Presented at the 1999 Meeting of the
Human Factors and Ergonomics Society (HFES)
Houston, Texas

PERCEIVED MUSCULOSKELETAL LOADING DURING USE OF A FORCE-FEEDBACK COMPUTER MOUSE

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Abstract:

With 30 to 80 percent of computer work involving the use of a pointing device, engineers are constantly exploring new and better interface designs. The introduction of a force-feedback mouse, which provides high fidelity tactile cues via force output, may represent such a long-awaited technological breakthrough. However, force may also be a risk factor for musculoskeletal disorders of the upper extremity, especially those associated with the use of computer input devices. For a point-and-click task, we hypothesize that both the performance and the self-reported task difficulty and comfort (i.e. pain and discomfort) improve with the application of an attractive basin force field (gravity sink like effect) around the target in comparison to a typical mouse with no force field. Fifteen adult subjects performed a point-and-click task 520 times with and without an attractive force basin around the target. The movements varied in direction and distance, and the order of presentation was randomized. Movement times were significantly shorter ($p < 0.0001$) with the attractive force basin than without it. Perceived user discomfort and pain as measured through a questionnaire were also smaller with the attractive basin than with none. For the given task, the results suggest that the use of an attractive force-feedback basin may reduce the musculoskeletal loading during computer mouse use.

INTRODUCTION

With the advent of graphical user interfaces (GUIs), work on video display terminals increasingly involves a pointing input device, which is used in between 30 to 80 percent of computer activity (Johnson et al., 1993). Along with this increase, there has been an increase in the incidence of work-related musculoskeletal disorders in the office workplace (BLS, 1998). These disorders have been linked to prolonged work on video display terminals (e.g. Faucett and Rempel, 1996 and Berlqvist, 1995), although the injury mechanisms are not well understood. Along with motion, posture and vibration, the *force* exerted during a repetitive task is a risk factor (Silverstein et al., 1986, Armstrong et al., 1995).

Development of alternative pointing devices reported in the literature has focused on altering the musculoskeletal loading by changing the posture (e.g. Barr, 1996) or by changing the required muscle functionality with an alternative device (e.g. the trackball, Beaton et al., 1987). The parameters studied in these papers range from measuring muscle activity via electromyography, to measuring posture of the whole arm. Unlike the force-displacement characteristics of the computer key switch, these technologies provide the operator with no tactile information that might aid his/her in completing the given task.

Force-feedback or haptic devices provide tactile cues through the display of forces using motors and linkages with the aim of increasing human operator performance in both virtual and telerobotic environments. For telerobotic applications, the forces encountered by the remote manipulator are measured and re-displayed locally for the human operator. This valuable source of feedback aids the human controller in determining the actual state of the robot manipulandum. In the virtual environment, a model of the environment displays tactile cues such as simple bumps or attractive force-field basins around target icons, all via the haptic interface device. Several studies have considered the implementation of tactile feedback in computer pointing devices, particularly those used for interacting with virtual desktop environments. Akamatsu et al. (1994) examined a multimodal mouse, which varied friction during movements and displayed a vibration when crossing boundaries of interest. Both Hasser et al. (1998) and Eberhardt et al. (1997) examined the effects of attractive basins around target icons on the performance of a point-and-click task. For most of these studies, the time to complete a given task was reduced with the display of tactile cues. However, the musculoskeletal effect of using force-displaying technology in computer peripherals is still unknown.

The goal of this study is to investigate the application of a new technology, the display of tactile cues through a force-feedback haptic device. This study evaluates the perceived musculoskeletal loading during use of a force-feedback mouse via a psychophysical questionnaire. We have found that performance improves with the addition of force, so we hypothesize that perceived loading on the user remains constant or even decreases with the display of an attractive basin force field around the desired point-and-click target.

METHODS

Fourteen subjects, 10 male and 4 female, ranging in age from 22 to 40 years old, participated in the study. Subjects were free of any musculoskeletal disorders in the hand that manipulated the mouse. The Stanford University Institutional Review Board (IRB) approved all procedures.

Once seated at a workstation adjusted to each subject in accordance with ANSI-HFES recommendations (1988), subjects performed an automated point-and-click task. A set of 14 circular targets, 30 pixels wide with a center-to-center distance of 75 pixels, were displayed on the screen (Figure 1). During the test, the computer would highlight one of the targets and the subject would be instructed to point the cursor to that highlighted target and click on it as quickly as possible. Once clicked, the computer would deactivate the target and highlight the next target. Each subject performed 40 trials, each containing 14 targets, for a total of 520 movements. The targets were presented in random order. The mouse acceleration control panel was turned off. An electronic log automatically kept track of the distance and the movement time between targets.

For each movement, an index of difficulty I_d (Fitts, 1954) was calculated by

$$I_d = -\log_2 \frac{W}{2A} \text{ bits/response}$$

where W is the width of the target and the A is the distance to the center of the target. For the target configuration of Figure 1 there were 18 possible distances, hence 18 indices. The measured movement time for a given index of difficulty was averaged across trials within a subject and then averaged across subjects.

