



Evaluating the effect of four different pointing device designs on upper extremity posture and muscle activity during mousing tasks



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ABSTRACT

The goal of this study was to evaluate the effect of different types of computer pointing devices and placements on posture and muscle activity of the hand and arm. A repeated measures laboratory study with 12 adults (6 females, 6 males) was conducted. Participants completed two mouse-intensive tasks while using a conventional mouse, a trackball, a stand-alone touchpad, and a roller mouse. A motion analysis system and an electromyography system monitored right upper extremity postures and muscle activity, respectively. The roller mouse condition was associated with a more neutral hand posture (lower inter-fingertip spread and greater finger flexion) along with significantly lower forearm extensor muscle activity. The touchpad and roller mouse, which were centrally located, were associated with significantly more neutral shoulder postures, reduced ulnar deviation, and lower forearm extensor muscle activities than other types of pointing devices. Users reported the most difficulty using the trackball and touchpad. Roller mouse was not more difficult to use than any other devices. These results show that computer pointing device design and location elicit significantly different postures and forearm muscle activities during use, especially for the hand posture metrics.

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1. Introduction

As computer usage increases both at home and in the workplace, the incidence of musculoskeletal disorders (MSDs) associated with computer usage has also risen (Cook et al., 2000). Many attribute these increases to a rise in hours mouse use, as the association between MSDs (specifically of the hand, arm, and shoulder) and mouse usage is stronger than the association between hours of keyboard activity and MSD outcomes (Gerr et al., 2004; Ljmker et al., 2007). The specific design and placement of pointing devices, such as a mouse, has been evaluated to determine the effects on upper limb posture and muscle activity (Burgess-Limerick et al., 1999; Dennerlein et al., 2006; Jensen et al., 1998). Specifically, prolonged mouse use is associated with ergonomic risk factors including sustained muscle load and non-neutral postures related to extreme ulnar deviation, wrist extension and forearm pronation (Burgess-Limerick, 1999; Jensen, 1998; Karlqvist et al., 1998; Sjøgaard and Søgaard, 1998).

Most of the previous studies have focused on wrist and shoulder postures, along with forearm and shoulder muscle activities. For instance, several studies have shown that placement of the mouse closer to the center line of the operator reduces non-neutral shoulder and wrist postures as well as reducing muscle activity of both the forearm and the shoulder (Sommerich et al., 2002; Dennerlein, 2006; Kumar and Kumar, 2008, Harvey, 1997). Other studies have shown that the design of the pointing device has little effect on neck and shoulder posture and muscle activity; however, they do have an effect on forearm muscle activity (Lee, 2005, 2008). Despite all of this work, few studies have investigated hand postures. Those that did investigated hand postures related only to the button design and placement (Lee et al., 2007) or the size of notebook mice (Oude Hengel et al., 2008). Overall, very little has been done to explore the effects of different pointing devices on hand or finger posture to provide a better link between the design of the device and effects on forearm muscle activity.

Therefore, the goal of this study was to investigate the consequences of using four different computer pointing devices during typical computer tasks on the postures of the shoulder, wrist, and hand, as well as the muscle activity of the forearm and user perceptions of the devices. In a repeated measures experiment

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conducted in a laboratory environment, we evaluated four distinct device designs (a conventional mouse and three alternative pointing devices: a trackball mouse, a touchpad, and a roller mouse) placed on the work surface according to the users standard practices. We hypothesized that users would experience more non-neutral shoulder, wrist and finger postures, along with sustained forearm muscle load with some of the devices compared to the others.

2. Methods

Twelve right-handed adult participants (6 females, 6 males) with no history of neck or upper extremity musculoskeletal disorders volunteered and provided written informed consent for this repeated measure laboratory study. The mean anthropometric measures for the participants were typical of the average United States population (Table 1). Harvard School of Public Health Office of Regulatory Affairs and Research Compliance approved all protocols and informed consent forms. All participants completed the full study protocol using all four computer pointing devices to complete the two designed computer tasks, while having their posture and muscle activity recorded real time continuously.

