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Changes in posture through the use of simple inclines with notebook computers placed on a standard desk

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A B S T R A C T

This study evaluated the use of simple inclines as a portable peripheral for improving head and neck postures during notebook computer use on tables in portable environments such as hotel rooms, cafés, and airport lounges. A 3D motion analysis system measured head, neck and right upper extremity postures of 15 participants as they completed a 10 min computer task in six different configurations, all on a fixed height desk: no-incline, 12° incline, 25° incline, no-incline with external mouse, 25° incline with an external mouse, and a commercially available riser with external mouse and keyboard. After completion of the task, subjects rated the configuration for comfort and ease of use and indicated perceived discomfort in several body segments. Compared to the no-incline configuration, use of the 12° incline reduced forward head tilt and neck flexion while increasing wrist extension. The 25° incline further reduced head tilt and neck flexion while further increasing wrist extension. The 25° incline received the lowest comfort and ease of use ratings and the highest perceived discomfort score. For portable, temporary computing environments where internal input devices are used, users may find improved head and neck postures with acceptable wrist extension postures with the utilization of a 12° incline.

1. Introduction

In 2008, quarterly notebook sales exceeded desktop sales with over 9.5 million units sold (Mann, 2008). With their compact form factor and internal monitor and input devices, notebook computers are designed for portability; but the tradeoffs in design increase exposure to potential risk factors for musculoskeletal disorders (MSDs) relative to desktop computers. In particular, since the display and keyboard are connected, the height of the display is normally lower than recommended.

Compared to desktop computers, previous studies have shown that notebook computer use results in greater neck flexion and head tilt (Straker et al., 1997; Sommerich et al., 2002; Seghers et al., 2003), reduced range of neck movement (Szeto and Lee, 2002) and greater neck extensor activity (Saito et al., 1997; Villanueva et al., 1998; Seghers et al., 2003). Placing the notebook on a higher working surface, to optimize neck posture, is not a viable solution as it leads to increased discomfort in all body parts, including the neck (Price and Dowell, 1998). Elevating the whole notebook computer with a non-input device peripheral, such as a laptop station, does improve neck postures, reducing cervical spine torque and perceived strain (Berkhout et al., 2004).

As a result of these findings, practitioners and researchers typically recommend using an external monitor or elevating the notebook to raise the display screen and adding external input peripherals, especially for extended notebook use. This effectively makes the notebook equivalent to a conventional desktop computer setup. These recommendations, while useful in a semi-permanent workstation such as one's office, have limited portability and are therefore not often used in portable computing environments.

An incline, which raises the back end of the notebook computer and thus elevates the screen, is a simple portable peripheral that may improve head and neck postures for computing environments that have a non-adjustable, standard height desk (Kroemer and Grandjean, 1997) such as hotel rooms, airplanes, and cafés. An incline could be as simple as extension legs built into the notebook

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or even the power supply box placed underneath the back side. With the use of an incline, the keyboard is still attached to the monitor and therefore the hands have to follow the keyboard, which is also altered by the incline. Specifically, the incline leads to a positive keyboard slope, which has been shown to increase wrist extension (Simoneau and Marklin, 2001).

Therefore, the aim of this study was to compare postures and comfort in users working on a notebook computer placed flat on a fixed height desk, with the introduction of small devices to incline the notebook to 12 and 25 degrees with the proximal edge of the notebook remaining at the same level. We hypothesized forward head tilt and neck flexion angles would decrease with the use of the inclines, while wrist extension angles would increase. We also evaluated the addition of an external mouse and the use of a commercially available riser, which fully elevates the notebook, with an external mouse and keyboard on these same outcomes. We hypothesized that the commercially available riser would lead to smaller non-neutral head and neck postures compared to use of the notebook flat on the desk with an external mouse and smaller non-neutral wrist postures compared use of the 25° incline with an external mouse.

2. Methods

2.1. Study participants

Eight men and seven women (ranging in age from 22 to 36 (mean = 28.4, sd = 3.5)) participated in this study. All participants reported no current or previous history of head, neck, back or upper extremity MSDs and either owned or had experience working with a notebook computer. The mean anthropometric measures for the subjects were typical of a North American population (Table 1). Each participant gave informed consent prior to beginning the study. The Harvard School of Public Health Internal Review Board approved all protocols and consent forms.

