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 (6males 6 females) was performed where participants completed two mouse-intensive tasks while using a generic mouse, a trackball, a stand-alone touchpad, and a roller-mouse. An optical motion analysis system and an electromyography system monitored right upper extremity postures and muscle activity respectively. Roller-mouse associated with a more neutral hand posture (including lower inter-fingertip spread, finger extension) along with significantly lower forearm extensor muscle activity. Centrally located pointing devices (the touchpad and the roller-mouse) were associated with significantly more neutral shoulder postures and reduced ulnar deviation. In addition, significantly lower forearm extensor muscle activities were observed for these two devices. Despite being unfamiliar with the device, users reported that the roller-mouse was not more difficult to use than the other devices. These results show that both device design and location illicit significantly different postures and forearm muscle activities during use; and suggest that hand posture metrics may be important when critically evaluating pointing devices and their association with musculoskeletal disorders.

Introduction

As the time spent using computers continues to increase both at home and in the workplace, the incidence of musculoskeletal disorder (MSD) associated with using computers has also increased (Cook, 2000). In particular, computer use has been found to be associated with more MSDs in hand and arm than neck and shoulders, with stronger evidence suggesting hours of mouse activity being more of the culprit compared to keyboarding(Gerr, 2004, IJmker, 2007). Prolonged mouse use is associated with risk factors include non-neutral postures, specifically related to extreme ulnar deviation, wrist extension and forearm pronation (Burgess-Limerick, 1999, Jensen, 1998, Karlqvist, 1998), and sustained muscle activity (Jensen, 1998, Sjøgaard, 1998). Therefore, the design and placement of a pointing device (PD) have been explored based on their effect on shoulder and upper limb posture and muscle activity (Burgess-Limerick, 1999, Dennerlein, 2006, Jensen, 1998).

To date these studies have investigated mostly wrist and shoulder postures along with forearm and shoulder muscle activity with only a few investigating hand postures. For example, several studies have shown that placement of the mouse closer to the center line of the operator reduces awkward shoulder and wrist postures as well as reducing muscle activity of both the forearm and the shoulder (Sommerich, 2002, Dennerlein, 2006, Kumar, 2008, Harvey, 1997). Several studies have shown that the design of the pointing device has little effect on neck, shoulder, and upper limb posture and muscle activity however they do have an effect on forearm muscle activity(Lee, 2005, Lee, 2008). The few studies that have investigated hand postures have only explored the button design and placement (Lee, 2007) or the size of notebook mice (Oude Hengel et al., 2008). To the best of our knowledge, very little has been done to explore the effects of different pointing devices on hand (finger) posture providing a better link between the design of the device and the forearm muscle activity.

The aim of this study is to evaluate how both the design and placement of a pointing device affect hand posture in addition to their effects on forearm and shoulder muscle activity and wrist and shoulder posture. The four device designs included a standard mouse and three alternative pointing devices: a trackball mouse, a touchpad, and a roller-style device (roller-mouse) placed according to their standard practice. The study hypothesizes that posture and muscle activity will differ across different pointing device designs and their placement. Specifically, the study expects users to benefit from using alternative input device due to their designed functionality and its interaction with user's hand.

Methods

Twelve right-handed, voluntary human subjects (6 men, 6 women, 28± 7 yr) with no history of neck or upper extremity musculoskeletal injuries participated in 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.

Pointing Device Conditions and Experiment Protocol

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) with a mouse pad, a trackball (Logictech TrackMan Marble), a standalone touchpad device (ADESSO Smart Cat 4-Button Touchpad) , and a roller-style device (Contour RollerMouse Free 2). 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 between the subject and the keyboard, at the center of the table (Figure 1). The order of different pointing device conditions presented to participants was randomized, with a two-minute break provided in between tasks. 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 such that the j-h key of the keyboard was at resting elbow height. The location of the monitor and the keyboard were kept constant. In order to reduce the variability between devices, the cursor movement acceleration function of each pointing device was turned off.

For each device, participants completed two distinctive computer tasks: first three minutes of playing Solitaire and then five minutes of web browsing requiring reading comprehension to progress. Playing solitaire, which requires point-and-click and point-and-drag tasks in various areas of the computer screen, provided an opportunity for participants to familiarize themselves with cursor operations using different devices. . The customized web browsing tasks involved mouse operations of point-and-click, and point-and-drag along with intermittent test fields requiring keyboard operation providing interactions with both the keyboard and the designated pointing device. The web browsing task required approximately 90% mousing and 10% typing operation.

