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Evaluation of flat, angled, and vertical computer mice and their effects on wrist posture, pointing performance, and preference

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Abstract.
BACKGROUND: Modern computer users use the mouse almost three times as much as the keyboard. As exposure rates are high, improving upper extremity posture while using a computer mouse is desirable due to the fact that posture is one risk factor for injury. Previous studies have found posture benefits associated with using alternative mouse designs, but at the cost of performance and preference.
OBJECTIVE: To develop new computer mouse shapes, evaluate them versus benchmarks, and determine whether there are differences in wrist posture, pointing performance, and subjective measures.
METHOD: Three concept mice were designed and evaluated relative to two existing benchmark models: a traditional flat mouse, and an alternative upright mouse. Using a repeated measures design, twelve subjects performed a standardized point-and-click task with each mouse. Pointing performance and wrist posture was measured, along with perceived fatigue ratings and subjective preferences pre and post use.
RESULTS: All of the concept mice were shown to reduce forearm pronation relative to the traditional flat mouse. There were no differences in pointing performance between the traditional flat mouse and the concept mice. In contrast, the fully vertical mouse reduced pronation but had the poorest pointing performance. Perceived fatigue and subjective preferences were consistently better for one concept mouse.
CONCLUSION: Increasing mouse height and angling the mouse topcase can improve wrist posture without negatively affecting performance.

Keywords: Human-computer interaction, design, ergonomics

1. Introduction

The trend in computer input has shifted away from keyboard input to pointing device input as user interfaces have evolved from text-based to graphical user interfaces. Today, average active time on the mouse exceeds average active time on the keyboard by almost 3 to 1 [4, 12, 22]. The number of hours per day working on a computer has been identified as one of the key risk factors for Musculoskeletal Symptoms (MSS) [18], and research has linked intensive mouse use to MSS [6, 13]. High incidence of computer related MSS of the upper extremity has been reported, for example in a college

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student population [28]. The higher durational exposure of the mouse relative to the keyboard, and the observed link between mouse use and MSS [8] emphasizes that mouse design should be a key focus when seeking to improve comfort at the computer.

Several commercially available mice have been designed with the intent of improving user posture during mousing by making them more vertical. Early efforts focused on providing sculpted, non-symmetrical mice that were designed to improve comfort and wrist posture [1, 10]. Some of these mice designs have been shown to provide better posture during mousing [10, 11, 25]. Other studies have shown benefits in reduced muscle load for more vertical mice [11, 25, 27]. These benefits can translate into longer term comfort benefits. For example, testing of one vertical mouse demonstrated that the upright pronation-reducing design was successful at reducing subjective pain over a short period of use [1]. Unfortunately, of the 'neutral posture' mice reported in the literature, all have shown reduced pointing performance [1, 10, 25, 26]. Subjective preference measures have also generally been low for these inclinced mice [1, 26]. Reduced pointing performance and preference can serve as significant barriers to widespread adoption of a pointing device despite other ergonomic benefits that alternative designs may provide.

In this study, three concept mice with angled topcases were developed and evaluated against two benchmark mice: a traditional flat mouse, and a commercially available vertical mouse. The intent behind the designs of the concept mice was to reduce non-neutral upper extremity postures that may be associated with increased risk for musculoskeletal discomfort, while maintaining pointing performance. Specifically, the concept mice were designed to reduce: 1) forearm pronation, 2) wrist extension, 3) ulnar deviation, 4) extended finger postures, and 5) change the location of the contact area between wrist and the desktop.

These design criteria were informed by existing research on carpal tunnel pressure and wrist angle [5, 15, 19, 21]. Hydrostatic fluid pressure within the carpal tunnel has been one means to show the potential risks associated with various forearm, wrist and finger postures. Non-neutral wrist and forearm postures can increase the hydrostatic fluid pressure within the carpal tunnel and the increased pressure can impair nerve function and can lead to long-term damage [19, 21]. For example, Rempel et al. [19] determined that $\sim 45^\circ$ of forearm pronation and $\sim 45^\circ$ of finger flexion were postures both associated with reduced carpal tunnel pressure (CTP). These postures correspond with the targeted forearm and finger postures outlined in the mouse design criteria cited above. Similar to pronation and finger extension, elevated fluid pressure in the carpal tunnel has also been associated with wrist extension and ulnar deviation [15]. This prompted the design criteria to include promoting more neutral wrist postures.

