3
Random	53.36	25.96	11.16	35.07	13.78	7.58	24.10	10.72	5.91
Systematic-1	37.62	19.33	11.55	33.00	12.90	10.80	15.74	7.47	5.98
Systematic-2	45.60	18.28	14.08	31.87	14.69	10.61	19.00	7.44	5.64
Sys—random	27.87	14.35	10.92	21.42	11.12	7.65	17.47	6.58	4.56

S1: large size C1: low conspicuity
S2: medium size C2: medium conspicuity
S3: small size C3: high conspicuity

(B)

	S1*C1	S1*C2	S1*C3	S2*C1	‘S2*C2	S2*C3	S3*C1	S3*C2	S3*C3
Random	36.00	14.51	6.30	26.87	10.10	4.03	12.75	3.95	3.52
Systematic-1	31.75	8.75	6.93	20.27	8.71	6.67	13.52	4.62	3.75
Systematic-2	29.24	10.47	9.12	17.89	7.16	6.43	16.03	6.39	3.76
Sys-random	29.12	9.58	7.95	17.49	7.44	5.11	11.42	5.73	3.08

COGNITIVE PROCESS UNDERLYING SOFTWARE REUSE

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Programming activities are primarily cognitive. To develop a useful software engineering environment, it is important that its functionality supports the programmers' cognitive activities. The purpose of this study was to investigate cognitive process in software reuse. During the experiment, subjects verbalized their thinking process while they performed software reuse. From the analysis of verbal protocols, requirements of a software engineering environment were identified. In addition, the performance of novice and experienced programmers were compared. Implications of the results were discussed.

INTRODUCTION

Software reuse is defined as the process of exploiting existing software elements to create a new software (Shriver, 1987). Since the reused software is often flawless, this process enables the new software development not to start from scratch and the programming productivity can thus be enhanced. However, in reality, software reuse is not as cost-effective as it is expected (Fischer, 1987).

The software reuse process can be divided into the following stages: (1) locating the reusable components, (2) understanding the components, (3) modifying the components, and (4) composing the components (Biggerstaff & Richter, 1987). These stages comprise three categories of activities: (1) accessing the code, (2) understanding the code, and (3) adapting the code (Prieto-Diaz & Freeman, 1987). Software engineering researchers have devoted themselves in developing technologies to enhance these activities. Some (e.g, Prieto-Diaz, 1991) have proposed software classification schemes to facilitate the searching process. Others have developed a building-block system architecture and standardized reusable components (Biggerstaff & Richter, 1987). Based on these software engineering technologies, several prototypes of software engineering environments have been developed. For example, Neighbor (1984) developed a system called “Draco” which included an application generator and a transformation base.

Although these software technologies have demonstrated their successfulness in enhancing reuse productivity, their usefulness is rather limited. For one thing, different researchers have inconsistent notions about the difficulties that programmers often encounter. Therefore, the solutions proposed might not solve the right problem. For instance, Fischer (1987) contented that understanding the code to be reused is a prerequisite activity for successful software reuse. In this vein, he developed a prototype system that contained documentation, online help, and visualization tools to aid programmers in program comprehension. On the other hand, Lange and Moher (1989) argued that program comprehension is not a necessary step in software reuse. They observed one subject perform software reuse in an object-oriented programming environment. It was found that the programmer employed several code reuse techniques that allowed her to avoid deep understanding of code details. This finding was contradictory to Fischer’s contention. As to why this controversy exists, the authors argued that it might be due to the inheritance mechanism of the object-oriented programming environment and/or the programming experience of the subject. At any rate, the process of software reuse is not well understood; So, useful aids were not provided for the programmers use.

Another reason why software reuse technologies have not been very useful to programmers is that these technologies are not necessarily compatible with the programmers’ cognitive capabilities. In order to facilitate the software reuse process, programmers were required to follow certain software development processes which involves extensive cognitive activities (Biggerstaff et al, 1987). Without an extensive training and experience in the development processes, they cannot be productive in software reuse. However, the development processes usually impose high mental workload on programmers and cause problems to programmers rather than help them. The software reuse strategies that Lange and Moher (1989) found in their study indicated that programmers often adopted less cognitive demanding strategies such as copy/edit, model, and copy without modification. Therefore, a prescriptive model of the software reuse process is not necessarily useful to all programmers.

In order to develop a software engineering environment that will be useful to programmers, the cognitive process underlying the software design process must be understood. The purpose of the present study was to explore the cognitive process underlying software reuse. From an analysis of the cognitive process, one can identify difficulties that programmers encounter. This information can serve as the basis for the design of a computer-aided software engineering environment. In addition, subjects employed in this study comprised of both experienced and novice programmers. The processes that these two types of subjects used were compared. Such information can help us to identify the areas on which programming training programs should emphasize.

METHOD

Subjects

The experimental sample consisted of five subjects. Two were novice programmers. They were undergraduate students from the Computer Science Department at National Chiao Tung University and had less than one year of experience in C++. Three subjects could be classified as experienced programmers since they were professional programmers and had more than two years of experience in C++.

Experimental Material and Apparatus

Subjects were given the software code of a university personnel data base system written in C++. The programming activities were performed on a PC/AT compatible.

Procedure

Before the experimental session started, subjects filled out a questionnaire about their programming background. In the experimental session, they were told to develop a personnel data base system for a department store by reusing the software given as much as possible. As they were working on the program, they verbalized their thinking process. Their verbal protocols as well as their actions were recorded by a videotape recorder.

RESULTS

A protocol analysis (Ericsson & Simon, 1984) was performed to analyze the subjects' thinking processes during software reuse. It was found that there was a pattern of software reuse process among the subjects. That is, subjects tried to understand the existing software codes before they started working on the new program. The characteristics of the existing codes that subjects tried to understand included: the programming style, its functionality and structure, as well as data structures. In the program comprehension stage, subjects first attended to the declaration of data within each class, especially whether the data were private or public. For methods within a class, they spent much time to understand the implementation of the method; for instance, the nodes and root of a tree structure. Through this stage, subjects developed the knowledge of the program structure and functionality- i.e., mental model.

After the program comprehension stage, they began to search for reusable components. This search process was based on the objectives of the new program. Subjects looked for components which were analogous to the new ones.

Once the candidate components were found, they formulated a hypothesis of reusability and then tested the components to determine if the components would conform to the hypothesis and the use of these components.

In the code reuse stage, the reuse strategies subjects adopted could be classified into the following categories: (1) Copy those reusable components entirely for the new program; (2) Copy and edit the codes; and (3) Decompose those components which had similar structure to that of the new program and then duplicate the usable proportion of the components. After the duplication was completed, they modified the components as needed. After the codes were reused, subjects would test the new program to find out if the new program meet its objectives. If the new codes could not met the objectives, subjects would rewrite the codes.

With regard to the differences between novice and experienced programmers, it was found that experienced programmers first tried to understand the whole structure of the program, took notes about classes in the program and their relationships. Based on the information, they started with higher-level modules to understand each component of the program and planned the reuse process. In understanding the software components, they used a combination of top-down and bottom-up methods. Moreover, experienced programmers also paid attention to the changes that were caused by any modifications.

On the other hand, novice programmers spent a lot of time trying to understand the implementation rather than the top-level design information. They did not try to decompose the entire program into sections or large chunks. Rather, they inspected the codes line-by-line. For each class, they concentrated on the detailed parts. Thus, they often were overloaded. In the code reuse stage, furthermore, the novice subjects only reused modules or classes which were less complicated and they copied the entire codes rather than modifying them.

DISCUSSION

The results showed that programmers followed a sequence of activities in software reuse. They first tried to understand the program to be reused, searched for the appropriate reusable components and formulated a hypothesis of reusability, then modified and tested the components, and finally integrated the components into the new program.

Novice and experienced programmers differ in several areas. Experienced programmers have better problem solving abilities than novice programmers. They can make a plan in every stage of the software reuse process and predict the consequences of their actions. Moreover, they tend to decompose the program into large chunks on the basis of their plan. This finding conformed with the notion proposed by Jeffries, Turner, Polson, and Atwood (1981). Therefore, the programming education should concentrate on not only programming skills but also problem solving skills.

The second area is the mental models that novice and experienced programmers have. Since experienced programmers concentrated on high-level design information, they are able to develop a relatively complete mental model. Therefore, they are able to reuse not only the codes but also the design.

The third area is the reuse strategies. Experienced programmers can adopt a systematic strategy rather than “as-needed strategy” described by Littman, Pinto, Letovsky and Soloway (1986). In this vein, a software engineering environment should provide appropriate design documentation in an appropriate format.

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A Loglinear Model on Human Error Classification

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The objective of this paper is to find out the significant factors causing human errors so that the system designer can focus on these significant factors to reduce human errors. An experiment was conducted and the loglinear model was used to classify the causes of human error. The results of the experiment indicated that the external performance shaping factor (PSF), internal PSF, and stressor PSF were the statistically significant factors of human errors. In addition, the interactions between these three factors were also verified.

INTRODUCTION

It has been reported (Rouse and Rouse, 1983) that 70%-90% of system failures are directly or indirectly due to human error, and resulted in great damages to the systems or the human beings. Therefore, it is desirable to understand the mediating process or cognitive behavior of the human and investigate the potential factors of human errors so that an incident in the emergent situation can be prevented.

Several methods for analysis and classification of human errors have been developed. The work of Rasmussen (1987, 1982) provided great contribution in the definition of human error and a taxonomy to characterize human error with reference to task characteristics, human psychological mechanisms, environmental factors, etc. Rasmussen (1979) also adopted a human information processing point of view to discuss mismatches in the human interaction with a dynamic environment. The skill-based, rule-based, knowledge-based classification (which we shall henceforth abbreviate to 'SRK') is a result of Rasmussen's long-standing concern with how to reduce human error in the control of complex systems (Sanderson and Harwood, 1988). The SRK distinction has contributed to the development of a taxonomy of human malfunction and a framework for cognitive task analysis. However, classification of behavior does not spell out the relationship between levels or categories, nor does it provide an explanation for why one level might be chosen over another.

A systematic error classification system suitable for failures in the engine control room of a supertanker was presented by Van Eekhout and Rouse (1981). Johnson and Rouse (1982) used the modified classification system of Van Eekhout and Rouse for identifying errors of trouble shooting or fault diagnosis tasks. In addition, Nawrocki, et al. (1973) were devoted to describing a methodology for defining operator errors in man-computer communication systems. Most researchers have reached the conclusion that all human errors are not equally important or interesting and it can be seen that for error classification schemes to be useful they must be adapted to the particular task of interest (Johnson and Rouse, 1982). The evaluation of alternative causes and their effects on human errors and the underlying behavioral mechanisms responsible for producing errors are also suggested.

Therefore, the previous models of human errors could be viewed as frameworks in the assessment of human errors in emergency situations. Swain and Guttmann (1983) proposed the concept of PSFs which might influence the likelihood of a human error in a given situation. THERP (the technique for human error rate prediction) recognizes a host of problems which affect human reliability under the name of “performance shaping factors”. Embrey, et al. (1983) proposed the success likelihood index methodology (SLIM), and the basic rationale underlying SLIM is that the likelihood of an error in a particular situation depends on the combined effects of a relatively small set of PSFs such as environment, state of current practice or skill, and time constraints, etc. Vestrucci (1988) suggested the logistic model in which the success likelihood index (SLI) is related to logarithm of ratio of the failure probability to success probability. A critique has been proposed by Apostolakis (1988), and the major observations of this review are as follows. SLIM provides a highly structured approach for the derivation of human error rates under given conditions. However, the treatment of the weights and ratings in this model is internally inconsistent. In addition, the assumption that the weights of the performance shaping factors are independent of the task ratings may not accurately reflect some real-world situations.

After reviewed the above methods, this study has been started with a cognitive approach to the causes of human errors, and focused on building a quantitative model and making an inference of failure probabilities concerning all the causes. Then an experiment was conducted to verify the feasibility of the loglinear model. The loglinear model also provides a systematic approach for the interpretation of human error causes and the prediction of the human error rates. Moreover, in terms of the findings of the failure probabilities, the system designer or trainer will have some directions to follow to improve system reliability.

METHOD

A cognitive model

In modeling human performance for probabilistic risk assessment (PRA), it. is necessary to consider those factors that have the most effect on performance. Many factors affect human performance in a complex man-machine system. Some of these performance shaping factors (PSFs) are external to the person and others are internal. The external PSFs include the entire work environment, especially the equipment design, the written procedures, and oral instructions. The internal PSFs represent the individual characteristics—skills, motivations, and the expectations that influence one's performance. Psychological and physiological stresses result from work environment. in which the task demands for the operator in the system do not conform to his capabilities. The cognitive model proposed here was based on the studies of Swain and Guttmann (1983), but a modification was made.

Experiment

The human error data were collected from an experiment of the electron-beam evaporation system operated under emergency situations. The objective of this experiment was to verify the feasibility of the loglinear model, and search for the contributing factors and the functional form of human error mechanism. Twenty-nine graduate or undergraduate students of National Tsing Hua University participated in the experiment as subjects. All subjects were either industrial engineering or materials science engineering majors.

Both the primary and secondary tasks were simultaneously assigned to the subject who has acquired a systematically training in the operational principle and procedures for dealing with the emergency incidents of the electron-beam evaporation system. The primary task was to supervise the vacuum pumping process or the deposition process of the electron-beam evaporation system. Meanwhile, the secondary task was either to play a guess game or to operate an arithmetic test on an IBM PC/XT.

During the experiment, the subject was asked to report what and why he/she was doing whenever he/she took an action, and both actions and answers were recorded by the experimenter. After the experiment, the subject took a questionnaire to repeat and/or add some explanation of his/her actions and the experimenter could revise the answer of the previous record if necessary. The PSFs in the questionnaire were adapted from NUREG/CR-1278 for the electron-beam evaporation system. As taking the questionnaire, the subjects were asked to choose the most likely factor(s) which caused a specific error he/she made in the experiment.

RESULTS

The frequencies of factors which caused some specific human errors were shown in Table 1. Within the framework of loglinear models, it is important to look at all possible sources of variation and estimate the parameter effects. From the maximum likelihood analysis of variance table of the full or saturated model, it leaded to the consideration of a limited number of loglinear models as part of a preliminary step in the model-building process (Feinberg, 1981). An acceptable model is as follows.

$$\log m_{ijk}=u+u_{1(i)}+u_{2(j)}=u_{3(k)}+u_{13(ik)}+u_{123(ijk)} \quad (1)$$

From the maximum likelihood analysis of variance table based on the selected model in Eq. (1), we have the likelihood-ratio chi-square statistic G^2 to be not significant ($p=0.31$) which implied an acceptable fit of the model. In other words, a model which included first-order interaction between external PSF and stressor PSF and the second-order interaction between external PSF, internal PSF and stressor PSF was chosen to fit the data reasonably well.

There are some important results in this study. First, the loglinear model provides a systematic approach to obtain an adequate human error model from an aspect of human cognition. Second, an appropriate model was chosen and in which some PSFs were found out to contribute significantly in the reduction of the number of human errors. In addition, the first-order interaction (u_{13}) between external PSF (u_1) and stressor PSF(u_3) as well as the second-order interaction of these three factors (u_{123}) were also verified to be important parts of the human error model.

CONCLUSIONS

An experimental research provided us the human error data to build a loglinear model to describe the human error behavior. Moreover, the likelihood of error inducing the combined effects of three PSFs are estimated based on the optimal model. The systematic procedure of quantifying human error developed in this study may be beneficial to search for the significant factors and to build a model to predict the likelihood of the human error occurred in the other situations, such as an abnormal diagnosis system, and routine task system, etc.

Table 1. The contingency table of human error data.

Variables			Levels							
A.	External PSF		A1		A2		A3		A4	
B.	Internal PSF		B1	B2	B1	B2	B1	B2	B1	B2
C.	Stressor PSF	C1	1	1	27	6	10	12	8	10
		C2	14	7	71	32	25	14	12	14
		C3	5	4	15	19	11	4	11	9

* A1: Situational characteristics
A2: Task and equipment characteristics
A3: Job and task instructions
A4: Others
B1: Characteristics of people resulting from external influences

B2: Characteristics of people resulting f rom internal or others influences
C1: Distraction of secondary task
C2: Psychological stressors
C3: Physiological stressors and others

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A CROSS-SECTIONAL STUDY ON VDT WORKING ENVIRONMENT AND IDENTIFICATION OF RELATIONSHIP BETWEEN VDT WORK CHARACTERISITCS AND HEALTH HAZARDS IN KOREA

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In order to investigate the problems caused by the introduction of VDTs, this paper deals with results of the questionaire and the field survey on VDT working conditions of Korea conducted during spring 1991. In the questionaire survey on VDT working complaints, 150 VDT users and 79 non-VDT users of control group were selected. It was found that a significantly larger propotion of the VDT users reported musculo-skeletal complaints compared to the corresponding non-VDT users, particularly in neck, back, arm, wrist/hand, mid to lower back region. The survey results also showed that the rest and work break could be a more influencing factor than the total amount of VDT use as a cause of fatigue due to VDT use. No-resting group during VDT working complained more proportion of dissatisfaction. In the field survey on VDT working enviroment, 139 subjects were selected among the questionaire participants of VDT users. The group with a torso-to-thigh angle of over 100 degrees reported a significant less complaints on lumbar region than the others. The group permited the viewing angle between zero and 60 degrees below the horizontal plane passing through the eyes reported less discomforts on eye and neck regions than others. The group having viewing distance of about 63.5 cm reported the least frequent eye complaints. Moreover, the group which has viewing

distance of below 47.5 cm complained the highest eye discomfort.

INTROUCTION

Field studies have reported a high incidence of asthenopic symptoms among VDT operators (eg, Laubli et al, 1980; Dainoff, 1980; Smith et al, 1981; Ong et al, 1988; Starr et al, 1982; Starr, 1984; Nishiyama et al, 1990; Yeow et al, 1990). VDT workers reported a higher percentage as complaining of asthenopic symptoms than the corresponding non-VDT workers (Bergqvist, 1984).

The incidence of complaints by VDT users about stiffness and tenderness of the neck, shoulders, forearms, hands and fingers has been reported in many studies (ILO, 1990). However the results of cross-sectional studies are not consistent. It was reported (Frank, 1983; Komoika et al, 1981) that there were high occurrences of musculo-skeletal symtomatologys among VDT operators, while others (Bergqvist, 1984; Bolinder, 1981/1983; Canadian Labour Congress, 1982; Gould, 1983) failed to find such increases. In Switzerland, it has been noted (Granjean, 1982; Granjean, 1980) that 60 percent of data entery terminal operators were suffering from shoulder pain with considerable radiation of the pain, in comparison to 30 percent of the conversational operators and 25 percent of tradional office workers who did not use VDTs. These results show that musculo-skeletal disorders, particularly in the neck, shoulder and upper-limb regions, could develop depending on the type of work and how it is organised.

As the use of VDT in offices and factories is rapidly increasing in Korea, VDT work efficiency and occupational health hazards such as visual fatigue, eye strain, headache, muscular pains, etc. have been closed up as an important social matter. However, only a few field studies on VDT working have been conducted, and ergonomic principles are not well applied to the VDT workstations design in Korea. Hence, VDT workstations which have been designed unfitly for VDT working could have posed numerous asthenopic and musculo-skeletal problems for the VDT workers.

In order to investigate the problems caused by the introduction of VDTs, this paper deals with results of the questionaire and the field survey on VDT working conditions conducted during spring of 1991 in Korea. In comparison with the corresponding non-VDT users, fatigue symptoms caused by VDT use were analyzed. It was found the differences in complaints depending on the VDT use variables (in the questionaire survey) and the relationship between ergonomic factors and discomforts (in the field survey).

METHOD

Subjects

The cross-sectional study was designed to survey four different task groups at large scale firms where the use of VDT was very common. This study was divided into two surveys—1) Questionaire survey on musculo-skeletal discomfort in work with VDTs and 2) Field survey on VDT working environment.

Demographic characteristics of each task group investigated by the questionaire survey are presented in Table 1. As a control group, non-VDT clerical workers were selected. Each task can be characterized as follows;

Traditional clerical task: The tasks in this group was identical to the work at the traditional office which did not yet possess VDTs.

Clerical VDT task: In this group employees were occupied largely with typing work such as word processor, partly copying and printing documents. Their main activity was a data entry task but their work speed and quantity was slower and fewer than data-entray takers'.

Professional VDT task: In this group employees were programmers, operators, CAD/CAM designers, researchers or system operators. Their tasks are dialogue or data type inquiry tasks.

Data-entry task: Workers in this group were full-time numeric/Korean data-entry with a right hand. Typing speed was about 20,000–30,000 strokes/hour.

Table 1. The distribution of groups investigated by questionaire

characteristics / Job	n	Age		Women %	Operators Working 22 hours per week at VDT (%)
		mean	s.d		
Traditionl clerical worker	79	27.7	5.1	39.2	–
Clerical VDT worker	41	25.2	3.9	53.7	51.6
Professional VDT worker	96	27.3	4.3	22.9	84.8
Data-entry tasker	13	24.5	1.6	100.0	84.6
Total	229	27.0	4.5	38.4	76.4

s.d.=standard deviation

In the field survey on VDT working enviroment, 139 subjects were selected among the questionaire participants of VDT users.

Research Measures

Questionaire measures: A questionaire was designed to collect demographic information on the amount of VDT use, and the level of musculo-skeletal discomfort.

Demographic variables: (1) age(years) (2) sex (3) career

VDT use variables: (1) job tenure (2) hours of VDT use per week (2) work breaks (4) rest periods (5) the type of VDT work (6) degree of satisfaction at working (7) quantity of tasks (8) degree of difficulty when compared with other tasks

Musculo-skeletal discomfort variables: (1) eye (2) neck (3) right soulder (4) back (5) arm (6) right wrist/hand (7) mid to lower back(lumbar) (8) thigh (9) leg/foot

Subjects recorded the fequency of musculo-skeletal discomfort (pain, tenderness, stiffness, numbness or tingling) using 0–1 scale: 0=never, 1=frequently. But eye variables were divided into 14 items—eye fatigue, tear, blur, pain, double images, flicker vision, blurring of near sight, blurring of far sight, red eyes, shooting pains, flicker vision, and the eye discomfort score was made by the sum of 14 items.

Objective ergonomic measures: Based on the various guidelines for VDT workstation design (e.g, ANSI/HFS standard No. 100–1988 and WHO, 1987), key variables were selected and measured. These variables were measured under the ANSI/HFS standard No. 100–1988 and Sauter S.T. et al, 1991 defintions. The descriptive statistics of ergonomic measures are provided in Table 2.

All angles and distances were measured between two and three hours after the beginning of the morning work. All arm and hand angles were measured with the hands on the keyboard. Torso-to-thigh angle, viewing angle, head tilt were referenced against horizontal or vertical planes (Grandijean et al., 1983; Maeda et al., 1982) using a goniomter and distance (in cm) using a tape measure. Measurement of all angles and distances were reproducible to within one degree or one centimeter in a preliminary test.