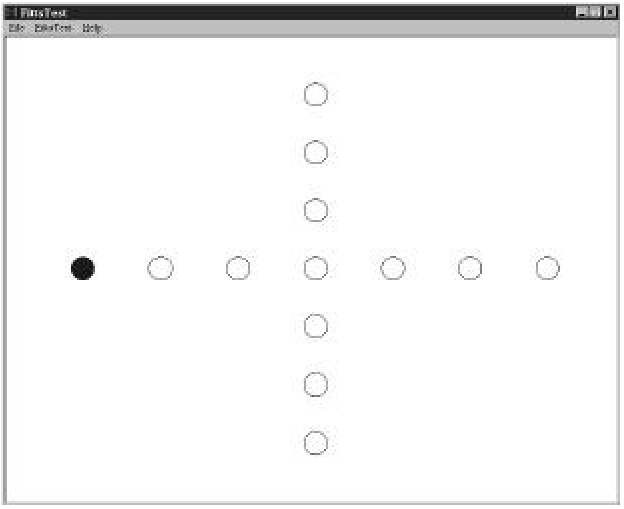

Figure 1: The simulated point-and-click task GUI window.

Figure 2: The *FEELIt* Mouse.

These 520 movements were completed twice per subject, once with an attractive force basin around the target and once without the force basin. The presentation order of the two configurations was random, and subjects were allowed to rest between each set. The mouse used in this study was the FEELIt force-feedback mouse (Figure 2, Immersion Corporation, San Jose, CA). The mouse is connected to a 2 degree-of-freedom (DOF) linkage system that has a range of motion of 1 inch by 1 inch. Electromagnetic actuators connected to the linkages of the 2-DOF system apply forces through the mouse in the plane of the tabletop. The maximum force produced is 3 ounces. For the force-feedback condition, the mouse software would activate an attractive basin (Figure 3) around the desired target, and disengage the force once a target was selected. The attractive basin was the same shape and centered with the visual target, with a radius twice that of the visual target.

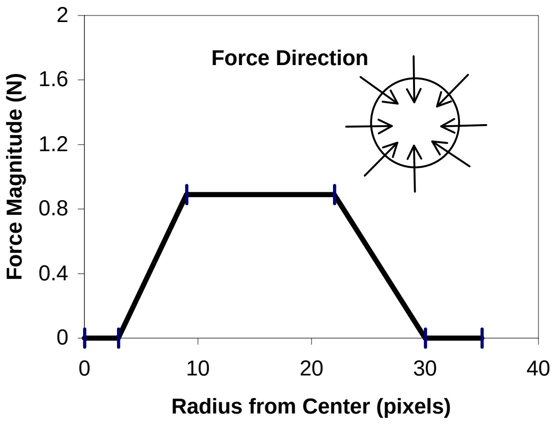

Figure 3: Attractive basin force-feedback algorithm. The force points inward towards the center of the visual target with a magnitude plotted.

At the conclusion of each test condition, each subject completed a questionnaire assessing their perceived musculoskeletal loading. The questions, posed on a visual analog scale modified from the Borg (1982) category ten scale, were designed to quantify difficulty, pain and discomfort felt during the task, and fatigue and soreness felt after completing the task. As an example, the verbal anchors on the scale for difficulty ranged from ‘very, very easy’, to ‘easy’, to ‘somewhat difficult’, and finally to ‘very difficult’. Since levels of exertion for the given task are low, we envisioned the modified Borg scale would provide the necessary resolution to observed differences between each test condition. Paired *t*-tests were used to find significant differences between the movement times and the psychophysical responses with and without force-feedback.

RESULTS

In accordance with other studies (e.g. Hasser et al., 1998), the movement times decreased with the implementation of the attractive force basin around the target (Figure 4). With the presence of an attractive force field, subjects performed 25% faster than without the attractive field. It follows that the Index of Performance, defined by Fitts (1954) as the Index of Difficulty divided by the movement time, increased. The average Index of

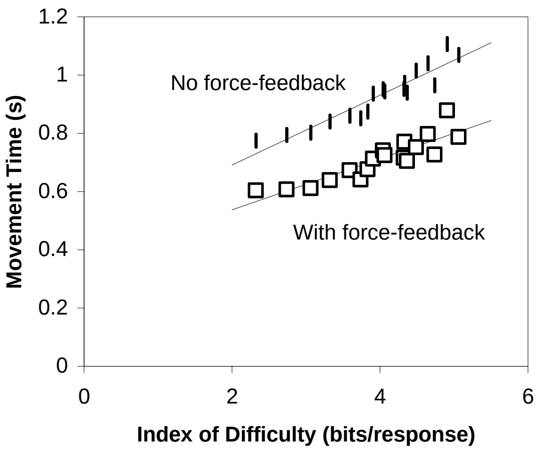

Figure 4. Smaller movement times occurred with the addition the attractive force-feedback basin.

