Alternative Computer Mouse Design and Testing to Reduce Finger Extensor Muscle Activity During Mouse Use

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Objective: The purpose of this study was to design and test alternative computer mouse designs that attempted to reduce extensor muscle loading of the index and middle fingers by altering the orientation of the button switch direction and the force of the switch. **Background:** Computer users of two-button mouse designs exhibit sustained lifted finger behaviors above the buttons, which may contribute to hand and forearm musculoskeletal pain associated with intensive mouse use. **Methods:** In a repeated-measures laboratory experiment, 20 participants completed point-and-click, steering, and drag tasks with four alternative mouse designs and a reference mouse. Intramuscular and surface electromyography (EMG) measured muscle loading, and movement times recorded by software provided a measure of performance. **Results:** Changing the direction of the switch from a conventional downward to a forward design reduced (up to 2.5% maximum voluntary contraction [MVC]) sustained muscle activity (10th percentile EMG amplitude distribution) in the finger extensors but increased (up to 0.6% MVC) flexor EMG and increased movement times (up to 31%) compared with the reference mouse ($p < .001$). Implementing a high switch force design also increased flexor EMG but did not differ in movement times compared with the reference mouse ($p < .001$). **Conclusion:** The alternative mouse designs with altered switch direction reduced sustained extensor muscle loading; however, trade-offs with higher flexor muscle loading and lower performance existed. **Application:** Potential applications of this study include ergonomic and human computer interface design strategies in reducing the exposure to risk factors that may lead to upper extremity musculoskeletal disorders.

INTRODUCTION

With the advancement in graphical user interfacing for personal computing, the computer mouse has become a standard peripheral device. However, intensive use of a computer mouse as an input device has been found to be associated with symptoms of upper extremity musculoskeletal disorders (Andersen et al., 2003) and pain specific to the forearm, wrist, and hand (Kryger et al., 2003; Lassen et al., 2004), such as that from forearm tendinitis. Although the specific mechanism and associations are still unclear, mouse users are exposed to prolonged working postures involving finger and wrist extension, which may be risk factors (Burgess-Limerick, Shemmell, Scadden, & Plooy, 1999; Jensen et al., 1998).

In addition to the finger and wrist postures, we have observed a sustained lifted finger prevalence of 48% during two-button mouse use (Lee, McLoone, & Dennerlein, in press). Users may be lifting and holding their fingers for prolonged periods above the buttons to prevent inadvertent activations by avoiding finger pressure on the buttons (Sogaard, Sjogaard, Finsen, Olsen, & Christensen, 2001).

The sustained muscular activation patterns of the finger extensor muscles required to lift and hold the fingers above the buttons (Jensen et al., 1998; Sogaard et al., 2001), in combination with

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extended wrist postures already observed from previous mouse studies (Karlqvist, Hagberg, & Selin, 1994; Keir, Bach, & Rempel, 1999), may contribute to the occurrence of upper extremity pain during intensive mouse use. Two-button mouse use may be analogous to typing, in which sustained extensor muscle loading has been reported to maintain unused fingers extended above the keys to prevent inadvertent key presses (Gerard, Armstrong, Foulke, & Martin, 1996; Keir & Wells, 2002).

Three forces may contribute to these inadvertent activations: gravity, passive muscle forces, and enslaving effects. Gravity tends to pull the fingertip downward in the direction of a conventional vertical switch design. The finger postures of the hand without active muscle activity results in slightly flexed finger postures, given the passive muscle force of the extrinsic finger flexors, and therefore passive internal muscle forces of the extrinsic finger flexors increase with the fingers in extended postures (Keir, Wells, & Ranney, 1996; Landsmeer & Long, 1965; Ranney, Wells, & Dowling, 1987).

Because conventional mouse shape and button designs promote extended finger postures for button activation, fingers are actively pulled opposite to the passive force of the extrinsic finger flexors. In addition, isometric fingertip force productions of one or more fingers create involuntary force productions of neighboring fingers (enslaving effects), as the extrinsic extensor and flexor tendons are interconnected at the hand and wrist level (Keen & Fuglevand, 2004; Zatsiorsky, Li, & Latash, 2000). Therefore, to prevent inadvertent activations, users may be lifting and holding their fingers above the buttons for prolonged periods to counteract gravity, passive muscle forces, and enslaving effects during coordinated finger force productions.

In addition to the design shape of the mouse, the internal keyswitch design may also affect this sustained lifted finger behavior. Previous research on keyswitch tapping on different switch designs has found that altering the orientation of the switch travel and changing the activation forces influences biomechanical loading on the upper extremity. Balakrishnan, Jindrich, and Dennerlein (2006) found that changing the keyswitch orientation to a positive tilt (fingertip directed away from the user) reduces finger joint torques and energies during the loading phase of keyswitch tapping. Depressing keyswitches with increased activation forces results in increased finger flexor and extensor muscle activity of the hand and forearm (Gerard, Armstrong, Franzblau, Martin, & Rempel, 1999; Rempel et al., 1997).

Therefore, we designed and implemented four alternative mouse designs that incorporated button redesigns that altered the orientation of the button switch direction and the force of the switch, with the goal of reducing finger extensor muscle loading and consequently reducing sustained lifted finger behavior during mouse use. The muscle activity, performance, and usability of the alternative designs were quantified through a laboratory-based experiment. We tested the hypothesis that the alternative mouse button designs would reduce extensor muscle loading in the index and middle fingers while maintaining the performance and usability of a conventional mouse design.

