Available online at www.sciencedirect.com

ScienceDirect

Clinical Biomechanics 23 (2008) 727–734

CLINICAL BIOMECHANICS

www.elsevier.com/locate/clinbiomech

Smaller external notebook mice have different effects on posture and muscle activity

Karen M. Oude Hengel [a,b], Annemieke Houwink [a,b], Dan Odell [c], Jaap H. van Dieën [a], Jack T. Dennerlein [b,*]

[a] *Faculty of Human Movement Science, VU University Amsterdam, Van der Boechorststraat 9, 1081 BT Amsterdam, The Netherlands*
[b] *Department of Environmental Health, Harvard School of Public Health, 665 Huntington Avenue, Boston, MA 02115, USA*
[c] *Microsoft Corporation, One Microsoft Way, Redmond, WA 98052, USA*

Received 21 September 2007; accepted 28 January 2008

Abstract

Background. Extensive computer mouse use is an identified risk factor for computer work-related musculoskeletal disorders; however, notebook computer mouse designs of varying sizes have not been formally evaluated but may affect biomechanical risk factors.

Methods. Thirty adults performed a set of mouse tasks with five notebook mice, ranging in length from 75 to 105 mm and in width from 35 to 65 mm, and a reference desktop mouse. An electro-magnetic motion analysis system measured index finger (metacarpophalangeal joint), wrist and forearm postures, and surface electromyography measured muscle activity of three extensor muscles in the forearm and the first dorsal interrosseus.

Findings. The smallest notebook mice were found to promote less neutral postures (up to 3.2° higher metacarpophalangeal joint adduction; 6.5° higher metacarpophalangeal joint flexion, 2.3° higher wrist extension) and higher muscle activity (up to 4.1% of maximum voluntary contraction higher wrist extensor muscle activity). Participants with smaller hands had overall more non-neutral postures than participants with larger hands (up to 5.6° higher wrist extension and 5.9° higher pronation); while participants with larger hands were more influenced by the smallest notebook mice (up to 3.6° higher wrist extension and 5.5% of maximum voluntary contraction higher wrist extensor values). Self-reported ratings showed that while participants preferred smaller mice for portability; larger mice scored higher on comfort and usability.

Interpretation. The smallest notebook mice increased the intensity of biomechanical exposures. Longer term mouse use could enhance these differences, having a potential impact on the prevention of work-related musculoskeletal disorders.

Keywords: Notebook; Computer mouse; Muscle activity; Posture; Hand size

1. Introduction

Computer use on the work floor has increased enormously in the last thirty years, with over half of all employees in the United States using a computer (Bureau of Labor Statistics, 2005). The number of people who are using a portable computer (notebook) is also rising. Designed for mobile workers, notebooks are now often used as a replacement for the desktop computer (Haesman et al., 2000).

Duration of computer use and specifically duration of computer mouse use are often associated with a high prevalence of upper extremity and neck musculoskeletal symptoms and disorders (Cook et al., 2000; IJmker et al., 2007). Biomechanical risk factors include non-neutral postures, specifically extreme ulnar deviation, wrist extension and forearm pronation (Jensen et al., 1998; Karlqvist et al., 1994) and sustained muscle activity (Gissel, 2000; Hägg, 2000); which are observed in computer work

---

[*] Corresponding author.
E-mail address: jax@hsph.harvard.edu (J.T. Dennerlein).

0268-0033/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.clinbiomech.2008.01.013

(Sjøgaard and Søgaard, 1998) and mouse work (Burgess-Limerick et al., 1999; Jensen et al., 1998).

The design of notebook computers provides ergonomic challenges for the user. More non-neutral postures and muscle load in neck and upper extremities were observed and more discomfort was reported when using a notebook than when using a desktop computer (Straker et al., 1997; Villanueva et al., 1998). Using the internal pointing device of a notebook computer was associated with more discomforts (Sommerich et al., 2002). As a result, recent prevention efforts have focused on using external input devices with notebook computers. In addition, there are several different external notebook mouse designs on the market that are often small in size to improve portability.

The effect of the design of input devices on biomechanical factors has long been explored. For example, Aarås and Ro (1997) found that the intensity and frequency of pain in the upper extremity was reduced after six months of using a joystick mouse that promoted less forearm pronation. Burgess-Limerick et al. (1999) found a decreased ulnar deviation but increased wrist extension when using a trackball device. However, very little has been done to explore the size of a mouse, hand size and their effects on biomechanical factors. Recently Johnson and Blackstone (2007) reported the effect of different mouse sizes relative to hand size; when using a standard mouse, greater ulnar deviation was observed for children compared to adults. When using a smaller mouse, smaller hands showed a decreased ulnar deviation compared to a standard mouse.

Therefore, the aim of this study is to determine the effects of different sized notebook mice on finger, wrist and forearm posture and muscle activity. Through a repeated measures laboratory experiment this study compares the intensity of exposures across different notebook mouse designs. The study hypothesizes that posture and muscle activity will differ across different notebook mouse designs and that hand size also influences posture and muscle activity. Specifically, the study expects that smaller hands will benefit from using smaller mice.