Dependent Variables: Posture

Finger spread and metacarpophalangeal flexion of subjects denoted hand posture for this study. An infrared three-dimensional (3D) motion analysis system (Optotrak Certus, Northern Digital, Ontario, Canada) was used to record hand posture with infrared light-emitting diodes (IRLEDs) mounted on the finger tips (for finger spread) and on the proximal interphalangeal joints (for flexion). The metacarpophalangeal joint of fingers were used as virtual markers digitized with a digitizing probe and tracked by the 3-D analysis system. Finger spread was 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 (Figure 2). Finger flexion for index, middle, ring, and little fingers was the angle between the vector from each virtual marker of the metacarpophalangeal joint to the IR-LED marker mounted on the proximal interphalangeal joint and its projected vector on the right hand plane, which was defined and calculated using the three point cross product vector method based on lateral and medial styloids (locations also tracked using virtual markers) and the metacarpophalangeal joint of the middle finger.

Other upper extremity postures included the wrist, elbow and shoulder joint angles calculated from the 3-D orientation of the hand, distal arm, upper arm, and torso measured with four rigid bodies (modeled using 3 IR-LEDs) mounted on each segment (Winter, 2005). Multiple bony landmarks, including right and left acromion, sternum notch, lateral and medial epicondyle of the right elbow, and radial and ulnar styloid of the right wrist were digitized with a digitizing probe and tracked according to their corresponding IR-LED cluster of each body segment. Data 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 (Winter, 2005). Using the anatomical position and the vertical as reference, joint angles 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, the forearm relative to the upper arm, and the hand/wrist orientation relative to the forearm. 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, Asundi et al., 2012, Winter, 2005).

Dependent Variables: Muscle Activity

During the experiment, surface electromyographic (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), four muscles of the right forearm (extensor digitorum(ED), extensor carpi radialis (ECR), extensor carpi ulnaris (ECU), and Extensor Pollicis Brevis (EPB)). Each electrode placement on the muscles was validated through EMG signal response to its corresponding muscle contractions. 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-second maximum voluntary contractions (MVC) were collected for each muscle. Participants were given 2 minutes between the same muscle contraction and the maximum signal obtained was used as the

MVC reference. Using such reference, all EMG results in this study were calculated and presented in terms of percentage of MVC to compare across subjects.

Dependent Variables: User Experience

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

Data and Statistical Analysis

For all dependent variables, including posture (in angles), muscle activity (in percentage MVC), and user experience (in a scale from 0 to 10), means and standard errors were calculated and used as the outcome measure for each task for each device. Statistical analysis was performed in the statistical package, JMP Pro 10 (SAS), using linear mixed model module; with participant as the random effect while using device and task as fixed effects. Interaction between the device and the task was also tested to identify potential learning effect. Variation for each outcome measure across the four input conditions was tested using repeated measures analysis of variance (RM-ANOVA), with a level of significance (alpha value) 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.

Results

The distances between index and middle finger, and middle and ring finger significantly differed across pointing devices with the smallest distances observed with the roller-mouse (Table 2). The roller-mouse was also associated with the least middle and ring finger extension (maximum flexion) compared to the three other devices tested, along with similar value as touchpad for the lowest level for index finger extension (Table 3).

All of the arm postures recorded significantly differed across pointing devices (Table 4). Shoulder abduction and shoulder flexion were significantly greater for mouse and trackball mouse. Ulnar deviation was found significantly higher for trackball. Shoulder internal rotation, forearm pronation and wrist extension were significantly higher for the touchpad device.

Muscle activity in the forearm muscles (ED, ECU and ECR) differed significantly across pointing devices (Table 5). Roller-mouse was associated with the least muscle effort from ED, ECR; it also required the lowest muscle effort from ECU as the touchpad.

When using the standard mouse, participants reported significantly less difficulty (Table 6) while trackball and touchpad were deemed most difficult; roller-mouse was reported to be no different from the other devices. In addition, mouse and roller-mouse had the lowest discomfort level reported; however, it was no significant with a p-value of 0.054.

Discussion

The goal of this laboratory study was to determine the effects of different pointing devices and their location on posture and muscle activity. The results, consistent with our hypothesis, indicate that exposure to biomechanical risk factors of the hand, forearm and shoulder differ across different pointing device conditions. During the experiment, roller-mouse condition had a more neutral hand posture with significantly lower forearm extensor (ED, ECU, ECR) muscle activity, while both touchpad and roller-mouse conditions were associated with a more neutral wrist and shoulder posture .