2.2. Experimental protocol

Each participant completed a standardized computing task six times, each with a different portable computing configuration: DESK, INC12, INC25, DESK + M, INC25 + M and RISER (Fig. 1). For the first configuration, a 15 inch notebook computer with two internal pointing devices (Int PD), a built-in touch pad and an isometric joystick (Thinkpad T61, Lenovo, Morrisville, NC, USA) was placed on top of a 72.4 cm high desk (DESK). For the next two configurations the notebook was placed on a 12 (INC12) and 25 degree incline (INC25), respectively, placed on top of the same 72.4 cm desk (Fig. 1). For the next two configurations, an external portable size mouse (Notebook Optical Mouse, Microsoft Corporation, Redmond, WA, USA) was added to the DESK (DESK + M) and INC25 (INC25 + M) configurations. For the last configuration (RISER), the notebook was placed on a laptop riser (Height Adjustable Laptop Stand, XBrand, Scottsdale, AZ, USA). This configuration also included the external portable size mouse as well as a full size QWERTY keyboard (KU-0225, Lenovo, Morrisville, NC, USA). The RISER configuration was the only one which included an external keyboard. For all configurations, the edge of the desk was padded with a thin strip of foam to reduce contact pressure (not shown in the images). The order of the configurations was randomized.

To reduce variability associated with seated posture, participants sat in an adjustable office chair with seat pan height selected to match popliteal height when the thighs were horizontal (mean (SD) chair height = 44.8(5.2) cm). To reduce variability associated with horizontal keyboard location (Kotani et al., 2007), subjects were instructed to place the notebook at a comfortable horizontal distance from the edge of the desk before testing began. The distance from the edge of the desk to the J key on the internal keyboard was then measured and kept constant for all configurations except for the RISER configuration in which the distance to the J key on the external keyboard was matched. The horizontal distance of the notebook and riser, placed behind the external keyboard, was selected by the subjects; vertical height of the top edge of the notebook screen on the RISER was adjusted to subject eye height. Subjects were allowed to adjust the screen angle relative to the keyboard for each configuration.

The standardized computer task involved a combination of pointing and clicking on icons, typing text, a comprehensive reading exercise and selecting-dragging-and-dropping of icons. The task was designed to require relatively equal amounts of keyboard and mouse use as well as periods in which input devices were not used (e.g. reading text from the screen). For configurations that did not include the external mouse, subjects were instructed to use the touch pad. Productivity for each configuration was calculated as the total amount of time required to complete the task. Participants were instructed to complete the task at a comfortable pace. The task was designed to take approximately 10 min.

2.3. Apparatus

An infrared three-dimensional motion analysis system (Optotrak Certus, Northern Digital, Waterloo, Canada) tracked head, trunk and upper extremity kinematics. Five clusters of three infrared light emitting diodes (IREDs) fixed to a rigid surface were secured to the head, trunk, right arm, right forearm and right hand (Fig. 1). Three additional IREDs were placed on the base of the notebook and one on the top, right edge of the notebook screen. Using a single camera bank with 3 cameras, the 3-D locations of the 19 IREDs were tracked at 20 samples/s and data were recorded to a personal computer. The locations of specific bony landmarks relative to their associated IRED cluster (Table 2) were digitized using the systems digitizing probe. Then, modeling each body segment as a rigid body, the locations of these bony landmarks were calculated based on the translation and rotation of each IRED cluster (Winter, 2000). Data were digitally filtered through a low-pass, fourth-order Butterworth filter with a 5 Hz cutoff frequency and used to define local coordinate systems for each segment (Table 2). The shoulder IREDS for 2 participants came loose during the experiments. Shoulder, elbow and wrist posture data for these participants were discarded.

From local coordinate systems, rotation matrices were calculated (Winter, 2000) to obtain the orientation of the arm relative to the trunk, the forearm relative to the arm and the hand relative to the forearm. From these rotation matrices, Euler angles were calculated such that the first rotation was flexion/extension, the second was abduction/adduction and the third was internal/external rotation (pronation/supination for the forearm).