2. Methods

2.1. Participants

Thirty healthy, right handed adults (15 males and 15 females) participated in this study (mean age 29.8 yr., range 19–58 yr.; mean hand length 18.2 cm, range 16.0–21.0 cm). Based on the median value of hand length measurements (distance between the crease of the wrist and the tip of the middle finger), participants were categorized as having smaller or larger hands. Average hand length for the smaller hands group was 17.0 cm and for the larger hands group 19.4 cm. All participants provided signed consent and all experimental procedures were approved by the Harvard School of Public Health Human Subjects Committee.

2.2. Experimental design

Participants performed a standard set of pointing tasks with six different computer mice, while muscle activity and posture of the forearm and hand were measured. The six commercially available mice included one reference desktop mouse (Microsoft Wireless Optical Mouse 2000) and five notebook mice (Table 1; Fig. 1). The five notebook mice were (A) the Logitech VX Revolution Cordless Laser Mouse, (B) the Microsoft Mobile Memory Mouse 8000, (C) the Microsoft Notebook Optical Mouse 3000, (D) the Iogear Wireless Bluetooth Optical Mini Mouse, and (E) the Targus PAUM01U Ultra Mini Retractable [cord] Optical Mouse. The mice had different looks with regards to color, material and buttons; however, the mice were selected to differ most with regards to size and symmetry, while trying to keep other features as similar as possible. The software speed settings were adjusted to the same level and observed control display gains were similar across all mice. The order of the mice were balanced and randomly assigned to participants.

For all tasks, participants were seated at a workstation that consisted of a chair with no armrests, a work surface and a flat-panel monitor on a monitor stand. The components were all adjusted to each individual such that the participant's thighs were horizontal to ground and the table surface was at resting elbow height. The keyboard was centered with the participant and its position marked on the work surface. For each experimental condition, the mouse was positioned to the right of the keyboard.

The standard pointing tasks consisted of a large-sized point-and-click task, a small-sized point-and-click task, a dragging task and a steering task. Each task was omnidirectional and lasted for approximately one minute. The large-sized and small-sized point-and-click tasks and the dragging task consisted of evenly spaced target circles

Table 1
Mouse design features

ID	Length (mm)	Width (mm)	Height (mm)	*W*:*L* ratio	*H*:*L* ratio	*H*:*W* ratio	Weight (grams)	Symmetry
R	121	64	38	1:1.9	1:3.2	1:1.7	139	Symmetrical
A	105	64	41	1:1.6	1:2.6	1:1.6	116	Asymmetrical
B	84	65	41	1:1.3	1:2.0	1:1.6	82	Asymmetrical
C	90	52	34	1:1.7	1:2.6	1:1.5	57	Symmetrical
D	87	36	31	1:2.4	1:2.8	1:1.2	74	Symmetrical
E	75	35	23	1:2.1	1:3.3	1:1.5	28	Asymmetrical

R = reference mouse; *W*:*L* ratio = width:length ratio; *H*:*L* ratio = height:length ratio; *H*:*W* ratio = height:width ratio.

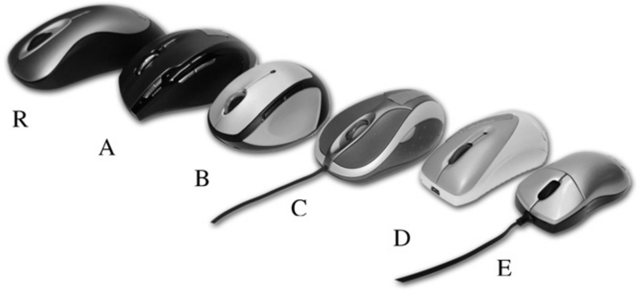

Fig. 1. Frontal-lateral view of the mice. From left to right: reference mouse, mouse A, mouse B, mouse C, mouse D, mouse E.

arranged in a large circle with a radius of 356 pixels. The target circles of the large-sized point-and-click task and the dragging task had a radius of 21 pixels whereas the target circles of the small-sized point-and-click tasks had a radius of 6 pixels. For the large-sized and small-sized point-and-click tasks, participants had to click on an active circle; for the dragging task, participants had to select (press the button) an active circle and drag it to the opposite side of the large circle (release the button). For the steering task, participants had to select a small target circle (9 pixels radius) and then move the circle from one point to another while maintaining its position within the boundaries of the tunnel (20 pixels wide and 120 pixels long). All tasks were presented via a custom developed software program in LabView (National Instruments, Austin, Texas, USA) on a monitor set to 1024 by 768 pixels. To measure performance, the program recorded the time to complete each task. Participants were told before the tasks to be as fast as possible while remaining accurate. They practiced each task with a desktop computer mouse that was not entered in the study. Participants also practiced with each mouse while being instructed to "hold and use the mouse as they thought they should when looking at the design".

2.3. Measuring instruments

During the experiment, surface electromyographic (EMG) electrodes (DE-2.1 Single Differential Electrode; Delsys, Boston, Massachusetts, USA) measured muscle activity for three forearm muscles and one hand muscle of the right arm. Electrodes were placed on the muscle bellies of the Extensor Carpi Radialis (ECR), the Extensor Digitorum Communis (EDC), the Extensor Carpi Ulnaris (ECU) and the First Dorsal Interosseus (FDI), as recommended by Perotto (1994). Placements were validated through palpation and signal response to isometric test contractions. The EMG signals were amplified and band-pass filtered (20–450 Hz, Bagnoli-eight amplifier; Delsys, Boston, Massachusetts, USA) before being digitally recorded at a sample rate of 1000 samples per second. To obtain data for normalizing the EMG amplitude, three 5-s maximum voluntary contractions were collected for each muscle. Participants rested between contractions for one minute.