2.1. Independent variables: pointing device conditions

Each participant completed a series of standardized mousing tasks four times, each with a different pointing device: a generic mouse (Lenovo 06P4069 Black 3-Button Wired Optical Mouse), a trackball (Logitech TrackMan Marble), a standalone touchpad device (ADESSO Smart Cat 4-Button Touchpad), and a roller-style device (Contour Roller mouse Free 2). All devices were set to the same pointer speed at 6 of the 11-point scale in Microsoft Windows XP® with the acceleration function disabled. The setting requires a 100 mm lateral mouse movement (or a 100 mm-equivalent of trackball rotation along one axis) to move the cursor across a 520 mm wide computer screen (24" size) based on a 1600×1200 resolution setting. Similarly, such a cursor-moving distance required the users to move their fingers laterally for 100 mm on the touchpad or rotate the roller bar on the roller mouse for an arc length of 100 mm. During the experiment, the mouse and the trackball were placed to the right side of the keyboard; whereas, the touchpad and the roller mouse were placed in between the participant and the keyboard, at the center of the table which are the conventional placement of these devices (Fig. 1). For all conditions, the participants sat at the same workstation, which consisted of a chair with arm rests, a monitor, and a generic keyboard with no number keypad. The height of the chair was adjusted such that the participant's feet could remain on the floor and the thighs would be parallel with the floor throughout the experiment. The height of the desk was set such that the j-h key of the keyboard was at resting elbow height. The height of the monitor was customized for each participant such that the upper edge of the screen display was at each participant's eye level. For each subject, the location of the monitor and the keyboard were kept constant for all conditions.

Table 1
Anthropometric measures of means (standard deviations) across all participants.

| | Males (N = 6) | Females (N = 6) | All |
|-----------------------|---------------|-----------------|-------------|
| Age (yrs) | 30.5 (8.5) | 24.7 (1.5) | 27.6 (6.6) |
| Height (cm) | 173.2 (6.6) | 166.7 (1.3) | 169.9 (5.7) |
| Weight (kg) | 68.8 (11.3) | 60.0 (4.1) | 64.4 (9.4) |
| Hand length (cm) | 18.1 (0.6) | 17.5 (0.9) | 17.8 (0.8) |
| Hand breadth (cm) | 9.1 (0.49) | 8.5 (0.6) | 8.8 (0.6) |
| Thumb CMC to tip (cm) | 6.3 (0.6) | 6.3 (0.4) | 6.3 (0.5) |

2.2. Independent variables: tasks

Participants completed two distinctive computer tasks with each of the four devices. The first task involved 3 min of playing Solitaire and the second involved 5 min of web browsing, which required reading and answering specific reading comprehension questions. Playing solitaire, which requires point-and-click and point-and-drag tasks in various areas of the computer screen, familiarized participants with cursor operations using different devices. The customized web browsing tasks involved both cursor operations (cursor movement, point-and click and click-and-drag) along with intermittent keyboard operations (typing) to simulate office work that requires interactions with both the keyboard and the designated pointing device. The web browsing task required approximately 90% mousing and 10% typing operation. The order of different pointing device conditions presented to participants was counter-balanced, with a 2-min break provided between tasks.

2.3. Dependent variables: posture

An optical three-dimensional motion analysis system (Optotrak Certus, Northern Digital, Ontario, Canada) recorded hand and upper limb posture. Infrared light-emitting diodes (IRLEDs) were mounted on each fingertip and proximal interphalangeal joint (PIP) of the participant's right hand. A rigid body cluster consisting of three IRLEDs attached to a metal structure was attached to the back (dorsal) side of the hand over the 3rd metacarpal bone between the wrist and knuckle. Three additional rigid bodies were attached to the forearm, upper arm, and chest. Locations of bony landmarks (right and left acromion, sternal notch, lateral and medial epicondyle of the right elbow, radial and ulnar styloid of the right wrist, metacarpophalangeal joints for digits II-IV of the right hand) were palpated, digitized and tracked according to their corresponding body segment IRLED cluster. Location data for each IRLED and digitized point were subsequently filtered through a low-pass, fourth-order Butterworth filter with a 10 Hz cutoff frequency and used to define local coordinate systems for each segment (Asundi et al., 2010, 2012; Winter, 2005).

Using the anatomical position and the vertical as reference, joint angles for the shoulder and wrist were defined by the rotation matrices describing the orientation of the distal segment relative to the proximal segment. Specifically, from the local coordinate systems, rotation matrices were calculated to obtain the upper arm orientation relative to the torso (shoulder), the forearm relative to the upper arm (the elbow), and the hand/wrist orientation relative to the forearm (the wrist). With these local rotation matrices, Euler angles for all body segments of interest were calculated to describe flexion, extension, abduction, adduction, and rotation (internal or external) of the right shoulder, elbow, and wrist (Asundi et al., 2010, 2012; Winter, 2005).