METHODS AND MATERIALS

Mouse Designs

The design goal for the alternative mouse designs was to allow users to easily activate the buttons through active motor control while making it difficult for inadvertent activations to occur through passive or gravitational forces. Four alternative designs were developed, and prototypes were constructed based on the same shape and chassis as a conventional mouse, designated the reference mouse (Figure 1a). The reference mouse was a USB-interfaced optical wheel mouse (IBM Model No. MO28UO) which is 32 (height) × 54 (width) × 114 mm (depth), weighs 94 g, and has a switch activation force of 0.64 N. The alternative designs were a no-right-button, a high-force, a push-forward, and a slide-forward mouse. All alternative designs had the same heel shape and scroll wheel as the reference mouse; differences were only in the left and right button designs.

The first alternative design, the no-right-button mouse, replaced the articulating right button on the front right side of the mouse with a nonarticulating fixed surface in contour with the original button (Figure 1b). This design would allow users to rest their middle finger, avoiding the possibility of right button inadvertent activations, and result in reductions in finger extensor activity. The left button switch activation force was the same as that for the reference mouse (0.64 N).

The second alternative design, the high-force

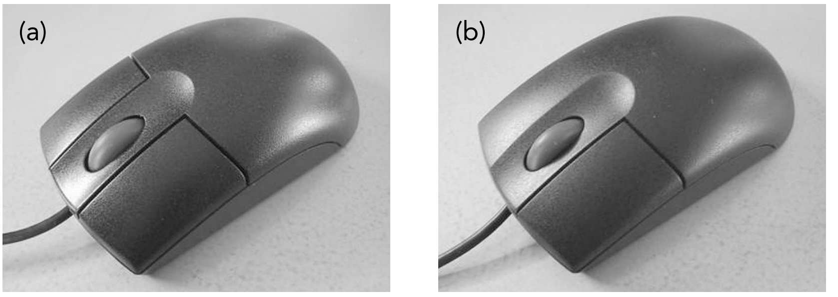

Figure 1. Superior-lateral views of (a) the reference mouse and (b) no-right-button mouse. The high-force mouse was completely identical in appearance to the reference mouse.

mouse, was identical in external physical appearance to the reference mouse; however, both of the switches of the base mouse were replaced with switches of activation forces twice that of the reference mouse (1.29 N). The increased button force was still within the range of the 0.5- to 1.5-N limit, in accordance with the ISO 9241-9 standard for non-keyboard input device design (International Organization for Standardization, 2000). Increasing the switch forces made inadvertent activations more difficult, allowing participants to rest their fingers on the buttons during nonactivating periods.

The third alternative design, the push-forward mouse (Figure 2a), changed the direction of the left button movement by incorporating an inclined 30° button slope from the horizontal (Figure 2b), approximately symmetrical from the vertical of the reference mouse design. The left button switch activation force was the same as that of the reference mouse (0.64 N); the right button was replaced with a fixed surface (same as the no-right-button mouse). The left button had a round and concaved surface, which allowed users to rest their fingers on the center of the button and to push forward to activate the mouse button.

The changed switch direction required a different motion of the fingertip than what is expected from the downward passive force mechanism of the finger. Hence, to activate the switch, the finger has to create a tip force direction orthogonal to the passive fingertip forces, which is in a forward direction, away from the user, rather than downward in the direction of the passive fingertip forces.

The fourth alternative design, the slide-forward mouse, also incorporated a push-forward left button switch direction but retained the same left button slope and overall shape as the reference mouse (Figure 3a). The left button switch activation force was the same as that of the reference mouse (0.64 N); the right button was replaced with a fixed surface (same as the no-right-button mouse). The left button of the slide-forward mouse had a ribbed rubber surface to increase the fingertip friction on the mouse button to allow participants to push their finger forward, thus "sliding" the button forward and activating the switch (Figure 3b). As with the push-forward mouse, the design goal for the change in switch direction was to allow participants to rest their fingers on the left button without worrying about inadvertent activations. However, the intent of the slide-forward design was to give an appearance similar to the reference mouse.

Experimental Design

Twenty participants (10 women, 10 men) were recruited for the alternative mouse testing in a

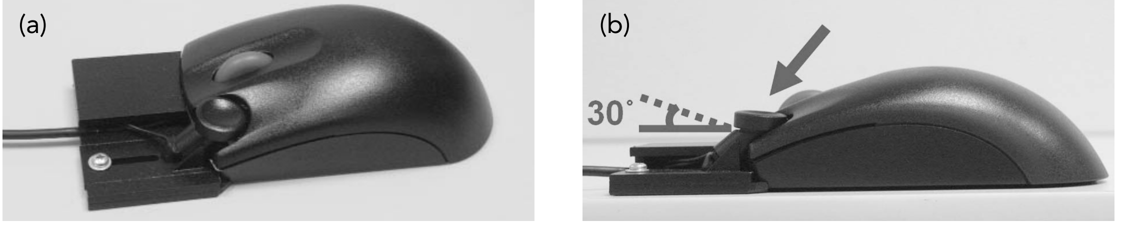

Figure 2. (a) Superior-lateral and (b) sagittal views of the push-forward mouse. The arrow indicates the button switch direction.