An electro-magnetic motion analysis system (Minibird; Ascension Technology, Burlington, Vermont, USA) measured position and orientation of the forearm, hand and index finger of the right arm at a sample rate of 20 samples per second. One small sensor (9 × 5 × 5 mm) was placed on the proximal phalanx of the index finger and two larger ones (12 × 7 × 7 mm) were placed on the metacarpus (midway on the third metacarpal bone) and on the forearm (between ulna and radius, on one third of the forearm as seen from the wrist). The Minibird system provided the orientation of each segment relative to the global reference frame. From these orientations, rotation matrices describing the orientation of the finger relative to the hand and the hand relative to the forearm were calculated. The associated Euler angles were calculated from these matrices representing the relative joint angles. Before starting the data collection, a reference position of the finger, hand and arm was recorded using a calibration fixture as described by Jonsson and Johnson (2001). The neutral postures of the metacarpophalangeal (MCP) joint and wrist were then defined as the index finger and hand aligned with the forearm with the palm of the hand flat on the calibration fixture and the forearm fully pronated. For the forearm, this position was defined as 90° pronation; therefore the neutral posture was defined as the forearm vertical on the work surface with the thumb pointing upward.

To measure the participants' preference and comfort, participants completed a questionnaire after each trial and then ranked the six mice after completing the protocol. The questionnaire consisted of four questions about usability and comfort with a seven point Likert response scale and two questions on difficulty and fatigue with a 10 cm Borg CR10 scale (Borg, 1990) where the verbal anchors were adjusted from 'strong' to 'difficult' and 'fatigued'.

2.4. Data processing and statistical analysis

The EMG amplitude was represented by a root mean square value calculated from the raw data over a 0.2 s moving window and then normalized by the root mean square value obtained during the maximum voluntary contractions. The maximum voluntary contraction value was the highest root mean square amplitude averaged from three maximum voluntary contractions. Relative joint angles of the MCP, wrist and forearm were calculated from the orientations of the finger, hand, and forearm Minibird sensors.

For each subject, mouse and task, summary statistics were calculated for postural data, muscle activity and task performance. The first and last ten seconds of each task were removed to ensure that the data contained actual mouse work. The summary statistics included mean, 10th, 50th and 90th percentile of the EMG amplitude and the relative joint angles. For the EMG values, Jonsson (1988) defined the 10th percentile as the static component of muscle load, and the 50th and 90th percentile as the dynamic components. For the postural data, the 10th to 90th percentile represented the joint's range of motion. For performance the average movement time was calculated, which was defined as the average time between each successful click, drag and tunnel steer.

Differences in the EMG and postural measures across all mice were analyzed using a repeated measures ANOVA; post-hoc pairwise comparisons were made using multiple t-tests for all mouse pairs with Bonferroni adjustment. To determine differences between all mice for smaller and larger hands, a between factor was added to the repeated measures ANOVA. To distinguish differences between mice, separate repeated measures ANOVA's were performed for both hand size groups. Subjective questionnaires and rankings across all mice were analyzed using a Kruskal–Wallis ANOVA. To distinguish differences between mice, separate Mann–Whitney U-tests were performed for both hand size groups. All statistics were performed using SPSS 13.0. Significance was noted for a probability of a false positive being less than 5% ($P < 0.05$).

3. Results

In general, postures were similar across the reference mouse and mice A, B, and C whereas mice D and E demonstrated some significant differences (Table 2). For MCP and wrist, mouse D had more non-neutral postures than the other mice. Mice D and E had higher MCP adduction (up to 3.2°) than the reference mouse and mouse C ($P < 0.001$). Mouse E also had higher MCP flexion (up to 6.5°) than the other mice ($P < 0.0001$). For wrist posture, mouse D had higher wrist extension than the reference mouse and mice B and C (up to 2.3° higher) for the 90th percentile ($P < 0.001$). For the 90th percentile ulnar deviation, the reference mouse was lower than mouse B and D ($P < 0.002$), with the largest difference with mouse D (3.2° lower). Forearm pronation showed no significant differences across mice. Range of motion of the MCP and wrist joints showed the same pattern of differences across mice; mouse D had higher values than the other mice ($P < 0.0001$). Range of motion for forearm pronation was higher for mouse A and D than the other mice ($P < 0.0001$), and these were not significantly different from each other.

In general, the notebook mice had lower FDI muscle activity compared to the reference mouse whereas for the finger extensor and for two of the wrist extensor muscles, mouse D had the highest activity levels (Fig. 2). For the FDI muscle activity, the reference mouse was higher than mouse A and D for the 10th percentile and higher than mouse A for the 50th and 90th percentile ($P < 0.01$). Mouse D was lower than mouse B and C for the 10th percentile ($P < 0.0001$). For the EDC muscle activity, the 90th

Table 2
Postural values (10th, 50th and 90th percentile) and dynamic value (range of motion (ROM)) with standard errors for right hand and forearm averaged across all tasks