Elevated CTP is also associated with external contact pressure on the palmar surfaces of the hand and wrist. Cobb et al. [5] showed that certain areas of the hand and wrist, especially the the base of the palm over the flexor retinaculum, were sensitive to external contact pressure. Contact pressure in those regions elevated CTP. Therefore, another potential benefit of more vertical concept mouse design may be to reduce contact pressure in those sensitive areas by shifting the contact area off of the base of the palm and to the ulnar aspect of the hand.

After the three concept mice were developed, it was important to evaluate them to determine how effective they were in meeting the design criteria, and therefore if any of them should be produced commercially. The goal of this study was to make this evaluation of the concept mice and determine whether there were benefits in wrist posture, pointing performance, perceived fatigue and preference relative to the flat and vertical benchmark mice.

2. Methods

2.1. Subjects

Twelve experienced computer mouse users (6 male, 6 female) who all self-reported to use the computer at least 10 hours a week were recruited to participate in this study. The mean age of the subjects was 32.7 years (range 20–52) and all subjects used the mouse with their right hand. Experimental procedures were approved by the University of Washington Human Subjects Committee and all subjects gave their informed consent.

Using the methods outlined in the ADULTDATA anthropometric handbook [30], hand length and hand breadth were measured from all subjects. Hand length was measured from the distal wrist crease to the tip of the middle finger and and hand breadth was measured from the medial side of the palm just below the little finger to the lateral side of the palm just below the index finger. The mean hand legnth of the subjects was 18.1 cm (range 16.6 to 20.1 cm) and the mean hand breadth was 8.8 cm (range 7.6 to 9.6 cm). Using US anthropometric data as a reference [30], hand lengths spanned from the $18^{\%tile}$ female to the $86^{\%tile}$ male and hand breadths spanned from the $37^{\%tile}$ female to the $96^{\%tile}$, so a wide hand size range was represented.

2.2. Mouse models evaluated

The experiment was a repeated measures design where subjects performed a series of standardized point-and-click tasks with five different mice (Fig. 1). The five models consisted of two benchmarks (Models E and F) and three concept mice (Models H, I and J). The two benchmarks were cast models of the Evoluent™ Vertical mouse (Model E), and the more traditional right-handed mouse, the Microsoft IntelliMouse Explorer for Bluetooth (Model F). All tested mice were cast models made out of BJB TC182 castable foam. The cast models were made functional by harvesting wireless optical tracking sensors from commercially manufactured mice and inserting them into the cast mouse bodies. All models where made of the same materials, finishes, and tracking engines to minimize confounding factors. The left buttons on the mouse models were made operational by installing and connecting a tactile switch under the flexible button surface.

The bodies of the three concept mice were similar in design. They were all approximately 61 mm wide and 60 mm tall at the highest point on the left mouse button and the topcases were angled roughly 20 degrees downward relative to a horizontal plane. The topcase slope and extra height was designed to help reduce forearm pronation. The concept mice all had thumb grooves roughly 25 mm off of the table surface with

Fig. 1. Top and rear view images of the mouse models tested. Model E (benchmark vertical mouse), Model F (benchmark flat mouse), and the three concept mouse designs - Model H, Model I and Model J.

the thumb groove for Model 'I' being slightly lower and less distinct.

The primary differences between the concept mice were the overall length and the design of back of the mouse where the thumb and palm of the hand rested. Model H was the shortest (105 mm), ball-like in shape and afforded the most flexibility in grip styles. Model I was the longest (130 mm) and had a large flange supporting the base of the thumb. Model J was a hybrid of Model H and I, intermediate in length (120 mm) with a smaller flange for the base of the thumb.

2.3. Experimental procedures

The test workstation was set up according to ANSI HFS 100 standards [2] to match the subject's stature. Subjects were allowed to make slight adjustments in table and chair height for comfort. Mouse performance was measured while subjects performed a series of standardized point-and-click tasks, as specified in the international standards for evaluating pointing device performance [29]. These tasks consisted of a series of omni-directional pointing tasks which consisted of alternately clicking on 18 evenly spaced round targets arranged in a circle (Fig. 2). As illustrated in Fig. 2, to perform the tasks, subjects would move the cursor with the mouse and click on the first active, black-highlighted target, the target would disappear, and then the target on the diametrically opposite side of the circle would become active, and the subject had to move the mouse to acquire this target and then click on it. This sequence continued until all 18 targets had been acquired. The series of tasks consisted of performing: 1) six large pointing tasks requiring gross movements with a center-to-center inter-target distance of 142 mm and target width of 12 mm - this target size was similar to the size of folders and icons on a computer desktop; 2) six medium pointing tasks requiring intermediate movements with a center-to-center inter-target distance of 71 mm and target width of 6 mm - half the size of the large targets and twice the size of the small targets; and 3) three small pointing tasks requiring fine movements with a center-to-center inter-target distance of 28 mm and target width of 2 mm - these small targets approximated the size of individual characters. The small, medium and large tasks all had the same index of difficulty according to Fitt's Law [7].