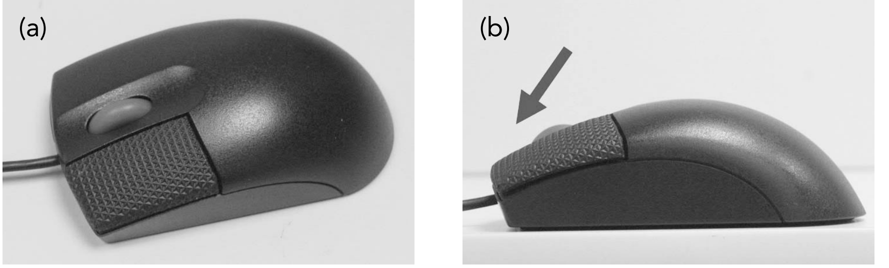

Figure 3. (a) Superior-lateral and (b) sagittal views of the slide-forward mouse. The arrow indicates the button switch direction.

controlled laboratory setting. The mean age in the sample size was 28.6 ± 5.3 years. Three of the 20 participants were left-handed (15%); however, all participants reported using their right hand for their mouse usage. All participants were experienced computer users with mean self-estimated computer usage times of 4.3 ± 2.6 hr per weekday. All participants reported no history of upper extremity musculoskeletal disorders. Informed consent was gained from all participants, and all experimental procedures were approved by the Harvard School of Public Health Human Subjects Committee.

Participants completed three mouse tasks using the reference mouse and the four alternative designs (15 total conditions) in a complete, repeated-measures study design. Participants were seated at an adjustable workstation with their feet flat and thighs parallel to the ground. The workstation consisted of an adjustable chair, an adjustable work surface for the keyboard and mouse, and a flat-panel monitor on an adjustable monitor arm. The workstation was adjusted for each participant in accordance with guidelines put forth by the Human Factors and Ergonomics Society (2002). The keyboard was placed near the edge of the workstation with the alphanumeric portion of the keyboard centered with the body's centerline. For each task and condition, the mouse was positioned just lateral to the right of the keyboard.

The three mouse tasks were a point-and-click task, a steering task, and an object drag task. The point-and-click and steering tasks were completed with a custom-developed software program developed in C++ (Dennerlein & Yang, 2001). The point-and-click task required participants to click on 15 circular targets (0.75 cm in diameter) laid out in a crosshair configuration. In a random presentation order, participants clicked each of the 15 targets three times for a total of 45 clicks. The next target was not displayed until successful selection of the current target.

The steering task required participants to move the cursor through 20 virtual two-dimensional horizontal and vertical tunnels of varying lengths and widths displayed as two parallel lines without going outside of these lines (Dennerlein, Martin, & Hasser, 2000). If participants steered the cursor outside the lines, they had to redo the steer until successful, before the next tunnel is displayed. The drag task required the participants to sort objects on the screen by shape and to reshape geometric shapes to match a phantom shape (Dennerlein & Johnson, 2006).

Prior to data collection, participants were given specific instructions on how to successfully complete each task. For each mouse design, the specific button switch direction and force designs were described in detail. Participants were allowed to practice using the mouse designs with the tasks until they "felt comfortable" with all the tasks and mouse designs. During data collection, participants completed all three tasks with each mouse design, all presented in random order. Prior to the start of each task, participants were instructed to complete all tasks "as fast, yet as accurately as possible." Instructions were consistent across participants.

During the experiment, surface electromyography (EMG) signals provided a measure of muscle activity in four hand and forearm muscles that articulate the finger and wrist joints. The muscles were the flexor digitorum superficialis (FDS), first dorsal interossei (FDI; a metacarpophalangeal joint flexor and interphalangeal joint extensor), extensor carpi radialis (ECR), and extensor carpi ulnaris (ECU).

In addition, the muscle activity of a fifth muscle, the extensor digitorum communis (EDC), was also measured. To ensure participation and reduce recruitment and selection biases, participants were offered the option to choose between indwelling or surface electrodes for the EDC. For those participants who chose indwelling EMG ($n = 10$), two parts of the EDC were measured: the index finger contribution (EDC_{ii}) and the middle finger contribution (EDC_{im}). Surface EMG signals of the EDC (EDC_s) provided an overall muscle activity measure rather than individual finger contributions measured by indwelling EMG.

Surface electrodes (DE-2.1 Single Differential Electrode, Delsys, Boston, MA) were placed on top of the muscle bellies in accordance with Perotto (1994). Placements were validated through palpation and signal response to isometric test contractions. For indwelling EMG, two pairs of bipolar finewire electrodes (50 μm diameter, stainless steel 316LMG H-Nylon, California Fine Wire) were inserted using 27-gauge needles, and placements were confirmed by observing the EMG activities (Burgar, Valero-Cuevas, & Hentz, 1997). The EMG signals were amplified, band-passed filtered (surface: 20–450 Hz, Bagnoli-8; indwelling: 20–2000 Hz, Bagnoli-4, Delsys, Boston, MA) and digitally recorded using a custom-designed computer data-acquisition software program at 1000 and 4000 samples/s for surface and intramuscular EMG, respectively.

