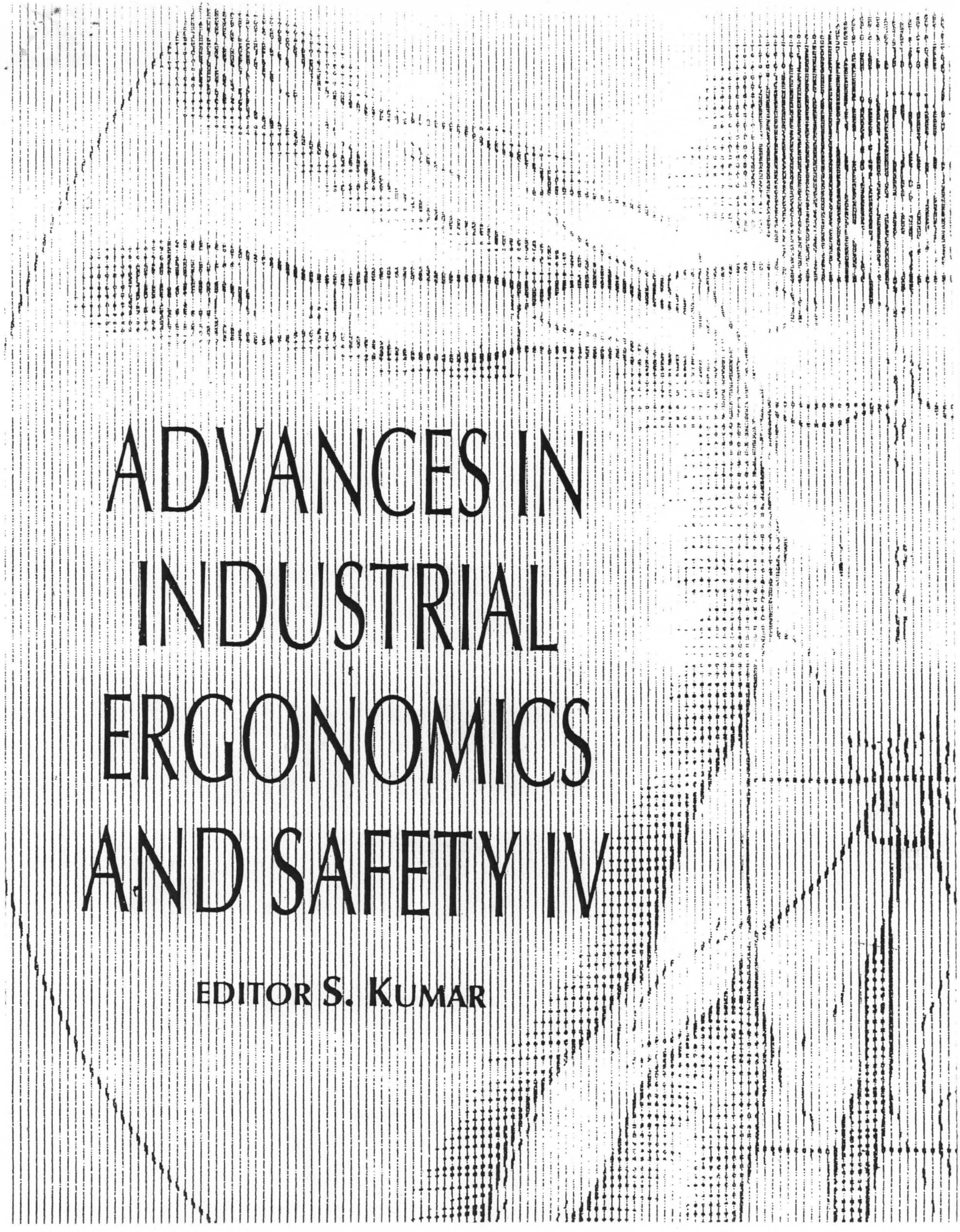

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PRELIMINARY TEST AND EVALUATION OF DATAHAND™ A KEYBOARD ALTERNATIVE DESIGNED TO PREVENT MUSCULOSKELETAL DISORDERS AND TO IMPROVE PERFORMANCE

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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 trade-offs 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.