While performing the point-and-click tasks, subjects were instructed to move the mice as fast as possible while maintaining a balance between speed and accu-

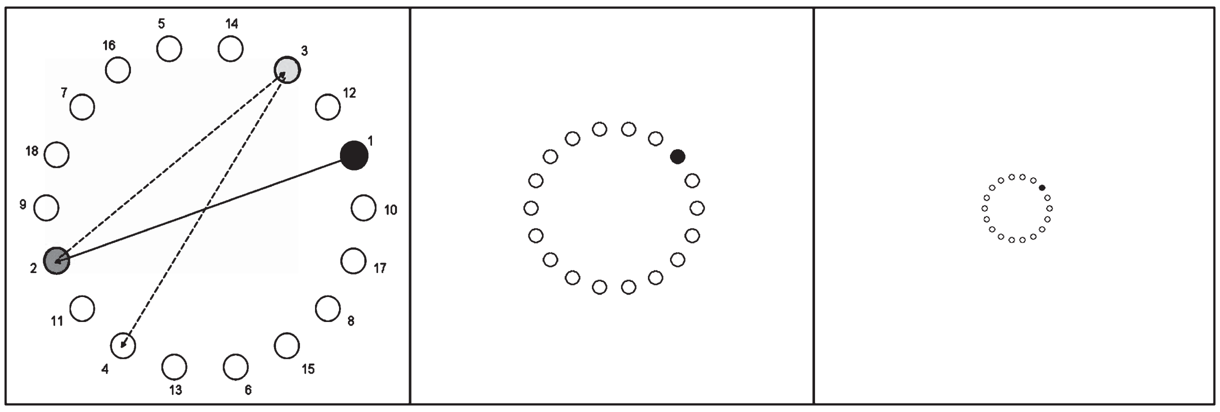

Fig. 2. Large, medium and small omni-directional pointing tasks. The numbers in large pointing task on the left shows the sequence of the pointing movements.

racy. Using a different traditional mouse than the one tested in the study, subjects were allowed to practice the tasks (typically 2 to 4 minutes) until they were comfortable with the how to complete the various tasks. Mouse model and task order were randomized and no instructions were provided as to how to grip or use the mice.

2.4. *Forearm and wrist posture*

Right hand wrist angles were measured using an electrogoniometer (Model XM-65; Biometrics; Gwent, UK), forearm pronation/supination was measured with an inclinometer (FAS-G; Microstrain, Inc.; Williston, VT) mounted to the distal end-block of the electrogoniometer, and all measures were collected and stored at 100 Hz on a portable data logger (Muscle Tester ME6000; Mega Electronics; Kuopio, Finland). As prescribed by the American Academy of Orthopedic surgeons [9], the neutral flexion/extension (F/E) position of the wrist was defined at the position where the horizontal plane formed by the back of the hand was in line with the plane formed by the back of the forearm. The neutral radial/ulnar (R/U) position was defined as the position where the third metacarpal was in line with the long axis of the forearm. This calibration posture accounted for and minimized any offset errors associated with forearm pronation [14]. With the inclinometer, subjects alternated between a hand-shake position with their hands perpendicular to the worksurface (0º) and a fully pronated position with their palms parallel to the worksurface (90º). Pronation/supination (P/S) measurements were relative to the neutral position (0º).

2.5. *Perceived fatigue and preference*

Perceived fatigue levels while using each mouse model were measured in the right hand, forearm, shoulder and neck using visual analog BORG CR-10 scales [3] administered before and after using each mouse. Before using the mice, subjects were asked to give their preliminary preferences based on visual appearance and touch. Then, after completing the series of omni-directional point-and-click tasks with each mouse, a series of eight mouse preference questions were answered. These questions employed a 7-point Likert scale ranging from 1- Strongly Disagree to 7- Strongly Agree. Finally, after using all mouse models, the participants ranked their final mouse preferences.