	Percentile	P	Mouse					
			Reference	A	B	C	D	E
MCP								
Flexion (extension)	10th	<0.0001	22.0 (1.5)^{A,D}	17.1 (1.8)^{R,C,E}	19.5 (1.7)^{C,E}	22.4 (1.4)^{A,B,D}	19.3 (1.6)^{R,C,E}	23.9 (1.5)^{B,C,D}
	50th	<0.0001	25.1 (1.5)^{A}	21.1 (1.7)^{R,C,E}	22.8 (1.7)^{C,E}	25.4 (1.5)^{A,B,E}	23.8 (1.6)^{E}	27.7 (1.5)^{A,B,C,D}
	90th	<0.0001	27.9 (1.5)^{A,E}	24.6 (1.7)^{R,C,D,E}	25.9 (1.8)^{E}	28.2 (1.5)^{A,E}	27.8 (1.6)^{A,E}	31.1 (1.5)^{A,B,C,D}
	ROM	<0.0001	5.9 (0.3)^{A,D}	7.5 (0.5)^{R,C}	6.3 (0.4)^{D}	5.8 (0.3)^{A,D,E}	8.5 (0.6)^{R,B,C}	7.1 (0.5)^{C}
Adduction (abduction)	10th	0.0001	8.9 (1.4)^{D,E}	9.1 (1.4)	8.6 (1.4)	9.1 (1.4)^{D,E}	10.5 (1.4)^{R,C}	10.8 (1.5)^{R,C}
	50th	<0.0001	10.5 (1.5)^{D,E}	11.2 (1.4)	10.5 (1.4)^{D}	10.6 (1.4)^{D,E}	12.9 (1.4)^{R,B,C}	12.8 (1.5)^{R,C}
	90th	<0.0001	12.2 (1.5)^{D,E}	13. 5 (1.4)	12.6 (1.4)^{D}	12.4 (1.4)^{D,E}	15.4 (1.4)^{R,B,C}	14. 9 (1.5)^{R,C}
	ROM	<0.0001	3.3 (0.2)^{A,B,D,E}	4.4 (0.2)^{R,C,D}	4.1 (0.2)^{R,C,D}	3.3 (0.1)^{A,B,D,E}	4.9 (0.2)^{R,A,B,C,E}	4.1 (0.2)^{R,C,D}
Wrist								
Extension (flexion)	10th	0.7966	28.8 (1.1)	28.0 (1.3)	28.2 (1.4)	28.2 (1.3)	28.5 (1.2)	28.1 (1.4)
	50th	0.0688	31.2 (1.2)	31.0 (1.3)	30.5 (1.3)	30.5 (1.3)^{D}	32.0 (1.2)^{C}	30.9 (1.4)
	90th	0.0003	33.3 (1.2)^{D}	33.2 (1.3)	32.5 (1.3)^{D}	32.4 (1.3)^{D}	34.7 (1.2)^{R,B,C}	33.2 (1.4)
	ROM	<0.0001	4.5 (0.3)^{A,D}	5.2 (0.3)^{R,B,C}	4.4 (0.3)^{A,D}	4.1 (0.2)^{A,D,E}	6.2 (0.5)^{R,B,C,E}	5.0 (0.4)^{C,D}
Ulnar (radial) deviation	10th	0.0179	−1.8 (1.6)	−1.4 (1.7)	0.6 (1.4)	−0.3 (1.6)	−1.4 (1.6)	−0.6 (1.6)
	50th	0.0590	0.9 (1.7)	1.9 (1.8)	3.2 (1.5)	2.3 (1.7)	2.5 (1.6)	2.5 (1.7)
	90th	0.0017	3.5 (1.7)^{B,D}	5.3 (1.9)	6.1 (1.6)^{R}	5.0 (1.8)	6.7 (1.7)^{R}	5.8 (1.8)
	ROM	<0.0001	5.3 (0.2)^{A,D,E}	6.6 (0.3)^{R,B,C,D}	5.5 (0.3)^{A,D,E}	5.2 (0.3)^{A,D,E}	8.1 (0.3)^{R,A,B,C,E}	6.4 (0.3)^{R,B,C,D}
Forearm								
Pronation (supination)	10th	0.2638	85.0 (1.5)	83.0 (1.6)	83.8 (1.5)	84.2 (1.4)	83.9 (1.4)	83.7 (1.4)
	50th	0.3727	86.4 (1.5)	84.8(1.5)	85.3 (1.5)	85.5 (1.5)	85.9 (1.4)	85.2 (1.4)
	90th	0.4246	87.8 (1.6)	86.7 (1.5)	86.7 (1.6)	86.9 (1.5)	87.8 (1.5)	86.9 (1.4)
	ROM	<0.0001	2.8 (0.1)^{A,D}	3.7 (0.2)^{R,B,C}	2.9 (0.2)^{A,D}	2.7 (0.2)^{A,D}	3.9 (0.3)^{R,B,C}	3.3 (0.3)

Positive values indicate flexion and adduction for MCP (metacarpophalangeal joint), extension and ulnar deviation for the wrist and pronation for the forearm.

Superscript letters denote significant differences; for example the 10th percentile for MCP flexion for the reference mouse, 22.0(1.5)^{A,E} means that this value is significantly different from the values for the 10th percentile for MCP flexion for mice A and E.

