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Changes in upper extremity biomechanics across different mouse positions in a computer workstation

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In order to determine differences in biomechanical risk factors across different mouse positions within computer workstations a repeated measures laboratory study was completed with 30 adults (15 females 15 males). The subjects performed mouse-intensive tasks during two experiments. One experiment examined three mouse positions: a standard mouse (SM) position with the mouse directly to the right of the keyboard; a central mouse (CM) position with the mouse between the keyboard and the body, positioned in the body's mid-sagittal plane; a high mouse (HM) position, which simulated using a keyboard drawer with the mouse on the primary work surface. The second experiment compared two mouse positions: the SM position and a more central position using a keyboard without a number keypad (NM). Electrogoniometers and inclinometers measured wrist and upper arm postures and surface electromyography measured muscle activity of four forearm muscles and three shoulder muscles. The CM mouse position was found to produce the most neutral upper extremity posture across all measures. The HM position produced the least neutral posture and resulted in the highest level of muscle activity. Compared to the SM position, the NM position reduced wrist extension slightly and promoted a more neutral shoulder posture. Little difference in muscle activity was observed between the SM and NM positions. In conclusion, of these alternative mouse positions, the HM position was the least desirable, whereas the CM position reduced overall awkward postures associated with mouse-intensive computer tasks.

Keywords: Workstation design; Computer mouse; Upper extremity biomechanics

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1. Introduction

The computer mouse has become an important tool for the control and operation of computers, as operating systems and software applications have evolved to graphics-based windowed environments. Mouse use may account for 30–80% of the time spent working at the computer (Johnson *et al.* 1993, Dennerlein and Johnson 2006). Prolonged force applied to the computer mouse and sustained non-neutral postures are two risk factors that may contribute to mouse-related upper extremity musculoskeletal disorders (Armstrong *et al.* 1995, Andersen *et al.* 2003). Karlqvist *et al.* (1994) demonstrated that mouse work required the use of extended non-neutral postures and muscle activity, which will vary with the location of the mouse relative to the operator.

The positioning of the mouse within the workstation is often an intervention for musculoskeletal symptoms and the position of the mouse has also been weakly associated with reduced productivity associated with musculoskeletal disorders (Hagberg *et al.* 2002). Yet in many workstations, mouse position is driven by furniture design. For example, workstations with keyboard trays that do not provide provisions for the mouse often require placement of the mouse on the desk surface. In a study of 1000 computer workstations 13% were observed to have their mouse at a higher level than the keyboard (Dennerlein and Johnson 2003). While this mouse position is prevalent in the workplace, the postural factors and muscle activities have yet to be studied. An alternative mouse position that is frequently promoted in Europe is placing the mouse in front of the user along the centre line between the user and the keyboard. This centred position is advocated because it allows for a more neutral posture of the shoulder and forearm as well as support of the forearm during use (Karlqvist *et al.* 1998). Harvey and Peper (1997) examined use of a track ball in this position, comparing it to use of a mouse in a standard position to the right of the keyboard, and found that the centred-position track ball produced less shoulder muscle activity. Sommerich *et al.* (2002) also compared a centrally located pointing device on a notebook computer (an isometric joystick) with an external mouse and demonstrated that the centrally located device was associated with greater postural fixity. Both of these studies, however, relate to pointing devices other than a mouse.

Another intervention is positioning the mouse on the left side of the keyboard, since the keyboard contains a number keypad to the right side, forcing the hand further away from the centreline of the body (Sommerich *et al.* 2002, Delisle *et al.* 2004). In a small intervention study Delisle *et al.* (2004) observed that shoulder flexion and abduction, as well as wrist extension, were reduced with left-handed mouse use. Dennerlein and Johnson (2003) reported that only 4% of observed workstations had the mouse to the left of the keyboard. Both Cook and Kothiyal (1998) and Sommerich *et al.* (2002) demonstrated that shoulder posture was more neutral for mouse use with a keyboard without a number key pad. Cook and Kothiyal (1998) also demonstrated a reduction in activity levels for the medial and anterior deltoid. Mouse bridges, which create a flat surface to place the mouse over the number keypad portion of the keyboard, are also utilized to move the mouse closer to the centre of the work area. The effects of force and specific muscle activities have not been examined for this position.

The goal of the present study was, therefore, to simulate a set of four different workstation arrangements representative of those in actual workstations (as shown in figure 1). The standard mouse (SM) position with the mouse directly to the right of the keyboard simulated the conventional mouse placement. The use of a keyboard drawer with the mouse on the primary work surface was simulated by the high mouse (HM) position with the mouse to the right of the keyboard and placed one keyboard depth away from the edge of the table and 50 mm above the resting surface of the keyboard. A central mouse (CM) position with the mouse centred between the keyboard and the user's body simulated a proposed alternative position. In addition, a workstation arrangement was simulated to represent the removal of the number key pad from the keyboard so that the mouse could be moved further towards the centreline of the user.