The unique aspect of our study comes from our emphasis on hand posture monitoring. Our results suggest that different pointing devices may induce significantly different hand posture and forearm muscle activity. Hand posture is generally influenced by the interaction between user's hand and the pointing device, and this interaction is dictated by how the device is designed to be held and operated. Both a mouse and a trackball required greater inter-finger spreads, greater finger extension, and higher extensor digitorum muscle activity during use. The roller-mouse's design to incorporate a clickable roller-bar with wrist support allows users to operate with lower inter-finger spreads and lower finger flexion along with lower forearm muscle activity. Moreover, while the roller-mouse had the same low level of forearm muscle effort as the touchpad, which can both be explained by the lack of "lifted finger" observed (Lee, 2007), our hand posture monitoring was able to further identify a more neutral hand posture (less finger spread and extension) associated with the roller-mouse. The finding suggests that hand posture measurement could potentially contribute more to pointing device design evaluation comparing to traditional methods that focused mainly on shoulder and forearm postures.

The shoulder and wrist postures were found to associate with the placement of the device. Specifically, devices that were placed on lateral locations, including mouse and trackball, induced greater shoulder abduction, shoulder flexion and rotation; whereas, devices placed near the centerline and close to the body, including touchpad and roller-mouse, were associated with a more neutral posture. This is consistent with Dennerlein's study in 2006 and Sommerich's study 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 comparing to a center-located mouse (Dennerlein, 2006, Sommerich, 2002). Although the present study did not find significant difference for MT and MD muscle activity across pointing devices as Dennerlein's study, this may be due to the fact that subjects supported their forearms on the desk surface during this experiment. Previous studies have shown forearm support can alter the relationship between sustained postures and muscle load (Delisle, 2006, Kotani, 2007). Furthermore, the effect of pointing device placement on posture and muscle activity of the upper extremity was reduced in the study since a keyboard without number pad was used instead of a full-size keyboard. Almost all studies have shown a reduction in shoulder flexion, abduction, external rotation, as well as reduced trapezius and deltoid muscle activities when the number keypad is removed(Sommerich, 2002, Karlqvist, 1998).

The implications of the present study results suggest that alternative devices such as a roller-mouse can affect posture for the better by inducing a more neutral upper extremity posture besides offering hand and arm supports; whereas configurations that increase non-neutral postures may lead to higher risk of MSDs. Laboratory studies have shown wrist postures beyond 15° ulnar deviation results in carpal tunnel pressures of 30 mmHg(Keir, 2007); this pressure level may be high enough to cause nerve dysfunction over a period of repeated exposures (Rempel, 1999). However, these relationships between upper extremity posture and potential MSD development need to be validated in future intervention studies.

The conclusions need to be considered within the limitations of the study. First, the generalizability of our results may be limited as the postures were recorded during a designed set of tasks; thus, the tasks may differ from computer work at a work place and lack the psychological pressures that come with a real world paying job. Secondly, the "neutral ranges" for postures of different body segments are still debatable, and the physiological response and the resulting MSD risks due to the exposures to awkward posture and sustained muscle activity remain unknown. Hence, the clinical significance of the study findings remains to be evaluated. Nonetheless, the effect of these small differences in posture and muscle activity may have a greater impact if the duration and frequency of exposure increases during a work day.

Conclusions

Overall, the study demonstrated that there are different degrees of exposures to non-neutral postures and sustained muscle activity that are dependent on the design and the placement of the pointing devices. For pointing devices selected in our study, the roller-mouse was reported to be easy to use because it was center-located with provided wrist and hand support, which produced more neutral shoulder, wrist and hand postures, along with reduced forearm muscle loads.