Performance across movements and subjects increased from 4.2 bits per second with no basin to 5.6 bits per second with the basin. The number of errors as quantified by mouse clicks outside the target area decreased by 43% with the implementation of force-feedback. All differences were significant ($p < 0.05$). Hence the implementation of force-feedback for this situation improved performance.

The average perceived task difficulty, pain and discomfort felt during the task and the fatigue and soreness felt after completing the task were all less when the attractive basin was present (Figure 5). Again, all the differences between the two conditions were significant ($p < 0.05$) except for the perceived soreness ($p = 0.24$). It is possible that this is because both muscle fatigue and soreness are qualities that are often only noticeable a short time after an activity has been completed, but subjects took the questionnaires immediately after testing.

DISCUSSION

The two main results presented provide evidence supporting the use of an exciting alternative new technology for the GUI pointing input device. Studies of computer pointing devices have focused on altering the geometry of the mouse affecting the posture or on an alternative passive device, like a track ball, which attempts to use different muscle groups. Force-feedback allows, for the first time, tactile feedback in the virtual GUI environment. For the simple point-and-click task presented here the technology improved operator performance and reduced the perceived pain and discomfort in completing the task.

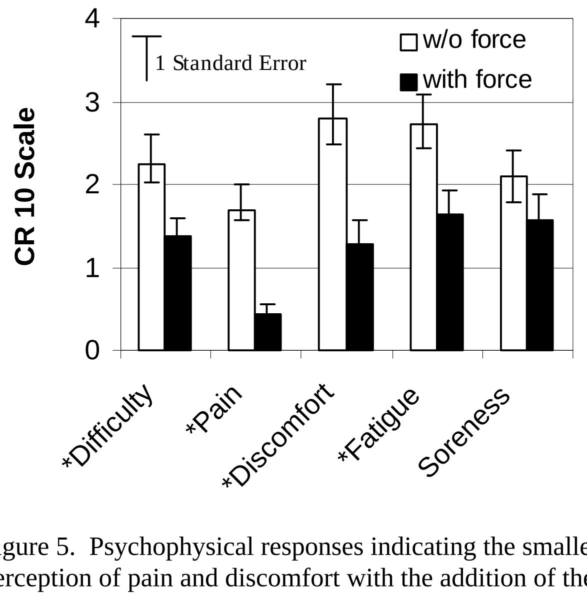

Figure 5. Psychophysical responses indicating the smaller perception of pain and discomfort with the addition of the attractive force-feedback basin. The asterisk (*) indicates a significant difference for the category (p<0.05).

The combination of increased performance and increased comfort of use as quantified through the perceived pain and discomfort questionnaire is not surprising. The point-and-click task is a rapid, goal-directed movement and may be segmented into three stages: first, acceleration towards the target, second, a slowing of the mouse as the cursor approaches the target, and third, a fine manipulation aligning the cursor with the specific target. The attractive basin allows the user to become, as one subject put it, “lazy” in the third phase of the movement. In this phase, the attractive basin helps align the cursor within the target, removing part of the task burden from the musculature; hence, reducing the required participation of the muscles needed for the fine control in the final phase of positioning. The dynamics of the attractive basin are faster than the motor control, allowing for the increase in performance.

The attractive basin is an ideal type of force-feedback algorithm in that it aids the intended movement. The directions of the forces were aligned with the intended direction of the movement. Other types of feedback algorithms may not have the same effect. For example, friction is a force that opposes the direction of movement, which may aid in the slowing portion of a movement but hinders acceleration and targeting portions. Akamatsu et al. (1994) added friction as a type of feedback to a system and saw no improvement in performance for such an algorithm. Most likely there is also an extra burden on the musculoskeletal system during such resistive force-feedback algorithms. When the force resists an intended movement it will most likely have adverse affects in terms of both acceptability of the user and in increasing the musculoskeletal loading.

This is a laboratory experiment and transferring the conclusions to a larger environment, such as the office workspace has several limitations. This study activated only one attractive basin at a time. In a true GUI environment, like a PC desktop, there will be most likely several attractive basins active on the screen at the same time, along with other types of forces. The presence of distracting basins may reduce the difference seen in our results. Further studies are needed that investigate the distracter effect. This simulated task was also a time-condensed series of point and click tasks (520 over a ten-minute period). Real world GUI tasks consist of many different activities, including pointing, dragging and steering. A longer exposure during a real work regimen would be more effective in determining the long-range characteristics of adding force-feedback technology to the office workspace.

In conclusion, the data presented here suggest that the introduction of force-feedback technology in the office workspace may increase human performance. The psychophysical responses suggest further that force-feedback technology may also reduce the exposure of the musculoskeletal system to force -- a risk factor for chronic musculoskeletal disorders.

ACKNOWLEDGMENTS:

The authors thank Immersion Corporation of San Jose, CA for donating the *FeelIt* Mouse and Christopher Hasser and Alex Goldenberg of Immersion for their technical support, and to Mark Cutkosky of Stanford University for sponsoring the experiments. This research was partly funded by Immersion Corporation.

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