2.6. *Data and statistical analysis*

With the inclinometer and goniometry data, mean postural values were calculated for each subject and then group mean postural values were calculated for Pronation/Supination, Flexion/Extension and Radial/Ulnar deviation. A program written in Labview calculated movement times between targets in seconds and the number of missed targets per trial. To reduce any additive effects of time, Borg scale rating data were normalized to the initial measurement so that comparisons between mice could be made. Normalization involved subtracting the Borg scale rating at the initial measurement from end measurements, thus, the change in Borg scale ratings relative to the initial measurement were being compared. All posture, performance, perceived fatigue and preference data were then tabulated and analyzed using repeated measures analysis of variance

(RANOVA) methods using the statistical program JMP (Version 7.0; SAS Institute; Cary, NC). Data are presented as means and standard error and differences were considered to be significant when *p*-values were less than 0.05.

3. Results

3.1. Posture

There were postural differences between the five mouse models tested, and average postures during the performance of the point-and-click tasks are summarized in Table 1. Model E, the vertical benchmark mouse, was operated with the greatest amount of wrist extension and the least amount of hand/forearm pronation. Model F, the flat benchmark mouse, required the greatest amount of ulnar deviation and hand/forearm pronation. Concept Model I was operated with the least amount of extension and Concept Model J the least amount of radial/ulnar deviation. On average, compared to the flat benchmark mouse (Model F), the concept mouse designs (Models H, I and J) reduced pronation by $13.1^\circ \pm 1.0^\circ$, ulnar deviation by $6.9^\circ \pm 1.5^\circ$ and increased extension by $1.6^\circ \pm 1.8^\circ$.

3.2. Performance

As shown in Table 2, during the performance of the omni-directional point-and-click tasks, there were movement time differences between the five mouse models tested ($p = 0.02$). Subjects consistently performed tasks the slowest with vertical benchmark mouse (Model E). There were only small differences in movement times between the concept mouse designs (Models H, I and J) and the flat benchmark mouse (Model F). Despite the tasks having the same index of difficulty, there were movement time differences based on task size ($p < 0.01$) but there was no difference by task size interaction ($p = 0.53$). Depending on the mouse model, the smaller tasks took 10 to 20% longer to complete. There was also an order ($p < 0.01$) and trial effect ($p < 0.01$). When cycling through the five mouse models, the subject's movement times were progressively faster with each subsequent mouse. With respect to trials, movement times decreased from the first to second trial ($p < 0.01$) but then were relatively stable for the remaining four trials.

Table 3 shows the accuracy of the mice in the form of number of missed targets. No statistically significant differences were found for missed targets.

3.3. Perceived fatigue and subjective preference

On average, the time to complete the suite of tasks with each mouse was 4 minutes. Table 4 shows the changes in perceived fatigue by body region after the 4 minutes of mouse use. In general, changes in perceived fatigue were small and mouse Model H had the lowest perceived fatigue levels for the concept mouse designs (Models H, I and J). Mouse Model H scored favorably in three out of four body locations while the vertical benchmark mouse (Model E) was rated as the least fatiguing in the wrist and shoulder regions.

Table 1
Mean (standard error) posture with each mouse. Means with different superscripts are significantly different [N = 12]. Lower values are generally preferred for more neutral postures

	Benchmark Mice		Concept Mice			*p*-value
	Vertical Model E	Flat Model F	Model H	Model I	Model J	
Extension	$41.2^{\circ\ a}$ (±3.0°)	$36.1^{\circ\ a,b}$ (±3.4°)	$40.7^{\circ\ a}$ (±3.0°)	$35.0^{\circ\ b}$ (±3.3°)	$37.4^{\circ\ a,b}$ (±3.5°)	$p = 0.004$
Ulnar(+)/Radial(-) Deviation	$3.9^{\circ\ a,b}$ (±3.0°)	$8.1^{\circ\ b}$ (±3.9°)	$1.6^{\circ\ a}$ (±3.7º)	$2.1^{\circ\ a}$ (±3.2°)	$-0.2^{\circ\ a}$ (±3.1°)	$p < 0.0001$
Pronation	$40.4^{\circ\ a}$ (±2.1°)	$70.5^{\circ\ b}$ (±2.4°)	$61.3^{\circ\ c}$ (±2.5°)	$56.4^{\circ\ d}$ (±2.4°)	$54.5^{\circ\ d}$ (±2.1°)	$p < 0.0001$