The results present these calculated joint angles relative to a reference posture similar to the 90-90-90 recommended postures for computer users (OSHA, 2003). For shoulder flexion/extension and ab-adduction the reference posture was with the torso vertical with the upper arms vertical next to the torso. For shoulder internal and external rotation, the reference posture is with the upper arm vertical, the elbow flexed 90° such that the forearm is horizontal and is perpendicular to the coronal plane. For the elbow the reference posture is with the upper arm vertical the elbow is flexed such that it is horizontal. For the wrist flexion/extension and ab-adduction the reference posture is with the same as the anatomical position with the 3rd metal carpal aligned with the long axis of the forearm. For supination and pronation the reference posture is with the upper arm vertical, the elbow flexed at 90°, the hand is fully pronated such that the palms are flat on the table.



Fig. 1. The general arrangement of the keyboard and pointing device for the four devices tested (A) Standard Mouse (B) Track Ball, (C) Touch Pad, and (D) Roller mouse. Instructions to participants allowed them to make adjustments to the specific location of the mouse and trackball, but to keep the general arrangement of the device relative to the keyboard as outlined in these photos. Instructions for the touch pad and roller mouse asked the participants not to make any adjustments of the relative location of the device relative to the keyboard.

Hand posture was quantified using two metrics: inter-fingertip spread and finger flexion. Inter-fingertip spread was defined as the distance between the adjacent finger tips (thumb to index, index to middle, middle to ring, and ring to little), calculated using the distance between the fingertip IR-LED markers. Finger flexion for index, middle, ring, and little fingers was defined as the metacarpophalangeal (MCP) joints flexion angle, calculated using the IRLED on the PIP joint, each virtual MCP marker, and the rigid body on the back of the hand. The reference hand posture was set such that all fingers were kept straight and parallel to the palm and the table with zero finger flexion; where the zero finger flexion is defined as the tip, PIP and MCP joints are all aligned and kept parallel to the hand plane.

2.4. Dependent variables: muscle activity

Surface electromyography (EMG) electrodes (DE-2.1 Single Differential Electrode; Delsys, Boston, Massachusetts, USA) measured muscle activity for the right middle trapezius, three right shoulder muscles (anterior, medial and posterior deltoids), and four muscles of the right forearm (extensor digitorum [ED], extensor carpi radialis [ECR], extensor carpi ulnaris [ECU], and Extensor pollicis brevis [EPB]). The electrode for the trapezius was placed at approximately 5 cm vertical distance from the midpoint between the spine and acromion. The electrodes for the anterior deltoid, medial deltoid, and posterior deltoid were placed on the ventral side approximately 5 cm from the acromion, on the dorsal side approximately 5 cm from the acromion, and on the lateral side approximately 5 cm from the acromion, respectively. The electrodes of the extensor carpi ulnaris (ECU) and extensor carpi radialis (ECR) were placed on the superior-ulnar side of the forearm approximately 6 cm distal to the lateral epicondyle and the superior-radial side of the forearm 20 cm proximal to the radial styloid, respectively. The electrode of the extensor digitorum (ED) was placed on the superior-ulnar side of the forearm approximately 8 cm distal to the lateral epicondyle, roughly along the line formed by the lateral epicondyle and midpoint of the two styloids. Electrode placement on the muscles

was achieved through palpation and validated through EMG signal response to corresponding muscle contraction exercises. After amplification, EMG signals were recorded at a frequency of 1000 Hz, rectified, and smoothed using a 3 Hz low pass filter. In order to normalize the signals for interested muscles, three 3-s isometric maximum voluntary contractions (MVC) were collected for each muscle with corresponding exercises. Participants were coached to gradually ramp up to reach an MVC by the experimenter while the experimenter resisted participants' force exertions using up to their entire bodyweight. Participants were given 2 min between the same muscle contraction and the maximum signal obtained was used as the MVC reference. Based on these references, normalization of EMG was calculated by percent MVC of each muscle. The median muscle activity levels in percent MVC were used to compare across participants.

2.5. Dependent variables: user perception

All participants responded to two survey questions about overall upper extremity discomfort and task difficulty after completing the two computer tasks for each device. The responses were marked on a 10-cm visual analogue scale (VAS) with 0 being the lowest level of discomfort/difficulty and 10 being the highest.