To normalize the EMG results across participants, we collected three 5-s isometric maximum voluntary contractions (MVCs) for each muscle. The experimenter manually restrained the movement of the joint that the muscle of interest articulates and instructed the participants to keep their other muscles relaxed while remaining focused on the individual muscle being measured for the MVC. For the wrist and forearm muscles, the directions were those defined by Buchanan, Moniz, Dewald, and Zev Rymer (1993). Participants sat upright with their shoulders at 0° of flexion and 45° of abduction, elbows at 90° of flexion, and wrist in neutral posture. The forearm was in a supinated position for the FDS muscle measurement and fully pronated for the muscles of the EDC, FDI, ECR, and ECU.

EDC_{ii} and EDC_{im} were measured with resistance to metacarpophalangeal joint extension from the dorsal side of the proximal interphalangeal joint of the index and middle fingers, respectively, with the metacarpophalangeal joint in 0° and proximal interphalangeal joint in 90° of flexion. Participants rested for 1 min between contractions. The MVC EMG normalization value was the maximum 90th percentile root mean square (RMS) amplitude of the three MVC contractions; the 90th percentile RMS amplitude was used in order to exclude random, spurious elements in the signal. Once recorded, EMG data were digitally high-pass filtered (5 Hz) to eliminate a small DC bias from the EMG system, and notch filtered (6th order Butterworth) between 59 and 61 Hz to remove the 60-Hz component observed during the resting signal, although every effort was made during skin and electrode preparation to minimize noise in the EMG signal.

Before and after using each mouse design, participants were asked to rate them on a 10-cm visual-analogue scale. Preuse questions involved approachability and usability (the latter termed *preusability* hereafter), and postuse questions involved usability (termed *postusability*), comfort, and task difficulty. (See Table 1 for specific language used in the questionnaire). No verbal explanations or cuing were provided. After using all designs, participants ranked each mouse from the most to least favorite based upon their overall subjective impression.

Data Analysis

For each condition, summary statistics were calculated from the EMG, performance, and usability measures. The 10th, 50th, and 90th percentile values of the normalized EMG signal amplitude provided metrics for the distribution of muscle activity. According to Jonsson (1988), the 10th percentile provides a measure of the task's static muscle loading requirement, whereas the 50th and the 90th percentiles provide a measure of the dynamic muscle loading task requirements. The EMG amplitude was represented by an RMS value calculated digitally over a 0.2-s moving window. The beginning and end data collection were synchronized with the beginning and end of the task; however, data from the middle 50% of the task were used to calculate the summary statistics to capture the change in muscle activity attributed to the different button designs and tasks.

Performance was measured for the point-and-click, steering, and drag tasks through movement time, defined as the total time in seconds to successfully complete all 45 clicks, all 20 steers, and all drags, respectively. Movement times for the point-and-click and steering tasks were calculated

TABLE 1: Subjective Usability Ratings Across Mouse Design Based on Self-Reported Visual-Analogue Scales

	Mouse Design				
Parameter	Reference	No Right Button	High Force	Push Forward	Slide Forward
Preusability: How much do you anticipate you would use this mouse? (0–10: 0 = *not at all*, 0 = *use all the time*)	9.0 (0.6)[a]	5.3 (0.6)[b]	2.7 (0.6)[c]	2.6 (0.6)[c]	2.9 (0.6)[c]
Approachability[1]: How approachable (preuse) is this mouse? (0–10: 0 = *not approachable at all*, 10 = *most approachable*)	9.3 (0.6)[a]	7.1 (0.6)[b]	6.0 (0.6)[b,c]	2.8 (0.6)[d]	4.2 (0.6)[c,d]
Postusability: After using this mouse, how much would you use this mouse? (0–10: 0 = *not at all*, 10 = *use all the time*)	8.9 (0.6)[a]	6.0 (0.6)[b]	2.4 (0.6)[c]	2.3 (0.6)[c]	0.9 (0.6)[c]
Comfort: How comfortable did the mouse feel? (0–10: 0 = *not comfortable at all*, 10 = *most comfortable*)	8.0 (0.4)[a]	7.3 (0.4)[a]	3.1 (0.4)[b]	3.8 (0.4)[b]	2.4 (0.4)[b]
Task difficulty: How difficult were the tasks? (0–10: 0 = *not difficult at all*, 10 = *most difficult*)					
Point and click	1.0 (0.4)[a]	1.0 (0.4)[a]	2.6 (0.4)[b]	2.8 (0.4)[b,c]	3.8 (0.4)[c]
Steering	1.9 (0.4)[a]	2.3 (0.4)[a,b]	2.7 (0.4)[a,b]	2.2 (0.4)[a,b]	3.7 (0.4)[b]
Drag	0.8 (0.4)[a]	1.0 (0.4)[a]	2.8 (0.4)[b]	3.2 (0.4)[b]	5.3 (0.4)[c]
Overall rank (postusability; no repeats; 1–5: 1 = *most favorite*, 5 = *least favorite*)	1.2 (0.4)[a]	2.3 (0.9)[b]	3.9 (1.1)[c,d]	3.4 (1.1)[c]	4.3 (0.6)[d]

Note. Values are in mean (standard error) rating; overall ranks are in mean (standard deviation) rank. Each parameter significantly varied across mouse designs. For each parameter, values with the same superscript letters denote groups without significant differences across mouse designs.