Table 2
Mean (standard error) movement times in seconds by mouse model while performing the large, medium and small omni-directional point-and-click tasks. Means with different superscripts are significantly different [N = 12]. Lower values are preferred for faster task completion

	Vertical	Flat	Concept Mice			*p*-value
	Model E	Model F	Model H	Model I	Model J	
Large Task	1.04^{a} (±0.07)	0.89^{b} (±0.07)	$0.91^{a,b}$ (±0.07)	$0.92^{a,b}$ (±0.05)	0.87^{b} (±0.06)	$p = 0.02$
Medium Task	1.03^{a} (±0.06)	0.88^{b} (±0.07)	0.88^{b} (±0.06)	$0.91^{a,b}$ (±0.06)	$0.90^{a,b}$ (±0.07)	$p = 0.02$
Small Task	1.21 (±0.12)	1.04 (±0.11)	0.99 (±0.07)	1.00 (±0.08)	1.04 (±0.06)	$p = 0.09$

Table 3
Mean (standard error) number of missed targets (out of 18 targets) by mouse model while performing the large, medium and small omni-directional point-and-click tasks. [N = 12]. Lower values are preferred for higher accuracy

	Vertical	Flat	Concept Mice			*p*-value
	Model E	Model F	Model H	Model I	Model J	
Large Targets	1.0 (±0.1)	0.7 (±0.1)	1.1 (±0.2)	1.1 (±0.2)	1.0 (±0.2)	$p = 0.31$
Medium Targets	1.5 (±0.2)	1.3 (±0.2)	1.7 (±0.2)	1.6 (±0.2)	1.4 (±0.3)	$p = 0.51$
Small Targets	3.1 (±0.4)	2.8 (±0.4)	3.3 (±0.3)	2.7 (±0.3)	3.6 (±0.4)	$p = 0.21$

Table 4
Mean (standard error) change in Borg CR-10 scale ratings after using each mouse by body region. The larger the number the more fatiguing mouse use was perceived to be [N = 12]

	Vertical	Flat	Concept Mice			*p*-value
	Model E	Model F	Model H	Model I	Model J	
Hand	0.64 (±0.25)	0.46 (±0.38)	0.00 (±0.22)	0.30 (±0.13)	0.75 (±0.26)	$p = 0.11$
Wrist	1.00 (±0.50)	0.28 (±0.31)	0.21 (±0.34)	0.96 (±0.36)	0.53 (±0.26)	$p = 0.32$
Forearm	0.74 (±0.33)	0.58 (±0.29)	0.15 (±0.16)	0.79 (±0.35)	0.77 (±0.27)	$p = 0.36$
Shoulder	0.90 (±0.28)	0.01 (±0.28)	0.08 (±0.17)	0.62 (±0.44)	0.57 (±0.26)	$p = 0.15$

Prior to the pointing tasks, the mice were ranked to determine preferences based on feel and appearance and the flatbenchmark mouse (Model F) was the most preferred mouse (Table 5). After subjects had performed the pointing tasks with all of the mice, the models were ranked again. After use, mouse Model F was still the most preferred mouse but mouse Model H had the greatest change in preference, starting as the 4th most preferred mouse and ending as the 2nd most preferred mouse. The vertical benchmark mouse (Model E) was the least preferred both pre and post use.

Table 6 shows that there were significant differences in preference across the mice tested. The flat benchmark mouse (Model F) received the most favorable response in all 8 questions while concept mouse Model H had the second most favorable response in 7 out of 8 questions and had the highest ratings of the concept mouse models. The vertical benchmark mouse (Model E) received the least favorable responses in all eight questions.

4. Discussion

4.1. Posture

The concept mice (Models H, I and J) promoted more neutral hand/forearm pronation and radial/ulnar deviation postures compared to the flat benchmark mouse (Model F). Mouse Models F, I, and J all had similar wrist extension values (average 36°), whereas Models H and E had slightly higher values for wrist extension (average 41°). The vertical benchmark mouse (Model E) had the greatest effect on reducing pronation.