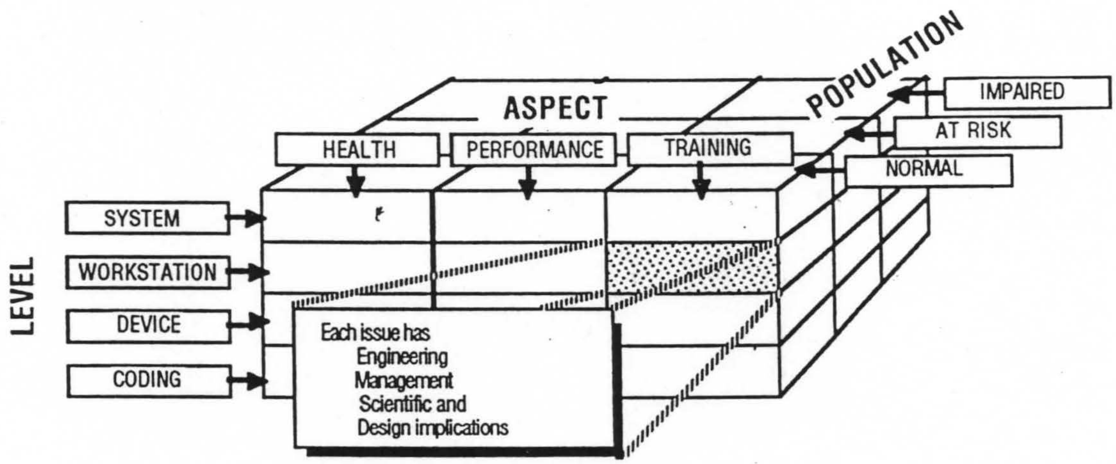

Figure 1. Evaluation space

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.