References

1. ASUNDI, K., ODELL, D., LUCE, A. & DENNERLEIN, J. T. 2010. Notebook computer use on a desk, lap and lap support: effects on posture, performance and comfort. *Ergonomics,* 53**,** 74-82.
2. ASUNDI, K., ODELL, D., LUCE, A. & DENNERLEIN, J. T. 2012. Changes in posture through the use of simple inclines with notebook computers placed on a standard desk. *Appl Ergon,* 43**,** 400-7.
3. BURGESS-LIMERICK, R., SCHEMMELL, J., SCADDEN, R., PLOOY, A. 1999. Wrist posture during computer pointing device use. *Clin. Biomech,* 14**,** 280–286.
4. COOK, C., BURGESS-LIMERICK, R., CHANG, S. 2000. The prevalence of neck and upper extremity musculoskeletal symptoms in computer mouse users. *Int. J. Ind. Ergon,* 26**,** 347-356.
5. DELISLE, A., LARIVIERE, C., PLAMONDON, A., IMBEAU, D., 2006. Comparison of three computer office workstations offering forearm support: impact on upper limb posture and muscle activation. *Ergonomics,* 49**,** 139-160.
6. DENNERLEIN, J. T. A. J., P.W. 2006. Changes in upper extremity biomechanics across different mouse positions in a computer workstation. *Ergonomics,* 49**,** 1456-1469.
7. GERR, F., MARCUS, M., AND MONTEILH, C. 2004. Epidemiology of musculoskeletal disorders among computer users: lesson learned from the role of posture and keyboard use. *Journal of Electromyography and Kinesiology,* 14**,** 25-31.
8. HARVEY, R. A. P., E. 1997. Surface electromyography and mouse use position. *Ergonomics,* 40**,** 781-789.
9. IJMKER, S., HUYSMANS, M.A., BLATTER, B.M., VAN DER BEEK, A.J., VAN MECHELEN, W., BONGERS 2007. Should office workers spend fewer hours at their computer? A systematic review of the literature. *Occup. Environ. Med.,* 64**,** 211-222.
10. JENSEN, C., BORG, V., FINSEN, L., HANSEN, K., JUUL-KRISTENSEN, B. 1998. Job demands, muscle activityand musculoskeletal symptoms in relation to work with the computer mouse. *Scand. J. Work Environ. Health,* 24**,** 418-424.
11. KARLQVIST, L., HAGBERG, M. AND SELIN, K. 1998. Computer mouse position as a determinant of posture, muscular load and perceived exertion. *Scandinavian Journal of Work Environment & Health,* 24**,** 62-73.
12. KEIR, P. J., BACH, J.M., HUDES, M., REMPEL, D.M., 2007. Guidelines for wrist posture based on carpal tunnel pressure thresholds. *Human Factors,* 49**,** 88-99.
13. KOTANI, K., BARRERO, L.H., LEE, D.L., DENNERLEIN, J.T., 2007. Effect of horizontal position of the computer keyboard on upper extremity posture and muscular load during computer work. *Ergonomics,* 50**,** 1419-1432.
14. KUMAR, R., KUMAR, S. 2008. A comparison of muscular activity involved in the use of two different types of computer mouse. *Int J Occup Saf Ergon,* 14**,** 305-311.

15. LEE, F. J., MCLOONE HE, KOTANI K, DENNERLEIN JT 2007. Alternative computer mouse design and testing to reduce finger extensor muscle activity during mouse use. *Human Factors,* 49**,** 573-584.
16. LEE, T. 2005. Ergonomic comparison of operating a built-in touch-pad pointing device and a trackball mouse on posture and muscle activity. *Percept Mot Skills,* 101**,** 730-736.
17. LEE, Y., SU, MC 2008. Design and validation of a desk-free and posture-independent input device. *Applied Ergonomics,* 39**,** 399-406.
18. OUDE HENGEL, K. M., HOUWINK, A., ODELL, D., VAN DIEEN, J. H. & DENNERLEIN, J. T. 2008. Smaller external notebook mice have different effects on posture and muscle activity. *Clin Biomech (Bristol, Avon),* 23**,** 727-34.
19. REMPEL, D., DAHLIN, L., LUNDBORG, G. 1999. Pathophysiology of nerve compression syndromes: response of peripheral nerves to loading. *The Journal of Bone & Joint Surgery* 81**,** 1600-1610.
20. SJØ GAARD, G., SØ GAARD, K. 1998. Muscle injury in repetitive motion disorders. *Clin. Orthop. Relat. Res.,* 351**,** 21-31.
21. SOMMERICH, C. M., HEATHER STARR, CHRISTY A. SMITH, CARRIE SHIVERS 2002. Effects of notebook computer configuration and task on user biomechanics,productivity,and comfort. *International Journal of Industrial Ergonomics,* 30**,** 24.
22. WINTER, D. 2005. Biomechanics and Motor Control of Human Movement-Third Edition.

Table 1. Anthropometric Measures across All Subjects

	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)

Table 2

Hand Posture: Across subject least square's means and standard deviations for RMANOVA from finger distance during each task

	Condition					Tasks			Condition x Task Interaction
Tip Distance (mm)	P-Value[1,2]	Mouse	Track Ball Mouse	Touchpad	Roller Mouse	P-Value	Solitaire	Web Surfing	P-Value
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

[1]Repeated Measures ANOVA with subject as a random variable, condition of 4 pointing devices and task as fixed effects.