Biomechanical parameters (posture, electromyography (EMG) and force) for these workstation arrangements were compared with those in a standard keyboard and mouse configuration. It was hypothesized that differences in biomechanical exposure measures for the wrist, arm and shoulder would exist between the simulated workstation arrangements.

2. Method

2.1. *Subjects*

A total of 30 subjects (15 males 15 females), all of whom could touch-type at 40 words per min or higher, were recruited through a temporary employment agency. They ranged in age from 21–39 years (mean 26.9 (SD 4.9) years). Based on a typing test performed before the experiment, the net typing speed of the subjects ranged from 41 to 77 words per min. All subjects reported using a computer for more than 10 hours per week and their occupations ranged from temporary office worker to software engineer. Their heights ranged from 155 to 188 cm with BMI ranging from 20 to 33 kg/m^2. The Harvard School of Public Health Human Subjects Committee approved all protocols and consent forms.

2.2. *Experimental protocol*

In the study the subjects completed a series of standardized computer tasks with the mouse in four different positions within an adjustable workstation. The workstation consisted of an adjustable chair without arms, an adjustable work surface for the keyboard and mouse and a flat-panel monitor on an adjustable monitor stand. The workstation was adjusted for each individual in accordance with guidelines put forth by Human Factors and Ergonomics Society (2002) and Occupational Safety and Health Administration (1997). The height of the table was adjusted such that the surface was level with the resting elbow height for each individual while sitting for all experimental conditions. The keyboard was placed near the edge of the workstation with the alphanumeric portion of the keyboard centred on the body's centreline. Forearm and wrist supports were not provided.

Four different mouse positions were tested during two experiments (as shown in figure 1). In the first experiment (Experiment 1) the first three mouse positions were tested. The SM position had the mouse located just to the right of the keyboard. The HM position had the mouse at the rear of the keyboard and 50 mm above the resting surface of the keyboard, emulating a workstation with a keyboard tray under the desk without provision for the mouse and the mouse placed on the desk. The third condition had the mouse placed centrally (CM) between the keyboard and the body and in the mid-sagittal plane. For this first experiment, the subjects performed two mouse-intensive tasks, text editing and intranet web page browsing, each designed to be completed in 5 min. The text-editing task required the subjects to use the mouse to select highlighted text in a word processing document, delete the text with the delete key on the keyboard using the right

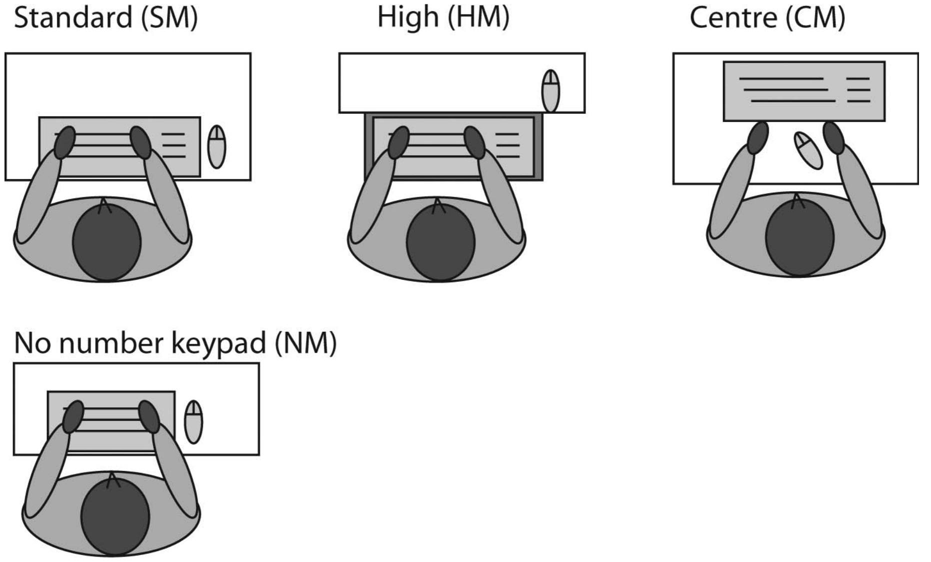

Figure 1. Workstation arrangements in the four experimental conditions tested (SM, HM and CM in Experiment 1, SM and NM in Experiment 2).

hand and then enter the corrected text, consisting of one to six letters, using both hands. The correct text was displayed within the word processing document in parentheses next to the highlighted text. This task was dominated by mouse dragging operations. In the web surfing task subjects viewed a series of photographs with a short descriptive text on a set of local intranet web pages (removing any delays associated with downloading from an actual site on the Internet). To navigate between the web pages, subjects used the mouse to click on the next page links, which were placed in random locations on the web page. This task was dominated by point-and-click operations.