[1]Approachability measures the level of perception on the lack of challenge for new products based upon initial appearance; higher approachability ratings indicate a perception of a lower challenge in order to use the product, in which challenge is considered a negative consequence.

from the cursor data recorded by the task software. A Labview-based (National Instruments) computer usage monitoring software program provided movement times for the drag task. For each condition, movement times were averaged for each participant.

In addition, the number of errors during the steering task committed by the participants per mouse design was recorded by the task software. Errors were summed up in the 20 steers of each steering condition, resulting in 100 values of errors (20 participants × 5 mouse designs). Subjective usability ratings were measured on pre- and postusability, approachability, comfort, and task difficulty scores on continuous scales from 0 to 10 (see Table 1 for definitions).

Differences in the EMG, performance, and usability metrics across mouse designs and tasks were analyzed using a mixed effects analysis of variation model (Proc Mixed) in SAS 8.0 (SAS Institute Inc., Cary, NC, USA). The dependent variables were muscle activity measures (10th, 50th, and 90th percentiles of EMG amplitude for the EDC_s, EDC_{ii}, EDC_{im}, FDI, FDS, ECR, and ECU muscles), performance measures (movement time for all three tasks and errors during the steering task), and usability parameters (pre- and postusability, approachability, comfort, task difficulty, and mouse rank).

All dependent variables were based on data from all 20 participants, except for muscle activities of the EDC_s, EDC_{ii}, and EDC_{im}, of which each of these variables were based on 10 participants. The independent variables (i.e., main effects used in the model) were mouse design (reference, no right button, high force, push forward, and slide forward) and task (point and click, steering, and drag), for a total of 15 conditions (5 mouse designs × 3 tasks). Participant was included in the model as a random effect. Interaction between task and mouse was tested but not found to be significant for all dependent variables ($p > .05$); therefore, the final models included only the main and random effects.

Least square means were computed in the mixed model, and multiple comparison adjustments for the p values and confidence limits for the differences of least squares means were completed using the Tukey-Kramer adjustment. Subjective rank scores across mouse design were analyzed using the Wilcoxon rank-sum (Kruskal-Wallis) test (Proc Npar1way in SAS). Significance was noted for probability of a false positive being less than 5% (i.e., $\alpha = .05$).

RESULTS

The alternative mouse designs affected muscle activity levels during mouse use (Figure 4). Only the no-right-button mouse did not differ for any of the measured muscles as compared with the reference mouse. For the high-force mouse, the 90th percentile EMG amplitude of the index finger extensor (EDC_{ii}) significantly increased 2.8% MVC as compared with the reference mouse ($p < .001$). The high-force mouse also had significantly increased 10th, 50th, and 90th percentiles of the EMG amplitude of the flexor muscle activities (FDS and FDI) and the 50th and 90th percentiles for the wrist extensor of the ECU ($p < .001$).

For the push-forward and slide-forward designs, the 10th percentile EMG amplitude of the index finger extensor (EDC_{ii}) significantly decreased 2.2% MVC and 2.3% MVC, respectively, as compared with the reference mouse (p < .001). The middle finger extensor (EDC_{im}) muscle activity followed the same trend as the index finger but did not reach significance, given the variability in the data. The 50th and 90th percentile EMG amplitude of flexor muscle activities (FDS and FDI) also significantly increased for the push-forward and slide-forward designs as compared with the reference mouse ($p < .001$). The muscle activities of the ECR and the EDC using surface electrodes (EDC_s) were not found to differ across mouse design.

In addition, muscle activities varied across the different tasks (Table 2). The 10th, 50th , and 90th percentile EMG amplitudes of the index finger extensor (EDC_{ii}) were significantly highest in the point-and-click tasks, whereas the 10th and 50th percentile EMG amplitudes of the ECU wrist extensor was statistically highest in the steering tasks ($p < .001$). For the finger flexors, the 50th and 90th percentile EMG amplitudes of the FDS and FDI were highest in the drag task.

The alternative mouse designs, mainly those that altered the switch direction (push-forward and slide-forward designs) also affected performance across tasks (Table 3). The no-right-button and high-force designs, both of which have the conventional vertical switch orientation, did not differ in movement time across all tasks as compared with the reference mouse. The movement times for the push-forward and slide-forward designs were found to be 14% and 15% longer, respectively, than for the reference mouse during the point-and-click task and 22% and 31% longer for the drag task, respectively ($p < .001$). Steering task movement times did not differ across mouse design, and there were no significant differences in the number of errors committed during the steering task across mouse design ($p = .118$).

The alternative mouse designs also affected user perception of usability and comfort (Table 1). The reference mouse was rated with an average of 8.8 out of 10 across pre- and postusability, approachability, and comfort parameters, whereas all alternative mouse designs ratings ranged from 0.9 to 7.3 out of 10. The no-right-button design was rated the second highest across all usability parameters, and it was the only design that had a postusability increase (0.7 out of 10) as compared with the preusability ratings. The pre- and postusability ratings for the high-force, push-forward, and slide-forward designs all followed the same trends across mouse design such that they were not found to be different from each other, yet they were rated significantly lower – on average, 6.3 and 7.0 out of 10 in pre- and postusability rating, respectively – than the reference mouse ($p < .001$).