Shoulder elevation and retraction were defined as the vertical and horizontal translation, respectively, of the upper arm relative to

Table 1
Mean (SD) anthropometric measures by gender.

Metric	Male ($n = 8$)	Female ($n = 7$)
Age (years)	28.8 (3.8)	28.0 (3.3)
Height (cm)	175.9 (5.5)	167.5 (4.4)
Shoulder width (cm)	34.6 (3.5)	30.8 (1.3)
Arm length (cm)	61.5 (3.3)	56.1 (1.1)
Hand length (cm)	19.0 (0.6)	17.9 (1.0)
Hand width (cm)	8.4 (0.3)	7.4 (0.3)

Fig. 1. Photographs of a subject working with a notebook computer on fixed 72 cm high desk inclined to 12° (INC12), inclined to 25° (INC25) and on a commercially available riser with external mouse and keyboard (RISER). Orientation of the global axes is shown in upper left corner of INC12. Five clusters of three infrared markers tracked the position and orientation of the head, trunk, arm, forearm and hand. From the segment orientations, relative joint angles were computed for the head, neck, shoulder, elbow, forearm and wrist. Position of the upper arm relative to the trunk provided measures of shoulder elevation and retraction.

the trunk. Neck flexion was defined as the angle between the vertical axis of the trunk and the line from the midpoint between the acromions and the midpoint between the tragi. Head tilt was defined as the angle between the global horizontal axis and the line from the right tragus to the right canthus. Viewing angle was defined as the angle between the global horizontal axis and the line from the midpoint of the subjects' right and left canthus to the top, center of the display (Sommerich et al., 2002).

Zero degree (0°) postures for the head, neck, shoulder, elbow, forearm (pronation/suppination) and wrist were defined as the posture assumed when the local coordinate systems of adjacent segments were aligned (e.g. the wrist is at zero degrees deviation when the zx planes of the hand and forearm are parallel). For the global reference frame, *X* and *Y* axes were aligned with the desk and *Z* was parallel to gravity (Fig. 1).

Table 2
Bony landmarks and local coordinate system for measured body segments.

Segment	Bony landmarks	Local coordinate system[a]
Head	Right tragus	*Y* axis – vector from the right to the left tragus
	Left tragus	*X* axis – vector from the right tragus to the right canthus
	Right canthus	*Z* axis – vector directed toward the apex of the head
	Left canthus	
Trunk	Right acromion	*Y* axis – vector from the right to the left acromion
	Left acromion	*X* axis – vector parallel with global *Z* axis (Note: The global *Z* axis is parallel and opposite to gravity)
	Top of sternum	*Z* axis – vector parallel and opposite to the global *X* axis
Arm	Right acromion	*Y* axis – vector from the lateral to the medial epicondyle
	Lateral epicondyle	*X* axis – vector from the lateral epicondyle to the right acromion
	Medial epicondyle	*Z* axis – vector directed toward the triceps
Forearm	Lateral epicondyle	*Y* axis – vector from the ulnar to the radial styloid
	Ulnar Styloid	*X* axis – vector from the ulnar styloid to the lateral epicondyle
	Radial Styloid	*Z* axis – vector directed toward the dorsal side of the forearm
Hand	2nd metacarpal	*Y* axis – vector from the 5th to the 2nd metacarpal
	3rd metacarpal	*X* axis – vector from the Dactylion to the 3rd metacarpal
	5th metacarpal	*Z* axis – vector directed toward the dorsal side of the hand
	Dactylion (with fingers extended)	

[a] *Z* axis is defined from the cross product of the first two defined axis. *X* axis is then redefined as the cross product of the *Y* and *Z* axis to ensure all axes are orthogonal.

The location of the notebook computer was defined by the vertical, horizontal and lateral position of the bottom, midpoint of the display relative to the subject's sternum. Viewing distance for each configuration was calculated as the distance between midpoint of the subject's right and left canthus and the top, center of the display.