In the second experiment (Experiment 2) two mouse positions were tested, the SM position and a no-number-keypad position. The SM was the same as in Experiment 1. For the no-number-keypad mouse (NM) position, the mouse was positioned to the right of the keyboard; however, the keyboard was moved to the left to emulate a keyboard that had a no-number keypad and allow the mouse to be moved closer to the centreline of the subject. For this experiment the subjects performed a set of graphical tasks, which took 5 min to complete. These tasks consisted of sorting objects on a page by geometric shape as well as resizing objects to match the size of a second object in the field. Since the keyboard was shifted over for this experiment, this task was chosen to minimize the need for interactions with the keyboard. The graphical tasks were dominated by mouse dragging operations.

2.3. *Apparatus*

The subjects wore a two-channel, glove-based electrogoniometry system (Wristsystem; Greenleaf Medical, Palo Alto, CA, USA) that measured wrist postures of both the left and the right hand. The system measured wrist flexion and extension and ulnar and radial wrist deviation. The system has a resolution of 0.1° and 2° accuracy over a $\pm 90^\circ$ range and was calibrated using a wrist jig in accordance with the methods described in Jonsson and Johnson (2001). Postures were recorded continuously by a data logger at 20 samples per second during the tasks. Digital differentiation of the data was used to calculate the wrist joint velocities and accelerations after the position data were digitally low pass filtered (sixth order Butterworth) with an 8 Hz cut-off frequency. Noise measured in a stable, non-moving postural signal created less than 0.2° per s and 1.5° per s^2 root mean square (RMS) values for the velocity and acceleration calculations, respectively. Using the same methods of Johnson *et al.* (2002), neutral posture was as defined with the ulnar border of the third metacarpal aligned with the axis of the distal forearm (Greene and Heckman 1994).

For the first 15 subjects, postural data for the right upper arm were collected using a three-axis orientation sensor (Model 3DM; Microstrain Inc., Winooski, VT, USA) placed on the lateral midpoint of the right humerus, defined as halfway between the lateral epicondyle and the acromion process. The 3DM measured abduction ($\pm 70°$) and flexion ($\pm 180°$) using inclinometers, and rotation ($\pm 180°$) using a magnetometer. A second posture measurement system was introduced (due to a hardware failure and then upgrade) for the last 15 subjects; this was an electro-magnetic motion analysis system (MiniBird; Ascension Technology, Burlington, VT, USA), which measured the orientation of the upper arm using two sensors, one placed on the forearm and one on the upper arm, midway on the humerus. Data were recorded through the serial port into a personal computer at 10 samples per second. The neutral position for the upper arm was defined with the subjects seated, shoulders relaxed with the elbows at their sides and the palms of the hands resting on their thighs.

The electromyographic (EMG) activity from four muscles of the right forearm and three muscles of the right shoulder were recorded during the tasks. The forearm muscles monitored were the flexor carpi radialis, the flexor carpi ulnaris, the extensor carpi ulnaris and the extensor carpi radialis. The three shoulder muscles monitored were the anterior deltoid, the medial deltoid and the upper trapezius muscles. Surface electrodes (DE-2.1 Single Differential Electrode; Delsys, Boston, MA, USA) were placed on top of the muscle bellies in accordance with anatomical locations as identified by Perotto (1994). Placements were validated through palpation and signal response to isometric test contractions. After amplification with a bandwidth of 20 to 450 Hz (Bagnoli-Eight Amplifier; Delsys), the EMG signals were recorded onto a personal computer at 1000 samples per second. The EMG amplitude was represented by a RMS value calculated over a 0.2 s moving window. To normalize the EMG results across subjects, three 5-s maximum voluntary isometric contractions (MVCs) were collected for each muscle while the experimenter manually restrained the movement of the joint about which the muscle of interest articulated. For the forearm muscles, the directions of the restrained movements were those defined by Buchanan *et al.* (1993). For the anterior deltoid the experimenter resisted shoulder flexion and for the medial deltoid shoulder abduction was resisted. For the trapezius muscle, subjects attempted to lift/shrug their shoulders with the direction of the resistance being applied vertically downward at the acromion. For these exertions of the shoulder muscle the upper arm was near the neutral posture, vertically aligned with the torso. Subjects rested for 1 min between contractions. The MVC EMG value used for normalization was the highest RMS amplitude averaged over a 1-s moving window from the three MVC contractions.