The slide-forward design was found to have the largest postusability decrease, with a difference of 2.0 out of 10. In terms of difficulty across tasks, the slide-forward mouse was the most difficult to use across all tasks, with the reference and no-right-button designs being the least difficult

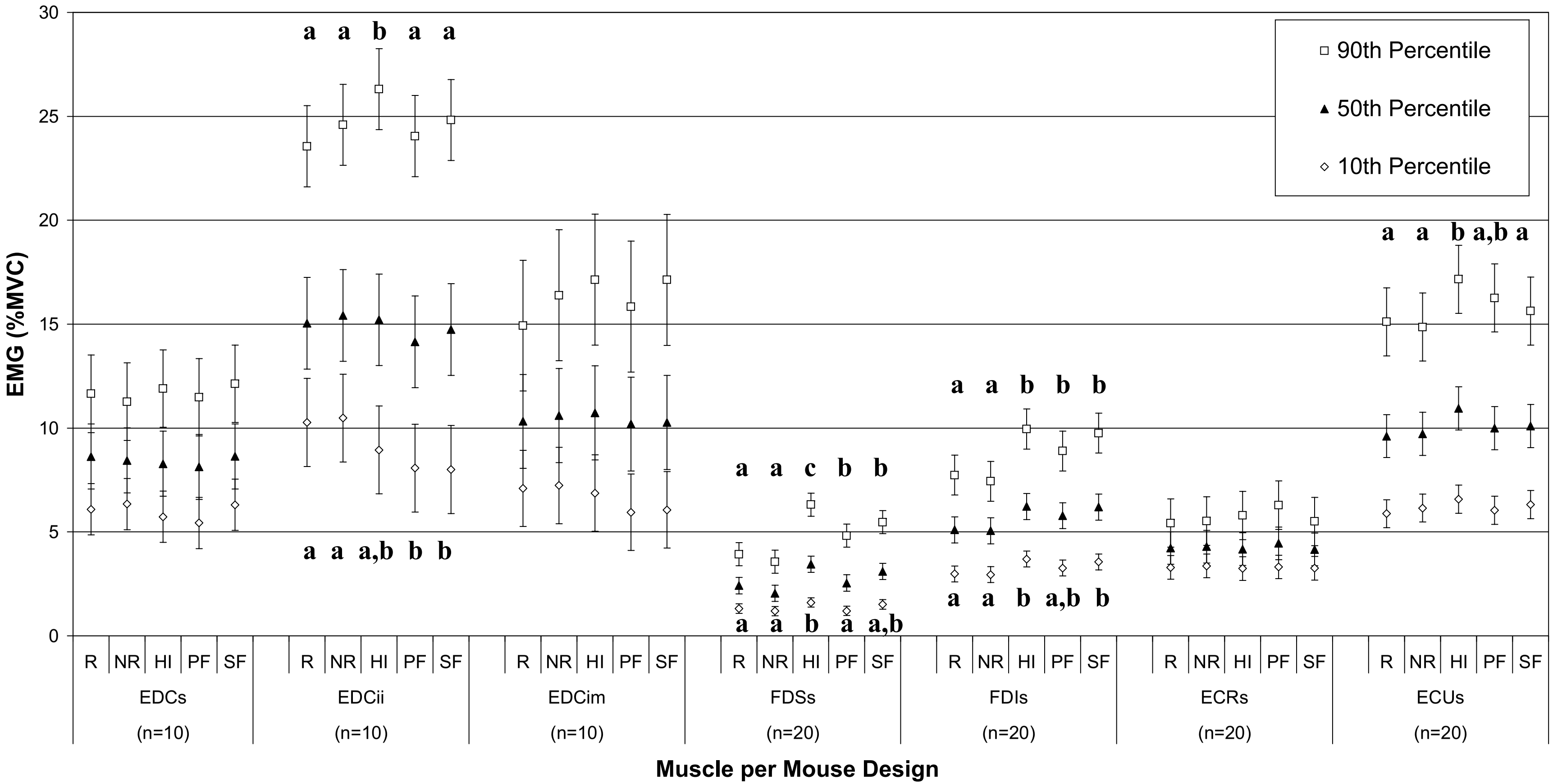

Figure 4. The 10th, 50th, and 90th percentile EMG amplitude distribution (and standard error) for the finger extensors (extensor digitorum communis using surface electrodes [EDC_s] and indwelling electrodes for the index [EDC_{ii}] and middle [EDC_{im}] fingers), finger flexors (flexor digitorum superficialis [FDS_s], first dorsal interossei [FDI_s]), and wrist extensors (extensor carpi radialis [ECR_s], extensor carpi ulnaris [ECU_s]) for the reference mouse (R) and four alternative mouse designs (NR = no-right-button mouse, HI = high-force mouse, PF = push-forward mouse, SF = slide-forward mouse) averaged across all three tasks (point and click, steering, and drag) during mouse use. Number of participants measured for each muscle is indicated. Same letters denote groups without significant differences, indicated only for the 10th and 90th percentile values.