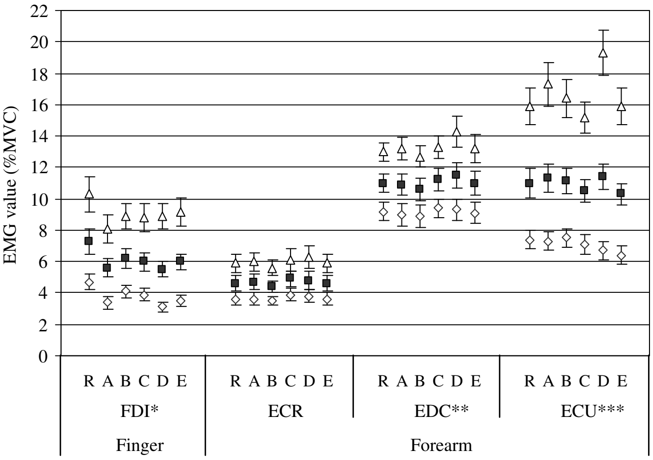

Fig. 2. Electromyographic (EMG) amplitude distribution (10th (◇), 50th (■) and 90th (Δ) percentile) values in percentage of maximum voluntary contraction (%MVC) for the hand (FDI) and forearm muscles (ECR, EDC and ECU). * Significant differences observed across mice for the 10th, 50th and 90th percentile ($P < 0.0065$). ** Significant differences observed across mice for the 90th percentile ($P < 0.0044$). *** Significant differences observed across mice for the 10th and 90th percentile ($P < 0.0050$). R = reference mouse See text for more details.

percentile and the mean value of mouse D were higher than mouse B and E ($P < 0.046$). For the ECU muscle activity, the mean value of mouse D was higher than mouse E and the 90th percentile was higher than mouse B and E ($P < 0.029$). For the 10th percentile of the ECU, mouse E was lower than the reference mouse and mouse B and C.

For the ECR muscle, nine participants were not entered in the analysis because there was interference observed that was larger than the EMG signal. Among the remaining participants no significant differences were found across the mice for the ECR muscle.

Participants rated mouse A the highest and D and E the lowest on usability and comfort but rated A the lowest and D and E highest for portability (Table 3). Mouse D was also rated the most difficult to use and the most fatiguing ($P < 0.001$). Participants rated mouse A the highest on appealing and usable looks ($P < 0.001$). After using all mice, participants ranked mouse D and E the lowest on comfort and usability (2.0 and 2.2, respectively) and mouse A the highest (5.3). For portability, mouse D and E were ranked the highest (5.3 and 5.4, respectively) and the reference mouse and mouse A the lowest (1.3 and 2.1, respectively).

Average movement times were similar except for mouse C, which had the fastest average movement time. Mouse C (1.12 s) had a faster movement time than the reference mouse (1.20 s) and mouse B (1.22 s) ($P < 0.001$); however movement time was not different from mouse A (1.15 s) and mouse D (1.16 s).

Participants with smaller hands had more non-neutral postures than participants with larger hands (Table 4). Participants with smaller hands had higher wrist extension and forearm pronation (up to 5.6° and 5.9°, respectively; $P < 0.045$). Furthermore, interaction effects existed between mice and hand size for wrist extension ($P < 0.042$). Participants with larger hands had more wrist extension for

Table 3

Self-reported subjective ratings across mice on a seven point Likert scale (questions 1–4), the Borg CR 10 scale (questions 5 and 6) and an overall ranking

Parameter	Mouse						
	P	Reference	A	B	C	D	E
Questionnaire							
1. The mouse is easy to hold [1 7][1]	<0.0001	5.0 (0.3)^{D,E}	5.9 (0.2)^{D,E}	5.1 (0.3)^{D,E}	4.7 (0.3)^{D,E}	2.8 (0.3)^{R,A,B,C}	3.1 (0.4)^{R,A,B,C}
2. This mouse feels comfortable [1 7][1]	<0.0001	4.7 (0.3)^{D,E}	5.7 (0.3)^{D,E}	4.9 (0.3)^{D,E}	4.4 (0.3)^{D,E}	2.6 (0.3)^{R,A,B,C}	3.0 (0.4)^{R,A,B,C}
3. I quickly adjusted to using this mouse [1 7][1]	0.0009	5.1 (0.3)	5.7 (0.2)^{A}	5.3 (0.3)	5.2 (0.3)	4.2 (0.3)^{A}	4.6 (0.3)
4. I would use this mouse if I had a notebook computer [1 7][1]	0.0001	3.3 (0.4)^{A}	5.0 (0.3)^{R,D,E}	4.2 (0.4)^{D}	4.2 (0.4)^{D}	2.9 (0.4)^{A,B,C}	3.1 (0.4)^{A}
5. How difficult was it to perform all tasks? [0 10][2]	<0.0001	2.1 (0.3)	1.4 (0.2)^{D}	1.7 (0.3)	1.5 (0.2)^{D}	2.6 (0.3)^{A,C}	2.3 (0.4)
6. How fatigued are you? [0 10][3]	0.0001	1.8 (0.3)	1.2 (0.2)^{D}	1.7 (0.3)	1.4 (0.2)^{D}	2.5 (0.4)^{A,C}	1.9 (0.4)
Overall rank							
1. Comfort [1 6][4]	<0.0001	3.9 (0.3)^{A,D,E}	5.3 (0.2)^{R,C,D,E}	4.4 (0.2)^{D,E}	3.5 (0.2)^{A,D,E}	2.0 (0.2)^{R,A,B,C}	2.2 (0.2)^{R,A,B,C}
2. Usability [1 6][4]	<0.0001	3.6 (0.3)^{A}	4.9 (0.3)^{R,C,D,E}	4.0 (0.3)^{D}	3.4 (0.2)^{A}	2.5 (0.3)^{A,B}	2.8 (0.4)^{A}
3. Portability [1 6][4]	<0.0001	1.3 (0.1)^{A,B,C,D,E}	2.1 (0.1)^{R,B,C,D,E}	3.4 (0.1)^{R,A,D,E}	3.3 (0.2)^{R,A,D,E}	5.3 (0.1)^{R,A,B,C}	5.4 (0.2)^{R,A,B,C}

Questions were given after using each mouse during the computer tasks and overall rank after using all mice.