At the beginning of the experiment and after completing the task in each configuration, participants indicated discomfort perceived in the neck, shoulder, upper back, lower back, forearm, wrist or hand on a 10 cm horizontal visual analog scale with two verbal anchors. The left anchor read "No discomfort" the right anchor read "Extreme Discomfort". Tick mark distance from the left side of the 10 cm horizontal line was measured for each body segment and summed to obtain a total discomfort score for each subject.

After completing the task in each configuration, participants also rated how comfortable and how easy to use the configuration was by indicating the degree to which they agreed with the following statements on a 7 point Likert scale: "This configuration was comfortable" and "This configuration was easy to use".

2.4. Data analysis and statistics

To assess the effect of configuration on the range of postures assumed during the task, distribution percentiles (10th, 50th and 90th) of angle were calculated from continuous measures of wrist (extension, deviation), forearm (pronation), elbow (flexion), shoulder (flexion, abduction, rotation, elevation, and retraction), neck (flexion) and head (tilt) and viewing angles. The 50th percentile provides a measure of the median posture by definition while the difference between the 90th and 10th percentile provides a measure of the range of motion. Mean viewing distance, mean horizontal, vertical and lateral distance of the notebook to the subject's sternum and mean productivity were also calculated.

Metrics across all configurations were compared using a 1-way repeated measures analysis of variance (RMANOVA) with configuration as the independent variable. If a significant configuration effect was found ($p < 0.05$), pair-wise differences were evaluated using the Tukey–Kramer HSD test.

Discomfort, ease of use, and comfort ratings were compared using the Friedman Test. If a significant treatment effect was found ($p < 0.05$), pair-wise differences were evaluated using the Student-Newman–Keuls test.

3. Results

Compared to placing the notebook flat on the desk, use of the 12° incline (INC12), 25° incline (INC25) and commercial riser (RISER), significantly ($p < 0.001$) reduced the vertical distance between the monitor and subject by 4.4 cm, 9.3 cm and 15.1 cm, respectively (Table 3). The RISER configuration also increased the horizontal and viewing distance. On average, viewing distance was nearly a half meter (52 cm) for all configurations except for the RISER configuration, which was 72 cm (Table 3). The "J" key of the internal keyboard (external keyboard for the RISER configuration) was placed an average of 24 cm (std. dev. = 4 cm) from the edge of the desk.

Viewing angle and postures of the head and neck changed significantly ($p < 0.001$) across configurations (Fig. 2). Pair-wise comparisons showed use of the inclines lead to smaller viewing angles, more upward head tilt and less forward neck flexion compared to the DESK configuration. Relative to the DESK configuration, viewing angle and neck flexion values decreased approximately 4° and 2°, respectively, with use of the 12° incline, while head tilt was elevated approximately 3°. Use of the 25° incline further decreased viewing angle and neck flexion 4° and 2°, respectively, and elevated head tilt 3°. These changes were seen at all percentile levels (10th, 50th and 90th). The small differences between 90th and 10th percentile values indicate head and neck postures were relatively static during the task. Adding the mouse to the DESK and INC25 configurations had little effect on head and neck postures.

Configuration had a significant ($p < 0.001$) effect on 50th and 90th percentile levels of shoulder abduction (Fig. 3a). Pair-wise comparisons indicated differences were primarily seen between configurations with and without a mouse. For example, 90th percentile shoulder abduction was 5° greater for the DESK + M configuration compared to the DESK configuration. The same change was observed between the INC25 + M and INC25 configurations. The inclines themselves (INC12 and INC25) did not have a significant effect on shoulder abduction compared to the DESK configuration.

Configuration also had a significant ($p < 0.001$) effect on all percentile levels of external shoulder abduction (Fig. 3b). Once again, pair-wise comparisons showed the differences were primarily seen between configurations with and without a mouse. Differences in 90th percentile external shoulder rotation between the DESK and DESK + M configurations and the INC25 and INC25 + M configurations exceeded 34°. The inclines themselves had no significant effect on external shoulder rotation.

There were no observed differences in shoulder flexion across configurations at any of the percentile levels ($p > 0.80$).