2.6. Data and statistical analysis

For all dependent variables, including posture (in angles), muscle activity (in percentage MVC), and user perception (VAS scale from 0 to 10), marginal means and standard errors were calculated for each task on each device. Variation for each outcome measure across the four device conditions and two software tasks was tested using repeated measures multivariate analysis of variance (RM-ANOVA), with participant included as a random effect. Interaction between device and task was included in the model. Significance criteria (alpha value) was set at 0.05. When a significant effect was found, a post-hoc analysis with Tukey's honest significance test was conducted across the four input devices and

two tasks. Statistical analysis was performed using JMP Pro 10 (SAS, Cary, NC) linear mixed model module software.

3. Results

3.1. Posture

Hand postural metrics differed significantly between devices for the index, middle and ring fingers (Table 2). The inter-finger distances between index and middle finger, and middle and ring finger differed significantly across pointing devices with the smallest distances observed with the roller mouse. The roller mouse was associated with significantly greater middle and ring finger flexion compared to the other devices tested, along with similar value as the touchpad for the highest level for index finger flexion. Task had a small but significant effect on index-middle and middle-ring fingertip distance: distances were greater when playing Solitaire than when web surfing. No interaction terms were significant.

All upper limb postures differed significantly across pointing devices (Table 3). Shoulder abduction and shoulder flexion were significantly greater for the laterally located mouse and trackball; whereas internal rotation and forearm rotation were significantly greater for the centrally located touchpad and roller mouse. Ulnar deviation was greatest for the trackball and least for the touchpad. The main effect of task and the interaction term between task and device was not significant for any upper limb postural outcome.

3.2. Muscle activity

Muscle activity varied significantly only for the forearm extensor muscles (Extensor Digitorum, Extensor Carpi Ulnaris and Extensor Carpi Radialis) across devices (Table 4). Significantly lower Extensor Carpi Radialis muscle activity was observed for the roller mouse compared to all other devices. The trackball was associated with the greatest forearm muscle activity, and had median values greater than 10% MVC for the Extensor Digitorum and Extensor Carpi Ulnaris. The main effect of Task was significant only for the trapezius: Solitaire had slightly lower, but statistically significant, muscle activity than web surfing. The interaction between Task and Device was not significant for any muscle activity outcome.

3.3. User perception

Participants reported significantly less difficulty using the traditional mouse than using the trackball and touchpad; the

roller mouse was reported to be no different from the three other devices (Table 5). Mouse and roller mouse had the lowest discomfort level reported, although this difference was just borderline statistically significant with a p -value of 0.054.

4. Discussion

The goal of this study was to determine the effects of different pointing devices on hand posture and forearm muscle activity. Consistent with our hypothesis, the results indicate that the degree of exposure to biomechanical risk factors such as non-neutral hand posture and increased forearm muscle load differ across pointing devices. The roller mouse condition had the smallest finger spread, greatest finger flexion and lowest forearm extensor muscle activity (Extensor Digitorum, Extensor Carpi Ulnaris, and Extensor Carpi Radialis). Both touchpad and roller mouse conditions were associated with a more neutral shoulder posture and smaller wrist abduction. The results of the present study suggest that specific alternative pointing devices produced more neutral postures of the fingers, wrist and shoulder.

The novel finding of our study is that different pointing devices induce significantly different finger posture and forearm muscle activity due to the design and affordance of each device. In the present study, we defined a neutral hand posture according to the physical therapy definition of a relaxed resting position (Warren, n.d.). Such a posture has the fingers gently curved and less spread apart; where fingers that are closer to fully straightened out (less flexed) are considered less neutral. During the experiment, the size and shape of the mouse and the trackball, allow users to rest their palm while holding the device. However, mouse users lift their index and/or middle finger(s) to click or scroll and trackball users scroll the tracking ball with one or two specific finger(s) while holding the device with the rest of the fingers. These constraints increased inter-finger spread, lowered finger flexion, and increased forearm muscle activity for both the mouse and the trackball conditions. Unlike a mouse and a trackball, the design of the touchpad eliminated the need to hold the device and therefore induced greater finger flexion and smaller finger spread. Additionally, touchpad use also resulted in lower forearm muscle activity, which may be explained Lee et al.'s work (Lee, 2007) that showed lower forearm muscle activity for pointing device use could be explained by the lower frequency and/or duration of "lifted finger" observed.

