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EFFECT OF VDT MOUSE DESIGN ON TASK AND MUSCULOSKELETAL PERFORMANCE

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Criteria for the design of a mouse input device are presented in which potential biomechanical constraints related to the skeletal geometry of the forearm and wrist are addressed. A methodology is described for evaluating this new mouse design on the basis of both task performance and motor coordination during a period of skill acquisition among both highly skilled and novice occupational mouse users. The synchronization of both task and musculoskeletal performance outcomes permits an integrated method for evaluating computer input devices in general in a way that addresses both health and productivity issues.

INTRODUCTION

Epidemiological and experimental evidence concerning the use of video display terminals (VDTs) suggests that certain biomechanical requirements for VDT mouse operation are potential risk factors for cumulative trauma disorder (CTD) of the forearm and wrist. These biomechanical requirements are fixed, maximum forearm pronation, fixed wrist extension, fixed wrist ulnar deviation, use of relatively limited wrist radial-ulnar deviation for task execution, repetitive keying force, mechanical pressure on the ventral aspect of the forearm and wrist by the work surface, and use of only one upper extremity for task execution (e.g., Armstrong *et al*, 1994; Attwood, 1989; Hünting *et al*, 1981; Karlqvist *et al*, 1994; Kucera *et al*, 1989; Läubli, 1987; Martin *et al*, 1994; Rempel *et al*, 1994; Zipp *et al*, 1983). These constraints may also adversely affect ultimate skill proficiency as well as skill acquisition among both highly skilled and novice mouse users, because they limit the number of musculoskeletal degrees of freedom available for the performance of mouse input tasks (Bizzi *et al*, 1991; van Emmerick, 1992; Vereijken *et al*, 1992). No commercially available mouse design eliminates all of these constraints, most notably fixed, maximum forearm pronation in conjunction with fixed wrist extension and ulnar deviation. Furthermore, studies of user proficiency with mouse devices have not adequately assessed skill acquisition as it relates to the musculoskeletal system.

This study has three objectives: 1) to evaluate the effects of mouse use on the forearm and wrist among occupational groups in a laboratory setting using pertinent musculoskeletal and skill proficiency outcome measures; 2) to design an alternative mouse that reduces the risk of forearm and wrist CTD and to determine the effect of mouse design on musculoskeletal outcome measures; and 3) to determine the effect of mouse design on skill acquisition and proficiency among both highly skilled and novice occupational mouse users.

The hypotheses to be tested in this study are: 1) use of a standard mouse will be associated with biomechanical constraints and tissue risks associated with the development of forearm and wrist CTD: namely, fixed, maximum forearm pronation, fixed wrist extension, fixed wrist ulnar deviation, use of wrist radial-ulnar deviation for mouse operation, and continuous, submaximal electromyographic (EMG) activity by the forearm pronators and wrist extensors and ulnar deviators; 2) the newly designed mouse, by virtue of its geometry, will reduce the biomechanical constraints and tissue risks found with the use of the standard mouse; 3) novice mouse users will demonstrate an increased rate of skill acquisition with the newly designed mouse as compared with the standard mouse as indicated by the improvement over time in the skill level, speed, accuracy, and motor coordination pattern with which an interactive mouse input task is performed; and 4) both highly skilled and novice mouse users will demonstrate better ultimate skill with the newly designed mouse as compared to the standard mouse as indicated by the ultimate skill level, speed, accuracy, and motor coordination pattern with which an interactive mouse input task is performed.