A significant effect of configuration was observed in 90th percentile ($p < 0.001$) shoulder retraction values (Fig. 4a) and in 50th percentile ($p = 0.013$) and 90th percentile ($p = 0.007$) shoulder elevation values (Fig. 4b). The RISER configuration resulted in 7 mm greater 90th percentile shoulder retraction and 5 mm greater 90th percentile shoulder elevation compared to the INC12 configuration according to pair-wise comparisons.

Configuration had a significant effect on forearm pronation ($p < 0.001$) at all percentile levels (Fig. 5a). Based on pair-wise comparisons, this effect was seen primarily between configurations with and without an external mouse. Compared to the DESK configuration, the DESK + M configuration resulted in 12°, 17° and 13° greater 10th, 50th and 90th percentile forearm pronation values. The INC25 + M configuration resulted in 10th, 50th, and 90th percentile forearm pronation values 10°, 16°, and 15° greater, respectively, compared to the INC25 configuration. No significant differences were observed between the DESK, INC12 or INC25 configurations. 90th percentile forearm pronation values were greatest for the RISER configuration compared to all other tested configurations.

Wrist extension was significantly affected by configuration ($p < 0.001$) at all percentile levels (Fig. 5b). Pair-wise comparisons found that compared to the DESK, 10th percentile wrist extension values were 7° and 15° greater for the INC12 and INC25 configurations, respectively. 50th and 90th percentile wrist extension values were similar between the DESK and INC12 configurations. The INC25 configuration increased 50th and 90th percentile wrist extension values 11° and 10°, respectively, compared to the DESK. Addition of the mouse to the DESK and INC25 configurations reduced wrist extension, with decreases of 6° and 7° for the DESK + M and INC25 + M, respectively, observed at the 90th percentile level. Wrist extension values were similar between the INC25 + M and RISER configurations. Compared to the DESK + M configuration, the RISER increased 10th and 50th percentile wrist extension angles by 8° and 6°, respectively.

Wrist ulnar deviation was significantly different across configurations ($p < 0.001$) for all percentile levels, primarily due to addition of the external mouse (Fig. 5c). Pair-wise comparisons showed ulnar deviation at the 10th and 50th percentile levels increased 4° and 5°, respectively, between the DESK and DESK + M configurations. Similarly, ulnar deviation at the 10th, 50th and 90th percentile levels increased 5°, 6° and 6°, respectively, between the INC25 and INC25 + M configurations. No significant differences were observed between the DESK, INC12 or INC25 configurations. Wrist ulnar deviation postures were also similar between the INC25 + M and RISER configurations.

Configuration affected ease of use ratings ($p < 0.01$) with pair-wise comparisons indicating the INC25 configuration rated significantly lower (i.e. not as easy to use) compared to all other configurations (Table 4). Comfort ratings differed significantly across configurations ($p < 0.01$). The DESK + M configuration received the highest comfort rating (i.e. most comfortable) while the INC25 configuration received the lowest comfort rating according to pair-wise comparisons. Discomfort scores also differed across configurations ($p < 0.01$) with pair-wise comparisons showing the lowest values were observed for the RISER configuration and highest values seen for the INC25 and INC25 + M configurations.

Configurations had a significant effect ($p < 0.001$) on productivity (i.e. time to complete the task). Pair-wise comparisons showed productivity was highest (i.e. shortest time to complete the task) for the INC25 + M configuration, requiring 8.4 min (std. dev. = 1.4 min) compared to all other configurations. Productivity was similar between the DESK, INC12, INC25 and RISER configurations (9.8 min (std. dev. = 1.2 min), 10.1 min (std. dev. = 1.7 min), 10.0 min (std. dev. = 1.6 min), 9.2 min (std. dev. = 1.3 min). Productivity with the DESK + M configuration was 8.9 min (std. dev. = 1.8 min).