Table 2. Descriptive Statistics for the Research Measures

	Mean	s.d	Range		
			10th	–	90th
Anthropometric* (n=139)					
Status (cm)	168.1	7.8	158.2	–	178.0
Sitting height (cm)	88.1	4.2	82.6	–	93.5
Eye height, sitting (cm)	77.3	3.9	72.3	–	82.7
Elbow rest height, sitting (cm)	25.2	2.4	22.3	–	28.4
Popliteal height, sitting (cm)	54.3	2.4	51.3	–	57.2
Buttock to popliteal length, sitting (cm)	44.4	2.2	41.4	–	28.4
Hip breadth, sitting(cm)	34.6	2.0	32.0	–	37.1
Ergonomic (n=139)					
Leg angle (deg)	97.2	20.0	70.8	–	121.6
Arm angle (deg)	108.6	18.7	86.0	–	134.0
Torso-to-thigh angle (deg)	102.3	11.4	87.8	–	116.0
Seat height (cm)	45.4	2.3	42.3	–	48.0
Seat depth (cm)	43.0	3.4	40.0	–	48.4
Seat width (cm)	47.0	3.5	41.0	–	52.1
Backrest height (cm)	66.5	4.1	61.3	–	71.6
Armrest height (cm)	18.0	2.6	14.9	–	21.5
Keyboard height (cm)	74.8	4.1	68.7	–	79.6
Worksurface height (cm)	72.0	3.5	66.2	–	75.6
Worksurface width (cm)	120.9	34.4	45.0	–	200.0
Worksurface depth (cm)	79.4	19.2	55.0	–	124.0
Screen height (cm)	101.0	7.4	90.9	–	110.0
Viewing angle for the display (deg)	12.0	7.3	4.0	–	21.2
Viewing distance to the display (cm)	60.8	10.7	48.0	–	76.2
Viewing distance to documents (cm)	54.0	9.4	40.8	–	66.0
Head tilt in viewing the display (deg)	30.1	7.6	22.0	–	39.0

Head tilt in viewing documents (deg)	26.4	8.2	15.0 –	36.2

* Measurement definitions and methods were the same as ANSI/HFS and Sauter S.L, etc., 1991.

Data analysis

The effects on the musculo-skeletal discomfort associated with the extent of VDT use variable were analyzed by nonparametric testing (eg: chi-squre test, Kruskal-Wallis test). To identify effects of ergonomic factors on the musculo-sketal discomfort, 139 subjects for field survey were divided into 3–6 groups according to workstation design or working posture definded in the ANSI/HFS guideline and other references. Each group was compared with the others by nonparametric tests.

RESULTS

Effects of VDT use variables

The type of VDT work: Among the VDT use variables, the effects of the type of VDT work on working complaints were analyzed and the results are given in Table 3 and Figure 1. Table 3 shows that there was no significant difference in eye discomfort between the four types of task (p=0.17). However, VDT user groups (data entry+professinal VDT+clerical VDT tasks) had more frequent eye complaints than non-VDT user group. Figure 1 shows that a significantly larger propotion of the VDT users reported musculo-skeletal complaints compared to non-VDT users, particularly in neck, back, arm, wrist/hand, mid to lower back region. In response to a group of questions with data-entry task fatigue prevailed on the most body parts except neck regions; particularly, a significantly increased frequency of complaints in arm, wrist/hand, mid to lower back, which can be easily explained by the handed operation of the keyboard.

Table 3. Discomfort of eye dependent upon the types of VDT work (scale: 0–14 points)

	Mean	s.d	Range 10th –	90th	p
Data-entry	4.69	2.98	1.4 –	9.8	0.17
Professional VDT	4.12	2.64	1.0 –	8.6	
Clerical VDT	3.79	2.39	1.0 –	8.0	
Traditional clerical	3.62	2.70	1.0 –	7.0	

The other variable of VDT use: Table 4 shows the results of discomfort complaints on other VDT use variables. Significant difference (p<0.05) in musculo-skeletal complaints were found between groups defined by the VDT use variables such as duration of VDT use or rest period. Table 4 clearly showed that the rest period could be a more influencing factor than the total amount of VDT use to fatigue symptoms on VDT work. Therefore, work break should be kept regularly for reducing VDT related fatigue.

Effects of ergonomic variables

The relationships between the somatic complaints and the workplace design parameters was analyzed using Kruskal-Wallis tests.

Leg angle: No significant relationship was found between thigh and leg/foot complaints and posture groups which were classified into three ranges of leg angle met with recommandation ANSI/HFS and ranges below/above them.

Arm angle: No significant relationship was found between shoulder, arm, and wrist/hand complaints and size of arm angle.

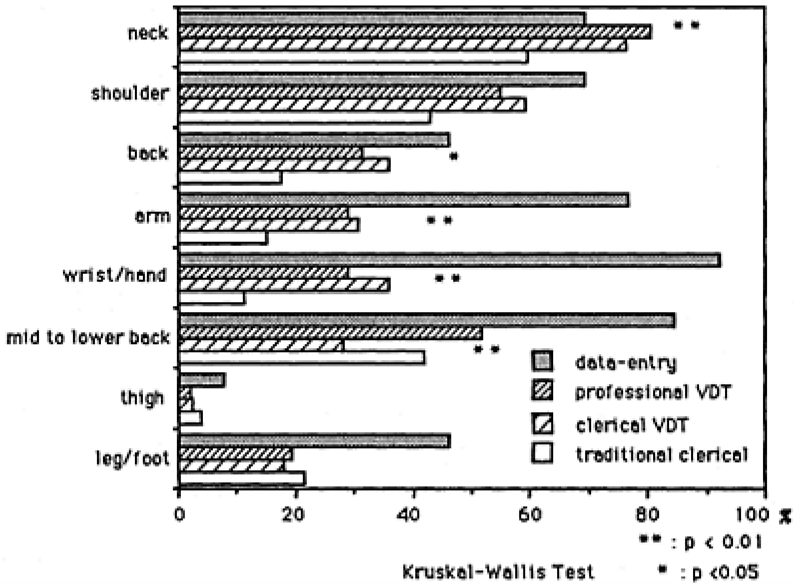

Figure 1. Musculo-skeletal discomfort due to the types of VDT work (x-axis: proportion of appeal)

Table 4. Complaints per the type of VDT use variable (n)

	Duration of VDT 1) working per week		Rest periods 2)		
Eye	1:4.4, 3.0	(21)	1:3.8,	2.5	(152)
Scale: 0–14 points (mean, s.d)	2:3.7, 2.1	(48)	2:4.4.	3.1	(74)
	3:4.1, 2.8	(53)	3:6.1,	3.4	(17)
	4:4.9, 2.6	(97)			
Shoulder (%)	no significant difference		1:54.6		
			2:63.5		
			3:88.2		

Back (%)	″	1:26.3 2:36.5 3:41.2
Leg/foot (%)	″	1:16.4 2:23.0 3:41.2
1) Duration of VDT working per week:	1='0–12 hours' 3='24–36 hours'	2='12–24 hours 4='above 36 hours'
2) Rest periods: 1='rest if necessary'	2='rest every periods given'	3='never rest until tasks end'

Torso-to-thigh angle: In testing the difference of complaints between groups—the group with a torso-to-thigh angle of over 100 degrees (ANSI/HFS recommendations) and the other group, no significant relationship was found on back, thigh, leg/foot. But the latter group reported more complaints on lumbar region significantly than the former group: 42.5% (n=80) and 55.6% (n=54), respectively (p=0.07).

Seat height, Seat width, and Seat depth: A significant relationship was not found between thigh, leg/foot complaints and these dimensions.

Backrest height, Armrest height, Keyboard height, and Worksurface height: No significant relationship was found between musculo-skeletal discomfort and ergonomic factors.

Worksurface width and depth: These dimensions of VDT users were almost satisfied with ANSI/HFS recommendations.

Viewing angle for the display: Table 5 shows that the group permited the viewing angle between zero and 60 degrees below the horizontal plane passing through the eyes reported less discomforts on eye and neck regions (p=0.07, 0.10, respectively).

Table 5. Relationship between viewing angle, eye, and neck complaints

Viewing angle(v)	(n)	Eye complaints			Neck complaints	
		mean	s.d	p	propotion (%)	p
v<0 deg	(29)	5.2	2.7	0.07	92.3	0.10
0<v<60 deg*	(101)	4.0	2.8		72.8	
v>60 deg	(0)					

*: ANSI/HFS recommandation

Viewing distance to the display and Relative distance to the display: Table 6 shows relationship between viewing distance to the display between eye complaints. Though the majority of the recommendations for viewing distance rely upon the results obtained through the observation of VDT operators, it is likely that the use of large CRT screens and the design of VDT furniture has affected the preferred eye-screen distance of about 63.5 cm (Helander, M.G. et al, 1984). The group having viewing distance of about (63.5 cm−0.5 s.d, 63.5 cm+0.5 s.d) reported the least frequent eye complaints (mean: 3.7). Moreover, the group which has viewing distance of below 47.5 cm complained the highest eye discomfort. The distribution of relative viewing distance (viewing distance to the documents minus viewing distance to the display) was a wide dispersion: mean −6.8 cm, s.d 10.9 cm, minimum −50 cm, and maximum 14 cm. But no significant relationship was found between eye complaints and relative viewing distance.

Table 6. Relationship between viewing distance and eye complaints

Viewing distance to the display (d:cm) (n)	Eye complaints mean	s.d	P
d<(63.5−1.5 s.d) (11)	5.5	3.4	0.10
(63.5−1.5 s.d)<d<(63.5−0.5 s.d) (43)	4.5	2.8	
(63.5−0.5 s.d)<d<(63.5+0.5 s.d) (53)	3.7	2.3	
(63.5+0.5 s.d)<d<(63.5+1.5 s.d) (18)	4.1	2.2	
d>(63.5+1.5 s.d) (9)	4.5	3.0	

* The s.d is 10.7 cm (Table 2).

Head tilt and Relative head tilt: There were some differences between head tilt to the display and head tilt to the documents: relative head tilt mean −3.1 cm and s.d 7.7 cm. But no significant relationship was found between eye or neck complaints and head tilt or relative head tilt.

CONCLUSIONS

This paper deals with results of the questionaire survey about VDT working complaints and the field survey on VDT working conditions of Korea. From this studies the following results were found;

1) Questionaire survey on VDT working complaints:

– A significantly larger propotion of the VDT users reported musculo-skeletal compaints compared to non-VDT users, particularly in neck, back, arm, wrist/hand, mid to lower back region. In response to a group of questions with data-entry fatigue prevailed on the most body parts except neck regions; particularly, a significantly frequent of complaints in arm, wrist/hand, mid to lower back.

– The rest and work break could be more influencing factor than the total amount of VDT use as a cause of fatigue.

– Non-resting group during VDT working complained highly proportion of dissatisfaction.

2) Field survey on VDT working conditions:

– In testing difference of complaints between groups—the group with a torso-to-thigh angle of over 100 degrees (ANSI/HFS recommendations) and the other group, no significant relationship was found on back, thigh, leg/foot. But the latter group reported a significant more complaints on lumbar region than the former group.

– Group permited the viewing angle between zero and 60 degrees below the horizontal plane passing through the eyes reported less discomforts on eye and neck regions.

– The group having viewing distance of about 63.5 cm reported the least frequent eye complaints. Moreover, the group having viewing distance of below 47.5 cm complained the highest eye discomfort.

– No significant relationships were found between the other ergonomic factors and complaints.

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CUMULATIVE TRAUMA ANALYSIS IN DIAMOND POLISHING OPERATIONS

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Frequent elbow flexion/extension and excessive wrist deviations has been observed in the diamond polishing profession. That fact initiated a study in the diamond polishing industry in Israel, which aimed to evaluate the specific hazards to the workers hands. Biomechanical analysis and epidemiology studies conducted on diamond polishers, indicated that this profession includes highly demands fast hand movement which cause cumulative trauma disorders in upper extremities. The outcomes determine the ergonomic and medical understanding for the injuries occurred to the upper extremity musculoskeletal system, such as Ulnaris Neuritis and Cubital Tunnel Syndrome, which so often afflict diamond polishers. Manual operations of the hand-held polishing tools, and detailed polishing performance evaluation is discussed in the presentation. The biomechanical profile of the polishing work cycle followed by kinesiological analysis is presented. These describe the harmful results to the hand and relate to the cumulative wrist trauma and the injuries affiliated with the diamond polishing profession.

INTRODUCTION

Previous studies stated that injuries as Ulnaris Neuritis, Cubital Tunnel Syndrome, Strains, and forms of Arthritis often afflict manual workers who perform polishing tasks on hard materials like in the glass and gem industry. Injury to the Ulnar Nerve is common among diamond polishers and is accepted as an occupational disease since 1952, as Schacke and Wolff (1985), stated in their study relating professional activities to injury. Ulnaris Neuritis has been reported as frequently found in glass polishers in Germany (Mayer, 1985). Ulnar Neuropathy and a form of Arthritis were reported by Vleeschdrager (1986), with linkage to the diamond industry. Eisen and Danon (1974), related in long to the trauma caused to hand maneuvers in such job demands and its ‘Mild Cubital Tunnel Syndrome’ effects.

Hommerich et al. (1985) stated that very often we find the Ulnar Nerve vulnerable to external lesions due to its anatomical position. In a longitudinal study, Ring et al. (1979), studied the effects of diamond polishing job demands on the neuro-muscular system of the polisher hand, these authors discussed the polishers occupational injury—called Neuritis Ulnaris and established criteria for pre-clinical diagnosis of the Cubital Tunnel Syndrome among polishers. On the basis of these findings they recommended that the Ulnar Nerve conductivity is to be used as a criterion for early warning in the ‘Cubital Tunnel Syndrome’. Similar hand movement and working body posture was observed in the glass cutting and polishing industry (Mayer 1985). The findings presented in this manuscript are therefore of interest to other similar manual professions.

The polishing process is based on extensive manual movement procedures, which consist on grinding a fixed rough diamond in a holder, over a layer of diamond dust bonded to a rotating polishing disks surface. A finished diamond has 50 to 80 polished facets, depending on shape, these facets are designed in a defined geometrical order, These facets are hand polished over a rotating disk and inspected with the bare eye using a hand held magnifier. The shape of this extremely hard carbon-stone called diamond, should be very accurate in proportions and angle of facets. because of many reasons, most of the bigger roughs (generally over 0.3 karat), are polished in a manual procedure. The Brilliant cut, which is the most popular geometrical shape, has 57 facets which are organized in a perfect symmetrical shape, this is to provide the most effective projection of “life” and “fire” to the finished diamond. Life and Fire, are the characteristics of the diamond which describes the effect and amount of light reflected back from within the diamond. The Brilliant’s facets are organized in six pre-designed girdles, and therefore are polished to the desired geometrical finished shape. It should be noted that due to this crystal’s superior hardness, and the organization of the molecules in the carbon rough, polishing in the ‘wrong’ grain direction might damage the diamond. Such damage will result not only in loss of value, but also in time consuming in the polishing correcting process. The repeatable searching act for the grinding position, along with the multi faces alignments, needed during the polishing act, are the mechanical reasoning for the extensive wrist and hand maneuvers performed at the grinding disk.

The hand held operating tools consist of; a diamond holder (Tang) which houses the rough stone during all polishing phases, the Tang is held always in the left palm. The second tool held by hand is the magnifying glass, this tool is held between the first, second and third fingers of the right hand and during inspection is viewed with the left eye. This method of operation is being imposed by a strict learning process while not accounting for handedness.

METHOD

A three video camera setup was employed to record the working routine in a real time industrial setup.in order to study the motion patterns involved in the polishing operation. The video cameras were set at the left, right and front of the polishing workstation at similar horizontal plane and elevation angles. This setup provided a clear sagittal view of the left and right hands, as well as coronal plane observations from the front view. Reflective spots and strip markers were attached on each of the upper extremity joints and along the arms; these were easily noted on the monitor and helped to observe hand rotations and planner movements. The three images were combined into a triple window video screen using a video mixer operational console. The recording setup is presented in figure 1. A time display was superimposed on the image, timing at the rate of four hundreds of a second. Images of the three cameras were restricted to the upper body which included: working area, arms, hands. The subjects received explanations about the movement recording analysis and were told to follow a normal working routine.

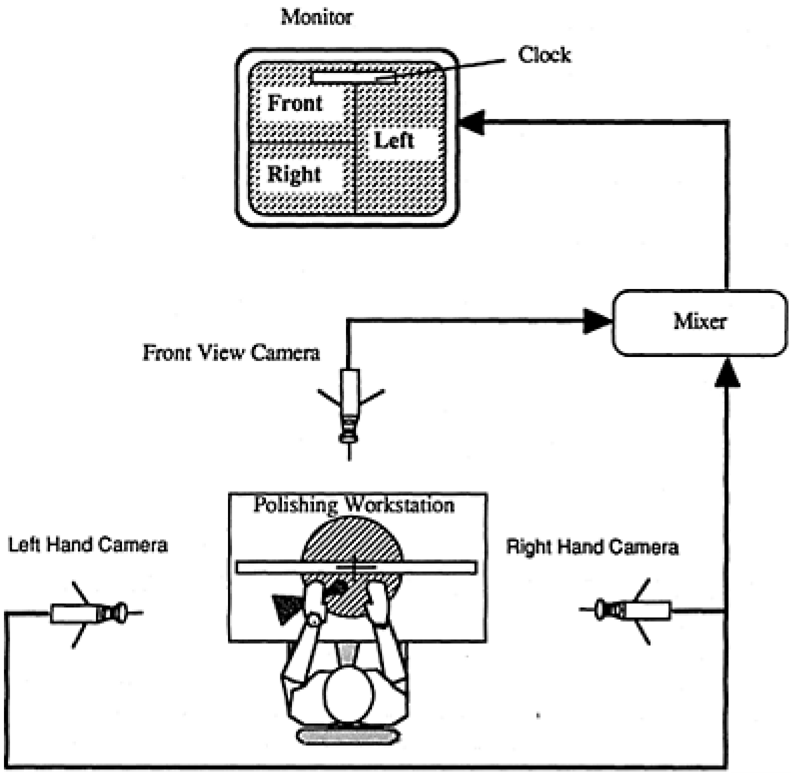

Figure 1. Instrumentation set-up for study of polishing motions.

The motion investigation was performed on working subjects at their actual industrial workstations, all data recordings were obtained during normal every-day routine. Upper extremity movements were assessed by 3-D video recordings, which was followed by micro-motion analysis and time study technics. Work routine for polishing the different facets has been broken into four identical and consistence elements. The basic elements has been found to be performed in a cyclic manner, the basic elements were: Polish, Inspect, Adjust of the Dop (the head of the Tang in which the stone is fixed), and Change the stone. A special recording form has been developed for the study, the form contains on the vertical axis the four major task elements, subdivided into position and status work categories for the right and left hand. The recorded videos were investigated in a 'frame by frame' procedure in order to establish the positions of wrist, hand and fingers relating to work elements. Analyzing the videos with the clock running in real time for hundreds of tasks, enabled the evaluation team to measure time durations and motions actually needed to perform each of the four basic motion elements. This analysis was repeated on a number of operators, who were performing all six different facets (three on the crown and three on the girdle), of the diamond.

RESULTS

It has been observed, that in all of the workstations, all the workers, operate the polishing task with the left hand holding the tang which is the traditional instrument used to hold the polished stone. The right hand was always holding the observation tool, which is a magnifying glass constructed in a metal frame. In order to apply pressure on the tang, to gain more friction forces, the right hand will support the left on the grinding wheel, while always holding the magnifier ready to be used. The right hand is seen always holding the magnifying glass in the three first fingers.

Analysis of motion patterns as obtained in this study indicated that most of the actual movement for both hands are performed by elbow and hand—flexion extension movements, by forearm pronation supination, and by wrist ulnar radial deviation movements. The results of the data enable to draw biomechanical profiles for the different motions as experienced in the actual process. The biomechanical profiles has been plotted in a graphical manner, which consists the four polishing stages (task elements) on the vertical axis along with frequency of movements, and angular deviation of the motion in concern. The graphs give simultaneous information of the left and right hand motions in bar graphs, with relation to the movement's frequencies. Which provided a comparative figure to study the kinesiology involved in the performance based on the number of motions per element of task, as the statistical mean of the total data analyzed in the study. Figures 2 describes the biomechanical profile of the left and right wrists—flexion extension motions. Biomechnical profiles alike were obtained for all joints of the two arms and hands.

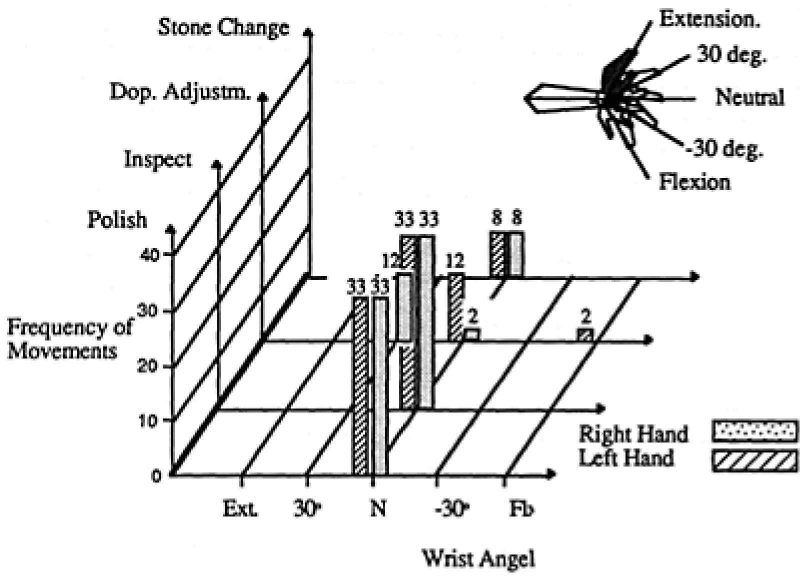

Figure 2. The biomechanical profile of the left and right wrists.

The repeated left hand ulnar deviation, is happening very frequent occurring in the polishing position, producing bending moments in the wrist that can cause nerve and tendon damage, as discussed by Tichauer (1978). This ulnar deviation occurs simultaneously to the application of force on tool, by pushing the diamond holder down to the grinding disk and exerting continues muscle tension while grasping it. For most of the time the right and left hands follow a parallel movement patterns. Right hand tasks are mainly divided by either holding the magnifying glass to the inspecting left eye while supporting the left hand, when in elbow flexion, or by putting pressure on the diamond holder head for better grinding when in elbow extension. The motions are very fast and high forces are involved in acceleration deceleration movements, so is the isometric stress and tension needed to maintain stability and control of the fine hand movements in the inspection and polishing acts. Time study analysis indicate that these movements are repeated between 4 to 5 thousands times (depending on size and shape of rough), in a normal working day.

DISCUSSION

It takes many years of training and experience to become proficient to the point were movements are almost embedded reflexes (innate) executed automatically on cue. On the face of it, diamond polishing seems to be a simple strait forward operation, and in a way it is, but it requires a lot of skill and experience. This is due the fact that each rough has its own characteristics—where inherent shapes, hardness, purity and geometrical variables require different grinding strategies. In contrast to all other industries were the manipulation of raw and processed material are controlled and manufactured according to exact specifications, the diamond stone rough is not homogeneous and each diamond crystal, large or small has to be treated, checked and categorized individually.

The biomechanical profiles obtained in the study, as well as time study performed on duration of the four elemental tasks, show that the polishers working maneuvers during most work phases, remains fairly limited in range except left hand movements. As seen observed from the videos taken that the right hand, normally in the flexed resting position is pressing hard during long hours on the elbow joint. This pressing motions exert pressure points along with friction forces at the bone, making the ulnar nerve vulnerable to external lesions at the cubital tunnel. The magnifying glass is held between the first, second and third fingers of the right palm under constant isometric pressure. Left hand palm grasps the tang with repeated ulnar deviation in the polishing position, producing forces that can cause nerve and tendon damage. Results obtained in the same manner for neck and shoulder movements, indicate unbalanced working posture, at the upper torso and head levels, this were observed to causes pathological deviation in the frontal plane. The following main anatomical and kinesiological findings were derived from the study at the elbow, forearm, and hand regions. The movements of the right and left sides are discussed separately;

Left Side, Elbow and Forearm: The extension of the elbow till 90 degrees to reach the disk is associated with a simultaneous pronation. This clockwise spinning movement of the left hand around a longitudinal axis is performed by the Pronator Teres (PT) and Pronator Quadratus (PQ). The main pronator is PQ. The PT functions were: flexion of the elbow and pronation. To act as a pronator antagonist of the PQ, the best solution to neutralize the flexion option. According to our observations, this is best done at 90 degrees flexion, where both insertion and origin are relatively slag and the muscle is at its middle range. At the same time, the angle of application of the PT on the humerus is the optimal for a pronation. When PT contracts, it will not only rotate the Radial bone but also pull from it drawing it against the ulna. This is an active ligament—like action. Without it the radial head would tend to subluxate whenever the PWQ brings the forearm to full pronation. All the above actions will lock tightly the forearm and wrist in such a way as to permit a more efficient effort during the polishing stage.