The finding that the roller mouse had more neutral posture and lower forearm muscle load suggests the design and affordance of a pointing device significantly affect the interactions between the

Table 2
Hand Posture: Across participant marginal means (and standard errors) for RMANOVA Device, Task, and their Interaction.

| | Device | | | | p -Value | Task | | Condition x task p -Value | |
|--|---------------------------|---------------------|---------------------|---------------------|---------------------|--------------|-----------|--------------------------------|-------------|
| | p -Value ^{a,b} | Mouse | Track ball | Touchpad | | Roller mouse | Solitaire | | Web surfing |
| Inter-fingertip distance (mm) | | | | | | | | | |
| Thumb to Index | 0.06 | 54 (4) | 62 (4) | 55 (4) | 58 (4) | 0.40 | 56 (4) | 58 (4) | 0.66 |
| Index to Middle | <0.0001 | 37 (2) ^A | 30 (2) ^B | 29 (2) ^B | 21 (2) ^C | 0.03 | 31 (2) | 28 (2) | 0.56 |
| Middle to Ring | <0.0001 | 28 (3) ^A | 28 (3) ^A | 24 (3) ^B | 23 (3) ^B | 0.01 | 27 (3) | 25 (3) | 0.21 |
| Ring to Little | 0.16 | 40 (4) | 42 (4) | 45 (4) | 41 (4) | 0.25 | 44 (4) | 42 (4) | 0.24 |
| MCP joint flexion angle (°) ^c | | | | | | | | | |
| Index | <0.0001 | 27 (3) ^B | 23 (3) ^B | 40 (3) ^A | 40 (3) ^A | 0.09 | 31 (2) | 34 (2) | 0.91 |
| Middle | <0.0001 | 22 (2) ^C | 22 (2) ^C | 39 (2) ^B | 44 (2) ^A | 0.03 | 30 (2) | 33 (2) | 0.58 |
| Ring | <0.0001 | 21 (3) ^C | 17 (3) ^C | 28 (3) ^B | 34 (3) ^A | 0.16 | 24 (3) | 26 (3) | 0.81 |
| Little | 0.18 | 25 (4) | 22 (4) | 26 (4) | 29 (4) | 0.49 | 25 (4) | 26 (4) | 0.80 |

^a Repeated Measures Multivariate ANOVA with participant as a random variable, fixed effects Device (4 levels), Task (2 levels) and their interaction. Bold values indicate a significant effect ($p < 0.05$).

^b For significant main effects, Tukey's Post-Hoc groupings are ranked such that A > B > C > D. Values with the same superscript letters indicate no significant difference.

^c Angle of flexion for metacarpophalangeal (MCP) joints of fingers II-V where 0° indicates the MCP-PIP vector is parallel to the hand plane.

Table 3

Upper Limb Posture: Across participant marginal means (and standard errors) for RMANOVA Device, Task, and their Interaction. All angles were calculated in relation to the reference posture.

| Angle (°) | Device | | | | Tasks | | | Condition × task interaction | |
|----------------------------|------------------------|---------------------|-----------------------|----------------------|-----------------------|---------|-----------|------------------------------|---------|
| | P-value ^{a,b} | Mouse | Track ball mouse | Touchpad | Roller mouse | P-value | Solitaire | Web surfing | P-value |
| Shoulder abduction | <0.0001 | 14 (2) ^A | 13 (2) ^A | 9 (2) ^B | 7 (2) ^B | 0.91 | 11 (2) | 11 (2) | 0.64 |
| Shoulder flexion | <0.0001 | 25 (6) ^A | 23 (6) ^A | 9 (6) ^B | 12 (6) ^B | 0.06 | 16 (6) | 18 (6) | 0.63 |
| Shoulder internal rotation | <0.0001 | 0 (2) ^C | 3 (2) ^C | 29 (2) ^A | 25 (2) ^B | 0.25 | 14 (2) | 15 (2) | 0.19 |
| Elbow flexion | 0.0160 | 12 (3) ^A | 10 (3) ^A | 7 (3) ^{A,B} | 0 (3) ^B | 0.94 | 7 (2) | 7 (2) | 0.91 |
| Forearm supination | 0.1153 | 21 (5) | 7 (5) | 14 (5) | 19 (5) | 0.53 | 16 (3) | 14 (3) | 0.56 |
| Wrist adduction | <0.0001 | 9 (2) ^B | 12 (2) ^A | 1 (2) ^D | 6 (2) ^C | 0.33 | 7 (2) | 7 (2) | 0.30 |
| Wrist extension | 0.0340 | 16 (3) ^B | 19 (3) ^{A,B} | 21 (3) ^A | 19 (3) ^{A,B} | 0.23 | 18 (3) | 19 (3) | 0.37 |

^a Repeated Measures Multivariate ANOVA with participant as a random variable, fixed effects Device (4 levels), Task (2 levels) and their interaction. Bold values indicate a significant effect ($p < 0.05$).