The mouse (Microsoft Intellimouse; Microsoft Corporation, Redmond, WA, USA) contained five miniature load cells (Model AIFP-PJ; Microstrain Inc, Williston, VT USA) with four load cells embedded between two stainless steel plates on the side of the mouse and one under the button, providing a measure of thumb grip and finger forces, respectively (Johnson *et al.* 2000). Calibration of the mouse indicated that the miniature side force sensing system had a sensitivity of 0.01 N, was linear ($r = 0.996$), and was accurate in measuring forces over the whole area of the side of the mouse. The side force-sensing system was also repeatable and had an average measurement error of 6.5% when 0.5 N was repeatedly applied 20 times. The button force sensing system was linear ($r = 0.983$) and moderately accurate in measuring forces over a 1.5 cm × 1.5 cm area (the average, absolute force measurement error over the area was 18.0%). Button force measurement was repeatable with an average error of 3.4% while measuring 0.5 N 20 times. The force signals were digitally recorded onto a personal computer at 200 samples per second and then digitally low-pass filtered at 20 Hz to remove high frequency noise and resonant vibrations from the work surfaces (approx. 100 Hz). To normalize force measurements subjects performed a MVC for force production. To normalize the force results across subjects, three 5-s MVCs were collected for the finger flexion and grip. For the mouse button force, subjects pressed with their fingertip on a force transducer and for the mouse grip force they squeezed a force transducer of the mouse between their thumb and fingers as described by Johnson *et al.* (2000). Subjects rested for 1 min between contractions. The force MVC value used for normalization was the highest amplitude averaged over a 1-s moving window from the three MVC contractions.

2.4. *Data and statistical analysis*

Summary statistics were calculated for the muscle activity and the upper extremity postural data. The beginning and end of the data collection were synchronized with the beginning and end of the task; however, only data from the middle 80% of the task were used to calculate the summary statistics. These statistics included the mean and standard deviation as well as the 10th, 50th and 90th percentiles of signal amplitude distribution, which provided a description of the range of the parameter values during the experimental conditions. For EMG values the 10th percentile represents the static muscle effort required by the task, whereas the 50th and 90th percentiles represent the more dynamic muscle requirements associated with a task (Jonsson 1988). For the postural measures, the difference between the 90th and the 10th percentile provides a measure of the range of motion and the 50th percentile provides a measure of the median posture by definition. For the velocity and acceleration the postural data were digitally differentiated and double differentiated, respectively, and then RMS values were calculated over the entire task.

Since the mouse forces consisted of both idle periods where the mouse was not being gripped or used and grip episodes, the mouse force data were analysed only for the grip episode. Grip episodes were defined when the mean force applied to the side of the mouse during a 100 ms moving window exceeded 0.08 N and the standard deviation of the force over that window exceeded 0.025 N. These threshold values were above the signal noise levels. Once an episode was identified, the average force and peak forces (95th percentile) as well as the duration of the episode were calculated. Based on the speed of volitional movements, episodes less than 150 ms were not included or analysed. These force parameters were then averaged across grip episodes to provide the summary statistics for each task.

For each summary measure, differences between the mouse positions were tested using a repeated measures ANOVA and Tukey's post-hoc analysis in JMP statistical software (version 4.0; SAS Institute, Cary, NC, USA). Significance was noted for probability of a false positive being less than 5% (i.e. $\alpha = 0.05$).

3. Results

3.1. *Experiment 1*

Wrist postures were significantly different in the three mouse positions of Experiment 1 with the CM position providing the most neutral wrist posture for all three conditions and HM position providing the least neutral wrist posture (figure 2). Wrist extension was the least for both the SM and CM configurations, with only the 10th percentile value differing between the two conditions. The more neutral posture achieved by the CM position was due to the significant reduction of ulnar deviation. Ulnar deviation was reduced by 6° and the median wrist posture was not significantly different than the neutral position.

Shoulder postures also differed significantly across the three mouse positions, with the CM position providing the most neutral shoulder posture for all three conditions and the HM position providing the least neutral (figure 3). The CM position greatly reduced the external rotation of the upper arm, by nearly 40° to a neutral posture. Flexion was also slightly reduced compared to the SM position. The HM position resulted in significantly greater flexion and abduction compared to the SM position.

There were some significant differences in muscle activity across the three positions (figure 4). For those muscles with differences, the SM position was associated with the lowest muscle activity and the HM position was associated with the highest activity. For the forearm muscles and the anterior deltoid of the shoulder, the CM position produced similar muscle activity to that in the SM position. For the trapezius and the medial deltoid the muscle activity was the highest for the HM position and the lowest for the SM position.