Left Side, Hand: During the act of polishing, the hand holds the tang in a “power grip”. As reviewed by Napier (1956), in the power grip hold, the forearm is pronated and the wrist is in ulnar deviation to allow better stabilization of the wrist and a more efficient adduction of the thumb. This attitude is conditioned by the tang’s form and permits the worker to exert full strength. During the act of inspection the hand will be in “precision grip”, as no special strength is required to hold the tang and make an accurate approach to the focal plane of the magnifying glass. This will be done in a neutral position of elbow and wrist.

Right Side, Elbow and Forearm: The right hand will be in “precision grip” during all of the cycle. This is the reason why the position of forearm and wrist are mostly neutral. The exaggerated flexion of the right elbow during inspection relates to the need to approach the glass to the eye. The difference between the flexion angles of the elbows during inspection is in direct relation to the focal length of the magnifying glass.

Right Side, Hand: To reduce the amplitude of the tremor movements, the worker will hold the glass in the most proximal position possible, i.e., between the proximal phalanges of the thumb and second finger. Another way to reduce the amplitude of the tremor is to apply a finger to the forehead. In this position tremor will be almost neutralized (as the eye and the glass move together) but this is achieved by a more pronounced flexion of the elbow.

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BIOMECHANICS CONSIDERATIONS AND ERGONOMIC DESIGN IN DIAMOND POLISHING

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A biomechanical study of motion patterns involved in the diamond profession indicates poor design of the tool and working postures. The study reveals antiquated methods which were established by strict learning processes, and are performed today exactly as they were done few decades ago. Work performance analysis of diamond polisher's, has been performed, focussing on the biomechanics of hand manipulations concerned with this high demanding job. Ergonomics aspects and manufacturing procedures have been studied to understand the 'secrets' of performance in this special job, reasoning of the contemporary workstations design have been revealed. The findings set engineering criteria for the design of advanced workstations.

INTRODUCTION

Analysis of manual work in diamond polishing and Epidemiology studies conducted in the past on diamond polishers and other similar craftsmen, indicated that these highly manipulative tasks which require frequent exertion and fast hand movements cause serious health problems, resulting also in economic ones. Contemporary diamond polishing workstations and polishing procedures has been found to be lack of technological updates and ergonomic consideration. Evaluation of upper body postures and manipulative hand motions involved in polishing tasks, led to new interest on the part of the diamond industry in ergonomic design of the workstation and the improvement of existing work practises. An extensive literature review did not reveal studies conducted over the years about the ergonomical aspects of workstation design in the diamond industry. Very limited research effort has been directed toward improving the working conditions in the polishing maufacturing processes, which about 80 percent of the workforce in the diamond industry is utilized. It should be mentioned that this particular industry has a lot of secrecy in the craftsman knowledge, many times the know-how is kept in close circles, transfer of profession has been done in the family, and development of skills were experienced between father and son.

For thousands of years diamonds offered the filling of fascination, beauty, richness and the value of capital. The history of cutting and polishing is poorly documented and the art remained a trade secret for many centuries. It is not clear where diamond cutting originated, whether in Europe or India but most likely in the fourteenth century. In Europe, the city of Venice is considered to be the place diamond facets polishing started, in 1330. Superstition probably delayed the emergence of any industrial process until then, since it was believed that alteration of the diamond's natural shape will destroy its magical properties.

In contrast to the on-going artisan creation in the inhabitant stone and the emergence of a great international industry, very little evolved or was done to improve questionable working condition. An historical review through diamond museums in industrially-developed countries, like England, South Africa, Belgium or Israel, and new producers of diamonds like India and Thailand, show that workplace design has not changed for over a hundred years. Different work situations recently photographed at industrial sites located in the worlds main diamond manufacturing countries (Diamond International, 1991), show that the polishing workstations, all over the globe do not differ in their conceptual design. The Indian polisher will be seen working while sitting on the floor, the Thai polisher who operates beside a wooden frame workstation, have the same hardware and procedures as the Israeli polisher. The number of workers in these countries are figured as 400,000 in India and about 8,000 in Israel; for all of them the knowledge of ergonomics has not been applied.

The shape of the diamond stone is designed to bring out and enhance the unique optical qualities of the diamond. Two main qualities are being sought: Life and Fire, which describes the effect and amount of light reflected back from within the diamond. The objective of the stone design is to make sure that most of the light entering the diamond and reflected internally, will be returned and not lost through the side surfaces. Diamonds are polished in a variety of traditional shapes divided into four main groups: Brilliant, Rose, Step and Bead cuts, each containing variations on a basic cut and requiring a similar manufacturing process. The combined effect created by both, Life and Fire is achieved by the accuracy of the exact measures and proportion of facets and angles of the polished diamond parts.

The Brilliant cut which is by far the most efficient optically, able to achieve maximum brilliance. The Brilliant cut consists of six types of facets arranged in two parts: The upper Pavilion and the bottom Crown. Usually a polisher will concentrate or specialize on polishing a specific facet girdle. This enables the factory owner to have better control on the quality of production and individual craftsmanship. The diamond is inspected closely by a specialist after every facet girdle was polished and is being reassigned again for the next facet to be polished.

The polished diamond process has the same pattern for all the stone types with very special care taken in the decision-making process for larger stones where the final value of the diamond can change considerably as a result of an act taken in the early part of the process chain. The production process is a one way sequential one: Diamonds cannot be normally repaired, some repair can be done only with a loss of value.

The first known description of diamond cutting (bruting) and polishing workstation (Bruton, 1981), was given in 1568 by the celebrated Italian goldsmith, Benvenuto Cillini, who wrote: “One diamond is rubbed against another until by mutual abrasion both take a form which the skilled polisher wishes to achieve. With the powder which falls from the diamond the last operation for the completion of the cut is made. For this purpose the stones are fixed into a small lead or tin cup, and with a special clamping device, are held against the steel wheel which is provided with oil and diamond dust.” From looking at the present working methods and human tasks, Cellini’s description could have been written today. He does not describe how the polishing disk was driven, but it was undoubtedly by hand. Although at present the disk is driven by a motor, the roll of the human operator has not changed. If we examine the tasks, tools, work method and the process of decision-making, one can see that the man-machine relationship has hardly evolved through the ages. This situation is very unique among all the other industries where enormous changes has occurred with the entry of automation, robotic and computer systems, completely changing the roll of man in the lope.

The polishing process is based on grinding the fixed rough diamond over diamond dust bonded to the polishing disks surface. Due to its hardness, only grinding by friction against similar carbon material is effective in manipulating the diamonds shape to its geometric and brilliant finish. A finished diamond consists of many polished facets (57 for the most popular Brilliant cut) organized in six pre-designed facet girdles of specific geometric shape. Figure 1 describes the typical polishing workstation used today in the diamond industry. This prevailing set up is found in most large and small workshops throughout the world.

ANALYSIS

By focusing at polishing workstation and studying the acts of the human performer, one can not ignore the macro system environment of the diamond industry. This system, like many other industries, is governed by three main factors, the Business factor, the technological factor and the human factor. The three factors are interrelated, while the business factor is the dominant one influencing the advance of technology, labor and working conditions. In considering the design methodology of a polishing workstation, polishing is but one of a number of processing tasks involved in the diamond production. We have on one hand to understand the current work process and human involvement in the existing industrial situation, but at the same time to analyze independently and objectively the polishing function in a future industrial environment where the balance between manual and automated work will be different from the present setup. Gilad and

Messer (1991/a) discuss two approaches to be considered in the design of workstations; One is Redesign of the existing polishing station aiming at an ergonomically and technically advanced workplace according to the ergonomic findings, the other is the Total Design approach, which is not based on a given workstation-as an input model.

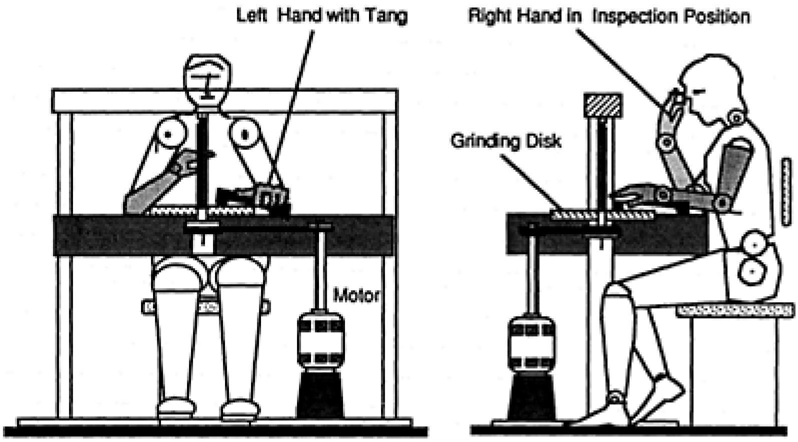

Figure 1. A typical layout of a diamond polishing workstation

The four basic polishing sub-work elements consist of: Polish, Hand to Inspect, Inspect and Hand to Polish elements. These elements were divided into three main task categories: Motoric tasks, Visual tasks, and tasks of Controlling the process. These tasks represent the basic factors of: Sensing, Decision Making, and Human Motions.

Figure 2 describes in graphical presentation a comparison of man and machine relations in the three, previous defined task categories, taken place in the polishing process, this present possible relations between the different categories and the design alternatives. It is assumed that moving down the graph, from maned towards machine operated workstation, will reduce operators' involvement by releasing most of the tasks to automation and 'smart machines'. This process will in turn redefine the human tasks giving it a supervisory role, which will rise to new and different ergonomic considerations.

Four workstations were designed based on the alternatives. For reasons of discretion we will limit the actual design suggestions in this presentation, but we will propose the general ideas to be considered in the ergonomical approach. Some details of technological considerations drawn out from the man-machine task compression, are described in Gilad and Messer (1992).

The first design is for a maximal man operator involvement with only passive mechanical support. This design can be considered as an ergonomic improvement on the present situation which includes workstation dimensions, procedures and hardware arrangement. These factors are set mainly from technical and mechanical reasons, resulting in secondary consideration to human comforts and anthropometry. The improvements are suggested on the basis of the existing workstation as outlined in figure 1.

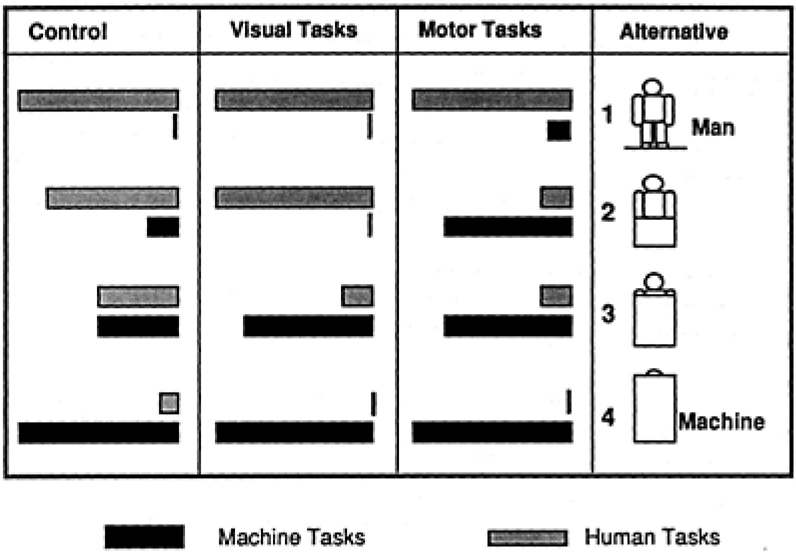

Figure 2. The man machine alternatives for workstation designs

In the second design, a transfer of most human motor tasks, the motions, has been assigned to the machine. At this design we still keep the visual-Sensor, and control-decision tasks, to be done by man. A major conclusions of the motion and time study, was that an operator has to repeatedly perform thousands of accelerated work cycles a day, using a poorly ergonomic diamond holder and magnifying glass tools—all resulting in upper extremity discomfort and injuries. This design comes to elevate the mechanical manipulation tasks through the introduction of a smart manipulator arms capable of executing all the needed repetitive motions and polishing tasks. This mechanical system would be able to guide and hold the diamond, sense, measure, limit and evaluate the progress of polishing. The operator at this station will be able to control machine performance via a command and control interface. It is so arranged that a single operator will be able to handle a number of manipulators in a single workstation.

In the third design, we transfer most of motor and visual tasks, motion and sensor to the machine, while keeping some of the commands and controls, the decision making, to the human operator. This design takes the polishing workstation one step further, incorporating an expert system, as visual control system replacing the human eye in all routine work. Operator will still be able to intervene at any point, enter setups and make human judgments on machine performance. The mechanical manipulator and the expert system will form a closed-loop system capable in performing all polishing tasks. Material handling, quality control and final say will still reside with the operator. The rough diamonds will arrive in colt holders, already pre-aligned and centered in a prior stage.

The forth design is the concept design, where an automated polishing machine-center has been designed. The machinery will be capable of handling all three task categories (motion, sensor and decision making), resulting in the ability to process a diamond from rough to polished. A fully automated workstation fed with rough diamonds pre classified and mechanically prepared, out putting complete or partially polished diamonds in a fully industrialized mass produced way. In this scenario human task will be reduced to mechanical supervision, some material handling and maintenance. The aim is that one operator will be able to control a number of workstations which will be arranged as a polishing center, such a production cell can work around the clock. This design needs prior preparation of the rough and tools. It is often that R&D projects are very limited in providing information to the published literature, we therefor do not reveal detailed workstation improvements of the designed products, which is today in a stage of development.

DISCUSSION

Adaptations of new technologies into the diamond industry is probably inevitable, particularly in highly technological countries like Israel which also has a relatively high cost of labor. Changes in design and using technical advances has been experienced already in bruting, cutting and cleaving operations in the diamond industry. But these three processes count for only 11 percent of workforce of the diamond industry. The polishing industry which is the majority, counting for about 80 percent of the workforce is performing still on manually workstations. Overview of past, present and future polishing workstations are presented in Gilad (1991/b).

Today it is, more and more hard to find young craftsman who seek to work in the polishing industry, at least in the developed countries, because of the difficult working conditions. By adopting new designs, the human role will change dramatically, there will be no more another skilled individual craftsmen, but multi-disciplinary technicians able to control a variety of technologies. A new model of a diamond factory will start to be developed, very unlike the present one. Work could be done around the clock and supervised from remote locations, such as an owners home via computer at any time.

At present time we still find this successful expanding diamond industry almost untouched by the enormous technological advances made in the last few decades, the production part that is. While almost all other sectors of industry went through ever changing technology that defined not only R&D and production system methods, but the products themselves, the diamond industry was sailing un-bothered in the sea of the world market. Or does it? Recently though market pressures and the arrival of new production centers, mainly in the Far East that are challenging the old established European centers, are forcing the industry to examine new methods and production systems and with it, the role of the human operator.

The study presented here is not only concerned with the ergonomic problems of the current setups, but is also a springboard to a better ergonomic workstation in the larger sense of the word. i.e. where ergonomics examines the role of the human operator at a variety of possible working scenarios and levels of man-machine (automation) interfaces, investigating the configurations of a future polishing workstation while giving the human factor design an equal weight to technology and other factors in the criteria setting process. Since the industry, in Israel, has shown interest and is funding improvements based on this study. It is therefore our believe that in the near future, the newly design ideas will be expressed in working prototypes for the benefit of the polishers in the diamond industry.

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PROBLEMS AND DEVELOPMENTAL NEEDS IN PRINTING AND POST-PRINTING TASKS

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The work and the working conditions in the different tasks in the printing industry were studied. Technological development was found to have improved working conditions and facilitated many operations. However, there are still traditional problems such as repetitive and machine-paced tasks. Developmental needs were recognized in job structures and responsibilities. The opportunities offered by the information technology to improve job contents have not been used sufficiently.

INTRODUCTION

The study presented in this paper is part of a larger survey in the printing industry. This paper focuses on the tasks in the printing and post-printing phases of the process. The introduction of information technology and new production methods has been rapid in the printing sector. The automated control systems, integrated lines, transport and storing systems are the typical applications. The printing phase will be increasingly more similair to the process industry. In the post-printing process, mechanization is still the dominating technological feature, although there are more integrated machine lines.

The working conditions of the printing industry have been a well studied industrial sector in Finland since the seventies (Seppälä et al., 1973, Kalimo et al., 1981). The efforts to reduce the health problems related to the work have been of great interest to employees' and employers' organizations. The environmental strain factors such as noise and chemical solvents were the major problems. The machine-paced work with repetitive manual operations caused much physical strain and health problems.

The aim of this study was to get basic knowledge about the present situation by describing and analyzing organizational and psychological issues such as task structures, division of labor, job content and demands, as well as the opinions of the employees. Special attention was paid to the impact of technological advance on task structures and job content. The results were compared to the previous findings in the printing sector.

MATERIAL AND METHODS

The study was carried out in 10 Finnish printing houses producing newspapers, magazines, books and other special products. The production machinery represent rather advanced applications as well as mechanized technologies. 371 people responded to the questionnaire, 44% of them from the printing and 56% from the post-printing phase. The average age of the whole group was 37.5 years. The subjects were divided into six groups according to production phase and occupation. The first group were the printers (n=125), the second the rotation workers (n=37), the third the operators of stand-alone machines (n=69), the fourth the manual workers at stand-alone machines (n=68), the fifth the operators of the automated mailing lines (n=22) and the sixth the mailing workers at the automated lines (n=50). The occupational groups corresponded to those of the previous studies (Seppälä, et al., 1973, Kalimo, et al., 1981).

The methods used were interviews, observations, job analyses and questionnaires. The organization, technology, allocation of tasks, and production technology were studied by interviewing. The job characteristics and strain factors were studied by questionnaires.

RESULTS

Machinery and job content in different occupational groups

The printers consist of all the operators working with the sheet-fed, rotary offset and rotogravure printing machines. Except for one female operator, the operators were all men. The printing methods have not changed although the application of information technology has been extensive. The control technology, remote control and integration of the printing phases have widely increased. The work with the different kinds of machines was rather similair. The printer's task includes more and more process monitoring. The highly automated control systems have significantly facilitated the printing work. In some cases there was a goal to include some preventive maintenance and repair operations in the printers' tasks. The technological advance has resulted in changes in the task structures. There is less need for assistant's jobs, e.g. due to the automated color feeding; some printing shops even worked without a supervisor. Some printing houses had adopted a positive tendency to train the rotation workers step by step to become printers.

The rotation worker corresponds to the previous printer's assistant. His task is mainly to load the paper rolls into the machine. Because of the automated operations, the relative proportion of the assistant jobs have decreased in this phase of the production. This can be perceived very positively, because this group had many problems due to the exposure to chemical solvents and monotonous and physically hard work.

The stand-alone machine operators work with the mechanized machine or automated machine lines in the post-printing phase. The process consists of separate phases such as collecting, bundling, cutting and addressing. The post-printing phase is still the least advanced part of the production, inspite of various automated facilities and equipment. The tasks involve taking care of the machine, and controlling the process and products.

The manual workers at the above-mentioned machine or machine lines are a traditional occupational group in the post-printing phase. Until now it has been typically a women's job, 87% of them were still women. The tasks mostly consist of loading and unloadig operations at the machine, like cutting, stitching and gluing. Various new machines and equipment, such as strikers, stackers, conveyor lines and other equipment have been introduced to facilitate the material handling. Despite the improvements there are still numerous material handling operations. The repetetive and short-cycled tasks connected with bad work postures and fixed work pace are characteristic features.

The operators of the automated lines are responsible for operating and controlling large modern mailing systems. The automatically controlled lines are a part of newspaper production process in which the rotation lines continue automatically to the mailing phase. The system can handle the addressing, bundling of different sized bundles and conveying to the various transport systems.

The mailing workers work at the above-mentioned automated lines. Their task is to follow the process and carry out some operations if needed. Computerized control systems and new equipment have replaced the previously heavy material handling, especially bundling, tying, lifting and carrying of bundles. Job rotation was carried out in the plants under study.

Job characteristics

The job characteristics, job satisfaction and experienced monotony in the different occupational groups are presented in Table 1.

Table 1. Mean values of the items related to job characteristics in the groups studied and tests with one-way analysis of variance.

Job characteristic	Occupational groups							
	1	2	3	4	5	6	F	
	n=125	n=37	n=69	n=68	n=22	n=50		
Qualif.demands	2.7	1.7	2.3	1.4	2.7	1.8	15.8	***
Challenge	2.4	1.4	1.9	1.3	2.1	1.4	14.9	***
Autonomy	2.8	2.1	2.4	1.5	2.5	1.8	9.2	***
Variety	2.4	1.8	2.1	1.7	2.1	1.9	6.0	***
Machine pacing	2.8	2.9	2.5	3.7	3.3	3.8	11.5	***
Satisfaction	2.0	1.7	1.8	1.4	1.5	1.6	2.8	n.s.
Monotony	2.6	2.8	2.9	2.9	2.9	2.7	2.7	n.s.

1=printer, 2=rotation worker, 3=machine operator 4=manual worker, 5=mailing operator, 6=mailing worker *** p<0.0001, NS=not significant

Significant differences between the occupational groups were found in the job characteristics. The printers and operators of the automation rated their jobs as demanding, independent and varying. The negative job characteristics cumulated in the manual workers' group. Job satisfaction and subjective experiences of monotony did not differ between the studied groups. Compared to previous studies, a slightly positive trend was seen among the rotation and automated line workers. They reported many improvements in the working conditions. The manual workers' situation had remained the same; the work was physically heavy and the job content was poor.

Physical strain in different occupational groups

The subjective evaluations of the physical strain are shown in Table 2. The results were compared to the corresponding ones from 1973 and 1981. The results revealed an obvious decrease in the experienced physical strain, except in the group of the manual workers, whose physical strain still constitutes a significant health problem.

Table 2. Experienced physical strain in the study groups in 1973, 1981 and 1991. Percentages of the subjects who reported much and very much strain in their work.

Occupational group	1973		1981		1991	
	n	%	n	%	n	%
Printer	6	35	15	47	5	4
Rotation worker	8	26	10	37	6	16
Machine operator	30	53	18	45	20	30
Manual worker	41	31	26	33	23	37
Mailing operator	35	47	16	20	1	6
Mailing worker	64	66	17	31	3	5

Environmental conditions

The environmental factors causing stress and strain are presented in Table 3. The results refer to the evaluations of the whole study groups in 1973 and 1991. Except for noise and chemical solvents, the influence of the other factors has decreased.

Table 3. The environmental factors causing stress and strain evaluated in 1973 and 1991. Percentages of subjects reporting much or very much strain caused by the factor.

Environmental factor	1973 n=815 %	1991 n=371 %
Noise	64	68
Dust	52	49
Draft	51	26
High temperature	28	20

Chemical solvents	32	36

Stress and strain factors in different occupational groups

The results of potential stress and strain factors in the different groups are shown in Table 4. The questionnaire items inquired about environmental factors, job content, work organization and social relationships.

Table 4. Stress and strain factors in the study groups. Percentages of subjects reporting much or very much stress.