TABLE 2: EMG Amplitude Mean (and Standard Error) Values for Each Task

Task	Muscle						
	EDC_s	EDC_{ii}	EDC_{im}	FDS_s	FDI_s	ECR_s	ECU_s
10th %							
Point and click	5.7 (1.2)	*10.2 (2.1)*[a]	7.0 (1.8)	1.4 (0.2)	3.4 (0.4)	3.2 (0.6)	*5.9 (0.7)*[a]
Steering	6.4 (1.2)	*9.6 (2.1)*[a,b]	6.6 (1.8)	1.3 (0.2)	3.1 (0.4)	3.4 (0.6)	*7.0 (0.7)*[b]
Drag	5.9 (1.2)	*7.7 (2.1)*[c]	6.3 (1.8)	1.3 (0.2)	3.3 (0.4)	3.3 (0.6)	*5.7 (0.7)*[a]
50th %							
Point and click	8.6 (1.6)	*16.3 (2.2)*[a]	10.9 (2.2)	*2.7 (0.4)*[a]	*5.7 (0.6)*[a]	4.3 (0.8)	*9.9 (1.0)*[a]
Steering	8.2 (1.6)	*14.4 (2.2)*[b]	10.0 (2.2)	*2.3 (0.4)*[b]	*5.0 (0.6)*[b]	4.3 (0.8)	*10.7 (1.0)*[b]
Drag	8.5 (1.6)	*14.1 (2.2)*[b]	10.4 (2.2)	*3.1 (0.4)*[c]	*6.3 (0.6)*[c]	4.2 (0.8)	*9.6 (1.0)*[a]
90th %							
Point and click	11.9 (1.9)	*27.0 (1.9)*[a]	*17.5 (3.1)*[a]	*5.1 (0.5)*[a]	*8.9 (0.9)*[a]	5.7 (1.2)	15.7 (1.6)
Steering	11.1 (1.9)	*22.3 (1.9)*[b]	*14.9 (3.1)*[b]	*4.0 (0.5)*[b]	*7.6 (0.9)*[b]	5.7 (1.2)	15.7 (1.6)
Drag	12.1 (1.9)	*24.7 (1.9)*[c]	*16.4 (3.1)*[a,b]	*5.4 (0.5)*[a]	*9.7 (0.9)*[c]	5.6 (1.2)	16.0 (1.6)

Note. All values are in percentage maximum voluntary contraction (%MVC). Italic values indicate significant differences of the EMG amplitude parameter across tasks (vertical). The same superscripts denote groups without significant differences.

($p < .001$). The reference mouse was ranked significantly higher than the alternative mouse designs ($p < .001$), with participants ranking the reference mouse as the overall favorite, followed by the no-right-button mouse, push-forward mouse, high-force mouse, and the slide-forward mouse (the least favorite).

DISCUSSION

This study developed and tested four alternative computer mouse designs that altered the orientation of the button switch direction and the force of the switch with the goal of reducing sustained extensor muscle activity during mouse use. We hypothesized that without sacrificing performance and usability of conventional mouse designs, alternative mouse button designs would reduce the required finger extensor activity during basic computer mouse tasks because the use of these designs did not require sustained lifted finger postures. The results illustrated that the 10th percentile EMG amplitude of finger extensor muscle activity did decrease with the alternative designs that incorporated a change in button switch direction.

This finding supports the idea that making it more difficult for inadvertent switch activations to occur may have resulted in users reducing their sustained muscle activity for the task's static muscle loading requirements. Although higher levels of finger flexor EMG activity in the FDS and FDI muscles were found, these levels are relatively low as compared with those for the finger extensors (EDC_s, EDC_{ii}, EDC_{im}). Therefore, implementation of the alternative designs with a change in switch direction may be worthwhile to consider, given the reduction in relatively higher muscle

TABLE 3: Mean Movement Times (and Standard Errors) in Seconds for the Five Mouse Designs Across Tasks

Mouse Design	Task		
	Point and Click	Steering	Drag
Reference	*42.2 (1.4)*[a]	37.2 (2.6)	*105.6 (5.5)*[a]
No right button	*42.7 (1.4)*[a]	35.1 (2.6)	*107.0 (5.5)*[a]
High force	*44.5 (1.4)*[a]	34.0 (2.6)	*108.2 (5.5)*[a]
Push forward	*48.2 (1.4)*[b]	35.9 (2.6)	*128.4 (5.5)*[b]
Slide forward	*48.6 (1.4)*[b]	35.5 (2.6)	*137.9 (5.6)*[b]

Note. Smaller movement times indicate better performance. Italic values indicate significant differences between mouse designs. The same superscripts denote groups without significant differences.

activity of the finger extensors, even with a tradeoff in small increases to the relatively lower muscle activity of the finger flexors. However, this needs to be taken in consideration of the lower performance and usability ratings associated with the alternative mouse designs.

Changing the direction or force of the mouse button switch affected muscle activity, performance, and usability measures. Simply removing the right button (i.e., no-right-button design) did not significantly change the muscle activity across all muscles or the performance across all tasks, as compared with the reference mouse. Increasing the switch activation force (i.e., high-force design) resulted in decreases in the 10th percentile EMG amplitude extensor muscle loading, although not significantly. However, significant increases in flexor muscle activity (FDI and FDS) were found in the 10th, 50th, and 90th percentile EMG amplitude as compared with the reference mouse.