Superscript letters denote significant differences between values, for example question 2 for the reference mouse, 5.9(0.2)^{B,D,E} means this value was significantly different from mouse B, D and E.

[1] 1: strongly disagree – 7: strongly agree.

[2] 0: not difficult at all – 10: very, very difficult.

[3] 1: not fatigued at all – 10: very, very fatigued.

[4] 1: least favorite – 6: favorite.

Table 4
Postural values (10th, 50th, 90th percentile and range of motion (ROM)) with standard errors for right hand and forearm averaged across all mice differed between hand sizes (main effects)

	Hand size	Posture				
		MCP *F* (*E*)	MCP Ad (Ab)	Wrist *E* (*F*)	Wrist *U* (*R*)	Forearm *P* (*S*)
10th	Small	20.2 (2.1)	11.1 (1.9)	31.0 (1.6)*	−0.2 (2.2)	86.7 (1.8)*
	Large	21.2 (2.1)	7.8 (1.9)	25.6 (1.6)*	−1.4 (2.2)	81.2 (1.8)*
	P	0.7300	0.2402	0.0245	0.7173	0.0442
50th	Small	23.6 (2.1)	13.1 (2.0)	33.8 (1.6)*	2.9 (2.3)	88.4 (1.9)*
	Large	25.0 (2.1)	9.7 (2.0)	28.3 (1.6)*	1.5 (2.3)	82.6 (1.9)*
	P	0.6563	0.2175	0.0247	0.6528	0.0363
90th	Small	26.9 (2.2)	15.3 (2.0)	36.0 (1.6)*	6.2 (2.4)	90.1 (1.9)*
	Large	28.2 (2.2)	11.7 (2.0)	30.4 (1.6)*	4.6 (2.4)	84.2 (1.9)*
	P	0.6624	0.2137	0.0239	0.6188	0.0378
ROM	Small	6.7 (0.5)	4.1 (0.2)	5.0 (0.4)	6.5 (0.4)	3.4 (0.2)
	Large	7.0 (0.5)	3.9 (0.2)	4.8 (0.4)	5.9 (0.4)	3.0 (0.2)
	P	0.6755	0.4604	0.8377	0.2857	0.2692

Positive values indicate flexion and adduction for MCP (metacarpophalangeal joint), extension and ulnar deviation for the wrist and pronation for the forearm.

* denotes significant differences between hand sizes averaged across all mice. *F* (*E*) = Flexion (extension); Ad (Ab) = Adduction (abduction); *E* (*F*) = Extension (flexion); *U* (*R*) = Ulnar (radial) deviation; *P* (*S*) = Pronation (supination).

mouse D than for the other mice (up to 3.6° higher). Such difference across mice was not observed for participants with smaller hands. No significant differences were found for EMG activity between hand sizes. There were, however, interaction effects between mice and hand size for the mean, 50th and 90th percentile of muscle activity of the EDC and ECU ($P < 0.044$). Participants with larger hands had higher muscle activity for mouse D compared to the other mice and no differences across mice were observed for participants with smaller hands. The ratings also showed significant differences between hand sizes. Participants with larger hands found it more difficult to work with mouse B, C and D than participants with smaller hands ($P < 0.048$). Furthermore, mouse A was ranked higher by participants with larger hands than participants with smaller hands on comfort, usability and portability ($P < 0.01$).

4. Discussion

The goal of this study was to determine the effects of different sized notebook mice on posture and muscle activity. The results of this study indicate that there are differences in biomechanical exposures across notebook mice. In general, the smallest mouse designs and participants with smaller hands had less neutral postures and higher muscle activities. Surprisingly, participants with smaller hands did not benefit from using the smaller mice; however participants with larger hands had more difficulty with smaller mice than with the larger mice.

Values for wrist extension for all notebook mice were higher than found in previous studies on mouse use (Burgess-Limerick et al., 1999; Dennerlein and Johnson, 2006; Keir et al., 1999). These differences could have been affected by many factors, for instance differences in protocol or measuring methods. Differences in mice could also be a factor, as the mice in the present study were smaller than in other studies. In fact mouse D, one of the smaller mice tested, had higher wrist extension compared to previous studies, while the other, mostly larger mice had similar values. In addition, this study recruited participants with smaller hands which has not been done in the other studies. This could have been another factor for the differences in values, as wrist extension was most different for participants with smaller hands, while larger hands had similar wrist extension values as in the other studies.

For wrist ulnar deviation, all notebook mice had higher values than the reference mouse; this difference for the 90th percentile was largest for mouse D. The values were within the values of previous studies (Keir et al., 1999; Sommerich et al., 2002). Keir et al. (1999) also found that smaller mice had higher wrist ulnar deviation. Johnson and Blackstone (2007), however, found that ulnar deviation decreased when children used a smaller mouse instead of a larger mouse. In the present study, participants with smaller hands did not have a decreased ulnar deviation when using the smaller mice. The children's mean hand size, however, was smaller than the smallest hand in the present study, which could be a reason for this difference.