Stress factor	Occupational groups					
	1	2	3	4	5	6
	n=125	n=37	n=69	n=68	n=22	n=50
	%	%	%	%	%	%
Environmental factors	63	51	43	62	36	53
Physically heavy work	4	16	30	36	5	6
Repetitive work motions	15	29	40	53	18	27
Uncomf fortable postures	18	22	24	37	14	22
Lifting and carrying	4	22	16	34	14	10
Hard work tempo	30	17	47	48	18	12
Tied up	26	22	34	47	23	24
Time pressure	37	31	28	36	36	29
Too much work	12	8	30	26	9	6
Low qualif ication demands	7	22	12	21	23	23
One-sided job content	14	30	28	32	18	31
Few career opportunities	11	35	19	22	36	25
Low challenges	10	32	16	21	27	33
Inconvenient working hours	22	32	14	14	45	26

1=printer, 2=rotation worker, 3=stand-alone machine operator 4=manual worker, 5=mailing line operator, 6=mailing worker

Environmental factors, such as noise, temperature and solvents, as well as time pressure, caused much stress and strain to all the subjects. Generally the printers and the operators of the automated mailing lines reported only few stress factors. The results indicated that automatization has improved the previous hard-driving machine-paced work of the mailing operators. The present problem of the line operators, i.e. inconvenient working hours, is nevertheless related to the product, newspaper. They were also dissatisfied with the opportunities for career advancement.

For the rotation workers the reduction in physical strain is an obvious improvement compared to their problems in the seventies. The operators of the stand-alone machines suffered from fast work tempo, repetitive work motions, and they also found themselves tied up to the workplace. The stress and strain factors cumulated in the tasks of the manual workers. The results don’t show any improvements in their working conditions from the seventies. The manual work at the mechanized machine is still very hard in spite of the automated equipment which should facilitate the material handling. The automatized lines have, however, made the work of the mailing workers physically much easier than it was in the seventies. Their major stress factors were related to job content. The one-sided and simple job content did not satisfy their expectations.

CONCLUSIONS

Although the technological progress has been rapid in the printing industry, some traditional problems were still encountered, e.g. monotonous and repetitive tasks, especially in the post-printing phases. On the other hand, technological development has in fact improved the working conditions and facilitated many operations, e.g. material handling. Especially the tasks of the rotation and mailing workers have become lighter. The work organization and tasks in the printing and post-printing phases differ greatly from each other. The tasks of the printing phase were mostly demanding and varying, whereas the tasks of the post-printing phase still contain only few challenging tasks, such as those of the machine operators. Typical problems cumulating in the last part of the process were poor job content, low occupational qualifications and physical and mental load. The work was regarded as monotonous, consisting mostly of short-cycled repetetive loading and unloading tasks. The findings from the production organization revealed a traditional allocation of tasks. The tasks were polarized into the demanding tasks of the machine operators, and to the manual tasks, typically performed by female workers.

The major strain was generally created by environmental problems, especially chemical substances. The present problems cumulated into the mechanized part of the post-printing phase and especially to the manual workers. Their job content consists of repetitive and simple work motions connected with hard work pace and poor job content.

The develoment of the different occupations seemed to follow the traditional trend. The tasks of the printers and operators of the automated mailing lines have become more and more demanding, independent and challenging. The tasks of the rotation and mailing workers have become physically lighter, but the job contents have remained as poor as before. The widely used job rotation at the automated lines has decreased the problems related to monotony, but not the problems related to low qualification demands. Fortunately, the organizations under study had plans and efforts to gradually enchance the tasks to include all the operations needed to operate the process, even a part of the maintenace and repair operators.

The findings indicate that the technological advance has in fact improved many of the physical problems in the printing sector. When the traditional problems decrease, more attention should be paid to the opportunities allowed by the new technologies, to release the human work capacity for the planning and controlling operations. Some organizations among the data have already faced the challenge and started comprehensive efforts to train and educate highly qualified and capable personal.

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OCCUPATIONAL HEALTH CARE AND WORK PLACE DESIGN

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INTRODUCTION

In Finland, occupational health care (OHC) has been stipulated by law since 1979 (Vaaranen, 1988). The law obligates all employers to provide preventive health services for all their employees. Services have to be based on workplace surveys and the analysis of possible existing health hazards and risks. The occupational health personnel then have to inform the workers about the hazards and needs for corrective measures. They also have to help the technical personnel to carry out improvements by providing knowledge about the human being, and they have to perform health examinations of the workers. Curative care can be added voluntarily. In connection to all these activities, a fair amount of data on workers, working methods, organizations and environments are gathered at the occupational health care unit (STM 1989).

Some recent regulations, e.g. the Act on Labour Safety, revised in 1988, and agreements of labour markets, have emphasized the application of these data and other health aspects to the ergonomic designing and structuring of work and the work environment. This has become especially important because the avarage age of the working population, as well as the number of retired people, is growing fast in Finland. In 1990 about one quarter of the working population was over 45 years old, and by the year 2000 their proportion will be almost 50 %. Even though the official retirement age is 63–65 years, already now the average age at retirement is 58 years, due to the great number of disability pensions. The most common cause of disability is musculoskeletal diseases. In addition, it has been estimated that already now about 10 % of the people at work have some disability. It can be assumed that also their propotion will increase in the future.

The designing and building of healthy and safe work and workplaces is an important part of the activities intended to maintain and promote the health and work capacity of people (Launis 1990).

Planning done in collaboration with occupatinal health care specialists provides an opportunity to apply and use the collected data, experience and knowledge of occupational health personnel in a constructive way. So far, however, it has not been customary practice, and in the contrary there are only few examples of such collaboration.

AIMS

The aim of this study is to develop appropriate and effective strategies, methods and skills to enhance collaboration between technical designers and OHC personnel. The basic questions are:

WHEN—at which phases of the design process collaboration is effective and purposeful,

WHAT—the quality of data and information provided by OHC,

HOW—the manner and form of delivery of the information,

WHO—the role of different occupational health care professionals (doctors, nurses, physical therapists) and with whom should they be working together in the design process.

MATERIAL AND METHODS

The research project is a so-called developmental intervention. It is carried out as case studies in three OHC units, two of which are the own units of big companies with approximately 3500 workers, the third one is part of a municipal health care center. This center serves the 12 000 employees of the city plus 4500 people employed by 488 small or medium-sized companies. The personnel of the OHC units are mainly responsible for the development of collaboration. The researchers act mainly as promoters, consultants, observers and recorders of the process.

The research project will be carried out during 1991—1993. The partly overlapping phases of the project are:

1. the description of the current OHC and design systems and existing collaboration as well as the attitudes of designers and OHC personnel.
2. the analyses of the development items, preparation of the needed supplemenetary material and organization of the necessary training.
3. the formulation of the collaboration models
4. testing of the models in real design processes,
5. Evaluation of the project, remodelling if needed and reporting.

RESULTS

The results are available from the first two phases. For the description of the current situation 33 occupational health professionals and 9 designers were interviewed. Annual reports and plans of action and other documents were analyzed.

Occupational health care

Only 3–4 persons among the occupational health personnel had had some sporadic collaboration with the technical designers. The attitudes were, however, positive and all were willing to participate in the development work.

The OHC personnel felt themselves rather incompetent and unsure. There was no history or policy for such activity in the companies. The employees have been used to immediate medical services and consider them most important. The doctors and nurses also feel guilty if they don't fulfil these expectations. The health professionals do not understand the design process or the technical terms, so they hoped to get some basic training in these aspects first.

The work place analyses had been done in 60–70 % of the work sites. The used methods, reporting and data bases served mainly the correction of existing workplaces or the planning of occupational health services. The data collected in connection with health examinations, curative and rehabilitation work, or the sickness statistics were not in such a form that they could have been used in the designing of new workplaces. The occupational health professionals were, however, used to working together with the people at the workplace, and so, helping them to participate was considered important.

All the occupational health care units had an automatic data processing system, but the programmes had not been developed adequately.

Design

Of the 9 designers, only one had worked together with occupational health personnel previously. The attitudes of the designers were also more sceptical in general. They had not seen the workplace analysis reports, and many of them were not convinced that they would get new, useful information from the health professionals. The image of occupational health care among the designers was still medical and nursing care—quick relief for ailments. Some of them also demanded that the provided information had to be well anlyzed and clear, because according to them "there is no time for theories" in designing any more.

However, most designers were willing to try out the collaboration and its development. This may be due to the general 'participatory' atmosphere in our society today, as well as to the economic recession.

The usual information sources of the designers were technical books, standards and norms. Their knowledge of ergonomics and available literature was rather poor, and the designers wished to have training in ergonomics and more information about health care.

Development programmes

The results were presented to each unit in a common meeting where the development needs and measures were discussed and planned together.

In each company a project group including both health care and technical professionals has been formed. The group has planned and organized joint seminars and meetings in each company. The technical people have taught the occupational health personnel the basics of the planning system and construction process of the company, and the architects have described their working methods. the occupational health care people have informed the technical personnel about their work, especially the work place analysis methods and data bases. The two professional groups have thus become more familiar with each other.

The contents and usefulness of the work place analysis methods and data systems are being analyzed and their improvement has been started.

The project groups have already started to develop models which include guidelines and ways of collaboration. The basis of these models is a triangle:

In each company, a building project has been chosen for testing the collaboration model. These are a kindergarten, a bank office and an ordinary office building.

The project group has assessed the existing data and knowledge connected to the work in question, as well as collected research reports and other relevant information.

A work conference was arranged at the Institute. All the project groups participated in it and thus had a chance to change experiences and discuss mutual problems and search for solutions. Similar conferences will be arranged for every sixth month, as the first one proved to be very useful.

CONCLUSIONS

The pertinent two professional groups have had only incidental connections so far, even though all the interviewed persons considered it important and were willing to develop the collaboration. Besides the different professional culture and history, the major problems were the lack of a common language and understanding of each others' work. Joint education and practical experiments are therefore necessary.

Occupational health care gathers a vast amount of data on workplaces and workers, but the implementation and use of the data in workplace design requires that the collected data be worked out and analyzed together with the pertinent health and technical professionals.

The development of collaboration between two professional groups with a totally different background requires time, support from the company's management, and good motivation of all participants. We have been able to get a process started. In time we will find the answers to the questions: WHEN, WHAT, HOW and WHO?

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DEVELOPING TECHNOLOGY AND JOB REDESIGN IN THE PRINTING INDUSTRY

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Technological development and the parallel changes in the organization of work and job characteristics were studied in ten printing companies. The utilization of information and communication technologies has increased rapidly in recent years, and entirely new production methods will be adopted in the near future. This development makes possible the integration of the previously split production process and the redesigning of jobs into meaningful entities.

INTRODUCTION

The production of a printed product entails surprisingly many phases and details. The complexity of the production varies to some extent depending on the type of product (newspaper, magazine, book, etc.) and the number of colors and pictures used. In the traditional production method, the process has been split up into relatively narrow phases and tasks in parallel with a strict division of labor.

The printing industry is one of the branches in which the problems of repetitive work, monotony, and polarization of jobs were found in the studies conducted in the 1970s and in the beginning of the 1980s (Kalimo et al, 1981; Seppälä, 1986; Cooper and Davidson, 1987). The polarization of job structures started to emerge along with the mechanization and automation in the beginning of the 1970s. In the prepress phase this happened when the hot metal technology was replaced by photocomposing. Different persons performed typographical coding, typesetting by means of a punched tape machine or a computer terminal, proof reading, and finally photocomposing in order to produce text columns. After that other persons made the page layout and inserted the text columns and pictures on the page original (so-called paste).

In this kind of organization of work, especially the job of the persons doing only typesetting was extremely repetitive and one-sided. Opportunities to improve the situation were limited, due to the specialization and narrow training of different occupational groups, as well as the limitations of technology.

Rapidly developing information and communication technologies have opened new opportunities to integrate production processes and to redesign jobs. Microcomputers, text-processing programs, desk-top publishing programs and digital image processing make possible and feasible the integration of separate production phases and the combining of tasks into larger and more meaningful job entities.

This paper presents preliminary results from a survey conducted in the Finnish printing industry in 1991. The aim of the survey was to chart the current situation and trends in technology, the organization of work, job contents, perceived work load, as well as the needs and opportunities for further development of work.

MATERIAL AND METHODS

Ten companies representing different company sizes and types of products (newspapers, magazines, books and special products) were selected for the research in cooperation with representatives from the employers' and employees' unions. The data on the production flow, technology, the oganization of work and typical jobs were collected by interviewing production managers, supervisors and employees. Furthermore, all production workers were asked to fill out a questionnaire on job characteristics, the impact of new technology, and stress and strain. The questionnaire was answered by altogether 726 empoyees of whom 315 worked in the prepress jobs. This paper deals only with the developments and jobs in the prepress phases.

RESULTS

Trends in technology, organization and jobs

Associated with the increased use of microcomputers, PCs, and word-processing software in general, the working procedures of journalists and the customers of the printing industry changed radically in the 1980s. Instead of writing a paper manuscript to be sent for typesetting to a printing shop, the journalists and customers prepare the texts themselves, and store them on magnetic disks or send them via communication networks to a printing firm. This has decreased the typesetting work in composing departments. This development together with the development of page-making softwares, especially desk-top publishing (DTP) programs run in microcomputers, have created a need to change the whole prepress production process.

The generic tasks in the prepess phase required to produce a printing sheet, as well as the proportion of respondents performing these tasks, are listed in Table 1. The percentages total more than one hundred, because the majority of the workers perform more than one task.

According to the division of labor dominant in the 1970s/ each of the tasks listed in the Table 1 was performed by one individual worker specialized namely in this task. As mentioned above, the firms are currently advocating multiskilling and larger job entities supported by the developing technology. This can be seen from the figures of Table 2 illustrating the number of different combinations of tasks in a job reported by the respondents.

Table 1. Generic tasks in the prepress phase and percentages of respondents performing different tasks (n=267).

Task		% of respondents
1	prearrangement of material	24
2	typographical coding	13
3	receiving, converting and finishing raw text	20
4	typesetting manuscripts	17
5	proofreading	11
6	taking a text printout	19
7	preparing advertisements	28
8	preparing black and white photos	15
9	preparing color photos	9
10	making a page layout	26
11	taking a page printout	15
12	assembling pages and photos	35
13	proofing	14
14	making a printing plate	13

Table 2. The number of different task combinations reported by the employees (n=262).

No. of tasks in a job	Respondents	
	n	%
1 task	87	33
2–3 tasks	84	32
4–5 tasks	50	19
more than 5 tasks	41	15

In the companies studied, very few persons did only the typesetting of manuscripts (3 out of 267 respondents). Most of the previous text writers were working, at least part of a work shift, on the so-called “raw text” sent by the customers. This consisted of converting the format into a form suitable for the system used in the printing firm, typographical coding, proofreading and making corrections.

In some places one person made also, in addition to the tasks mentioned above, the page layout and printed out a complete original of a page into which the pictures were attached afterwards. The advertisements, in particular, were usually composed by one person by means of a special terminal or a micro equiped with a page-making program and a graphic interface.

Furthermore, desk-top image scanning systems were being used in some companies, in which case one employee could produce a final page original containing texts, graphics and black and white photos.

Finally/assembling the entire press sheet is a phase which has developed much in recent years. In the advanced computerized systems it is possible to design page layouts, process color pictures and produce the final printing sheet within one system by digital technique.

This kind of integration, already materialized, and the integration to be carried out in the coming years, have opened up entirely new possibilities to design jobs. It has also put pressures on changing the organization of work and on retraining of employees into new multiskilled work because the old working procedures and division of labor are no longer feasible.

The extent of the use of computerized technology in work tasks is presented in Table 3, categorizing respondents according to the number of different computerized equipment they use in their jobs.

Table 3. The extent of the use of computerized equipment in performing one's work tasks (n=294).

No. of equipment	n	%
No computerized equipment	119	40
Only one unit	73	25
Two or three units	65	22
Four or more units	38	13

Persons who do not use coputerized technology at all were usually doing page layouts, assembling text and films manually by clip and paste technique while working on four-color products. Prearrangement of material, coding and proofreading are also done without computers.

Computerization and job content

One question debated much in recent years is: Does computerization make jobs more narrow and impoverished or wider and enriched, compared to the traditional techniques? This question was analyzed by cross-tabulating the number of

Table 4. Relationship between the number of computerized equipment used in one's job and the number of tasks in one' s job. Percent of respondents (n=262).

No. of equipments used	No. of tasks			
	1	2–3	4–5	5 or more
No computerized equipment	56	35	8	1
Only one unit	36	42	14	7
Two or three units	16	30	34	20
Four or more units	3	10	29	58

tasks performed by a person and the number of computerized facilities he/she uses in his/her job. From Table 4 it can be seen that the extent of the utilization of computerized technology and job content are clearly interrelated: the larger the job content, the more modern computerized equipment is being used. Job content and the number of equipment are not completely related, however, because with a modern desk-top publishing program one can perform several tasks with one micro. Previously the tasks were carried out by separate machines or in several manual phases.

Computerization, job entity and job characteristics

The question whether the utilization of computerized equipment and job content are related to experienced job characteristics was studied by comparing different user groups by two-way ANOVA. The significant effects found are shown in Table 5. Opportunities to use one's skills and abilities and the challenges of work—development potential—are connected to the extent of job entity, whereas computerization brings with it mental effort and problems related to mastering one's work. However, the use of several equipment is seen as an opportunity to develop oneself at work. No significant interactions were found.

Table 5. Significant effects of use of computerized equipments and number of tasks in a job on some experienced job characteristics.

Job characteristics	No. of equipment	No. of tasks
Opportunities to use one's knowledge and skills		*
Mental activity required in one's work	*	
Have to perform tasks with inadequate training	*	
Perceives some work tasks too difficult	*	
Opportunities to develop oneself at work	*	
Work tasks offer challenges compatible with abilities		*

General job satisfaction was not related either to the number of computerized equipment used or the number of tasks in the job entity. 70% of all respondents were satisfied or very satisfied with their jobs.

Experienced changes in job characteristics

The questionnaire included a series of questions dealing with possible changes in job chacteristics in recent years. From Table 6 it can be seen that more than 50% on average did not experience any changes in the characteristics inquired. However, there is a consistent tendency according to which about one quarter to one third of the respondents felt that the properties of work, traditionally connected to desirable job design goals, had more often increased than decreased. These include especially variety of work, the feeling of being able to accomplish something, responsibility, opportunities to affect the quality of work, and learning new things. The difficulty of work refers to new challenges related to the new technology and larger job content.

Table 6. Changes experienced in some job characteristics in recent years. Percentage of respondents (n=315).

Job characteristic	Decreased	No change	Increased
1. Attractiveness of work			
Interesting work	20	54	26
Variety of work	14	56	30
Meaningfulness of work	17	56	27
Feeling of accomplishment	10	62	28
2. Autonomy and control			
Independent decisions	8	63	29
Responsibility	2	63	35
Choosing how to do one's work	7	74	19
Affecting quality	8	56	37
Feeling of mastering one's job	6	53	41
3. Development potential			
Utilization of skills	12	60	28
Difficulty of work	13	45	41
Learning new things	10	41	49

In order to find out the extent to which the utilization of computerized technology was associated with the changes in the recent years, the answers ('decreased', 'no change' and 'increased') were analysed, controlling for the number of computerized equipment used. The responses to the alternative 'increased' are presented in Table 7.

The changes are related to the extent of the use of computerized technology, even though some increases had occurred in all groups (Table 7). The differences in favor of the computerized groups can be seen especially clearly in the job characteristics, e.g., how interesting the work is, variety of work, meaningfulness of work, utilization of skills, difficulty of work and learning new things. The differences are not so clear in the variables related to autonomy and control. These are obviously aspects which are more connected to organizational matters and time constraints determined by customers.

Table 7. Experienced changes ('increased') in job characteristics and the extent of the utilization of computerized equipment (% of respondents).

Job charcteristics	No. of equipment used		
	does not use	one	two or more
1. Attractiveness of work			
Interesting work	9	27	37
Variety of work	17	33	38
Meaningfulness of work	22	41	55
2. Autonomy and control			
Independent decisions	22	34	35

Opportunities to control one's work tempo	11	17	23
Choosing how to do one's work	11	22	26
Affecting quality	36	37	42
3. Development potential			
Utilization of skills	15	29	39
Difficulty of work	22	41	55
Learning new things	36	56	59

SUMMARY AND DISCUSSION

The printing industry is one of the most rapidly developing fields of industry in which competition for the markets is hard. This creates pressures to cut costs and lead times. This also means that firms must be capable of producing fresh news and printed poducts of high quality, and they must be able to serve flexibly and promptly firms which advertise their products.

To be able to do this, companies are forced to invest in advanced information and communication technologies and to develop further the integration of the production processes. Production can be automated considerably as regards processing, transforming, transmission and storing of information. However, in order to produce a printed poduct which is attractive and informative, a lot of human design work is needed. This concerns especially advertisements and special products such as posters and various four-color products (magazines, catalogues, etc.). Consequently, even though the number of employees needed is decreasing, those who are left must be multiskilled and motivated professionals. They have to master text processing, as well as layout design and color work.

The findings from our study reveal that the developments in technology described above are really happening with increasing speed. The proportion of persons who do not utilize computers in their work is diminishing. Along with the developing technology and increased competition, a new organizational thinking is emerging. This means larger job entities and more meaningful job contents. The previous highly split division of labor has almost disappeared. Consequently, many desirable job characteristics (see e.g., Hackman and Oldham, 1980) have increased in recent years.

At the same time as the increasing utilization of advanced technology is opening new opportunities for job redesign, there is a risk of overload and strain if the training is inadequate or the new duties must be assumed before adequate skills have been acquired.

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SOME FINNISH GRAPHIC COMPUTER-AIDED METHODS FOR BETTER ERGONOMICS AND SAFETY

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INTRODUCTION

Several ergonomic computer-aided design, “ergoCAD”, programs have been developed in various countries during the 1970s and 1980s. In addition to simulation of human being, i.e. the human model facility, they generally also contain various routines for analysing and visualizing the human-machine interface. A comprehensive review of computer-aided (CA) workplace design has recently been compiled by Karwowski et al. (1990).

Obviously the most common application is to employ graphic CA methods for solving reach, posture or visibility problems whether under seated or standing conditions. Thus quite static anthropometric human models have proved reasonable and useful. Other commercial applications that serve a mainly ergonomic purpose are those for energy expenditure prediction and human static strength prediction in manual materials handling (Chaffin 1988).

In addition to designing or analysing purposes, computerized simulation is also useful in an educational context. Computer simulators teach us about some aspects of the real world by imitating or replicating it. The general purpose of the computer-aided instruction (CAI) is to help the student build a useful mental model of some part of the real world.

SOME FINNISH APPLICATIONS

Finnish "ergoCAD" applications have also been anthropometrically oriented. The first ergoCAD application to be used at the Kuopio Regional Institute of Occupational Health was developed in collaboration with the University of Oulu for the Computervision CAD system (Väyrynen et al. 1985, Väyrynen 1988). Known as MINTAC, it was used to analyse work postures in forest machinery maintenance and to rate them according to the Finnish OWAS method (Fig. 1). OWAS, i.e. Ovako Working posture Analysing System, was developed from experiences obtained in the steel industry (Karhu et al. 1977, Suurnäkki et al. 1988). OWAS have been used both for developing individual working methods and for comparing ergonomics of machinery (e.g. Väyrynen 1984, Väyrynen and Könönen 1991).

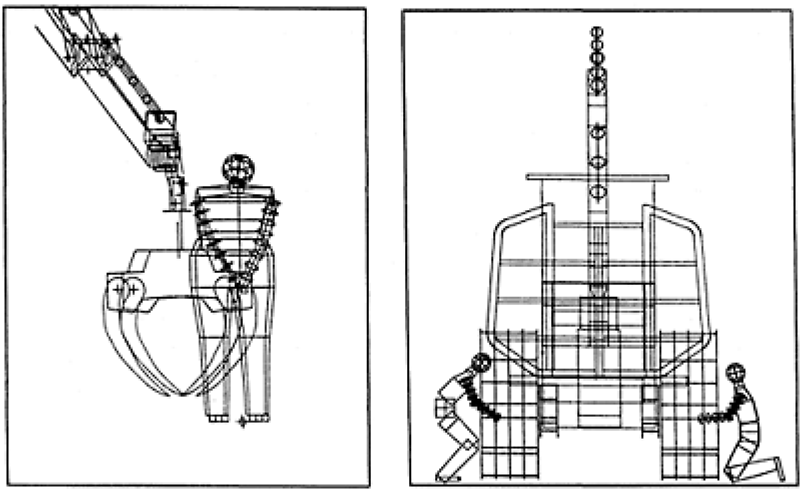

Figure 1. The Finnish anthropometric 3-D human model MINTAC can be placed in a working environment modelled by a CAD system to evaluate work postures, for example.