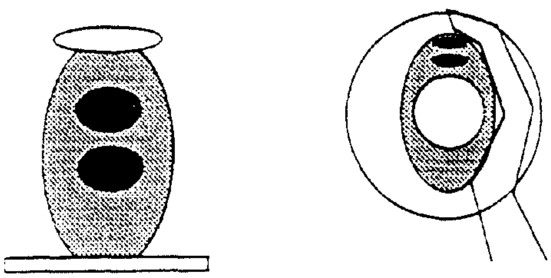
MOUSE DESIGN CRITERIA

There are few studies in either the epidemiological or the experimental literature that examine the long term musculoskeletal effects of mouse use. Attwood (1989) found that Computer Aided Design and Drafting operators reported higher discomfort levels in the dominant upper extremity (i.e. that used for operation of the mouse) than comparison groups, especially at the end of a working shift. Outcomes consisted of subjective reports of pain and discomfort and were obtained over a limited time period. In a brief case report, Norman (1991) described two cases of occupationally related flexor tendinitis of the second and third digits in individuals who used a mouse as a primary VDT input device.

A number of ergonomically designed mouse devices are commercially available. However, scientific evidence supporting their effectiveness in alleviating risk for musculoskeletal injury is not readily available due to the sparse literature in this area. Therefore, it is difficult to evaluate such devices. None the less, it is evident from simple inspection which risk factors have been decreased by these designs. Fixed wrist extension has been generally reduced in many designs by the introduction of a curved top housing. However, most mouse designs still require extreme forearm pronation for operation.

In light of what is known about the musculoskeletal constraints that contribute to forearm and wrist CTD among keyboard operators and other industrial populations, it is clear that the currently available ergonomic mouse designs do not completely address such risks, e.g., fixed, maximum forearm pronation in conjunction with fixed wrist extension and ulnar deviation resulting in mechanical pressure on the ventral aspect of the forearm and wrist by the working surface.

For the purposes of this study, a new mouse housing geometry was developed according to the following design criteria: 1) the forearm will be maintained in a position of neutral pronation-supination during mouse operation; 2) the wrist will be maintained in a position of neutral radial-ulnar deviation during mouse operation; 3) excursions of the mouse on the work surface will be performed by wrist flexion-extension; and 4) the design will be appropriate for either right or left handed use.



A B

FIGURE 1: Schematic drawing of the new mouse design prototype as viewed from behind (A) and above showing upper extremity orientation (B).

The resulting prototype, depicted schematically in Figure 1, has a housing that conforms to the contours of the palm of the hand, a posterior face upon which the thenar eminence rests, a flared top with a constricted groove for grasping with the thumb and fingers, and large, curved buttons centered at the back of the device for operation with tactile feedback. The ulnar aspect of the hand rests on the oval base.

METHODOLOGY FOR THE ASSESSMENT OF SKILLED MOUSE PERFORMANCE

Another important consideration in the experimental study of occupational mouse use and design is user proficiency. Proficiency is related to the level of skill (or the performance of an observable behavior) which a user demonstrates when performing goal-directed tasks (Magill, 1989). In the case of the mouse, such tasks might include the speed and accuracy with which the screen cursor is displaced and key functions executed. Such skills will have a direct bearing on work productivity and should be considered in the study of occupational mouse users. Mouse design, in addition to its potential influence on the development of CTD, may also affect user proficiency.

Several studies have investigated user proficiency with mouse and other input devices. In summary, the mouse is faster and more accurate in text selection and pointing functions than the isometric joystick, touch stylus, finger touch, and pushbutton pointing devices (Card *et al.* 1978; Epps, 1986; Loricchio, 1992; Mack *et al*, 1991). Loricchio observed further that, even though they may make more errors when using the mouse, novice users prefer the mouse over other pointing devices. To a greater or lesser extent, these studies investigated the nature of skill acquisition in the development of mouse user proficiency, but not with respect to musculoskeletal or motor coordination outcomes. Such outcomes have been largely unexplored in the experimental literature concerning mouse use.

In a musculoskeletal context, one of the factors known to affect skill proficiency is the constraints imposed by the environment in which a performer is required to function (Newell *et al.* 1989). This has implications for both the acquisition of new skills as well as the upper limits imposed on ultimate skill in a variety of motor tasks. For example, during the early stages of motor skill acquisition, individuals tend to "freeze" musculoskeletal degrees of freedom, which means that the joints comprising the musculoskeletal linkage involved in task execution are strongly linearly coupled with respect to their angular excursions (Bizzi *et al*, 1991; van Emmerick, 1992; Vereijken *et al*, 1992). This stiffening strategy is accomplished by the simultaneous contraction of agonist and antagonist muscles about the joints being controlled. As the individual becomes more skilled, this linear coupling relaxes, and the joints interact in a freer manner that is associated with a more rhythmic, alternating pattern of muscular activity.