The smallest mice had the highest MCP adduction (D and E) and flexion (E). A reason for this could be that for these mice the participants positioned their hand and forearm to grip and control with their fingers in a different manner. Unfortunately, this behavior could not be confirmed as this was not recorded in the study. No difference was found between hand size groups; however this could be because this difference was not captured by the Minibird sensor on the proximal phalanx. After observations of hand positioning on the mice, participants showed different postures than expected. It was expected that participants with larger hands would claw their fingers (hyper extension of the MCP and flexion of the proximal and distal interphalangeal joints) in order to have a precision grip with a small mouse and activate the buttons at the same time.

However, it was observed that participants mostly flexed the MCP and increased flexion of the proximal and distal interphalangeal joints. There were no previous studies found that measured MCP postures; therefore these values could not be compared to other studies.

Pronation of the forearm did not differ across mice. This was contrary to what was expected, because the asymmetric shape of mouse A and B was designed to promote less pronation. It could be that participants did not use mouse A and B as the design intended; or that longer use of the mouse would have led to a less pronated forearm posture.

For muscle activity, ECU had the highest values and ECR the lowest. This was related to posture, as all participants used the mice in ulnar deviation and users were allowed to rest their arms and portions of their hands on the work surface. Mouse D required the most dynamic activity for the ECU; this corresponds with the range of motion in the present study, which was highest for mouse D. This difference was affected by hand size; as ECU muscle activity for mouse D was only higher for larger hands. In the present study, the anti-pronation mice (A and B) did not show decreased ECU values. This is contrary to results from previous studies by Chen and Leung (2007) and Gustafsson and Hagberg (2003) who found decreased ECU values for anti-pronation mice. These different results could indicate that the mice used in the present study were not slanted enough or that the participants did not use the mice as the design intended.

The EDC showed less dynamic activity than the ECU. Mouse D still required most dynamic muscle activity compared to the other mice which could be a result of a more lifted finger posture observed for mouse D than for the other mice. Although EDC values for mouse A and B did not differ from the other mice; Chen and Leung (2007) and Gustafsson and Hagberg (2003) did find differences in EDC values for anti-pronation mice. This difference could indicate that the participants did not utilize the anti-pronation design feature of the mice in the present study.

FDI muscle activity was the highest for the reference mouse; this was supported by lower adduction values of the MCP; as a function of the FDI is also abduction of the MCP joint. Sommerich et al. (2002) also found higher values for a desktop mouse compared to an internal notebook pointing device. A reason for the higher FDI values for the reference mouse could be that the buttons were larger and participants had to abduct their index finger to reach the middle of the button.

The participant's ranking matched the postural and muscle activity data; participants rated mouse D as least favorite on comfort and usability. The ratings also showed that participants with larger hands found working with the smaller mice harder than participants with smaller hands, with the exception of mouse E. Although participants were consistent in rating mouse B as most favorite, this was not supported by the posture and muscle activity measurements.

The mouse with the most non-neutral postures and highest muscle activity (mouse D) was one of the smallest mice. In addition, mouse D had the largest width to length ratio and the smallest height to width ration (Table 1). The combination of size and ratios may have constrained how the user held the mouse and therefore this constraint added burden to the user while using it. The effect of mouse D was, however, most present for participants with larger hands. The smallest mouse (mouse E) did not differ much with the larger notebook mice and the desktop mouse in terms of postures and muscle activity. The reason for this could be that participants with larger hands could enclose their whole hand around the smallest mouse, and only moved the mouse with their fingers. That is they were more constrained relative to the smaller hand users on how they could hold the mouse. This was not possible with mouse D because of the longer length; therefore participants had to use their wrist more to move the mouse.

The differences across mice were small in terms of absolute numbers; however these could have a large impact when participants work for a longer time period with the psychological pressures and demands of a job. Even these small absolute differences could potentially increase injury risk because there is no consensus on what postures can increase injury risk. Marcus et al. (2002) for instance, found a higher risk of hand and arm disorders when participants used a computer mouse in more than five degrees of radial deviation in the wrist than when working in a neutral range of –5° to 5° of ulnar deviation. The values for ulnar deviation found in the present study varied between being within the neutral range provided by Marcus et al. (2002) and being outside this range, therefore even a small absolute difference could be clinically relevant.

The conclusions made in this study are limited to mouse use in a laboratory workstation. Participants worked for only one hour with different mice and most of them did not previously work with notebook mice; which could have affected results. Another important note is that although the notebook mice were selected on different sizes and shapes, there could be other confounding factors for design features (e.g. weight, texture, grip or wired versus wireless) that may play a role in the biomechanical differences. The different biomechanical effects could therefore not be attributed to the design aspects but only to the whole mouse. However, speculations could be made to ascribe the effects on the design features. Furthermore, only computer mice that were labeled as notebook mice were used in this study; but this is an arbitrary classification because there is no clear definition of what makes a notebook mouse different from a desktop mouse. Despite these workstation-related limitations, this study has made an important attempt to research biomechanical risk factors associated with notebook mouse use, which has not been done before.