As mentioned in the methods section, no instructions were given on how to use or hold any of the concept mice. These mice were designed so the front of the mouse would point slightly inward towards the centerline of the user's body if held with no inward/outward rotation of the arm and the wrist in a neutral radial/ulnar posture. Most subjects were observed to not hold the mouse with the front pointing in as designed, but rather with the front of the mouse parallel to the right edge of the keyboard, a posture which required more ulnar deviation and extension than intended orientation/posture. So, it seems that ulnar deviation and wrist extension may be further reduced with some instruction on how to position and hold the mouse, and this has been verified in other work [11].

4.2. Performance

All of the mice used identical optical tracking engines, so the observed performance differences are attributable to the differences in shape/design of the mice. The flat benchmark mouse (Model F) and the concept mice (Models H, I, J) had similar pointing times during the performance of the point-and-click task. However, the vertical benchmark mouse (Model E) was significantly slower than the other four mice.

The fact that the concept mice performed as well as the flat benchmark mouse in pointing performance was encouraging from a design standpoint. The lack

Table 5
Preliminary mouse model preferences before use and final mouse model preferences post-use. Bottom row is the mean rank for each mouse model [N = 12]. Lower values represent stronger preference

	Preliminary						Final				
	Vertical	Flat	Concept Mice				Vertical	Flat	Concept Mice		
	Model E	Model F	Model H	Model I	Model J		Model E	Model F	Model H	Model I	Model J
1^{st}	1	7	2	1	1	1st	1	8	1	1	1
2nd	0	4	2	3	3	2nd	0	0	7	3	2
3rd	0	0	2	3	7	3rd	2	4	2	1	3
4th	1	1	6	4	0	4th	1	0	1	5	5
5th	10	0	0	1	1	5th	8	0	1	2	1
Mean Rank	4.6	1.6	3.0	3.1	2.7	Mean Rank	4.2	1.7	2.5	3.3	3.2

Table 6
Mean (standard error) responses to mouse preference questions using a 7-point (1 = Strongly Disagree, 7 = Strongly Agree) Likert scale. Scores within each row with the different superscripts are significantly different [N = 12]. Higher values represent stronger preference

	Vertical	Flat	Concept Mice			
	Model E	Model F	Model H	Model I	Model J	*p*-value
1. This mouse was easy to use	3.3^{a} (±0.54)	5.7^{b} (±0.31)	5.2^{b} (±0.27)	$4.4^{a,b}$ (±0.50)	$4.4^{a,b}$ (±0.47)	$p = 0.004$
2. This mouse feels comfortable	3.0^{a} (±0.49)	5.5^{b} (±0.31)	$4.8^{b,c}$ (±0.35)	$3.6^{a,c}$ (±0.48)	$3.7^{a,c}$ (±0.53)	$p = 0.002$
3. The overall shape of this mouse looks appealing.	3.3^{a} (±0.49)	5.4^{b} (±0.34)	$4.3^{a,b}$ (±0.41)	4.8^{b} (±0.32)	$4.3^{a,b}$ (±0.46)	$p = 0.004$
4. It was hard to make errors using this mouse	3.0^{a} (±0.43)	5.2^{b} (±0.47)	$3.9^{a,b}$ (±0.47)	$3.5^{a,b}$ (±0.52)	3.6^{a} (±0.36)	$p = 0.006$
5. I like using this mouse.	2.8^{a} (±0.55)	5.3^{b} (±0.38)	$4.3^{a,b}$ (±0.37)	3.8^{a} (±0.45)	$3.8^{a,b}$ (±0.54)	$p = 0.001$
6. I can quickly complete tasks using this mouse.	3.2^{a} (±0.47)	5.4^{b} (±0.42)	$4.2^{a,b}$ (±0.44)	3.8^{a} (±0.46)	$4.0^{a,b}$ (±0.46)	$p = 0.003$
7. I quickly adjusted to using this mouse.	4.1^{a} (±0.54)	6.0^{b} (±0.41)	$5.1^{a,b}$ (±0.36)	$4.4^{a,b}$ (±0.45)	$4.4^{a,b}$ (±0.47)	$p = 0.02$
8. I would buy this mouse.	2.7^{a} (±0.61)	5.2^{b} (±0.39)	$3.4^{a,b}$ (±0.56)	3.0^{a} (±0.52)	2.9^{a} (±0.42)	$p = 0.005$
Average	3.2	5.5	4.4	3.9	3.9	

of the performance decrement with the concept mice indicated that it was possible to alter wrist and forearm posture during mouse use without the negative impact on performance that has been seen in previous studies with other alternative mouse [1, 10].