If the constraints of the environment impose certain requirements for muscle activity, motor skill acquisition may become more physically demanding and ultimate skill attainment may be curtailed. For example, use of the mouse may require constant activity of the forearm pronators and the wrist extensors and ulnar deviators to maintain the fixed forearm and wrist positions needed to grasp the device. The constant activity in these muscle groups for periods as short as one hour may lead to muscle fatigue, especially among novice users.

In this study, a methodology was designed to measure performance during mouse use both in terms of speed and accuracy and musculoskeletal coordination. For this purpose, a series of timed targeting tasks of increasing difficulty were devised using LabVIEW® for Windows (National Instruments).

Two types of tasks were developed: an excursion-and-click task, in which subjects sequentially position the cursor over eight targets and click with the index finger function key; and a click-and-drag task, in which subjects sequentially select eight targets with the index finger function key and, while maintaining key depression, drag the targets to a circular receptacle. Difficulty level is determined by target diameter in the excursion-and-click task. The three target diameters increase in difficulty from approximately 22 mm to 12 mm to 5 mm. Difficulty level is determined by receptacle size in the click-and-drag task. The three receptacle diameters increase in difficulty from approximately 25 mm to 15 mm to 5 mm. Subjects are given 10 seconds to successfully complete the excursion-and-click task and 20 seconds to complete the click-and-drag task. Three versions of each level of difficulty are presented to the subject in succession with the targets arranged randomly on the screen. The time and location of each function key input is recorded automatically for later calculation of speed and accuracy. In addition, the screen (x,y) coordinates of the target paths during the click-and-drag task are recorded at 55 ms intervals.

Joint motions about the wrist (flexion-extension and radial-ulnar deviation), forearm (pronation-supination) and elbow (flexion-extension) are monitored using a Polhemus 3Space™ Tracker (McDonnell-Douglas) at a sampling rate of 20 Hz. In addition, EMG activity of eight muscles are monitored at 1000 Hz using surface electrodes: biceps brachii, pronator teres, pronator quadratus, flexor carpi radialis, flexor carpi ulnaris, extensors carpi radialis, extensor carpi ulnaris, and extensor digitorum communis. The data sampled from the targeting tasks, 3Space™ Tracker and EMG systems are synchronized.

According to preliminary work, approximately 60 subjects will be required to differentiate between skilled and novice mouse users with respect to speed and accuracy performance measures. Therefore, healthy occupational VDT users will be selected according to their prior experience using the mouse (30 skilled and 30 novice). A repeated measures design will be followed in which subjects return on 5 separate occasions for testing according to the regimen outlined in Table 1. This schedule will ensure adequate practice while controlling for fatigue effects associated with prolonged mouse use and will best reflect skill transfer, or the extent to which the learner has truly incorporated the new motor behavior associated with mouse use.

Two mouse devices will be tested in each session: the new, forearm neutral, design and a standard, forearm pronated, design. The order in which the mouse devices are tested will be randomized for each subject at the first test session and that order will be maintained throughout the remainder of the test sessions. For all subjects, the excursion-and-click task will be tested first followed by the click-and-drag task. For both task types, testing will proceed from the easiest to the most difficult level. In this manner, subjects will always progress through the procedure in an easy to difficult sequence.

TABLE 1: Schedule of testing sessions for skilled and novice user groups. The full procedure (target tasks, motion, and EMG) will be performed on three of the five testing sessions. For the remaining two sessions, only the target task performance will be tested. This design will minimize the time commitment required of the subjects.