In conclusion, posture, muscle activity and participant's comfort and preference suggest that the smallest mice were not optimal to use, particularly for participants with larger hands. Overall, this study demonstrates that mouse D had the most non-neutral postures and highest EMG values, which were most pronounced for participants with larger hands. These findings were also supported by the subjective ratings. Because exposure to biomechanical risk factors can increase the risk for musculoskeletal symptoms and disorders, it is important to design a notebook mouse that is portable yet does not increase biomechanical exposures.

Conflict of interest statement

In full disclosure, Dan Odell is an employee of Microsoft, a partial funding source for this study. Dr. Odell took part in the specific selection of mice, study design and the selection of specific outcome measures presented; however, he did not participate in the analysis and interpretation of the results. There is no other potential conflict of interest or the appearance of a conflict of interest with regards to the study.

Acknowledgements

This work was partly supported by a gift from Microsoft Corporation. The authors thank Pete Johnson for his work on the development of the mouse task program. Many thanks go out to our colleagues at the Harvard Occupational Biomechanics lab for their support and advice, in special Che-Hsu (Joe) Chang for all his valuable suggestions during the writing of this manuscript.

References

Aarås, A., Ro, O., 1997. Workload when using a mouse as an input device. Int. J. Hum. Comput. Interact. 9, 105–118.

Borg, G., 1990. Psychophysical scaling with applications in physical work and the perception of exertion. Scand J. Work Environ. Health 16, 55–58.

Bureau of Labor Statistics, 2005. Computer and internet use at work in 2003. US department of Labor, Bureau of Labor Statistics, Washington, DC.

Burgess-Limerick, R., Schemmell, J., Scadden, R., Plooy, A., 1999. Wrist posture during computer pointing device use. Clin. Biomech. 14, 280–286.

Chen, H.M., Leung, C.T., 2007. The effect on forearm and shoulder muscle activity in using different slanted computer mice. Clin. Biomech. 22, 518–523.

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.

Dennerlein, J.T., Johnson, P.W., 2006. Different computer tasks affect the exposure of the upper extremity to biomechanical risk factors. Ergonomics 49, 45–61.

Gissel, H., 2000. Ca^{2+} accumulation and cell damage in skeletal muscle during low frequency stimulation. Eur. J. Appl. Physiol. 83, 175–180.

Gustafsson, E., Hagberg, M., 2003. Computer mouse use in two different hand positions: exposure, comfort, exertion and productivity. Appl. Ergon. 34, 107–113.

Haesman, T., Brooks, A., Stewart, T., 2000. Health and safety of portable display screen equipment. Health & Safety Executive, United Kingdom. 304/2000.

Hägg, G.M., 2000. Human muscle fibre abnormalities related to occupational load. Eur. J. Appl. Physiol. 83, 159–165.

IJmker, S., Huysmans, M.A., Blatter, B.M., Van der Beek, A.J., Van Mechelen, W., Bongers, P.M., 2007. Should office workers spend fewer hours at their computer? A systematic review of the literature. Occup. Environ. Med. 64, 211–222.

Jensen, C., Borg, V., Finsen, L., Hansen, K., Juul-Kristensen, B., Christensen, H., 1998. Job demands, muscle activity and musculoskeletal symptoms in relation to work with the computer mouse. Scand J. Work Environ. Health 24, 418–424.

Johnson, P.W., Blackstone, J.M., 2007. Children and gender-differences in exposure and how anthropometric differences can be incorporated into the design of computer input devices. Scand J. Work Environ. Health Supplement, 1–7.

Jonsson, B., 1988. The static load component in muscle work. Eur. J. Appl. Physiol. 57, 305–310.

Jonsson, P., Johnson, P.W., 2001. Comparison of measurement accuracy between two types of wrist goniometer systems. Appl. Ergon. 32, 599–607.

Karlqvist, L., Hagberg, M., Selin, K., 1994. Variation in upper limb posture and movement during word processing with and without mouse use. Ergonomics 37, 1261–1267.

Keir, P.J., Bach, J.M., Rempel, D., 1999. Effect of computer mouse design and task on carpal tunnel pressure. Ergonomics 42, 1350–1360.

Marcus, M., Gerr, F., Monteilh, C., Ortiz, D.J., Gentry, E., Cohen, S., Edwards, A., Ensor, C., Kleinbaum, D., 2002. A prospective study of computer users: II. Postural risk factors for musculoskeletal symptoms and disorders. Am. J. Ind. Med. 41, 236–249.

Perotto, A., 1994. Anatomical Guide for the Electromyographer: The Limbs and Trunk, third ed. Charles C. Thomas, Springfield.

Sjøgaard, G., Søgaard, K., 1998. Muscle injury in repetitive motion disorders. Clin. Orthop. Relat. Res. (351), 21–31.

Sommerich, C.M., Starr, H., Smith, C.A., Shivers, C., 2002. Effects of notebook computer configuration and task on user biomechanics, productivity, and comfort. Int. J. Ind. Ergon. 30, 7–31.

Straker, L., Jones, K.J., Miller, J., 1997. A comparison of the postures assumed when using laptop computers and desktop computers. Appl. Ergon. 28, 263–268.

Villanueva, M.B., Jonai, H., Saito, S., 1998. Ergonomics aspects of portable personal computers with flat panel displays (PC-FPDs): evaluation of posture, muscle activities, discomfort and performance. Ind. Health. 36, 282–289.