[2]For each dependent variables, values with the same superscript letters indicate no significant difference and groupings are ranked such that A>B>C>D, evaluated using Tukey's Post-HOC

Table 3

Finger Flexion: Across subject least square's means and standard deviations for RMANOVA from finger flexion during each task

	Condition					Tasks			Condition x Task Interaction
Angle of Knuckle and Palm (°)*	P-Value[1,2]	Mouse	Track Ball Mouse	Touchpad	Roller Mouse	P-Value	Solitaire	Web Surfing	P-Value
Index Finger	**<0.0001**	27(3)[B]	23(3)[B]	40(3)[A]	40(3)[A]	0.09	31(2)	34(2)	0.91
Middle Finger	**<0.0001**	22(2)[C]	22(2)[C]	39(2)[B]	44(2)[A]	0.03	30(2)	33(2)	0.58
Ring Finger	**<0.0001**	21(3)[C]	17(3)[C]	28(3)[B]	34(3)[A]	0.16	24(3)	26(3)	0.81
Little Finger	0.18	25(4)	22(4)	26(4)	29(4)	0.49	25(4)	26(4)	0.80

[1]Repeated Measures ANOVA with subject as a random variable, condition of 4 pointing devices and task as fixed effects.

[2]For each dependent variables, values with the same superscript letters indicate no significant difference and groupings are ranked such that A>B>C>D, evaluated using Tukey's Post-HOC.

*Signifies flexion angle between vector of finger mcp to proximal knuckle and the hand plain, with 0 degree being no finger flexion.

Table 4

Arm Posture: Across subject least square's means and standard deviations for RMANOVA from arm posture during each task

	Condition					Tasks			Condition x Task Interaction
Arm Angle (°)	P-Value[1,2]	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**	78(3)[B]	80(3)[A,B]	83(3)[A,B]	90(3)[A]	0.97	83(2)	83(2)	0.93
Forearm Pronation	**<0.0001**	159(13)[B]	161(13)[B]	201(13)[A]	228(13)[A]	0.85	188(11)	186(11)	0.97
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

[1]Repeated Measures ANOVA with subject as a random variable, condition of 4 pointing devices and task as fixed effects.

[2]For dependent variables, values with the same superscript letters indicate no significant difference and groupings are ranked such that A>B>C>D, evaluated using Tukey's Post-HOC

Table 5.

Muscle Activity: Across subject least square's means and standard deviations for RMANOVA from EMG data during each task

	Condition					Tasks			Condition x Task Interaction
Percentage MVC[3]	P-Value[1,2]	Mouse	Track Ball Mouse	Touchpad	Roller Mouse	P-Value	Solitaire	Web Surfing	P-Value
Middle Trapizius	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	**<0.001**	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

[1]Repeated Measures ANOVA with subject as a random variable, condition of 4 pointing devices and task as fixed effects.

[2]For dependent variables, values with the same superscript letters indicate no significant difference and groupings are ranked such that A>B>C>D, evaluated using Tukey's Post-HOC

[3]Maximum Voluntary Contraction

Table 6.

User Feedback: Across subject least square's means and standard deviations for RMANOVA from subject survey under each condition

	Condition				
User's Feedback	P-Value[1,2]	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)

[1]Repeated Measures ANOVA with subject as a random variable, condition of 4 pointing devices and task as fixed effects.

[2]For each dependent variables, values with the same superscript letters indicate no significant difference and groupings are ranked such that A>B>C>D, evaluated using Tukey's Post-HOC

Figure 1Workstation arrangements in the four experimental conditions tested. Subjects were free to adjust location slightly for both mouse and trackball; whereas, touch pad and roller-style mouse were kept stationary

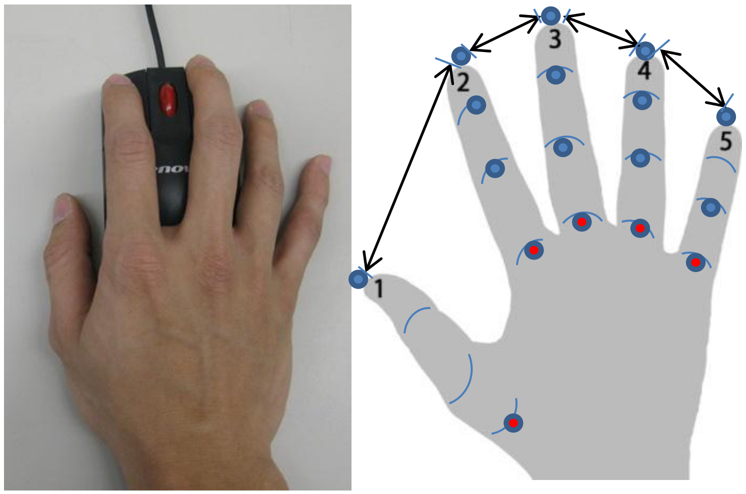

Figure 2Marker Locations for Finger Spread