Test	Wks	PROCEDURE	
		Part	Full
1	0		X
2	1-1.5	X	
3	2-2.5		X
4	3-3.5	X	
5	4-4.5		X

DATA ANALYSIS

To address the hypothesis concerning the role of environmental constraints in limiting the ultimate achievement of skilled mouse use, speed and accuracy measures for the targeting tasks will be compared through a nested two-way ANOVA with the factors user experience (skilled and novice) and mouse type (standard and new design). The nested factors will be difficulty level (three levels) and performance outcome (speed and accuracy). To address the hypothesis concerning the effect of initial user experience (skilled or novice) and of mouse design on skill acquisition, the slopes of the mean performance curves for the outcomes of speed and accuracy will be compared using ANCOVA. To address the hypothesis concerning the presence of constrained forearm and wrist postures and the use of limited range of joint motions for mouse operation, average joint angles and angular excursion amplitudes will be compared by paired samples Student's t-tests across mouse design. Analysis of the motion and EMG data with regard to motor coordination patterns may include the comparison of angle-angle diagrams of adjacent joints in the upper extremity, the presence of muscular concontraction, and the onset of agonist and antagonist muscle activation during wrist movements.

SUMMARY

This study will add to the growing body of literature information concerning the extent to which risk factors for the development of forearm and wrist CTD exist among occupational mouse users. It will evaluate a new mouse designed specifically to reduce these risk factors. It will explore the influence of the environmental constraints imposed by mouse design on the acquisition of a complex functional task. Finally, it will investigate the effectiveness of an ergonomic solution intended to balance the problems of worker risk and the upper limits to skilled mouse performance. Such knowledge will foster our approach to the prevention of occupationally related CTD in computerized offices and will enhance our understanding of the limits to skill acquisition and proficiency imposed by constraints in the human-machine interface.

ACKNOWLEDGEMENTS

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SUMMARY OF RESULTS

Subjects: 3 "skilled" (2 M, 35 & 46 y; 1 F, 45 y) and 2 "novice" (1 M, 30 y; 1 F, 37 y)

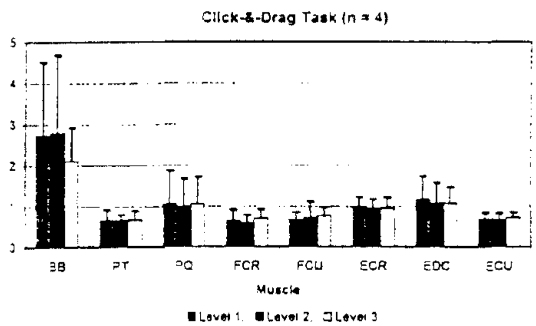
Results:

Speed & Accuracy: Two-way ANOVA showed differences in Speed and Accuracy by mouse type (less with "new" design, $p < 0.001$) and by level of task difficulty (decreased with increasing level of difficulty, $p < 0.001$), E-&-C task.

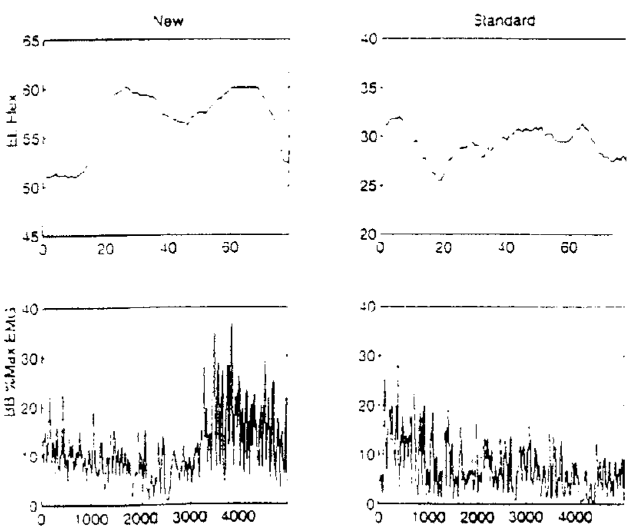
Mean Joint Angles: Calculated over 10 sec trial period for lowest level of difficulty of E-&-C (n=2 "skilled", 1 "novice").