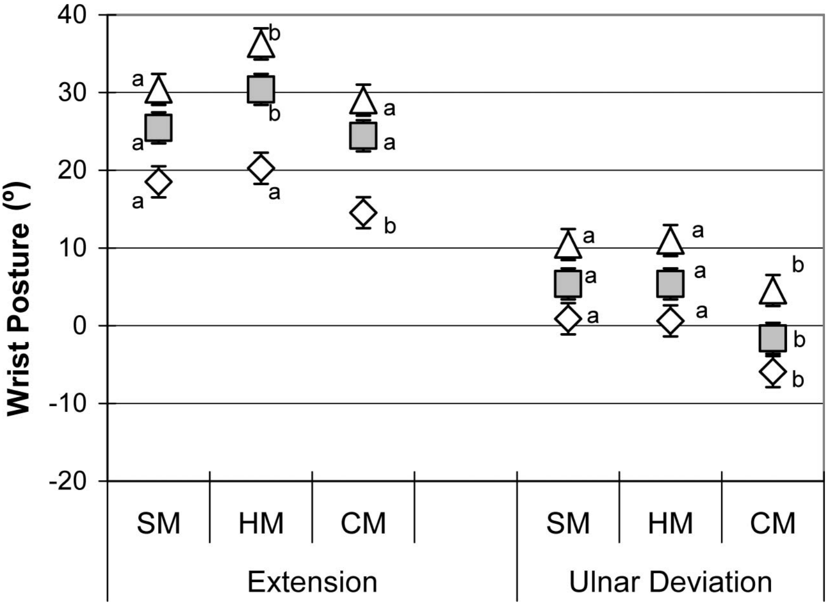

Figure 2. Wrist postures (10th (◇), 50th (□) and 90th (Δ) percentile) across the three mouse positions for Experiment 1. SM = standard mouse; HM = high mouse; CM = centre mouse. The error bars represent the standard error. The same letters denote groups without significant differences.

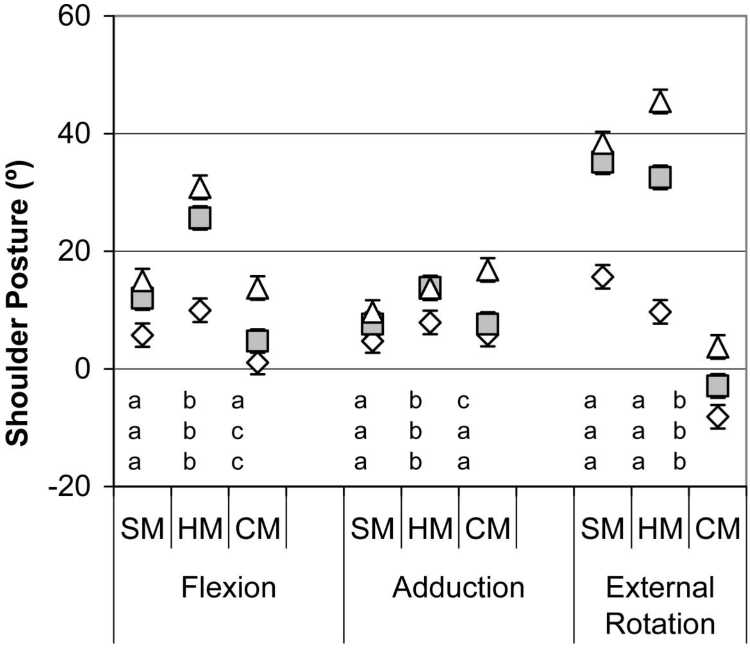

Figure 3. Shoulder postures (10th (◇), 50th (□) and 90th (Δ) percentile) across the three mouse positions for Experiment 1. SM = standard mouse; HM = high mouse; CM = centre mouse. The error bars represent the standard error. The same letters denote groups without significant differences.

During experiment 1 the forces applied to the mouse were low and showed no significant differences across the three mouse positions (table 1).

3.2. *Experiment 2*

There were significant differences in wrist extension between the SM and the NM positions (figure 5). Wrist extension was slightly greater in the SM than in the NM position. While not statistically significant, ulnar deviation was slightly less in the SM position than in the NM position.

There were significant differences in shoulder posture between the two mouse positions (figure 6). The NM position reduced flexion, abduction and external rotation by approximately 50% from the SM position.

Only the medial deltoid showed a significant difference between the two mouse positions, with lower levels of muscle activity associated with the NM position (figure 7). All other muscles had almost identical EMG activity levels between the two positions.

Average grip force on the mouse was slightly higher ($p < 0.05$) for the NM position compared to the SM position (table 1).

4. Discussion

The results show that differences in exposure to biomechanical risk factors of the wrist, forearm and the shoulder do exist across the different simulated workstation