^b For significant main effects, Tukey's Post-Hoc groupings are ranked such that A > B > C > D. Values with the same superscript letters indicate no significant difference.

Table 4

Muscle Activity: Across participant marginal means (and standard errors) for RMANOVA Device, Task, and their Interaction.

| Median EMG activity (% MVC ^c) | Device | | | | Tasks | | | Condition × task interaction | |
|---|------------------------|--------------------------|-------------------------|--------------------------|------------------------|---------------|-----------|------------------------------|---------|
| | P-value ^{a,b} | Mouse | Track ball mouse | Touchpad | Roller mouse | P-value | Solitaire | Web surfing | P-value |
| Middle Trapezius | 0.28 | 2.8 (0.4) | 2.4 (0.4) | 2.4 (0.4) | 2.3 (0.4) | 0.0001 | 2.1 (0.3) | 2.9 (0.3) | 0.89 |
| Anterior Deltoid | 0.47 | 0.8 (0.2) | 0.6 (0.2) | 0.8 (0.2) | 0.8 (0.2) | 0.58 | 0.8 (0.1) | 0.7 (0.1) | 0.31 |
| Middle Deltoid | 0.10 | 1.4 (0.3) | 1.2 (0.3) | 1.6 (0.3) | 1.2 (0.3) | 0.57 | 1.4 (0.3) | 1.3 (0.3) | 0.79 |
| Posterior Deltoid | 0.40 | 1.1 (0.2) | 1.1 (0.2) | 1.2 (0.2) | 1.1 (0.2) | 0.90 | 1.1 (0.2) | 1.1 (0.2) | 0.39 |
| Extensor Digitorum | <0.0001 | 8.7 (0.7) ^B | 10.2 (0.7) ^A | 7.9 (0.7) ^{B,C} | 6.9 (0.7) ^C | 0.83 | 8.4 (0.7) | 8.4 (0.7) | 0.99 |
| Extensor Carpi Ulnaris | <0.0001 | 8.9 (1.9) ^{A,B} | 10.2 (1.9) ^A | 7.8 (1.9) ^B | 8.4 (1.9) ^B | 0.89 | 8.8 (1.8) | 8.8 (1.8) | 0.58 |
| Extensor Carpi Radialis | <0.0001 | 7.6 (1.0) ^A | 8.3 (1.0) ^A | 7.8 (1.0) ^A | 6.6 (1.0) ^B | 0.90 | 7.6 (1.0) | 7.6 (1.0) | 0.73 |
| Extensor Pollicis Brevis | 0.11 | 5.2 (1.0) | 5.1 (1.0) | 5.8 (1.0) | 4.8 (1.0) | 0.14 | 5.5 (1.0) | 5.0 (1.0) | 0.73 |

^a Repeated Measures Multivariate ANOVA with participant as a random variable, fixed effects Device (4 levels), Task (2 levels) and their interaction. Bold values indicate a significant effect ($p < 0.05$).

^b For significant main effects, Tukey's Post-Hoc groupings are ranked such that A > B > C > D. Values with the same superscript letters indicate no significant difference.

^c Maximum Voluntary Contraction.

hand and the device. Similar to a touchpad, the design of the roller mouse allowed users to control cursor movement and clicks using almost any part of their hand without needing to hold the device or click using one specific finger. In fact, eleven out of the twelve users were observed to scroll the roller-bar with all four fingers close together while tapping on the roller-bar without much finger lifting. Hence, the roller mouse allowed for a more neutral hand posture with greater finger flexion and smaller finger spread compared to both a mouse and a trackball. Furthermore, a more neutral hand posture with smaller index-middle finger spread and greater middle and ring finger flexion was associated with the roller mouse compared to a touchpad (Table 3). This may be explained by the design of the roller mouse which allows multiple fingers to operate the device. The touchpad requires users to operate with a single finger while keeping other fingers from contacting the track pad to avoid unintended cursor operation. This causes the greater index-middle finger spread and less flexion

(greater extension) of the middle and ring fingers which we observed.