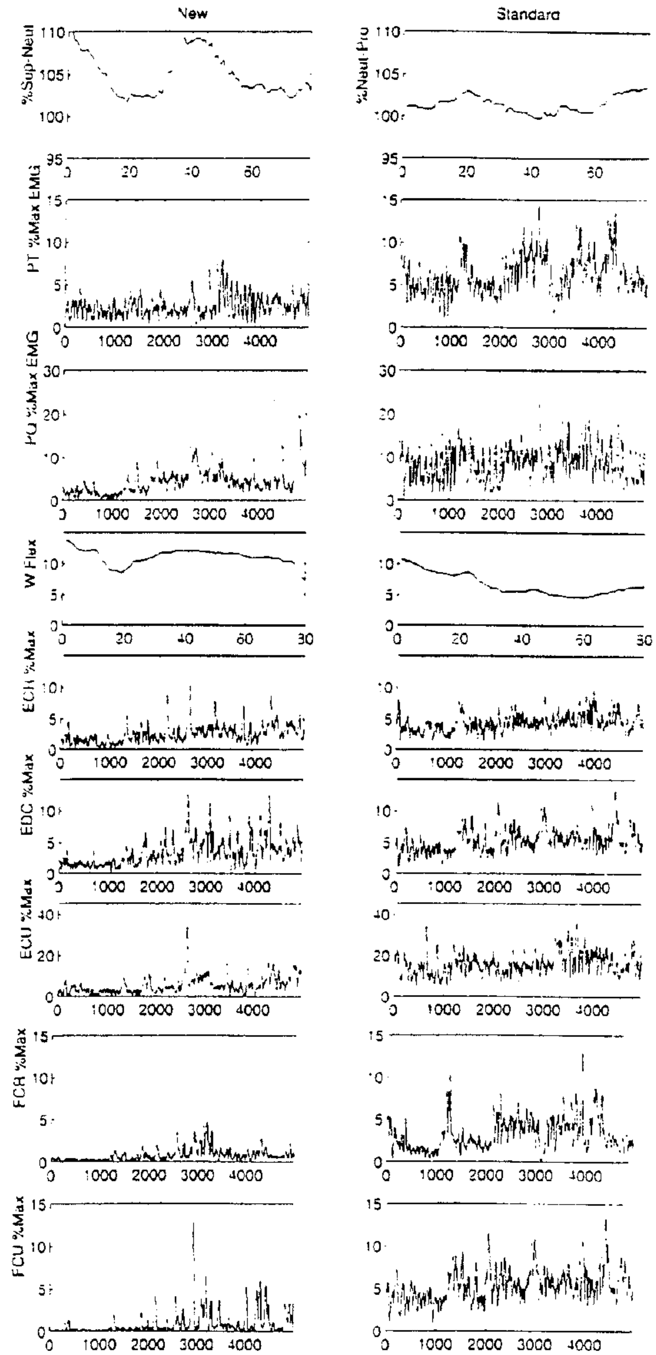
	NEW	STANDARD
Elbow Flexion (deg)	56 ± 6.4	46 ± 19.2
Forearm P (%N-P), S (%S-N)	107 ± 25.5% S-N	34 ± 17.1% N-P
Wrist Extension (deg)	7 ± 16.1	15 ± 20.8
Wrist Ulnar Deviation (deg)	4 ± 1.2	13 ± 7.6

Average RMS EMG Ratios: Ratios of "new"/"standard" design by level of difficulty, 3 "skilled" & 1 "novice".



Motion and Normalized EMG: One "skilled" user for corresponding E-&-C trials at lowest level of difficulty.





Conclusions: 1) "Standard" design associated with risks for CTD; 2) "New" design reduces some risks; 3) Speed and accuracy are consistent with skill of "skilled" users; 4) Novice users of the "new" design did not show relatively high activation of forearm muscules, which suggests that risk reduction counteracts motor skill acquisition strategies; 5) Activation of the biceps higher with the "new" design, which suggests that proximal activation is required for its operation.