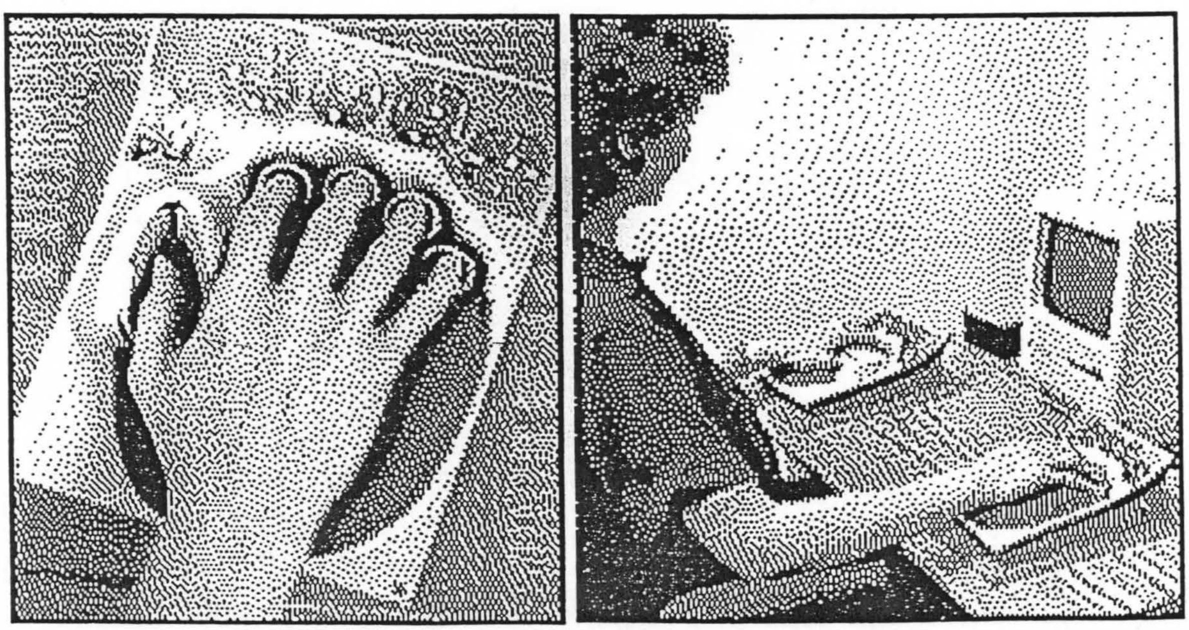

Figure 2. DATAHAND™, an alternative to the keyboard

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

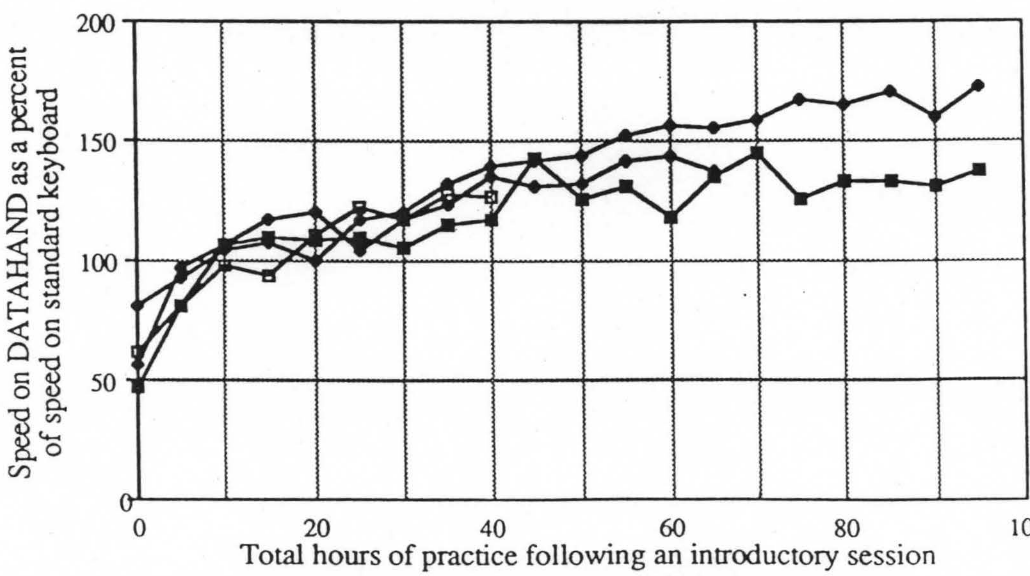

Figure 3. Performance with DATAHAND as a function of practice

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

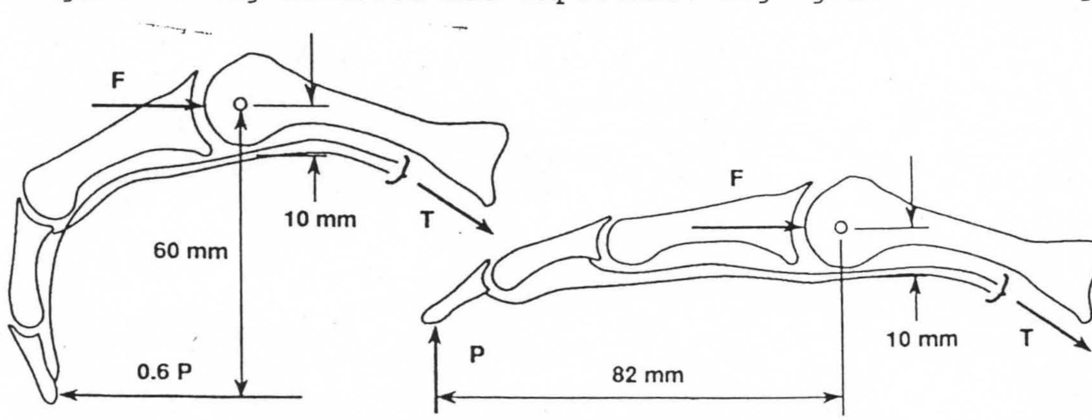

Figure 4. Finger working position for DATAHAND and the keyboard

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 .6P. The joint force F is then calculated as 8.2P for the keyboard, and only 3P 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.

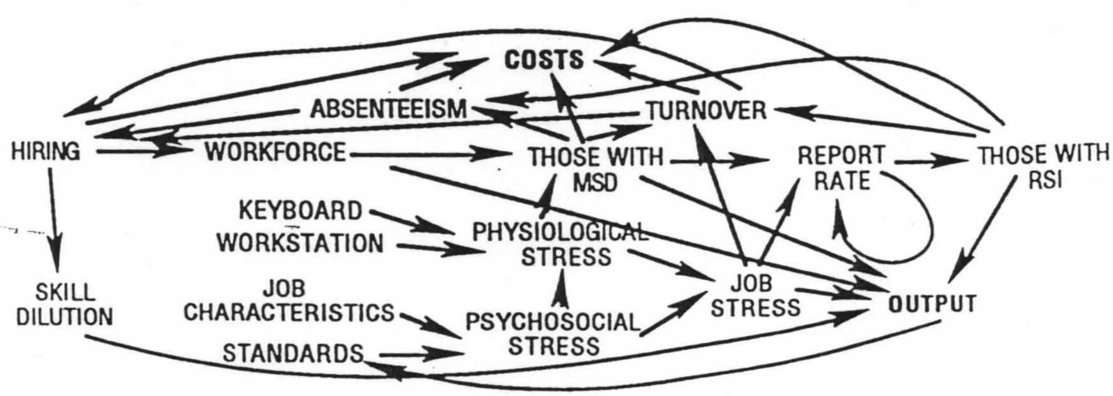

Figure 5. System level causal interactions

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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