Besides MINTAC, two further ergoCAD applications have been developed in Finland, one for Computervision in Tampere (Leppänen and Mattila 1987) and one for PCs in Helsinki (Launis et al. 1988). The latter, which is AutoCAD compatible, is know as ergoSHAPE.

The fourth of the Finnish applications OWASCA (OWAS Computer Aided) is intended to visualize work postures and to provide training in posture analysis in accordance with the OWAS system (Fig. 2, Väyrynen et al. 1990). Thus it belongs among CA methods, especially CAI methods, but not actually among CAD methods.

The program operates with human posture figures, external manual load and the OWAS action category, which ranks the strenuousness of each posture combination on an ordinal scale (urgency of correction). The human model (stick diagram) has 14 links and is controlled by parametric vector graphics. The natural limitations on human movement are taken into account.

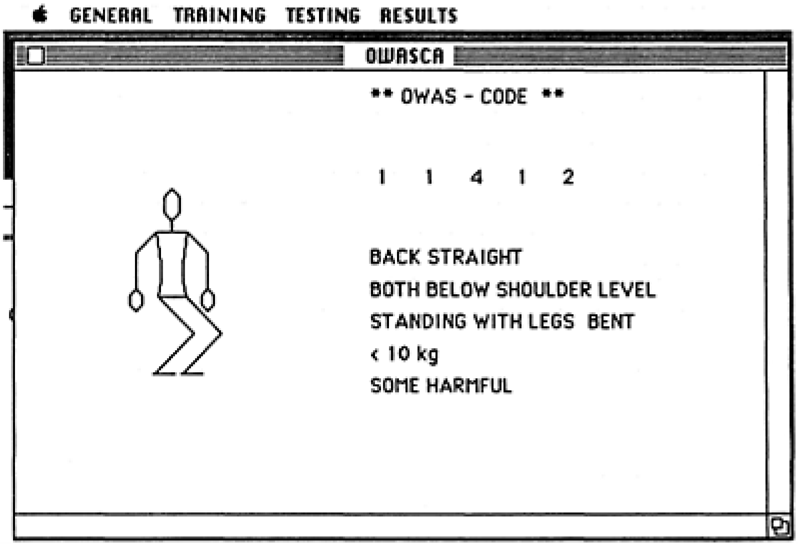

Figure 2. OWASCA is a microcomputer-based software product including human model facilities.

The potential users of OWASCA, in addition to designers, are safety and health personnel, and one of the main applications is the training of OWAS specialists. The OWASCA software is a basic instrument for redesigning work methods in order to reduce the postural load. The effective redesigning of work spaces and designing of new work spaces nevertheless needs a graphic CAD program to work with OWASCA, and at present the OWASCA software is not compatible with any commercial CAD software.

A limited computer-aided safety simulation formed a sub-task within the project “Simulation of production disturbances involving human intervention in dangerous zones” (Häkkinen and Väyrynen 1990). The possibilities offered by existing commercial graphic production simulation software were studied, and the feasibility of creating a kinematic computerized human model for simulating certain human physical actions in disturbance situations were tested (Fig. 3). Apart from production machinery simulation, the human model was also AutoCAD compatible. This simulation aimed to analyse accidents due to disturbances when operating with hand tools in the construction industry. Another application in this project was for demonstration of the safety distances of machines to prevent entry into danger zones.

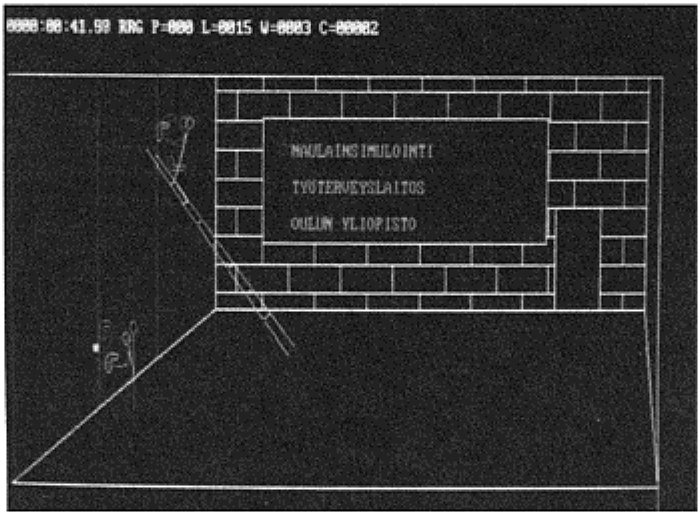

Figure 3. Production and its disturbances are simulated dynamically. The static graphics (environment) are produced by AutoCAD and the movements of humans, tools and products are animated by CADmotion (Photo, Kaisu Kekkonen).

Another kinematic graphic, analytical human model developed at the University of Oulu is aimed at calculating the velocities and accelerations of a human musculo-skeletal system during work (Fig. 4, Leinonen et al. 1990). The coordinates of worker's joints are fed to the computer model via a video-tape analysis.

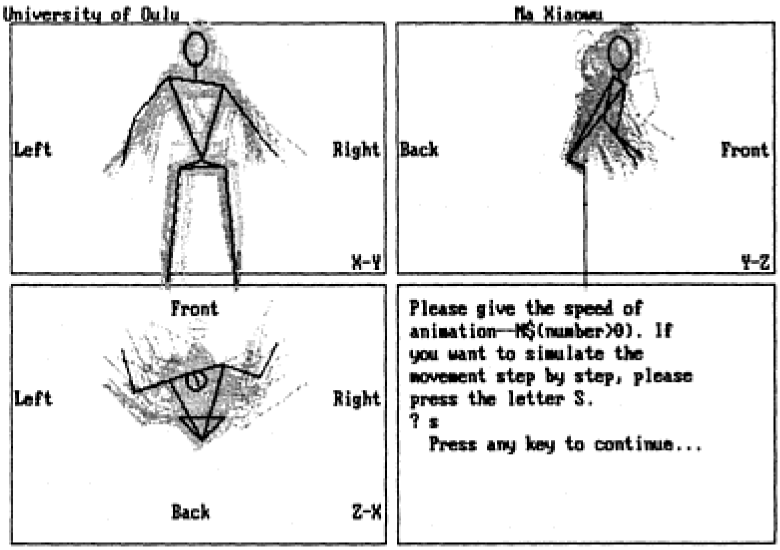

Figure 4. An example of task movement animation.

CONCLUSIONS

Task animation is essential if the aim is to proceed from anthropometric “static” ergoCAD towards “more dynamic” ergo& safetyCAD. For this purpose graphic animation of the figure representing the human body, or some part of it, is needed. This kinematic human model can then be integrated into commercial CAD/CAI software or graphic dynamic production simulation software.

Both planning and instruction have to be emphasized for better ergonomics and safety. Simulation, whether in the laboratory or on computers, is a promising technique which has not yet been fully exploited, but we must still remember that simulation is an instrument and not a substance.

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ANXIETY AND COMPUTORIZED WORK

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The anxiety stimulated by work threaten the physical integrity, mainly, the mental integrity of workers. The work with computorized systems has a certain distance between the task's prevision (the methods) with its execution. One of the manifestations is the anxiety produced by working situations with high responsability, uncertainty and a lack of trust in relation of the variability of a system.

Mostly, the anxiety, besides the lack of sufficient knowledge of the operational system, is also related to the decisions, memorization and the treatment of informations; creating a great mental charge.

INTRODUCTION

A computorized workstation should be adapted to workers of a specific qualification, by knowing their physical and psychical possibilities and particularities.

The mainly points of the ergonomic study in the area of Human-Computer Interation (HCI) are: repeated tasks, information control and the operation of the equipment. And the work's consequence on workers maybe related with breathing, optical, posture and mental problems.

Information control and working charge, as well the cognitive process, are the main problem concerned with anxiety in computorized work.

ANXIETY, WORKING LOAD AND MENTAL HEALTH

In relation of mental health problems, will be approached the problem of working load, and it's three aspects: physical, cognitive and psycoemotional.

Wisner (1987) found that the anxiety is the main subject between the pshychic suffering with workers.

Anxiety is a reaction of a risc, a latent danger that doesn't exist but would be exist. The anxiety caused by the computorized work threaten the worker's physical integrity and, mainly, mental integrity.

Anxiety is one of the most important mental reaction that causes psychosomatic diseases and it's like an avalanche, because they are firmly linked.

The intensity of the mental overload have the power to cause mistakes, accidents and delays by the anxiety provoked during a certain type of work, because of this, there is a need to analyse the interations between working conditions and the production's quality.

In the computorized work, even in the activities that have a low working load were fatiguing because of the presence of anxiety and mental stress, because of the high level of information and decisions allied to many quick tasks during a working journey that needs attention, and that creates an extra and hidden working load.

COMPUTORIZED SYSTEMS AND THE MENTAL WORKING LOAD—THE PRESCRIPT WORK AND REAL WORK

It was observed (Wisner, 1987) that it's growing the number of the activities with cognitive working load because of the computorization. Because these situations of work needs tasks with an extreme organization and the work's rhythm is rapid and intense.

The cause of the psychoafetive repercutions connected to the working organization and execution conditions of tasks is the distance and the difference between the real work and the prescripted work.

One of these psychoafetive repercution is the anxiety provoked by working situations with a high level of responsability, by the uncertainty and the lack of trust in relation to the variability of a system (Dejours, 1988).

This anxiety is normaly turning around the safety and the possibilities of accidents and/or incidents. Because the factors that inspires some accidents or incidents almost results from the inadequated interations between the man, the task and the working environement.

Part of anxiety should be provoked by worker's lack of knowledge (ignorance) in relation of the operational system, the functioning methods of equipment. Mainly times, they only know the minimal essential to operate the functioning of the system. If the workers had a certain experience, they will have sufficient familiarity to surpass unusual situations and also will be possible the antecipation of the results of some decisions.

So, training is one of the keys to minimize anxiety in a computorized work, because worker's knowledge is a powerful way to increase trust in working environement.

There is many physical and psycho-emotional problems that usually turns around in a computorized production sector. These problems frequentely affects workers of computorized sectors of digitalization, operation, optical reading and microfilming, where the mental charge of working and the cognitive process is intense; so, there is a need of an ergonomic analysis to point and face the specific problems and the sources that should create injuries.

The computorized work doesn't present, at first time, a risc of immediate accidents, because in this area and in this kind of work occurs diseases at long term (Cleiman et al, 1985). The incidents are a commom fact to face that may occur at any time, it's unpredictable but it may be avoided by using the technique of anticipation (terotechnology), by maintening the equipment and foreseeing tasks to be executed.

The work with computorized systems has a certain distance between the task's prevision (the methods) with its execution.

The worker should need to adapt, operate adjustments in relation of the distance between prescript work and the real work. And the distance between real work and prescript work also implicate in a certain aspect of the working load: the psycoafetive reflectation connected to the working organization and conditions of execution.

One of the manifestations is the anxiety produced by working situations with high responsability, incertitude and a lack of trust in relation of the variability in a system.

Mostly, this anxiety, besides the lack of sufficient knowledge of the operational system, is also related to the decisions, memorization and the treatment of informations; creating a great mental charge, that would generate a neurotic syndrome and/or stress.

CONSEQUENCES AND PROPOSITIONS

As Iida (1990) observed, the work with the new technologies has many stress sources in workers.

The work performed in such environements where the new technologies were predominant may give as consequences problems related to the worker's physiological and psycho-social aspects, like: isolation, absence of communication, effects of excitation originated from brain's superactivity (the person cannot stop to think about his work, and it could generate insomnia, nervousness, appetite loss, etc.), generally associated to the attention, concentration, information processing, decision making and doubts.

The artificial environement, noise, vibration and temperature were other factors that could also turns into a cause of stress and anxiety in a computorized working environement.

To have an idea, it will be necessary to respect some points from a computorized working sector to be put into effect.

a) Observation of the working rhythm to verify a need to change (or not) the quantity of the working load.
b) To consider the Ergonomy to establish premises to the improvement of the working conditions.
c) To get a way to establish a normal working rhythm for the worker through the working organization of the interprise. As an example: the introduction of a break during the working journey, to avoid repeated moviments to be extended during a excessive period of time.
d) To look for way to humanize working environement.
e) To emphasise working safety and the working medicine.

f) To not forget the training, because knowledge is essential.
g) To certificate that the system has a good maintenance control. Because when the equipment works well, the worker is sure of his work.

All these points should be transformed in the cause of stress and anxiety if they were not respected. Because stress and anxiety appeared in function of an excessive working load and also from inadequate working conditions. That's why the importance of a efficient manegement to improve and get good working conditions in computorized working sectors to maintain mental health of workers by preventing the stress.

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GOALS, PHILOSOPHY AND PEDAGOGY OF ENGINEERS TRAINING IN ERGONOMICS IN FEDERAL UNIVERSITY OF RIO DE JANEIRO

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The engineers training in the Federal University of Rio de Janeiro began in 1970, with the creation of the production engineering program at COPPE, and then in graduate level in the Industrial Engineering Department (1972). In this paper it is showed its present structure, based on nine keywords—prevention, reliability, error, assistance, workplace, adaptation, adequation, fatigue, stress—and guided to three major design preocupations—Productivity, Quality and Health in the working life.

INTRODUCTION

The Federal University of Rio de Janeiro (UFRJ) is one of the pioneers in introducing Ergonomics in the engineers training, in several levels (graduate schools, Master of Sciences and Philosophical Doctor degree) and different ways (academical formation, line-management training and staff management workshops, courses and advices to work unions and other demanders). The first activity of this kind began in 1970. Nowadays the total training involves seven professors and an annual public of aproximately 130 students and professional. Table 1 shows the quantitative aspects of the training menu.

Table 1—Modalities and annual public of trainings

kinds of Public	Modalities	Timeload	Anual Public range
Academ.	Graduate	90 h	90/100
	M.Sc.	48 h	12/20
	Ph.D.	36 h	8/15
Profess.	Line Management	12 h	10/20
	Staff Management	04 h	5/10
	Workers	20 h	15/30
Totals			130/195

GOALS

The goals of the entire training set is to transmit to engineers, managers and technical staff of enterprises and their workers the main concept of human centered approach of the organization and technology, in order to analyse, to design and to develop production systems.

Its philosophy is based on a technical/social ans spiritual appreciation of production systems in confrontation to the disseminated industrialism, where performant machines and well stablished procedures are suficients to their design, operation and management.

PHILOSOPHY: TOWARD A TRADITIONAL WISDOM OF THE WORK

The concept of human centered approach is founded in a holistic vision of the activities of women and men at work. This way of seeing production systems believes that work has not only utilitary purposes. People work for their livelihood, that's true. At work, women and men produce goods, receive their paid, develop and practice their professional skills. But that's not all. In their workplaces people have the opportunity to exercise the most human capability: the solidarity. Since the beginning of human kind, men and women have learned that to share their competences and abilities as well as their deficiencies is a good way to improve technical aspects of production systems. In certain cases that is the actual best way. And more, it is a good way to organize a brotherhood.

The main result of a production system is not the production, but the workers, that is, the women and men that made the products. They are not the same after the cycle of production. During the days of work, people changed. This transformation occurs not only due to the material aspects of the work system. There is an energy flow integranting working people, and the name of this energy is solidarity. Solidarity is the main door for the search of the transcedental character of the human work. This is the traditional wisdom of the human being. In the present age, the society has too decreased the importance of the human work as one of the pathes for the encounter of men and women with the sacred aspect of the production systems. So, the concept of workload must includes the physical, the cognitive, the psychic and the spiritual attribute of human work.

This is the reason why the scientific method, only, has not the power to explain all the aspects of tha activities of women and men at work. There is no profane science able to evaluate the human work in its totality. The ergonomists and correlative professions should not forget this fact and the training underlines it. The technical intervention of these experts is only a part of it can be done. The human work is not a matter to be analised only by the scientifical method approach. It is necessary to improve—or to recuperate—some methods based in the traditional wisdom of human kind. The use of intuition, life experiencies. body consciousness and so on, becames an imperative, in this sense.

The concept of human centered approach adopted here is not based in the Human Relations Theory, not also in the present participatory management movements, like QCC. Its main idea is to remember to people their connection with the work, the other people and with the universal order. It is very important to put the cosmic character of the human work in the work analysis and design. The forgetfulness of this character can be a very strong mistake of the ergonomists, engineers and all people involved with the work study. It must be changed and drived to an actual human centered approach. That summarizes the philosophy of the training.

PEDAGOGY

Table 1 shows the key and the contents of the program for training in Ergonomics in Federal University of Rio de Janeiro.

Table 2—Keywords and contents of trainning in Ergonomics in Federal University of Rio de Janeiro

Module	**Keywords**	**Contents**
Safety	Health	Accidents, Incidents, Diseases, Discomfort, Deathes, Multilations
	Prevention	Protection, standards, Hazards, charts, Laws
	Reliabilty design	Fault, link, Imbrication, Sociotechnics Forecasting, Retrospective
Classical Ergonomics	Fatigue	Physical workload, Energetic cost, Sleep Aging, Labor consomation.
	Adaptation	Anthropometry, Fisiology, Perception Man-machine, Interfaces
	Workstation design	Reach, Postures, Efforts, Stereotypes Visibility, Readbility, Self-Adjust
Cognitive Ergonomics	Error	Anxiousness, Dispersion, Mistake
	Assistance	Strategies, Reasonings, Logics, Mental Models, Operative languages, Shoptalk Algorithms, Problem solving, Competence
	Job-aids design	Compatibility, Self-configuration, Help levels.
Hollistic Ergonomics	Stress	Suffering, Subjectivity, Blockades Syndromes, Phsychis defenses
	Adeguation	Subjectivity, Lifelikeness, Gestalt, Simbolics, Dignity
	Hollistic design	Negociation, solidarity, convivial design, psychodrama, cinetics.
	Traditional	Intuition, Symbolism, life experience, body consciousness,

	Wisdom	sacred, spirituality

The program contents and learning techniques emploied to communicate essentials ergonomics keywords (KW) is based on appropriate combinations of some Ergonomics Design Techniques (EDT), their philosophycal preocupation (PP), the associated epistemological discussion (ED) and the social repercussions (SR) of non-ergonomics production systems developement. Each trainnig has a major emphasis as a guideline, since the pedagogy varies in f onction of level and ways of training (academical or professional training).

The pedagogical structure of modules is based on the principle of multiactivities and multisourced in learning. Technics employeed are Professor Lecture, Collective lectures, Visual trainning, Groups dynamics, Self-knowledgement, Participation simulation and Pschodramas.

Academical Pedagogy for graduating engineers

The public of this training are adolescents aged from 19 to 23 years. Due to a social process of selection, a great part of these students have not yet an experience as workmen and, in certain cases, they have never gone into a computer workplace, a shop, a buiding site and so on. However, their social and spiritual origins had yet made a development of an ideology and and an acquired behaviour in terms of a look to the working life.

The aim of this training is to learn how to look, to see, to heard and to feel the manifestation of life in the working places and in the working time. The students must constitute several groups to have an experience of studying one actual working situation upon the phylosophy described upper.

They do it not only with their own capabilities but also sharing their experiences with the involved workers, their representative union and the technical staff concerned. This sharing can be just some talks, but it is not rare that other personal links are stablished with the workers and union agents, as well as with people of the technical staff. The general methodological recommandation is to colllect answers for the same questions with different actors in diferents places of the organization and with diferents manners, since the speech is not the only way to people’s expression.

Academical pedagogy for graduates

The main distinction between master of sciences and phylosophical doctor degrees is the orientation of trainning. In master of Sciences the aim is to prepare students to be able to research, they must accomplish an life experience in researching to obtain the related degree. The philosophical doctor degree has the ob jective of prepare masters of sciences to be able to acquire the academic metier, that is be able to perform training and thesis advisoring. In this sens we don’t have, by the moment, the intention of forming experts in ergonomics and safety, but just prepare instructors in this matter.

Pedagogy for Professionals

In this field our trainning, even following the same structure and philosophy, is adequated to the context in which it occurs. In general this kind of training is prepared with the training division of enterprises or the staff of the social groups (Unions, Schools, Scientific Associations, Congresses etc.) and a special group of activities are designed in fonction of the negociated aims (promotion of ergonomics and safety, formation of basic team, qualifying existing groups and so on).

The general pedagogy is to involve not only our group, but also a group integered by people from the demander, which will have the task of carrying on the ergonomical or safety intervention.

CONCLUSION

In this short paper the main objective was to show the academical work of the group of professors in Rio de Janeiro, Brazil.

In phylosophical terms the objective was to show the need of introducing in Ergonomics some of the oldest techniques of the traditional wisdom of humanity. In fact Ergonomics is a new science, so it needs the help of old sciences.

In general terms my intention was to share with my colleagues in this International congress the experience of the group in which I work and, in the spite of increasing solidarity between us all.

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OUTSOURCED SERVICES IN THE BUILDING INDUSTRY: SAFETY EVOLUTION OR RISKS TRANSMUTATION?

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Outsourced services are the present macroergonomics discussion in the Brazilian building industry due to the technical problems that it solves and to the safety matters that it brings about. The ascending displacement of certain building site tasks does not eliminate their intrinsic risk but transmute them. New and underrated safety problems appears on the links of the remaining d building site process and the incoming product of outsourced services.

THE EVOLUTION OF THE BUILDING TECHNOLOGIES IN BRAZIL

The building technology evolution in Brazil follows three basic trends (VIDAL, 1991): (i) one **first generation,** where the main preocupation was the rationalization of the conventional process; (ii) a **second generation** when the technical search was to concept the building production as a shipbuilding paradigm and (iii) the **third generation,** that I've called the outsourced services (VIDAL, 1988), and it can be defined as a whole production strategy combining positive aspects of both preceding generations, in managerial terms.

These generations are a frame to classify the several ways of building, and I prefer to talk in terms of a trajectory of the technology rather than to propose a label for some building processes. Table 1 summarizes the categories employed in this research about the evolution of the building technology (VIDAL, 1989; 1991).

The first generation: rationalization of the conventional

The first generation—rationalization—has introduced a conflict in stablished labor culture, and this has resulted in conflicts oppositting staff and workers, that is, between planning and execution. Since building work process is strongly dependent on workers' competence, classical task rationalization (Taylor, 1911) was, in fact, difficultly introduced. One cannot subestimate labor reactions, spelly in this case, in which the general context is very different from mass production.

From a technical viewpoint the variability in building work process is much more elevated than in the general manufacturing situations. This requires a continuous review of the task assignment which is not compatible to the idea of planning. Thus, the rationalization was limited to the introduction of timeblocks for groups of building actions such as a definite part of the structure, for instance. Otherwise, we don't observe any significative technical introduction as transfer machines, concrete pumpage, kits for iron cloth assembly and so on.

Table 1. Categories in generations of the building technology

Dimensions	Trajectories in Industrialization of building		
	Architecture	Building Technics	Work organization
Hardware	Components' Flexibility	Elements' Particularities	Spatial Division of the work
Software	Modular Coordination	Standards' Compatibilities	Manuf facturing Asembling
Socialware	Mass Production	Increasing Risk gravity	Structure of the groups

In a social approach it is necessary to add an antropotechnological consideration, related to autoritarism in production relations which can be observed in Brazil. In the literature it is very common to relate labor insatisfaction with bad results on quality and quantity levels. We can verify this general statepoint in Brazilian building sites of the first generation, since the only technological change was, in effect, a new organizational design whereas the management didn't presents any sensible difference. This configures a kind of inadequated **socialware** since, on the first hand, we can see that it is very important to involve the workers and, on the other hand, the only action effectued is to change their working methods. The workers configure this socialware as a clear demonstration of doubt in their capacities.