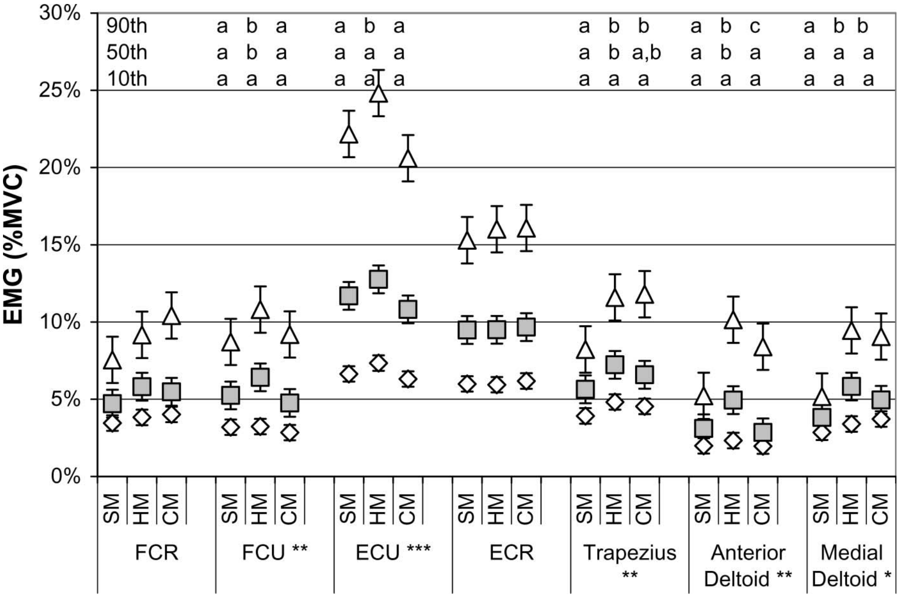

Figure 4. Electromyographic (EMG) amplitudes (10th (◇), 50th (□) and 90th (Δ) percentile) across the three mouse configurations for Experiment 1. MVC = maximum voluntary isometric contraction; SM = standard mouse; HM = high mouse; CM = centre mouse. FCR = flexor carpi radialis; FCU = flexor carpi ulnaris; ECU = extensor carpi ulnaris; ECR = extensor carpi radialis. The error bars represent the standard error. Significance differences across conditions are denoted as *for the 50th percentile only, **for both 50th and 90th percentile and ***for the 90th percentile only. For those muscles the same letters (top of the graph) denote groups without significant differences.

Table 1. Forces applied to the mouse for the two experiments. Mean and (standard error) values are presented.

	Condition	Average side force (N)	Peak side force (N)	Average button force (N)
Experiment 1	SM	1.0 (0.1)	2.3 (0.2)	0.9 (0.1)
	HM	0.9 (0.1)	2.1 (0.2)	0.9 (0.1)
	CM	0.8 (0.1)	2.2 (0.2)	0.9 (0.1)
Experiment 2	SM	1.2 (0.1)[a]	2.7 (0.3)	1.4 (0.1)
	NM	1.4 (0.1)[b]	3.0 (0.3)	1.5 (0.1)

[a,b]denote groups with significant differences.

SM = standard mouse position; HM = high mouse position; CM = central mouse position; NM = no-number-keypad mouse position.

arrangements, with the alternative mouse positions (the CM and NM positions) resulting in more neutral postures than the SM and HM positions. Thus, SM and HM configurations, which are common in the workplace (Dennerlein and Johnson 2003), produce less neutral postures compared to the alternative CM and NM configurations.

The results of moving to the CM position are corroborated by previous studies in the literature, where the studies of Karlqvist *et al.* (1998) and Sommerich *et al.* (2002) found a

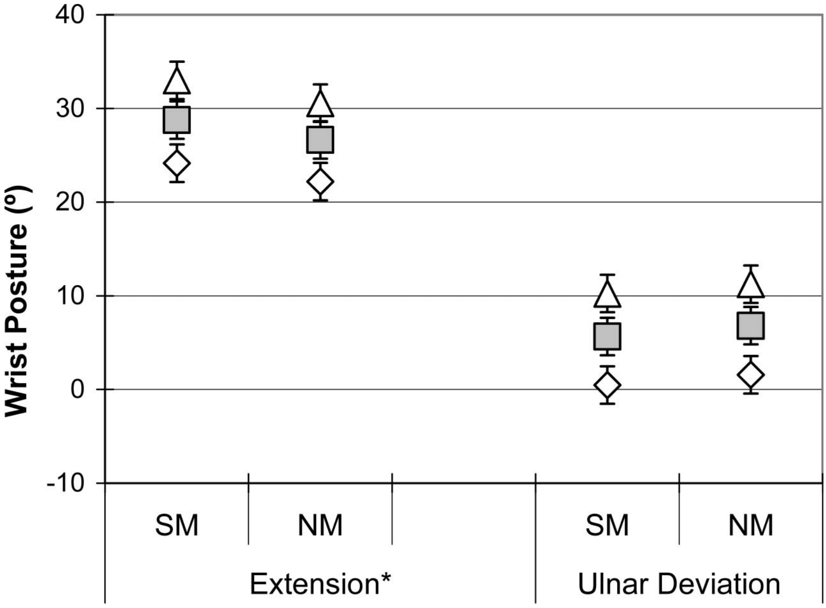

Figure 5. Wrist postures (10th (◇), 50th (□) and 90th (Δ) percentile) across the two mouse positions in Experiment 2, comparing the standard position (SM) to the no-number-keypad position (NM). The error bars represent the standard error. *denotes a significant difference at $p < 0.05$).

similar significant decrease in external rotation. Unlike Karlqvist *et al.*'s study, the centre position in the present study produced less wrist ulnar deviation. These differences could be due to systematic differences between the measurement systems (optical tracking vs. electrogoniometer) or due to differences between mice (Apple vs. Microsoft Intellimouse). Sommerich *et al.* (2002) saw a decrease in wrist extension and also a decrease in postural variability, which was not observed in the present study; however, their pointing device was a touch pad not a mouse and this probably accounts for the differences rather than the location alone. While Harvey and Peper (1997) observed a decrease in shoulder muscle activity, both the present study and Karlqvist *et al.* (1998) found small increases in shoulder EMG; however, Harvey and Peper used a trackball in the centre location, so again the differences could be due to the type of device and not to the location alone.