Model E's relatively slower pointing speed is likely due to its vertical orientation. The difference was that mouse Model E primarily required flexion and extension of the wrist to move the mouse side-to-side. In contrast, wrist deviation was used to move the traditional flat mouse side-to-side, and a combination of wrist deviation and extension was used to move the concept mice side-to-side. It seems that either this wrist flexion/extension motion is inherently slower, or something else (such as the larger size of Model E) accounts for the reduced pointing speed.

4.3. Subjective preferences

Subjective measures showed preference for the traditionally designed flat mouse (Model F) both pre and post mouse use. This is not a surprising finding as this mouse was chosen as the benchmark due to its high comfort ratings amongst flat mice, and was most similar to the traditional mice which participants were most familiar with. In contrast, the other mouse designs (Models E, H, I and J) were unfamiliar. Model H ended up as the second most preferred overall, and the most preferred of the concept mice. Model H had the greatest change in preference pre and post use going from the 4th to the 2nd most preferred mouse. Subjects ranked mouse Model H as the most preferred concept mouse because, due to the shorter length and ball shape, this mouse was the best fit for their hand and was more easily controlled than the other concept mice. Subjects felt Model I was too big and Models I and J did not fit their hands as well as Model H. The vertical benchmark mouse, Model E, was disliked overall. It was seen as too big, didn't fit the hand well, required the most drastic change in control strategy and was noticably slower and more difficult to control than the other mice.

4.4. Final mouse selection

In the end, all three concept mice had relatively similar performance in posture, pointing speed, and

Fig. 3. The commercially manufactured mouse based on concept mouse Model H.

learning, but one model, mouse Model H, differentiated itself due to more favorable perceived fatigue and preference ratings. Mouse Model H was also observed to best accommodate a variety of grip styles. These benefits led to mouse Model H being selected as the final model for commercial development as the Microsoft Natural® Mouse 6000/7000 (Fig. 3).

Previous alternative mouse designs have also demonstrated improvements in posture and discomfort. However, these alternative mouse designs have often resulted in reduced pointing performance and/or low marks for subjective preference [1, 10, 25, 26]. The final concept mouse model selected from this study reduced these pitfalls by providing posture and comfort benefits along with a pointing performance and learning curves comparable to the commercially sold mice similar to the flat benchmark mouse (Model F).

It is anticipated that the postural improvements promoted by the final production mouse will follow the trends of the postural and musculoskeletal health improvements associated with split keyboard designs. With split keyboard designs, early research demonstrated improvements in posture and subjective comfort [17, 20, 24]. These improvements were later linked with long term comfort benefits and a reduction in the risk of musculoskeletal disorders and symptoms [23].

4.5. Study limitations

The main limitation of this study is the short exposure time that each participant had with each mouse – roughly 4 minutes with each mouse. This means that only initial performance was captured from users who were novices with all of the mice, except for the traditional mouse, Mouse F, was the most familiar. Another potential limitation, is that only a single Index of Difficulty [16] was used in the pointing performance tasks. In the future, testing an array of indexes of difficulty could be desirable.

4.6. Future study directions

The concept mouse design selected for manufacture and sale was designed to address a number of identified postural risk factors which may be associated with intensive mouse use. However, to what degree this new design will benefit mouse users in the long-term is a research question that should be answered by future studies. To best answer the question of long-term effects, a longitudinal, randomized control trial that evaluates musculoskeletal symptoms and disorders with mouse use over an extended period of time would be desirable. A separate line of research could evaluate the other biomechanical risk factors addressed by the design. In particular, muscle loads, carpal tunnel pressure and the contact area/pressure over the hand and wrist associated with operating the mouse may be worth evaluating with the new mouse design. It would be interesting to see if further design modifications might address the issue wrist extension as described in 4.1.

5. Conclusions

The concept mice in this study offered less pronated and deviated postures relative to the flat benchmark mouse without negatively affecting pointing performance. These postural benefits were created by increasing the mouse height and angling the topcases of the concept mice. In contrast, the vertical benchmark mouse was successful in reducing wrist deviation and forearm pronation, but pointing performance was adversely affected and preference ratings were lower. Therefore, some pronation reduction has been shown to be beneficial. But, it is possible to go too far and negatively affect performance and preference. The concept mouse with the best overall performance in this study was selected for commercial production.

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