The problems of this technological choice are related to the costs for sustainning a desired level of performance. Since this generation does not present significative changes in **hardware** level of technology, as well as it doesn't consider the effects of the variability, like the variations in the execution of the tasks, the production flow in the building site devellops itself under greater disciplinary pressure (FERRAZ, 1991). In Brazil this first generation was not really successfull because the social conditions did not make possible to the intensification of these kinds of actions.

The second generation: the prefabrication way

The second generation, prefabrication, changed the building process by supressing various building tasks as well as displacing some of them to a component production unit.

These building systems were designed by combining the principle of the closed system—architectural and production design for each building—and the principle of open cycle—the production of the elements and the assembly of the produced parts can be spatially separated. In fact, this second generation has begun in the 70's with the great building operations in Brazil. Face to the importance of the number of demands, the building firms organized several spaces for supporting building sites. From the initial stockage functions, they have evolued to some primary preparations of materials such as cutting iron, sawing wood and so on.

The link with the first generation can be stablished by looking at the spatial organization of the building site. The great part of the rationalized building sites presents a clear separation between preparation and productive spaces. It was precisely a part of these preparation activites that was reported to the supporting spaces, out of one building site, but preparing materials for an increased numbers of different sites. The distinctive characteristic was the passage from the initial stage (prepared materials) to an strucutured building component production.

The experiments in the prefabrication way have produced an special demonstration of difficulties of partial technology transfer in the component production units as well as in the assembly building sites.

The **component production units** were not designed within an industrial approach, but only in a manufacturing one. We could see (NUNES E VIDAL, 1989) that component production units were, in fact, an assembly of artifacts and mindfacts of the building site in a fixed space instead of using up-to-date technology like telematic robots and other automated devices. The actual option was to build a provisional unit since the building site is also provisional, and we could register this **provisional** feeling as something very important in the building workers' job ideology.

The **building sites** were also very touched by this second generation. In a large field investigation (VIDAL and coll., 1991) it was observed that milimetric requires of prefabrication was not compatible with consolidated skills of the construction workers. In this sense the sucess of some firms using this building systems was related to an importation of competences from industrial sectors, particularly shipbuilding and automobile. These competences are technical (e.g. transfer equipments) but also organizational ones (interaction between groups without supervising interventions)

The third generation—the outsourced services

Face to the problems in prefabrication, several building firms have chosen outsourcing production strategy instead of closed systems in prefabrication, technology adopted by several great entreprises in Europe (BRUNA, 1977). It's important to note that this option is related to particularities of habitational crisis in Brazil, as well as the specifity of anthropotechnological context.

The outsourcing strategy has appeared as a redefinition of the principles of rationalization joined togheter with prefabrication schedules. Instead of a radical innovation—changes on the product and manufacturing process—it was concepted as a new start from conventionnal process. The production design replaced the building site in the center of the planning but some segments of the building process were outsourced. In this case the mainly orientation was not essentially to reduce building site activities but to submit them to special requirements defined out of the building sites.

Mentioned outsourcing has two essentials characteristics, as follows:

(i) Outsourcing by a truncated process (HIRATA, 1977, apud VIDAL, 1985), meaning services execution in a rationalized or even industrialized way of only a strategical part of the process as well;

(ii) Displacement of technical and human management from builders to service firms, creating disagreements between respectives working groups.

The option for a truncated process, also called dilapidated transfer (KERBAL, 1991), is the form by what partial transfer appears in this generation. Builders must provide at the building site all previous conditions to service execution (i.e. preparing moldings) and to the ending tasks (i.e. to slump the concrete), whereas the outsourced services are produced in industrial context.

The disagreements in management are produced by the differences between respective technical cultures and this can be observed by analysing the temporal structure of activities (THEUREAU, 1979). It is possible to see that at least two kinds of external given times are introduced: the first one is the preparation deadline and the second is the allowed time to ending tasks. Thus, the introduction of timeblocks, which was very difficult in the first generation, has met this present form.

In a general overview these characteristics lead to five important reprecussions in the working process, as well:

(a) Introduction of interlocking systems resulting in the coactivity forms changing and in its repercussions intensifying;

(b) Autonomy loss of the building site heading, where external inputs from outsourced services keeps labour cadence;

(c) Disruption of working process into two segments; By one side we get outsourced services performed in a more rationalized situation, using machinery and devices more adequated and, consequently, in high productivity level; on the other side old builder's collective with the same handing tools submitted to time and precision constraints;

(d) Changes in some building tasks, in order to adjust the coexistence between insourced and outsourced tasks; to operate these kinds of tasks the workersm need to develop new cognitive signs and its correspondent operating representations.

METHODOLOGICAL DISCUSSION

Considering that construction industry is a very large field of researching, our study field gets into the delimitation from the building production; being more specific, we have observed tasks related to a special moment of the building process, the structure making off. This choice was suggested by technical innovation scheduling made in the beginning of the research.

Work analysis and ethnometodology were the methods of investigation layed out. We combined observation reports and images of workers in real activity—what they really do for executing tasks—with verbal protocol analysis involving all subjects in building site related to observed work.

In the aim of work analysis we got attention to every incident resulting in changes on the usual way of working (i.e. increasing verbal communications, accelerated posture changing and exclusive cooperation and helping among different teams in the same workplace).

To collect the workers speech we get as subjects all people involved, from workers to engineers, at the building site. We have indexed each speech taped into conditions of obtainning (inside or outside workplace, in spite of proximity of chiefs or not). The validation of content speech analysis was executed by the time we used to show and discuss work observations with workers and management separatedly. Those cares provided the quality control of the results so as they had permitted the inclusion of new categories during the field research. Finally we have not led on the development of the dialog with the intention of rising up the workers' speech like a free flow.

In terms of safety we give more emphasis to the interlocking situations, particularly the situation that I've called **boundary tasks,** that means, all the aspects involving the relationship between workers in the building site and outsourced service workmen.

A REPORT OF TWO TIPICAL SITUATIONS

The first one was the object of our paper in the XI Congres of the I.E.A., Paris, '91. We observed the production of a flag using pre-fabricated iron cloth, cut and put in place by the local staff and delivery of pumped concrete applied and slumped by the same staff.

The second one is a great freeway to the airport—the "Linha Vermelha", and it is essentially based on the field records of my collaborator Marcelo Figueiredo, who has been following this construction since 1990. We have observed the links between metalic flags and concrete structures, each of them executed by different enterprises.

Concrete delivery to a small building place

The first remark deals with the real fragmentation of conventional building workmen staff. Effectivelly, there are no professionals of cement involved in these activities at the building site; the concrete applicator workers don't need, theoretically, the required qualification to refuse bad concrete and this fact causes an increased workload to engineering level. Since engineer operation monitoring could not be always possible, workers are led to take decisions during pompage.

Concret pompage is linked with the building site by tubes and it is operated at the concret-truck in the ground level. Communication is not so easy and the most the building grows, incidents get increased up. The hardware of the linkage is a flexible rubber pipe with its weight, when empty, around 40 Kg and it should get its weight up to 130 kg during pomping operation. This pipe has no device to handle and his extremity must be displaced to do the application. The staff of this operation is composed of nine men, as the following: six to translate this pipe, one to guide them and two to displace the slumper and its electrical motor. The group of six workmen follows the indications of the guide and just after them, go two workers operating the slumper. The operation once previously executed cannot be submitted to a feedback, inspite of spoiling all the prior operation, causing, this way, serious damage to structure safety. So that, they have to concrete the slap step by step. Displacement of the concrete flowing pipe is also difficulted by the obstacles that are found in the place on where the concrete is applicated.

By the organizational point of view we can observe clearly the division effects of workers in different staffs: the operating staffs of the building site and outsourced services staff. By the time the pompe is operated at the truck, pompage velocity has its control out of attainment of operating staff. Therefore, there's a workman of the outsourcing staff who interfaces all communications with the truck operator whose central preocupation is to guarantee the best and the fastest concret flow, once he's submitted to his enterprise's constraints (his productivity is measured in delivered cubic meters).

We've got, saw and heard from workers various dimensions of their workload. In the physical level we can estimate what signify the combination of weight, difficulty of displacement and repercussions of frequents disharmonics mouvements like an unbelievable ballet. Looking into the cognitive aspect, we stand out the defeance of workers' strategy in application to define a physical-economical itinerary, respecting the conditions of avoiding the operational feedback, as shown, and curves formation on the pipe during the operation as so as possible. Thus variabilities in this task make lots of obstacles to this intention. In the psychics level, this is very important because a too curved pipe can provides the whip effect with a fast increase in concrete pression. Since body protection is not available, these risks are very real; so that anxiousness occupies their souls.

Metalic flags over concrete arcades

In this case we cannot think in terms of fragmentation because, in fact, we have an strict work division: Metallic flags and reinforced concrete arcades. Each of these elements is produced with different technologies (steel milling and welding for the first case, apply and molding concrete in site for the second), in different workplaces (in metalurgical plants and in the building site) and by differents teams (industrial and construction workmen).

The arcades in concrete must be produced in a high level of precision and this has several implications to the building process. Nevertheless this is not a serious problem because the workmen must **only** be more careful. Indeed the production of arcades becomes a crucial operation for construction workmen but their collective competence is adequate to this requirement.

The greatest problem appears in the operation of placing the metallic flags. Since it is an urban construction it was not possible to isolate the building site entirely because of the cost of the measures for a suitable isolation: local inhabitants circulation, remainning commercial activities and so on. It must be underlined that the freeway is been built over a very dense urban cloth and the construction given times were exiguous. The conjonction of these factors led to a very unsafe context for the operation and also an increasing workload, since workers an inhabitants behaviour had to be managed during the placing operations.

The metallic flag has differents dimensions, and we observed the placing of an 18-m metallic flag. The material is moved by combining two cranes, each one of them being responsible for the movement of one tip of the metalic flag. The communication support is not the voice but a complexe gestual code involving the two crane operators and a linkman. When the flag approaches the position point to groove the metalic flag in the concrete arcade it is not possible to the crane operators to have a visual control of their acts, in this sense they must be enterely guided by the linkman. The problem is that also this linkman, who is on the ground, cannot see this details, he must drive the workmen who are placed near the incase point. His job is not so easy because the crane operators and some of the placed workmen are from the metalurgical industry (a true team of blue collars, with their blue jackets) and the others from the construction enterprise (with their improvised uniforms).

The mental workload of the linkman is very large, since he must dispose of a extense basis of orientation, to cordinate the looking actions of placed operators and the moving action of cranemen and he needs not only to make very clear questions and to transmit precise instructions. The emotional workload is also very heavy, because the consequences of errors inludes risks of his own life, their coleagues' ones and also of lots of passer-by. This particular dimension of the workload is aggraved by the fact of differents cultures, and during the placing operations the major part of discussion have the linkman and the construction workmen as interlocutors considered by him as unqualified people. Indeed, this linked activity is not prepared at all, even a minimal trainning about the cooinned activity. These discussion are repercuted in the crane-linkman communications, increasing the risk level in the whole activity.

CONCLUSION

The evolution of building technology in Brazil follows three basic trends: rationalization of conventional process, prefabrication and services outsourcing strategy.

In both of the reported cases, the technical base of links presents desig errors that demand a high human reliability in order to obtain technical succes and preserve the worker's health. Even simple rules of ergonomics are not observed (handling recommandations in the first case, training and commnunication in the second case).

Organization layout creates more dificulties to the management of the variability by the workers themselves (VIDAL, 1985), which amout to be the essence of their cognitive activity. In botht cases it can be added that the coactivity in the boundary tasks creates even more difficulties.

We can also observe that regulations and others resources in this management schedule are imparted with the introduction of time constraints in both processes. I must remark that the most particular caractheritics of conventional building work process is precisally the impossibility of separeting actions and regulations and safety-maintenance behaviour., These acts are executed by the same staff, often by the same worker. The outsourcing strategy has been a source of difficulties to the integrated practice of these acquired skills by the workers, often leading to accidents and near-accidents..

It is very interesting to observe that our first annotations have been confirmed with the second research field. This shows, unquestionably, that te outsourcing strategy should find better solutions for artefacts, mindfacts and sociofacts in which it is based. Based on the sudies of the GENTE/COPPE it can be said that risks in construction are not supressed, They were simply transmuted. They were displaced to the components production unit (second generation) and, if we look to the boundary situations (third generation), they are specially worsened by the introduction of a kind of cultural noise in the commnunication between field workers and outsourcing personel.

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THE INTRODUCTION OF DIGITAL SYSTEMS IN THE CONTROL ROOMS OF OIL REFINERIES IN BRAZIL

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The introduction of digital systems in refineries is a sophistication of the technology of the established control and instrumentation technology combined togheter with recent data processing advances. The technical performance of this innovation allows gretaer control possibilities such as simultaneous treatement and optimisations. This reinforces the mitical belief in the power of technical solution which reigns among the technical staff. However, technical options may find their limits in the underestimation of the ergonomic aspects in the design of softwares, which increases risks and possibilities of material and production losses not to mention the loss of efficiency and realiability.

THE INTRODUCTION OF DIGITAL AUTOMATION IN PETROCHEMICAL PLANTS

Petrochemical plants are going through a special kind of evolution: a sophistication process (VIDAL, 1978) which steams from the introduction of **control automation** and **procedure automation**. The purpose of that is to increase the efficiency of the integration between production steps by managing discontinuities.

In the international scene we can see that a major introduction of Digital Distribution Control (DDC), and related technologies of Advanced Control (AC), Process

Optimization (PO) and Control Desk Engineer (CDE) is being concluded, with some Optimization systems already in commercial operation. In Brazil, petrochemical plants are following this international technological trend in process automation, specially with the introduction of DDC and CDE.

The DDC

The DDC is a digital-based control automation to replace analogical eletronic-pneumatic control systems. DDC is a first step toward future developments in control automation, such as AC and PO. The first should make possible setting up plants near their technical limits by enhancing the stability of the process. PO can identify the optimal operating bands. The advantages of employing DDC are summarized on table 1.

In Brazil not only the new plants are being builted with CDD's but also the old ones are going trough a substitution process This technological migration in oil refineries is a step in learning the possibilities of the new technology.

Table 1—Technical and Economical advantages of DDC

* Informations on real time
* Increased regulation and control devices precision and speed
* Operation mode available near unit tolerance limits
* Automation of management routines
* Expanded Management Ressources (alarms, trends pictures and performance reports
* Flexibility (possibility to change control configuration
* Possible links with hinder introductions (AC and PO) de processo
* Increasing Technical reliability and process information
* Possibilities on process simulations

The CDE's

The other category is the **procedure automation** through to operational integration of CDD information at the master control center. Control centralization is a worldly trend and industrial experiences show that global optimizations are more easily obtainable with operation integration. Recently, some new refineries in Brasil were conceived according to this philosophy: they don't have DDC technology yet but proces in centralized control hardware (e.g Cubatao-SP).

Procedure automation philosophy is to create conditions that ensure that a plant unit can be driven from an emergency state to a safe situation without the need of additional operators. In order to accomplish that, it is necessary:

1) to eliminate some of the manual activities of production operators field and laboratory analists

2) to increase safety and reliability of operations and equipments

The technical basis of this tecnology assumes the intensive usage of **process analyzers** and **laboratory automation** to produce quality parameters in real time.

To put it in technological terms: in order to make the interchangeability of digital systems possible, the development of a homogemeous process instrumentation for CDE's is needed. That would allow a simplification of the data architecture as well as it would make it easier to establish optimization functions and cut the global facilty costs.

METHODOLOGICAL STEPS

The modernization of petrochemical plants, according to such direction is actually modifying job contents and suggesting new work organization forms which have a positive as well as a negative impact on operation activities and consequently repercussions in plant performance and reliability.

To study this scenery we must employ multiple methods. The initial approach was to combine Risk Charting Procedure (De Simoni e Mattos, 1984) and Demand Analysis (Wisner, 1974). The construction of operating models was proceeded to based on a retrospective search of the modernization process, through Work Analysis procedures of both analogical and digital instrumentation operating situations and on some deep analysis for the evaluation of the real present situation using Action Cours Study (Theureau et alii. apud Wisner, 1990). Finally, a problem forecasting was tried with Future Work Situation Analysis (Daniellou, 1985, apud. Wisner, 1990).

ANALYSIS OF THE ACTUAL WORKING SITUATION

Genesis of the research

This academic investigation came to meet a concern the refinery's management toward the follow-up of the modernization process in their plants. Preliminary negociations were not simple because our approach was at the same time very interesting and somewhat cumbersome.

Social representation on automation design

In the first visits for charting ergonomic aspects we could observe clearly that automation design and implantation in oil-refining plants bore the underlying idea of taking automatization as far as possible. We could also note that the operators' activity wasn't the central matter, and it was subject mainly to technical choices.

According to Freyssinet's propositions (1990), automated systems design is founded on three kinds of social representations, namely: the mechanical productivity paradigm, the charm of up-to-date technology and the claimed irrationality of the operators' behaviour.

The first kind of social maintains as a truth the myth of job compactation (work elimination and/or operation supressing) as the only valid way to increase productivity.

The second paradigm derives from the social of engineers in our society. This paradigm states a deep conviction on technical solutions are the ultimate and most effective way for solving all problems, be them of productive, social or organizational nature. This can be illustrated by the belief that the evaluation on what japanese trading success is essentially supported by well developped and well managed automation. Its corollary is the search for doing better than men without them.

The third brings an implicit distrust of the operators' behaviour. In this representation the real activity is "not reliable", since it's made up of approximations, individual intuitions and doubtful concerns. It is, thus, entirely incompatible with the needed rationality of technology and it must be removed from technical life. The general ideology is: "'on one hand, operators are ultimatelly human beings too likely to flop under pressure, too subject to emotions as well as to failure and to doubt; on the other hand they are just employees, how can we share with them the company's goals?"

Premises

Face to that, we adopted the following as premises:

- Modernization is guided by job compactation criteria
- Automated control systems design is done with an insufficent knowledge of real situation of operating activity, which reveals inconsistencies between the technical logic and the operating logic of introduced devices.
- The training procedures, as tentative **ex-post facto** adaptations to the introduction of technological novelties are also founded on a distorted image of the real needs for operating practices.

Global analisis of control room activities

The workers' production activities in processing plants are divided into control activity, inspection and maintenance.

In the automated situation, control activity (operation) consists of majorly routin, programmable and previsible actions, which are normally incorporated to the system in new situation, whereas in the analogical situation, control activities requires some routines to be done by operators. In both cases, These activities are, however, a fonction of the situation. They vary greatly depending on whether operation occurs in a calm or in disturbed periods.

When the unit is going through a **calm period,** the essential activity is vigilance. That means not only routine inspections (procedures) but also a dynamic follow-up to be able to manage the system in cases of perturbations (diagnostic actions). Since both actions and procedures are indissociable parts of their work, operators must be attentive to the development of processing. This situation will not change essentially with the introduction technologies introduction. At **disturbed periods** the activity changes to the management of alleatory events based on personnal and collective diagnosis.

In general, the basic activity is **process regulation,** which consists of foreseeing and correcting the instabilities and deviations of the process. Regulation is intended to keep the production in the stablished quantity and quality specifications. This stipulates which adjustements and compensations should be made by the operators on the process variables in order to bring back these parameters to their theoretical values face to the general objectives and partial corrective results of the actions taken during operation.

This activity includes making up mental model of the process that allows the quick realization of the current process status, as well as the adoption of algorithmic procedures and the developement of new ones. It shall be noted that this movement is not individual, but part of a collective logic of room and field operators. In such a context, work organization becomes a dynamic task assignment (cf. TERSSAC, 1990).

Hypothesis

Since real activities are underestimated by force of disconsidering of the individual experience of operators, we estimate that this modernization intensifies the cognitive dimension of the workload, and, thus, possibilities on operators's assistence allowed by the new technologies are simply wasted.

To develop this general enunciation, we formulated partial hypothesis in which the following aspects were underestimated during the conception and implantation stages of the digital automation process:

(a) the precision effects on the display of parametres, which lead to the need for attention levels greater than those the analogical instrumentation requires;

(b) the operational value of personal and collective skills obtained by experience in disturbed periods and the difficulties introduced by the new device to reproduce some of them;

(c) the origin of control action not only in keyboard stimuli but also as a result of previous diagnosis.

(d) the interaction between control room and field inspection;

(e) the importance given to the adaptation of analogical control skills to the digital situation in training, excessively busy with computer handling principles.

RESULTS

We are dealing with a very complex and extense research field with both antropotechnological (WISNER, 1984) and macroergonomical considerations (BROWN Jr., 1991) in the sense that we have to do not only a search on the adequaty of digital automation to the organization but also consider some local specifications.

In this paper we present some considerations on five points: (i) work organization; (ii) software and hardware dimensions; (iii) the participatory aspects of development and implantation; (iv) the trainning; (v) the impactation of new system on operating activity.

The impact in work organization level

The concern with job compactation is present, since the comparison with refineries from other countries shows that brazilian plants have too may people working in similar shifts. This discussion has strongly emerged when new brazilain work laws established the six-hour workshifts.

The advantages of digital automation relate only to the technical and economical aspects. The labor computing is done according to this logic and under the mechanical productivity paradigm. As a result, we can see that the adoption of a minimum equipage criterium leads to difficulties in replacing operators in case of sickness and others causes of absences. The technical criterium adopted was the controled loops: 150 loops per keyboard operator and 30 loops per field operator. Unfortunaltely, we not able to make comparisons with others situations at the moment.

The new technology brings up sensible changes in communications (man-equipement interactions, circulation of reports and man-man communications) and we could see also new requirements for this element of the contents.

The introduction of CDE’s will surely reduce the amout of keyboard operators. In consequence remnant operators on CDE should be supervising more than one unit, as well as field operators should recover a more extensive area. They are the new multivalent operators.

The organization context will certainly be very different of the present organization, because this multivalent operator will need not only much different training but, also, will have to develop new ways of interacting with field operators, since the present **tête-a-tête** operational dialogues won’t happen, and they are absolutely necessary for solving disturbances on processing.

The configuration of the system: software annotations

We could annotate five software problems: the global visual evaluation loss, the expected software operator’s behaviour, the profusion of alarms, the screen customization and the tags’ codification.

The first difference between the analogical and the digital situation is the loss of possibility of an instantaneous vision of the unit, replaced by an action of search and/or construction of this information. If, on one hand this constructed and/or searched information is really richer and more precise than the visual diagnosis in analogical situations, on the other hand, these atributs are not always important. Therefore in most of the situations on won’t work better, only more…

The behaviour basis adopted is to transmit to the keyboard some kinds of alarms to warn operators that one or several linked variables have run out of their optimal bands, hoping that every is responded to propmtly. The real operators behaviour, however. is not the same that was taken in consideration to develop the program. Indeed, they don’t start their activities in consequence of alarms, but following actions induced by their own diagnosis or respecting collective decisions.

The third problem related to alarms results from the structure of the devices themselves. Since the CDD can control a great number of parameters and variables and also compute the reliable intervals of optimal processing, we can see a great number of alarms activated at the same time. This results in a sound pollution into the control room, so operators turn alarm beeps off. After a certain time, even screen indication are disconsidered as something unimportant and we can see a operation-without-alarms in fact.

It shall be noted that the customization means of the software screen presentation are not explored. This contradicts a general trend in software design and introduces standardization where it is not necessary.

The last observation refers to the changes in tags (codes of activable devices in the unit). These codes were all changed in the software design and this creates difficulties in the cognitive migration to the new system as well as it shows no consideration avec for the human cost to memorize the old tags. The philosophy adopted here seems to be the inverse of the precedent.