The results for removing the number keypad on the keyboard also compare well with previous studies by others in the literature. Almost all studies have shown a reduction in shoulder flexion, abduction and external rotation when the number keypad is removed or the keyboard is offset to the side (Karlqvist *et al.* 1998, Sommerich *et al.* 2002, Delisle *et al.* 2004). In terms of wrist posture, only Delisle *et al.* saw a reduction in wrist extension similar to the results in the present study; yet their study examined left-handed mouse use where that side of the keyboard is not extended. While a small reduction in the EMG in the trapezius and medial deltoid was seen in the present study, only Cook and Kothiyal (1998) reported decreases in the medial and anterior deltoid muscle EMGs.

No other studies have examined a configuration similar to the HM position and no other studies have reported the effects of mouse placement on grip forces. Karlqvist *et al.* (1998) did examine the effects of having the mouse pushed further away from the edge of

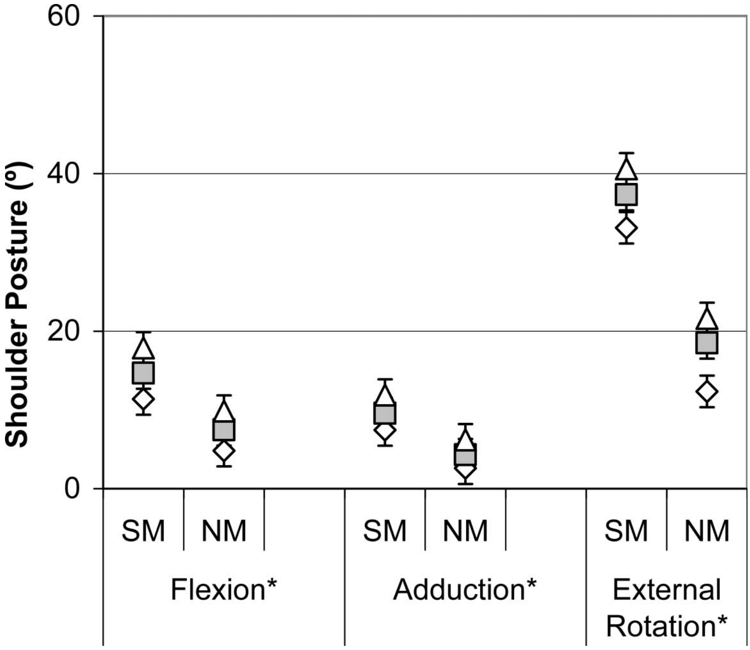

Figure 6. Shoulder postures (10th (◇), 50th (□) and 90th (Δ) percentile) across the two mouse positions in Experiment 2, comparing the standard mouse (SM) position to the no-number-keypad (NM) position. The error bars represent the standard error. *denotes a significant difference at $p < 0.05$.

the table and some of the trends observed here were similar to those found by Karlqvist *et al.* While, in the present study, a trend of decreasing force was seen with the CM position, the differences were not statistically significant. For the NM position a small but significant increase in grip force was observed. It is not clear why there was a difference between positions but one possible explanation may be the unfamiliarity with the NM position resulting in slightly higher forces applied to the mouse. There was not a corresponding increase in forearm muscle EMG; however, EMG was not measured for the muscles directly associated with the gripping of the mouse.

The implications of these results suggest that alternative placements of the mouse within the workstation may reduce the strain on the upper extremities, as others have suggested (e.g. Sommerich *et al.* 2002). The CM position might be difficult to implement due to current limitations in the work surface depth of some furniture; however, if keyboards can be placed further away from the edge of the work surface, which has been shown to be slightly protective for hand and forearm symptoms (Marcus *et al.* 2002), then the mouse can easily be placed in between the keyboard and the user. This CM placement is dependent on the task. Many of the guidelines for computer workstations are keyboard-centric, in that the keyboard is placed up front and centre in the workstation arrangement. However, if mouse usage is the primary activity of a computer user, then perhaps the workstation design should accommodate the CM position or be flexible enough to be able to move the keyboard so that the mouse can be positioned closer to the body's centreline. A wireless mouse and keyboard provides for more flexibility, in that this will eliminate the tangling of cords and movement limitations due to the cords.