The shoulder and wrist postures appeared to be associated with the placement of the device. Specifically, devices placed laterally (mouse and trackball) induced greater shoulder abduction, shoulder flexion and rotation; whereas, devices placed near the center-line and close to the body (touchpad and roller mouse) were associated with a more neutral posture. This is consistent with previous work done by Dennerlein et al., in 2006 and Sommerich et al., in 2002, which reported greater shoulder abduction, flexion, external rotation, and ulnar deviation values measured for a mouse located on the right side of the keyboard compared to the center (Dennerlein, 2006; Sommerich, 2002). The effect of pointing device placement on posture and muscle activity of the upper extremity was reduced in the study since a keyboard without a number pad was used instead of a full-size keyboard. Many studies have shown a reduction in shoulder flexion, abduction, external rotation and reduced trapezius and deltoid muscle activities when the number keypad is removed (Sommerich, 2002; Karlqvist et al., 1998). The present study did not find significant difference for middle trapezius and medial deltoid muscle activity across pointing devices, which may be due to participants supporting their forearms on the desk surface and altering the relationship between sustained postures and muscle load (Delisle et al., 2006; Kotani et al., 2007).

The conclusions of this study need to be considered within their limitations. First, this is a laboratory study and is based on an ideal placement for each pointing device. Hence, the generalizability of our results may be limited as the data were collected during a designed set of tasks with an ideal work station setup. The added

Table 5

User Perception: Across participant marginal means (and standard errors) for RMANOVA from participant survey under each condition.

| User's feedback | Device | | | | |
|-----------------|------------------------|------------------------|------------------------|------------------------|--------------------------|
| | P-value ^{a,b} | Mouse | Track ball mouse | Touchpad | Roller mouse |
| Difficulty | <0.001 | 0.6 (0.4) ^B | 2.6 (0.4) ^A | 2.6 (0.4) ^A | 1.5 (0.4) ^{A,B} |
| Discomfort | 0.05 | 0.9 (0.5) | 2.1 (0.5) | 1.2 (0.5) | 0.8 (0.5) |

^a One-way repeated measures ANOVA with participant as a random variable. Values in bold indicate a significant effect ($p < 0.05$).

^b For significant main effects, Tukey's Post-Hoc groupings are ranked such that group A > B > C > D. Values with the same superscript letters indicate no significant difference.

features and settings for the pointing devices may differ from those at a work place, and the experiment did not incorporate psychological pressure of a real world paying job that can also affect the biomechanics of the participants. Secondly, since the relationship between MSD risks and the exposures to non-neutral posture and sustained muscle activity remains unknown, the muscle activity differences across pointing device operations observed in our study may have limited clinical relevance. While no acceptable or unacceptable ranges of posture exist for computing and risk for MSDs, it is generally believed that less neutral (or more awkward postures) and higher muscle activity is associated with higher risk of MSD outcomes. Thus, the direct association and the dose–response effect between a 2%MVC difference observed in our study and the MSD risks remains unknown. Nonetheless, the effect of these small differences in posture and muscle activity may have a greater impact if the duration and frequency of exposure accumulate during a work day. There are also anecdotes in published reports that show alternative pointing devices do help people who have existing upper extremity pain to perform work tasks with less pain (Dardashti, 2003).

In the study, all participants were familiar with the use of the mouse, trackball and touchpad, but had no previous experience working with a roller mouse. However, it was still deemed easy to use compared to the other devices tested. As both a roller mouse and a touchpad can be operated using both hands, potential future studies could focus on forearm and hand posture monitoring of both hands. This study was not a full factorial design in terms of device placement as the experiment focused on devices being used for their standard practice at a work place for right-handed users. Future studies should investigate placing all pointing devices at the same location relative to the user to reduce the effect of device placement on users' shoulder and wrist postures. Finally, using the hand metrics developed in this study, a future comparison between computer pointing devices and tablet computers may be informative to investigate modern computer work and MSDs as tablet computers have become more popular in office and home work settings.

5. Conclusions

Overall, the study demonstrates that different degrees of exposures to non-neutral postures and sustained muscle activity are dependent on the design and the placement of the pointing devices. The findings also suggest that hand postures should be monitored when evaluating pointing devices as the affordance of pointing devices can cause non-neutral finger and hand postures that induce significantly different forearm muscle activities.

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