Higher muscle activities from the finger flexors were expected to overcome the increased switch activation force, which is consistent with Gerard et al. (1999) and Rempel et al. (1997), who found that typing on keyboard keyswitches with increased switch activation forces resulted in increased flexor muscle activity. Although higher finger flexor muscle activity was required to depress the buttons, the performance of the high-force design was not significantly different from that with the reference mouse. However, all usability ratings of the high-force design, except for steering task difficulty, were significantly lower than those for the reference mouse. This suggests that participants did not prefer having to push with more effort on the button to achieve task completion, as compared with the switch force of a conventional mouse design.

In support of the change in button switch direction (i.e., push-forward and slide-forward designs), the 10th percentile EMG amplitude of the index finger extensors significantly decreased with these push-forward button designs, supporting our design goal. Although the decrease may initially seem relatively small (up to 2.5% MVC), this may have a greater effect on the musculoskeletal system over a longer period.

However, similar to the high-force mouse, these designs were associated with higher flexor muscle activity (FDI and FDS) and lower performance and usability ratings, although a different mechanism may explain the increase in flexor activity. Because force at the fingertip is applied in a forward direction and the fingertip is fixed during button switch activation, the push-forward design was observed to require the proximal phalange to extend at the proximal interphalangeal joint, simultaneously flexing at the metacarpophalangeal joint, and the fingertip was extended forward. Thus, the increase in finger flexor activity was found.

This reciprocal motion (Landsmeer & Long, 1965) of the finger joints is analogous to the joint movement and coordination found during the preloading and loading phase of tapping on a positive-tilted keyboard keyswitch (Balakrishnan et al., 2006) and vertically oriented keyswitches (Jindrich, Balakrishnan, & Dennerlein, 2004; Kuo, Lee, Jindrich, & Dennerlein, 2006). Further kinematic studies with EMG profiling are needed to understand the differences in finger joint coordination, muscle activity, and energy between alternative computer mouse buttons with push-forward designs and conventional vertical switch designs.

The increased flexor muscle activity observed for the slide-forward mouse can also be attributed to the button design, which requires high normal forces necessary to create the friction force for the forward button movement and activation of the switch. The creation of friction force requires normal forces in which the relationship is defined with the coefficient of friction. With perfect coefficient of friction (i.e., 1), the friction force can be at best equal to the normal force.

Compared with the other mouse designs, the slide-forward mouse requires a different motor control strategy in that the user needs to create a force vector in the direction that is away from the user and with enough pressure to simultaneously (a) overcome the switch activation force and (b) prevent slipping of the finger on the button surface throughout the button travel. This effect may partially explain the lower postusability, comfort, and task difficulty ratings, as compared with those of the push-forward mouse, and the lowest usability across all designs.

In terms of usability, both the push-forward and slide-forward designs were not favorable as compared with the reference mouse. As expected, the push-forward mouse had lower preuse approachability ratings than did the slide-forward mouse. However, participants rated the push-forward mouse as more comfortable, easier to use, and favorable after using it, although the difference was small. The most common critique of the slide-forward mouse was the difficulty in activating the left button (by sliding the button forward) and moving the mouse simultaneously, which requires a motor control strategy different from that required by conventional mouse designs.

Some limitations inherent in the study design place the findings in a specific context. First, exposures to the alternative mouse designs were limited, and participants may not have fully adapted to the button design changes in terms of motor control and coordination. This study examined the more immediate effects of button design changes, so performance may improve with greater familiarity; however, research with longer exposures would be needed. Limitations in the experimental protocol may account for the paucity of significant results, such as the lower statistical power for the finger extensors (because of the smaller number of participants choosing indwelling electrodes) and measuring the MVC of the FDS muscle with the forearm in a supinated position (for accessibility), given that forearms are pronated during mouse tasks.

Second, the alternative designs were based on a two-button mouse design and therefore, in order to generalize to other mouse designs and shapes (i.e., one-button mouse, trackball), further research would need to be conducted. Third, only left-button tasks were tested in this study, as the no-right-button, push-forward, and slide-forward designs did not have a right button; everyday computer use may include tasks with scrolling and right clicking.

Last, there were no kinematic data of the fingers providing a direct measure on reducing sustained lifted finger behavior for the alternative designs. Future research can quantitatively validate this with biomechanical and motion analysis instrumentation, such as miniature finger joint electrogoniometers and high-speed photography (Jindrich et al., 2004; Kuo et al., 2006). However, such instrumentation may affect the true finger behavior and performance during mouse use.

In conclusion, the findings of this study showed that the alternative mouse designs with altered button switch direction and switch activation force resulted in reduced finger extensor muscle activity, however, trade-offs with higher flexor muscle loading and lower performance and usability existed. Therefore, further research is needed to further address the issues of performance and usability in alternative mouse designs that attempt to reduce finger extensor muscle activity. Understanding how computer mouse button designs affect motor control, performance, and usability will help gain further insight into reducing the exposure to risk factors that may lead to upper extremity musculoskeletal injuries associated with intensive computer mouse use.

ACKNOWLEDGMENTS

The authors would like to acknowledge the support of Microsoft Corporation, the Liberty Mutual Harvard Program in Occupational Health and Safety, the National Institute for Occupational Safety and Health–supported Harvard Education and Research Center (T42 OH008416-01), Kansai University's Overseas Research Program, all the participants who participated in the study, Dan Odell, and Che-Hsu Chang.

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Date received: January 31, 2006
Date accepted: December 21, 2006