The configuration of the system: hardware annotations

Some hardware observation can also be made. The introduction was restricted to the change of control hardware, and did incluided the contruction of a new room. Therefore the old lighting—designed for an analogical configuration—is not adequated to CDD terminals and it produces reflection and darkness on the screen. As of consequence, we have the introduction of the classical postural problems in the CDD workplace—and operators feel it, because this is also a result of innovation!

To this observation we can add that keyboards as well as furniture do not meet the specifications proposed in the known ergonomical literature about work with VDU's.

On the participation of workers in development and implantation

As discussed above, job compactation was the main concern. In such conditions, participatory attitudes become more difficult, since a self-defensive context is created. The contradiction here is to involve operators on the discussion of relevant matters such as safety, operational stability and reliability but not to discuss job supression.

The participation was limitted to two operators of the studied unit. These men, as soon the new system was considered to be operational, were supposed to train the others. In fact they were obliged to exchange continuous shifts to help the other operators during the first start-up and for the following twenty days. Even now, two years after, not all operators declare themselves able to command the unit.

The evaluations about this participation program participatory aspects are not unanimous: The technical staff maintains that it has been a success whereas the operators group manifest a generalized insatisfaction. The result was an increase on the gap between two groups that should be ever more integradted.

Training

Two problems concerning training were diagnosed: opportunity and contents.

The first aspect is related to the general design of implantation strategy, that lost the opportunity of building skills at the same time in which the system was being developed.

The second one rests on the mainly preocupation on transmission of keyboard skills—easily acquired by young operators—and on the underestimation of the difficulties of translating old analogical situation skills to new tools—the major problem of the more experienced operators. This fact reinforced the dismissal expectations and was not useful to the training situation.

Negative impactations on operating activities

Some problems in operating activities are not supressed, namely the process variability and the sensors reliability.

Since technological innovation affects only control and not the actual process, not only the variability stimuli endure as they are aggraved, because the new system is more able to show them. The new sensors, on the other hand, are so unreliable as the old ones. Combined with the increased available information available this induces greater demands on the operators' activities.

Another problem may be added to these two: the number of situations in which multiple events occur (when quick diagnosis won't allow choices) is increased.

Positive impactations on operating activities

We would like to expose at least some positive aspects in this technological migration according to an ergonomical evaluation. These aspects were the feeling of control, some physical aspects related to the workload and feedback time.

The operators effectively feel more control possibilities with digital control. Several of the collected verbal protocols confirm this general feeling.

The reduction of displacements needed in disturbed times was welcomme. This holds true for displacements in the control room as well as in the field.

Finally, feedback time is much better in automated than in analogical mode, reducing one of the sources of anxiety, a real psychic stresspoint in the operating activity.

CONCLUSION

The aim of this paper wasn't to be a quantified argumentation about control room activity but only an overview, since this research goes on looking at the operation of some european refineries from where the brazilian modernization was cloned. However, it was possible to build a frame for others developments that we could exchange with other fields of research.

Our final conclusion is optimistic, since the number of calm periods is increasing, and this not a mere technical result. We can do better by taking into consideration some of the recommendations above, in the sense of creating actual operator assistance instead of the present cognitive work intensification as shown above.

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MACROERGONOMIC ASPECTS IN THE INTRODUCTION OF DIGITAL SYSTEMS IN THE PETROLEUM REFINING CONTROL ROOMS IN BRAZIL

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The modernization of control rooms in refineries in Brazil has been made within a perspective of high efficiency, reachable by the introduction of DDC's. If a DDC installation makes possible the increasing of the process stability, by introducing more precision in control actions, then the unit performance would be raised. This assumption could not be verified through the present analysis of the most complex petroleum plant in Brazil, since it has got this atribution just because of holding the greatest number of diversified units. Digital automation technology depends on adequate changes in the preceding work organization, and productivity gains are more efficiently obtained through a socio-technical job redesign than through the introduction of expensive but questionable technologies.

INTRODUCTION

This paper contains an evaluation of the technical performance of the Catalitic Cracking Unit, placed inside one of the oldest and most complex refinerie in Brazil. This unit used to work since 1964, making use of the pneumatic system of process control, until the period that went from October 16 to December 28, 1988, when a programmed break in the system took place. This break aimed to making the introduction of the DDC—Digital Distributed Control.

The present evaluation aims to identify the critical factors concerning the performance of the unit, specially focusing the influence of the DDC. The premise in this paper is based on the idea that, as the introduction of the DDC has led the process to become moresteady, this through a higher precision of control, then the performance of the unit would be liable to get better.

METHODOLOGY

The evaluation of the mentioned unit has been based upon the following items:

a) Some of the performance indexes, which were monthly collected by the process engineering division;

b) Interviews made with the refinerie technical staff (engineers and technicians), aiming to make a selection of the main points, and a consecutive analysis; the explanation about these points are one of ours analithical targets;

c) Data from 1988 and 1989, correspondent to 2 periods of 10 months, one previous and the other posterior to the installation of the DDC. Some data from 1987 and 1990 are going to be used as well, with the objective of enhancing the analithical periods of time. Concerning with the data from 1990, the main aim is verifying whether the results gotten in 1989 have been consolidated or not in 1990.

d) The performance of the two main products from the unit: the gasoline -GLN- and the Liquefied Petroleum Gas—GLP;

e) Tests of the Statistical Significance Level, in order to identify the degree of importance of the variations that have been verified.

RESULTS

The indicators taken into consideration for analysis follow:

Average monthly input processed in each day of operation

An average measure of the monthly input processed each day of operation showed that it has progressively decreased from 1987 to 1990. The reasons for this decrease in 1988 and 89 are going to be described later, in the indicator related to the “loss of production and its causes”. Besides these reasons, two other causes can illustrate a more complete explanation: the reduction of the quality of input, measured by the degree API-American Petroleum Institute- and the increase in the rigidity of convertion, which is obtained through the increase in the temperature of reaction inside the converter and mainly through the reduction of the combined input temperature with a consequent increase of the relation catalyser/oil.

When the input quality—gasoil—can be considered good, specially in terms of the mentioned degree API and the residue of carbon, the processed input can reach 7,500 cubic meters per day. In comparison to this potential value, the average monthly input processed each day of operation, in the year of 1987, was 14.52% below; in 1988, 15.91% below; in 1989, 18.93% below and finally, in 1990, it was 26.44% below the capacity input of the unit.

Analysing the period between 1987/88 and comparing it to the one between 1989/90, we can verify that the month when the unit processed the greatest input volume was June, 1988 (7,083 cubic meters per day), **previously to the DDC introduction**. On the other hand, the month of April, 1990 was the time one when it processed the least (4,853 cubic meters per day), hence **posterior to the innovation**.

Monthly programmed input.

The average value of the programmed input in the years of 1987, 88, 89 and 90, has consecutively decreased, similarly to what has happened to the average monthly input processed in each day of operation.

These values have also remained below the input capacity of the unit, which is 7,500 cubic meters per day, mainly due to the reduction of the input quality. In 1987, it was 10.44% below; in 1988, 11, 33% below; in 1989, 14.67% below and finally, in 1990, it was 23, 80% below the input capacity of the unit.

Loss of production and its causes

The loss of production that is going to be mentioned here is the difference between the annual programmed input and the effectively processed input referred to each year. In 1988, there was a total loss of 135, 105 cubic meters of gasoil while in 1989 we had a loss of 152, 027 cubic meters.

In 1988, the causes that contributed the most for the mentioned loss follow, in a decreasing sequence: problems with the equipments (32.0%), utilities (30.9%) and programming (12.1%); operational problems (11.8%); non-registered problems (11.6%) and finally, others in instrumentation (1.6%).

In 1989, after the DDC installation, the problems that contributed the most for losses were, in a decreasing sequence: trouble in the after-break adjustment (30.2%), in the equipment (27.2%) and in utilities (25.4%); operational problem (15.2%) and also others, due to mistakes in programming (2.0%).

Unit breaks

In 1987, the unit remained innative for the period of 15 days, missing the processing of 99,038 cubic meters of gasoil. In 1988, it had another break of 75 days, misssing the processing of 478, 489 cubic meters of gasoil. In 1989, the break lasted for 68 days and we had a processing loss of 412, 327 cubic meters of the mentioned substance and finally, in the year of 1990, there was a 41-day break which made the unit miss the input processing of other 233, 700 cubic meters.

In the period between the years of 1987/88, previous to the DDC installation, the unit has had a total of 17 days of non-programmed breaks, while in the one between 1989/90, it’s had other 109 days. Among these 109 days, 92 have been due to a strike of the operators which was taking place and also to an explosion of the CO boiler that happened.

During these days of break, the unit had a total processing missing of 110, 546 cubic meters of gasoil in the period between 1987/88, and of other 646, 027 cubic meters in the one between 1989/90.

Efficiency of the unit

The efficiency of the unit, measured through the volume percentual of gasoline- GLN and GLP, has progressively improved from 1988 to 1990. However, this improvement cannot be considered to be only due to the introduction of the DDC, considering the fact that from the 2nd. semester of 1990 onwards the operational aim of the unit has become the search for a maximization of the production of GLP, due to the crisis in the Persian Gulf.

The main difficulty that has been found in this analysis while inferring about the influence of the DDC is the existence of several other factors, at least as significative as the DDC, and that affect the performance of the unit as well. One of them was the knowledge of the working process of the mentioned unit, that has led its operators to maximize the production of GLP, in spite of the decrease in the input quality.

Specific energy expenditure

The specific energy expenditure in 1989 had a reduction of 4.3% in comparison to the year of 1988, not consolidating itself in 1990, when it returned to the same levels of 1988.

Specific expenditure of chemical products

An analysis of the data about the expenditure of 5 chemical products used in the cracking process has been made. Several results have been inferred from this analysis, as described in table 1.

Table 1. Specific expenditure of chemical products

Catalyser	In 1989, the specific consumption of catalysers has been reduced in 25.2%. This improvement cannot be ascribed merely to the use of the DDC, since the type of catalyser used has frequently changed during the years of 1988 and 1989. Then, in 1990, the consumption recovered its growth and the reduction decreased from 25.2% to 16.81%, in comparison to 1988.
Valentioxy	The specific consumption of Valentioxy showed a percentual reduction of 52.46% in 1989, then decreasing to 5.73% in 1990. Therefore, there wasn't a complete consolidation of the advantages obtained after the installation of the DDC.
Sode at 100%	The consumption of sode at 100% had a raise of 38.2% in 1989, if compared to 1988.
Merox 2	The consumption of this product had a consecutive raise of 44% and 68% in the years of 1989 an 90, in comparison to the previous year of 1988.
Die-Ethanol-Amine (DEA)	This product had a growth in its consumption of 7.49% in 1989, therefore following the raise of consumption of sode at 100% mentioned above.

Quality of the gasoline

The quality of the gasoline, which can be measured through an index called MON (a measurer of its octanage), had an improvement of 0.5% in 1989 and 0.86% in 1989, this mainly due to the reduction of the input quality, the increase of the rigidity of convertion and, finally, the raise of the ratio catalyser/oil.

CONCLUSION

The performance of the studied unit is shown at table 2. The general conclusions can be synthesized as follows:

(1) The enhancing of the stability of the unit, as an advantage of the DDC installation, couldn't be verified, since the processed volume after the DDC was smaller than the values performed without this technical innovation. This can be due to several factors, such as the reduced quality of the inputs, whatever it was not possible for us to evaluate the precise contribution of this interference.

(2) Just after the introduction of the DDC the processed volume was smaller than the volume performed at the year before. This shows that the continuity in plant operation is mainly dependent on other factors than on the control system itself. In fact, the problems with the instrumentation produced losses of only 1, 6% in '88 (with pneumatic control) and 7, 4% in '89, that is, 2,192 and 11,308 cubic meters of gasoil, respectivelly. It must be considered that the losses in 89 have been entirely due to errors in the keyboard operation. The software configuration was not able to verify these human errors, that often occur when a new operating skill is required.

Table 2. Performance variation of the studied unit
Annual and monthly parameter average

Performance parameter	Evaluated measure	Variations	
		Annual	Monthly
Processed Volume	Monthly average per daily processing	−	N.E.
Programmed Volume	Monthly value	−	
Production Loss	Monthly Prog. Input-Monthly Proc. Input	−	
Unit Breaks	Monthly innative days	−	
Efficiency of the unit	Percents of processed volumes of GLP and GLN	+	C
Energy Expenditure	600, 150 and 20 psig of the used steam, gas volume, and fuel oil	+	C
Chemical Products Consumption	Catalyser	+	A
	Valentioxy	+	A
	Sode at 100%	−	C
	Merox 2	−	C
	D-E-A	−	C
GLN quality	MON	+	B

Obs: + Qualitative indication of better performance
− Qualitative indication of worse performance

A Means that the monthly average collected in ’88 and ’89 have a difference which significance level is below 0.05; thus the variation must be considered

B The significance level obtained was placed between 0.05 and 0.10; thus we take the variation as significant,under the condition of having a posterior checking through the analysis of different data

C The significance level is greater than 0.10; the variation should not be considered.

(3) We have shown that the pneumatic control was not a determining factor of the production loss as a whole. During the ten months that preceded the introduction of the DDC, the production loss was equivalent to a processed volume of 135, 105 cubic meters. After this technical innovation, there was a loss of 152,027 cubic meters. Even if we discounted the 64,000 cubic meters related to the start-up period in January ’89, which came after a long production break needed to the DDC introduction, the total production loss would fall back to 87,627 cubic meters with a new profile of problem factors. It’s important to underline that, under these conditions, the problems in the equipment and utilities would continue to be the principal factors of operational discontinuity, and, the most important, **they would have increased their relative weight**. Table 3 summarizes these performance parameters.

Table 3 Production loss and DDC introduction in percentuals of processable volumes

Problem Sources	Before DDC	After DDC	Disc. Breaks
Equipments	32.0	27.2	47.2
Utilities	30.9	25.4	36.5
Operational	11.8	15.2	12.9
Programming	12.1	2.0	3.4
After-break adjustments	–	30.2	–

(4) The efficiency of the unit, measured by the GLN percentual volume, has increased in ’89 after the DDC introduction but this improvement was not verified in ’90, when this performance was worst than the values reached in ’88. The GLP percentual volume has increased in both years but the differences were not significant (α>10%).

(5) Among the principal factors related to the efficiency of the unit we can mention the acquired operational skills, as suggests another paper in this congress (DUARTE & VIDAL, 1992). One of the golden rules of the processing is: “the smaller the input quality is, the smaller the efficiency of the unit will be”. Our first evaluation in this sense does not come to corroborate this rule, as shown in table 4. In fact, it can be seen in this table that in several months the low input quality has not produced an efficiency fall, fact which used to happen frequently. This stability in the efficiency level cannot be merely ascribed to the DDC performance, but essentially to the operators’ action.

Table 4—Efficiency of the unit related to operators' field of action

Operators' field of action	F	M	A	M	J	J	A	S	O	Average
Temperature of Reaction	+	+	−	−	+	+	−	−	−	+
Comb. Input Temperature	+	−	+	−	−	−	−	−	−	−
Input quality	+	−	−	−	−	−	−	−	−	−
Efficiency of the unit	+	−	+	+	−	+	−	+	−	+

The operators can normally act upon the temperature of reaction to counterbalance the fall of the input quality. Therefore the observed positive variation was not enough to produce expected compensatory results. In reality, the operators have built another field parameter, the combined input temperature, which presents a significative negative variation. This parameter can be taken as the actual explanation for the considerable success obtained in the efficiency sustain, in spite of the mentioned fall in the input quality.

(6) The technical-economical performance of the unit showed to depend mostly upon other factors—such as the loss caused either by unexpected or by planned breaks—than upon the possible improvement that can be caused by the DDC in terms of the increase of the efficiency of the products, besides the decrease of the consumption of the raw material (gasoil) and chemical products, as well as the raise in the quality of the products.

(7) The most important conclusion obtained was that the previously used pneumatic control system **was not** a determining factor neither for losses, nor for the falls in the technical performance of the unit and in the quality of the products. In this manner, a hypothesis that could be worked on is the idea that the greatest advantages of the usage of the DDC, in contrast to the previously used pneumatic system, lie on:

* Growth of the reliability due to the decrease of the maintenance effort (cost)

* Growth of the accuracy in the data to be processed and in the information delivered to the final control instruments

* Possibility of having an off-limit growth in the control system as, for instance, an increase in the number of control networks

* Possibility of building an hierarchical control system, in which we are able to change regulatory control level to advanced and otimization control level

* Growth of the number of information obtained about the production process, through computer screens

* Growth of the ease of identification of defects in the control system, through self-diagnosis circuits

* Possibility of simple and immediate alteration of the philosophies of control and also of the man/machine interfaces

* Reduction of the purchasing and maintenance cost

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EMG ACTIVITY OF SELECTED COMPONENTS OF THE ERECTOR SPINAE AND MULTIFIDUS MUSCLES IN THE LUMBAR SPINE MEASURED USING WIRE ELECTRODES DURING THE PERFORMANCE OF LOADED AND UNLOADED TASKS.

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INTRODUCTION

A detailed understanding of lumbar spine kinematics should include an accurate description of the recruitment and activity patterns of the muscles known to control specific vertebra. Previous investigations have used either surface or wire electrodes to record EMG signals from specific muscles, but in most cases, the vertebral insertion of the particular muscle slip studied was not known (Andersson, 1975, Sihvonen, 1991, Wolf, 1991). Recent descriptions of the lumbar musculature (Macintosh, 1986, 1987) have clarified the structural anatomy. One previous paper uses a method exploiting this anatomic detail but for only one muscle group (Valencia, 1985). We have used this information to locate accurately both level-specific and muscle-specific insertion points for wire electrodes in the lumbar spine.

METHODS

The EMG activity of the iliocostalis (IC), longissimus (L) and multifidus (M) muscles in the lumbar region of the spine were measured using fine wire (51 µm diameter) electrode pairs. The muscles were sampled bilaterally at the level of L3 and unilaterally at the level of L4 to provide both side to side and level to level comparisons for each muscle group. For each subject, a total of nine muscles were sampled.

A technique for producing the wire electrodes with a defined geometry has been developed. The two key features of the electrodes were 1) the bare portions of the two wires of the bipolar electrode are maintained at a fixed distance from each other and 2) the bare portions are offset 5 mm from the tip of the inserting needle. This configuration allows an accurate and repeatable placement of the electrode with respect to the anatomical reference points.

The electrodes were placed as follows: 1) an array of small radiopaque lead balls was positioned over the lumbar region of the prone subject, 2) an anterior-posterior x-ray was obtained to define a relation between the lead balls and bony landmarks, 3) the posteriorly projected locations of the transverse and spinous processes were noted on skin surface, 4) a hypodermic needle (with wire electrode pair in place) was inserted vertically at the selected entry site, deep enough to contact bone, and 5) the needle was withdrawn leaving wire electrodes in place. The entry points were the tip of the L4 transverse process for the iliocostalis inserting on L3, the middle of the L4 transverse process for the L3 longissimus, and the upper edge of the lamina near the base of the L4 spinous process for the L3 multifidus.

Five volunteers were recruited, 4 male, 1 female, 33–50 years old (Mean=44.6), all without any back pain or disorders. Data were collected during a set of defined trunk motions while the subject was standing with a pelvic restraint system. This system provides a fixation at three points: Posteriorly at the sacrum and anteriorly at the left and right anterior superior iliac spinae. The angle of the trunk was monitored in two planes using a pair of analog inclinometers. The test tasks were as follows: 1) Flexion without additional load, 2) flexion with 20 lbs held to the upper chest with hands, 3) left lateral bend without additional load, 4) right lateral bend without additional load, 5) left lateral reach: a 10 lb left hand-held weight was moved laterally from near the left shoulder to the 90° arm-abducted position, 6) right lateral reach: symmetric to the left lateral reach, 7) a reference position which consisted of holding 20 lbs horizontally with straightened arms to the front of the body. The data were collected over a 6 to 8 second period which included the initial position, motion phase, and final position of each task. Each measurement was repeated once.

The EMG signal was amplified with skin mounted preamplifiers (Motion Control, Salt Lake City, Utah), sampled at 2048 Hz, A/D converted and stored digitally. The signals were post-processed by high pass filtering at 10Hz and computing a 50 ms RMS. The data was normalized using an averaged RMS obtained while the subject was in the reference position. For the purpose of this report we analyzed the normalized initial and final position values for each of the 6 tasks described above.

RESULTS

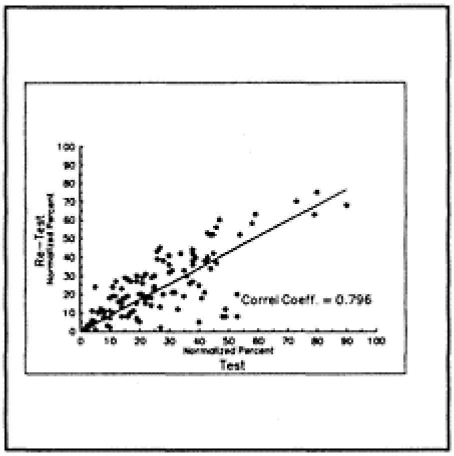

Fig 1. Test/Re-Test EMG signal data during the initial position portion of the test.

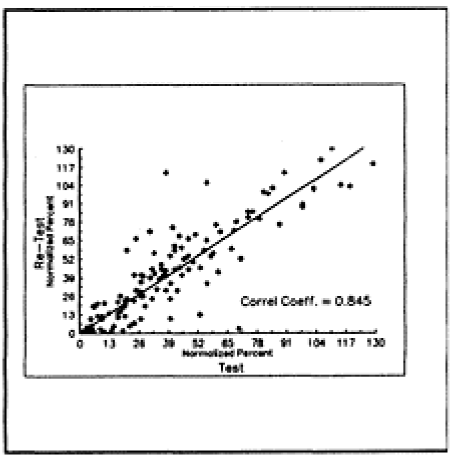

Fig 2. Test/Re-Test EMG signal data during the maximum effort portion of the test.

Repeatability of the EMG measurements were analyzed for both the initial and final position values. The correlation coefficient for the first and second measurements in the initial positions was 0.80 and in the final positions, 0.85 (Figs 1 and 2).

Flexion with and without additional load

The normalized EMG values for each muscle (IC, L, and M) attaching to L3, both left and right (Figures 3 and 4), and L4 left (Figures 5 and 6) are shown. The EMG activity increased in all of the muscles during the flexion effort and the average activity for each muscle was greater for the loaded effort. For each muscle there was side to side and level to level differences without any clear trend.

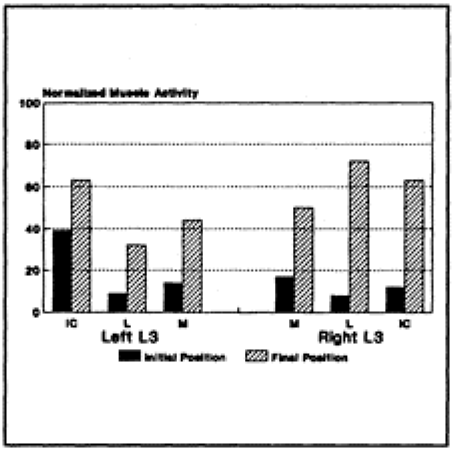

Fig 3. Trunk flexion without additional load.

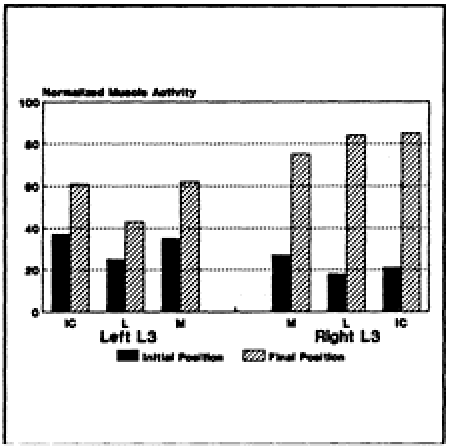

Fig 4. Trunk flexion with 20 lb additional load.