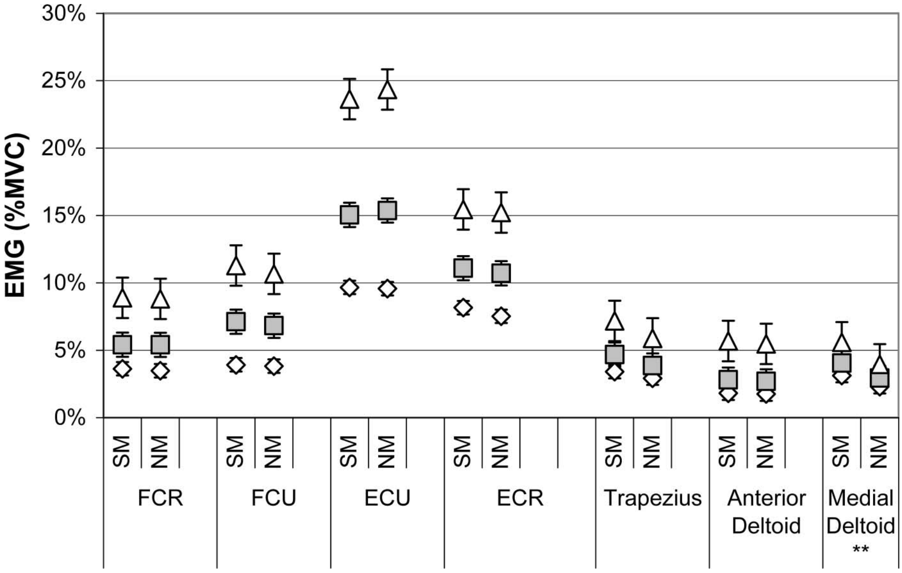

Figure 7. Electromyographic (EMG) amplitudes (10th (◇), 50th (□) and 90th (Δ) percentile) across the two mouse positions in Experiment 2, comparing the standard mouse (SM) position to the no-number-keypad (NM) position. MVC = maximum voluntary isometric contraction; FCR = flexor carpi radialis; FCU = flexor carpi ulnaris; ECU = extensor carpi ulnaris; ECR = extensor carpi radialis. The error bars represent the standard error. **denotes a significant difference at $p < 0.01$.

Well-designed keyboard trays that have movable mouse trays can accommodate some of these alternative configurations. When space is at a premium, there are keyboards or alternative pointing devices that position the pointing device in the centre between the keyboard and the user. From a keyboard design standpoint, there are commercial keyboards that can be purchased without number keypads, which will allow positioning of the mouse closer to the centreline of the body.

Another issue to consider is that the authors, as well as others, have observed large postural changes for the upper extremity with little change in muscle activity across the different mouse configurations. The postural difference will change muscle properties such as strength capabilities and the passive forces on the muscles, tendons and ligaments. There is inherent variability in muscle activity and, as a result of this variability, it is often difficult to quantify small changes with short exposure periods. In addition, the levels of activity are quite small; however, the duration of exposure of computer workers can be quite long. Since specific injury mechanisms are unknown, it is difficult to conclude whether muscle activity or posture is more important.

These conclusions do need to be taken within the context of these laboratory experiments and their associated limitations. First of all, the postures were recorded during a specific set of tasks and not during actual work. Exposures do differ depending on the task (Dennerlein and Johnson 2006) so there is the possibility that the effects of mouse position reported here differed with the task. The statistical analysis did test for interaction between task and position and no significant interactions were found. Furthermore, the impact on keyboarding posture when the various mouse positions were adopted was not measured or quantified. In terms of exposures, it is not known whether these small differences matter. However, the effect of these small differences may be magnified over the course of a day (or even weeks or months) and/or have a greater impact when combined with concomitant increases in the duration and frequency of the exposure.

The main limitations of this study are primarily the short duration of exposure in terms of learning effects and that the simulations did not expose the subjects to the psychological pressures and demands associated with real world tasks in a paying job. In addition, a limited number of muscles and postures were monitored during these tasks. For example, the EMG of the trapezius was measured but shoulder elevation (that is, raising of the acromion relative to the torso), which may be associated with activity of the trapezius (Karlqvist *et al.* 1998), was not monitored. Also, arm support was not controlled during the tasks utilizing the mouse and, therefore, with the mouse-intensive tasks shoulder activity may be lower than during actual work activities (Visser *et al.* 2004). Furthermore, there may have been limitations with the measurement techniques. The accuracy of the upper arm postural measurements may have been compromised by differences in soft tissue movement relative to the movement of the underlying bones. As the upper arm rotates externally, the bone may move further than the outer layers of muscle and skin tissues. Therefore, the absolute measures of internal and external rotation were most likely underestimated. However, this was a repeated measures design and differences were observed across the conditions; hence not changing the overall conclusions. In addition, using two different measurement systems may have added variability to the data. No significant differences were observed in data collected on subjects wearing one system compared to the subjects wearing the other system.

5. Discussion

In conclusion, this study demonstrated that there are differences in the exposures to various biomechanical risk factors, which are dependent on where the mouse is positioned within the computer workstation. The SM position does not provide the most neutral shoulder and wrist posture, whereas certain alternative positions were shown to produce more neutral postures and reduce muscle loads. Finally, in computer workstations where the mouse is located at a different height than the keyboard, less neutral postures and greater levels of muscle activity will result.

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