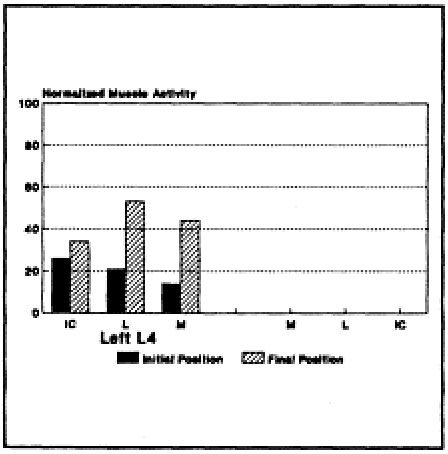

Fig 5. Trunk flexion without additional load.

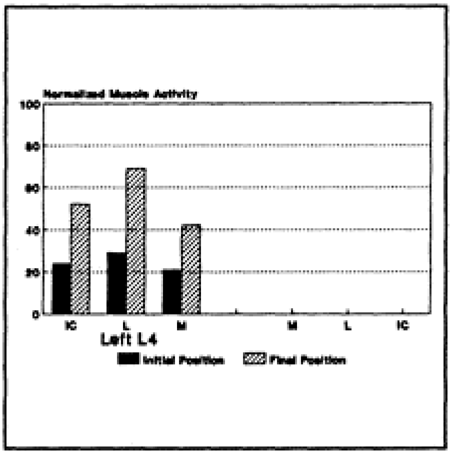

Fig 6. Trunk flexion with 20 lb additional load.

Lateral Bending

Similar data for lateral bending are shown in Figures 7 and 8. For all muscles except one, the average EMG activity increased during the motion and the activity was greater on the ipsilateral side where, for the more lateral muscles, the largest increase in activity was noted.

Horizontal abduction of the upper limb

The normalized EMG values for each muscle (IC, L, and M) attaching to L3, both left and right, are shown in Figures 9 and 10. The average EMG activity was much greater on the contralateral side in the final position. The more lateral muscles were more active on the contralateral side than medial muscles. At the L3 level ipsilaterally, the EMG activity decreased.

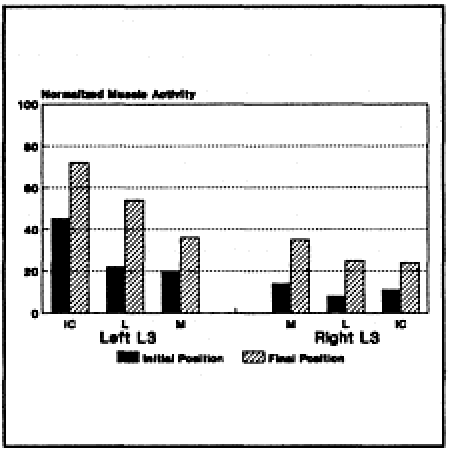

Fig 7. Lateral bend left without additional load.

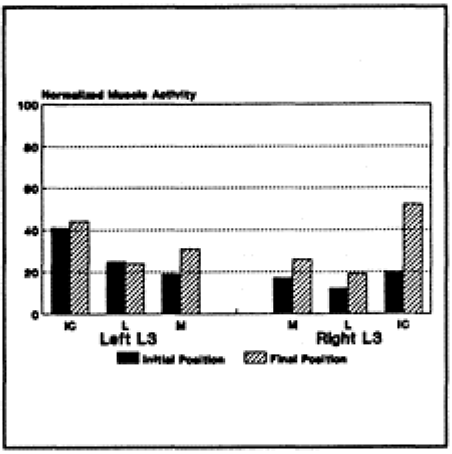

Fig 8. Lateral bend right without additional load.

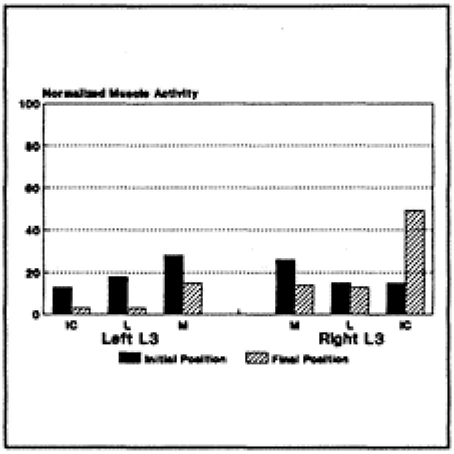

Fig 9. Left lateral reach with 10 lbs load.

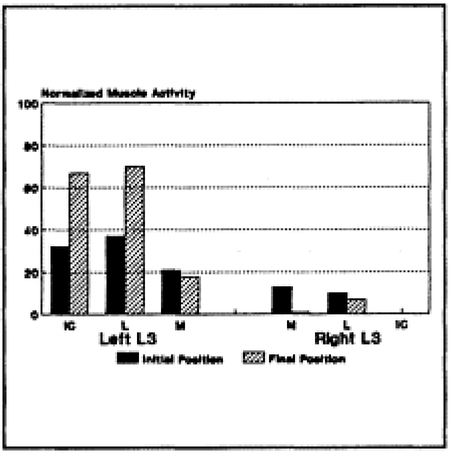

Fig 10. Right lateral reach with 10 lbs load.

DISCUSSION

This preliminary data suggest a differential activity both between vertebral levels and between sides and that the recruitment of the different muscle groups may vary considerably both within and across subjects without back pain. Some of this may be explained by a difference in the coupled motions at adjacent vertebral levels due to asymmetric but repeatable trunk motions.

In this study, the muscles examined during mediolateral activities behaved differently during static activities (Figures 9 and 10) than during dynamic activities (Figures 7 and 8). This suggests that it may not be appropriate to extrapolate conclusions about dynamic trunk muscle activities from studies of static EMG measures only.

The EMG activities of the different muscle groups during dynamic activities appear to be more evenly distributed than in static activities. This may be a factor in muscle fatigue development during different types of activities.

The level of detail provided by this method may yield information otherwise unobtainable concerning muscle behavior in people with certain types of spinal motion abnormalities or instabilities. From the ergonomic point of view, it may provide additional possibilities for occupational analysis.

CONCLUSIONS

1. A new method is described which allows placement of electrodes in various muscle slips all of which attach to a specific vertebra.
2. Test-retest correlation coefficients (same electrode placement) are encouragingly high (0.80 and 0.85).
3. Measured muscle activation patterns are intuitively reasonable in certain major respects, although intriguing and not-readily explained patterns also occur.
4. Further method development (including muscle-vertebrae relation validation) and normative data collection from normal and abnormal subjects are in progress.

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ACKNOWLEDGEMENTS

This work was conducted at the Vermont Rehabilitation Engineering Center and supported by a grant from the National Institute of Disability and Rehabilitation Research, USOE H133E80018.

APPENDIX

INTERNATIONAL FOUNDATION FOR INDUSTRIAL ERGONOMICS AND SAFETY RESEARCH

CONSTITUTION

BE IT KNOWN TO ALL THAT WE, THE UNDERSIGNED, HAVE VOLUNTARILY ASSOCIATED OURSELVES TOGETHER FOR THE PURPOSE OF FORMING A CORPORATION UNDER THE GENERAL NON-PROFIT CORPORATION LAW OF THE STATE OF OHIO, AND WE DO HEREBY CERTIFY:

ARTICLE 1— Name and Incorporation

1. The organization is the **International Foundation For Industrial Ergonomics And Safety Research (IFIESR),** hereafter referred to as the **FOUNDATION**.
2. The FOUNDATION is a non-profit organization incorporated in the State of Ohio, United States of America.

ARTICLE 2— Goals

The FOUNDATION goals are the advancement of industrial ergonomics and safety research by:

1. Organizing **Annual International Industrial Ergonomics and Safety Conferences** (the **FOUNDATION** shall be the primary sponsor),
2. Supporting **Advances in Industrial Ergonomics and Safety Volumes,**
3. Supporting research and application projects, world wide, either in cooperation with other government or private organizations or on its own initiative,
4. Cooperating with other organizations operating in this field,
5. Encouraging education in the field of industrial ergonomics and safety,
6. Exchanging information with other individuals and organizations,
7. Acting as information resource center in the field of industrial ergonomics and safety.
8. Publishing news letter or other material to promote communication among members on matters of common interest and importance.
9. Establishing research priorities in the field on the basis of current and future needs.

ARTICLE 3— Duration

The FOUNDATION is established for an indefinite period (perpetual existence).

ARTICLE 4

1. The FOUNDATION is a non-profit entity and is not authorized to issue shares of stock.
2. The FOUNDATION shall not have or exercise any power or authority, nor shall it directly or indirectly engage in any activity, that would prevent the FOUNDATION from qualifying and continuing to qualify as a corporation described in **Section 501 (c) (3)** of the **Internal Revenue Code of 1954,** as now in force or afterwards amended, contributions to which are deductible for Federal Income Tax purposes.
3. The FOUNDATION shall be non-political and shall not engage in any transaction defined as **prohibited** under **Section 503 of the Internal Revenue Code of 1954** as now in force or hereafter amended.
4. This FOUNDATION does not contemplate pecuniary gain or profit to the members thereof, and that the funds of the FOUNDATION, whether received by gift or income from membership dues or conferences, and regardless of the source thereof, shall be used exclusively for charitable, educational, and scientific purposes, objectives and activities of the FOUNDATION as the EXECUTIVE COUNCIL, hereafter referred to as the **EC,** may from time to time define and determine.
5. No compensation or payment shall ever be made to any member except as a reimbursement for actual expenditures made for this FOUNDATION.
6. Upon the termination, dissolution or winding up of this FOUNDATION in any manner or for any reason whatsoever, any assets remaining after paying or adequately providing for the debts and obligations of the FOUNDATION shall be donated to recognized educational institutions that have established tax exempt status as defined in **Section 501 (c)(3) of the Internal Revenue Code of 1954** as now in force or hereafter amended.

ARTICLE 5— Members

The FOUNDATION has members. The FOUNDATION can admit both individual members and institutional members, such as associations, research institutes, universities, industries, and the like, who/which are considered by the FOUNDATION to be representative in their country in the field of industrial ergonomics and safety. More than one member from each country can be admitted, provided they satisfy the admission criteria. The FOUNDATION decides on the admission of a member.

The FOUNDATION shall not invite individuals or institutions to join the FOUNDATION. Individuals or institutions shall, however, be admitted if they express an interest in the goals of the FOUNDATION and want to become a member.

ARTICLE 6— Member Responsibilities

The FOUNDATION members shall undertake the responsibility to promote, support, and advocate the goals of the FOUNDATION **(ARTICLE 2)** in every reasonable and feasible way.

ARTICLE 7— Termination of Membership

1. Membership can be terminated by a member by giving a written notice to the **Chairman or Secretary** of the **FOUNDATION**.
2. The FOUNDATION shall terminate membership if the member is no longer considered supporting the goals of the FOUNDATION or no longer actively represents the field of industrial ergonomics and safety.
3. Membership shall also be terminated by **February 15th** of the year if the **Treasurer** does not receive the annual membership dues for the year by **January 15th** of that year.

ARTICLE 8— Membership Dues

1. All individual members shall be charged membership dues annually. The minimum annual contribution shall be determined by the FOUNDATION.
2. All institutional members shall be charged membership dues annually. The minimum annual contribution shall be determined by the FOUNDATION.
3. Institutional members, as well as individual members, can, and are encouraged to, contribute more than the minimum amount set by the FOUNDATION.

ARTICLE 9— FOUNDATION Authority

1. The FOUNDATION members shall meet at least once every year. The **regular meeting** shall be held **during** the Annual International Industrial Ergonomics and Safety Conference in the country where the conference is held. The EC of the FOUNDATION can call additional FOUNDATION meetings at appropriate times and locations. The FOUNDATION members shall be convoked in **writing**.
2. The FOUNDATION can also make decisions without meeting, under the condition that relavant proposals have been sent to all FOUNDATION members, that all members have given their vote in **writing,** and that no member has objected to this mode of decision making.
3. The FOUNDATION is entitled to enter into agreements that help it meet its goals. The **Chairman** and **Secretary legally** and **otherwise,** represent the **FOUNDATION** in such matters. The general principles of the agreement are approved by the FOUNDATION members.

4. Each member of the FOUNDATION shall have one vote. The decision to admit an individual or an institution and the like shall be taken by simple majority of the registered members.

ARTICLE 10— Executive Council (EC)

1. The FOUNDATION shall have an EC, headed by its **Chairman**. The EC shall consist of the following:

    a. The **Founder** and the **four founding members,**
    b. The **General Editor (Founder)** of the **Advances in Industrial Ergonomics and Safety Volumes,**
    c. **Two persons** assigned by **institutional members** representing all institutional members,
    d. **Chairman, Secretary, and Treasurer** of the **FOUNDATION,**
    e. **Immediate past, present,** and **immediate future Chairmen** of Annual International Industrial Ergonomics And Safety Conferences (these members will assume responsibility at the end of the regular annual FOUNDATION meeting; each member shall enjoy a **three year term**).

2. Each EC member shall have **one vote**. Decisions shall be taken by **simple majority** of the members **present**.
3. EC members shall keep office in accordance with **this and section 5 of this Article**. **That does not** apply to members who come under **Section 1c and 1e of this article**. **Institutional representatives** (para 1 c) shall enjoy two year terms at the end of which institutional members shall ask the FOUNDATION to either reappoint them or furnish the FOUNDATION with the names of new representatives. The term of these representatives shall be from the end of a regular FOUNDATION meeting until the term end FOUNDATION meeting.
4. EC members described in **Section 1a and 1b of this article shall be permanent members and shall not be removed without the individual's approval**.
5. The FOUNDATION shall elect from its members, by simple majority, a **Chairman,** a **Secretary,** and a **Treasurer,** and such other persons the **FOUNDATION** thinks suitable. The **term** of these elected officials shall be three **years**. **No officer shall serve two consecutive terms.** He/she may be reelected to office after three years.
6. The **Chairman** and the **Secretary** are authorized to represent the **FOUNDATION** by law and otherwise.
7. The EC shall meet when so desired by a majority of its members.
8. The EC shall authorize expenditures only according to a written budget, approved by the FOUNDATION. Budgets must be approved every year at the regular FOUNDATION meeting. The Treasurer shall present the annual budget and the balance sheet to the members at the regular FOUNDATION meeting, in writing. Expenses not anticipated, but necessary, shall be approved by the FOUNDATION members either by a mail vote or at other scheduled meetings. The statement of need and amount shall be prepared by the Treasurer.

ARTICLE 11— Conference Locations

During each annual conference, the FOUNDATION members shall review the plans proposed by the EC and decide on the locations of future conferences. Locations of at least the next five conferences shall be finalized. The EC shall be entrusted with the task of appointing Conference Chairs. Any proposals submitted to the FOUNDATION, with the intent of hosting a future conference, shall also be reviewed at this time.

ARTICLE 12

The **FOUNDATION shall neither engage in organizing exhibits at its annual conferences nor shall it permit the conference chairmen to do so**. Individual exhibitors shall be permitted to exhibit **provided they independently make all the necessary arrangements and sign a contract with the conference chairman relieving him and the FOUNDATION of all liabilities. financial. legal, or other**. The exhibitors shall pay the FOUNDATION a nominal fee (to be determined by the EC) for the privilege of exhibiting during the duration of the conference.

ARTICLE 13— Conference Chair Authority

1. The Conference Chair shall formulate the Program and Organizing Committees and get the submissions reviewed.
2. He/she shall serve as **Editor** of **Advances in Industrial Ergonomics and Safety Volume** for **that year** and work in close association with the **General Editor** of the **Advances Series**.
3. The **Conference Chair** shall **determine** the registration fee.

ARTICLE 14— Finances

The financial support of the FOUNDATION shall consist of:

1. The membership dues described in **Article 7,**
2. Contributions from conferences (to be determined by the FOUNDATION),
3. Any legal acquisitions by the FOUNDATION, such as legacies, gifts, and interest income from investment of reserves.

ARTICLE 15

The FOUNDATION can decide to modify this constitution or to dissolve itself. Seventy-five percent of the registered votes are required to do so. **Article 10(4)** of this constitution, however, **shall neither be modified nor changed**.

ARTICLE 16— Proxy

In all FOUNDATION meetings, but not in those of EC, a member can replace himself/ herself by a written proxy.

ARTICLE 17

The FOUNDATION, from time to time, shall honor individuals who have done their utmost for its development or for the advancement of industrial ergonomics and safety.

ARTICLE 18— Bylaws

The FOUNDATION is entitled to lay down **Bylaws** with a view to the carrying into effect this constitution, and can modify the Bylaws. The Bylaws may not be in contravention of the constitution.

Finally, the founders declared that for the first time the FOUNDATION consists of the founder and the five founding members; this FOUNDATION shall expand in accordance with this constitution.

This instrument was executed in the month of March of the year Nineteen Hundred and Eighty-Six.

SIGNATURES:
Anil Mital (Founder & Chairman)

____

Biman Das (Founding Member & Secretary)

____

Waldemar Karwowski (Founding Member & Treasurer)

____

Shihab S.Asfour (Founding Member & Conference Chair)

____

Fereydoun Aghazadeh (Founding Member & Immediate Future Conference Chairman)

____

BYLAWS

1. The FOUNDATION shall have the following categories of members:

<u>(Full) Member</u>

1. Must possess appropriate academic/educational qualifications in the form of relevant advanced degrees at the M.S./Ph.D. level, approved by the EC.

2. Must have at least 5 years research experience in Industrial Ergonomics and Occupational Safety as evidenced by significant research publications, research reports, other research activities.
3. Shall have all the privileges of membership including participation in the IFIESR General Meeting.
4. Shall be a voting member and eligible for holding any office in the IFIESR.

Associate Member

1. A person who does not possess either the appropriate academic/ educational background and/or research experience in Industrial Ergonomics and Occupational Safety to become a (Full) Member (Items 1 and 2 under (Full) Member).
2. Shall have an active interest in Industrial Ergonomics and Occupational Safety research and the application of ergonomics research results in industry.
3. Shall have all the privileges of membership including participation in the IFIESR General Meeting.
4. Shall not be a voting member and ineligible to hold any offices in the IFIESR.

Student Member

1. Shall have provided documentary evidence of being enrolled as a fulltime graduate student.
2. Shall have an active interest in Industrial Ergonomics and Occupational Safety research and the application of ergonomics research results in industry.
3. Shall have all the privileges of membership including participation in the IFIESR General Meeting.
4. Shall not be a voting member and ineligible to hold any office in the IFIESR.

Honorary Member

1. Shall be a recipient of CERTIFICATE OF RECOGNITION and not a member of the FOUNDATION (in case the recipient is already a member, he/she shall retain his/her current membership status).
2. Shall have all the privileges and rights of a (Full) Member.
3. Shall not be required to pay any annual membership dues but is encouraged to do so on a voluntary basis.

2. The FOUNDATION shall have the following awards:

DISTINGUISHED ACHIEVEMENT AWARD (FOUNDATION's main award)
The recipient must:

1. be a member of the FOUNDATION.
2. have made significant contributions towards promoting the goals and objectives of the FOUNDATION over a sustained period of time (at least 5 years).
3. be prominent in the field of Industrial Ergonomics and Occupational Safety.

CERTIFICATE OF RECOGNITION

The recipient must:

1. be prominent in the field of Industrial Ergonomics and Occupational Safety.
2. deliver either the conference keynote address or the banquet address.

OUTSTANDING INDUSTRIAL ERGONOMICS APPLICATION AWARD

1. Only one award will be given each year. No award will be given if no worthy works are submitted.
2. The work must be presented at a Annual International Industrial Ergonomics and Safety Conference and submitted for inclusion in Advances in Industrial Ergonomics and Safety.
3. The recipient(s) must not belong to the research and development arm of the organization and his/her organization must be engaged in industrial activities.
4. The duration of recipient's employment at the organization where this work was done will not be a factor.
5. The award will be given for a specific "piece of work" instead of the "body of work" a person has done over years or a lifetime.
6. The award will include a citation and promotion in all Foundation literature (newsletter, Advances volumes, etc.).

Nomination Guidelines

1. Any Foundation member can nominate a individual(s) for this award.
2. It is the responsibility of the nominator to furnish all supporting evidence (patent information, photographs, reports, internal citations, relevance of the work, cost savings, supporting letters, etc.). The supporting documents (10 copies) should permit complete and unbiased evaluation of the work.
3. Nomination of a person(s) is understood to mean that the nominee(s) has agreed to all the terms and conditions described in the award guidelines. It is the responsibility of the nominator to inform the nominee of the award guidelines.
4. Nominations must be received by November 1 to be considered for the award to be given in the following year.

3. The Newsletter Editor shall be a member of EC.
4. The FOUNDATION shall have a President-Elect. His/her term in the office will be one year following which s/he will take over as President for one year. The President-Elect shall be a member of EC.
5. The EC can invite observers to attend its meetings for the purpose of reporting progress on specific items.
6. The Foundation shall have a nomination Committee:

   1. The Nominating Committee shall comprise of the President-Elect, the Secretary, and one member of the Foundation who is not a member of EC (term 2 years), to assist the President-Elect in conducting the election. The President-Elect shall have the responsibility for conducting the election of new officers for EC (written ballot).

2. A Call for Nominations shall be sent to all Foundation members in January. The Call will have information on which nominee is not eligible, and on the rules of the election procedure. Nominations made/received after February 15 will not be considered. Candidates will be asked to prepare a 1-page biographical sketch for distribution with the ballot Ballots shall be sent to all Members and Honorary members by mail in the first week of March. All ballots, returned to the President-Elect by April 30, shall be counted.

7. The Foundation shall have an Award Committee:

   1. The Award Committee shall comprise of the President-Elect, Chairperson of the Conference, and a member of the Foundation who is not a member of EC. The term of this last member shall be two years.
   2. All nominations for awards shall be given to the Award Committe in writing no later than November 1, and must be signed by at least one member of the Foundation. Each member can nominate only one person for a single award and nominations shall be valid only for one election (nominations can be renewed for the next year).
   3. From the nominees, the Award Committee shall select the person(s) to receive each Award.
   4. Members of the Award Committee will not be eligible to make nominations during their term.

8. All day-to-day business of the Foundation will conducted by the President, the President-Elect, the Secretary, and the Treasurer.

AMENDMENTS (CHANGES UNDERLINED)

1. The title Chairman, used in Articles 9(3), 10(1) line 1, 10(1)(d), 10(5), and 10(6) for the head of the FOUNDATION shall be replaced by the word President.
2. Article 10(5)—The FOUNDATION shall elect from its members, by simple majority, a President-Elect, a Secretary, a Treasurer, and a Newsletter Editor, and such other persons the FOUNDATION thinks suitable. The term of the President-Elect shall be one year. following which his/her term as President shall be one year. The term of the Secretary and the Treasurer shall be two years. The Newsletter Editor shall have a one year. renewable. term. No officer, other than the Newsletter Editor, shall serve two consecutive terms. He/she may be reelected to office after two years.
3. Article 9(2)—The FOUNDATION can also make decisions without meeting, under the condition that relevant proposals have been sent to all FOUNDATION members, that all Members and Honorary Members have given the opportunity to give their vote in writing.
4. Article 9(4)—Each Member and Honorary Member of the FOUNDATION shall have one vote. The decision to admit an individual or an institution and the like shall be taken by the officers responsible for the day-to-day business of the FOUNDATION.

DISTINGUISHED ACHIEVEMENT AWARD

None to Date

CERTIFICATE OF RECOGNITION

1987 M.M.AYOUB

1988 K.H.E.KROEMER
1989 S.A.KONZ
1990 W.ROHMERT
1991 W.T.SINGLETON
1992 E.N.CORLETT

OUTSTANDING INDUSTRIAL ERGONOMICS APPLICATION AWARD

None to Date

AUTHOR’S INDEX

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