Table 3
Mean (SD) viewing distance and distance of the notebook to the sternum.[a]

Metric	p-Value[b]	DESK	INC12	INC25	RISER
Viewing distance (cm)	**<0.001**	55.7 (6.8)[A]	53.5 (6.3)[A]	52.1 (5.3)[A]	72.9 (9.6)[B]
Horizontal (cm)	**<0.001**	53.0 (6.9)[A]	52.7 (6.3)[A]	52.1 (5.0)[A]	75.8 (8.1)[B]
Lateral (cm)	0.935917	2.3 (5.6)	2.2 (5.6)	1.8 (5.0)	1.8 (9.1)
Vertical (cm)	**<0.001**	18.7 (2.5)[A]	14.3 (2.5)[B]	9.4 (2.7)[C]	3.6 (2.3)[D]

DESK – notebook placed directly on desk, INC12 – notebook placed on a 12° incline, INC25 – notebook placed on a 25° incline, RISER – notebook placed on a riser.
[A]Values with common superscripts were not significantly different based on Tukey HSD pair-wise comparisons.
[a] Conditions which included an external mouse are not shown as they did not affect notebook location.
[b] Bolded p-values indicate a significant difference across groups.

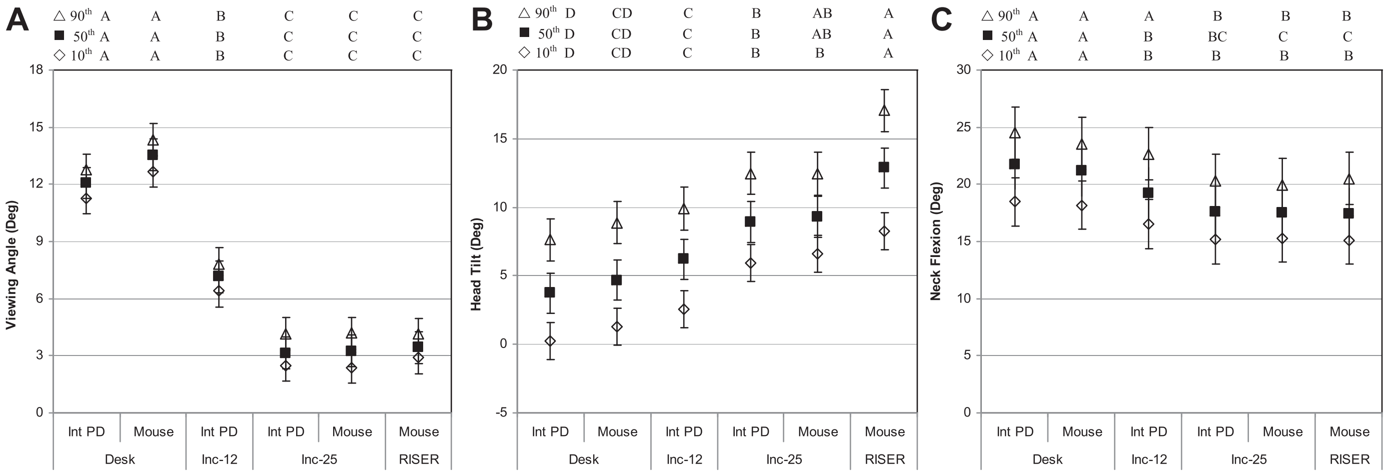

Fig. 2. Viewing, Head and Neck Angles. Viewing angle, head tilt and neck flexion varied significantly (all *p*-values from the ANOVAs were less than 0.001) across the conditions. Mean 10th, 50th and 90th %ile values with standard errors across conditions are presented. Int PD indicates the internal pointing device (touchpad) was used. The letters above report results from the Tukey post-hoc analysis. Values with the same letter were not significantly different. Values with different letters are ranked such that A > B > C.

4. Discussion

Our goal was to compare head, neck and upper extremity posture during notebook computer use with non-input peripherals aimed at elevating screen height. Consistent with our first hypothesis, the use of the simple inclines provides postural benefits for the head and neck at the expense of detrimental wrist postures, particularly with use of the larger incline. Partially supporting our second hypothesis, the RISER configuration led to smaller non-neutral head and neck postures compared to the DESK + M configuration. However, the RISER configuration did not result in more neutral wrist postures compared to the INC25 + M configuration. In addition, 90th percentile forearm pronation and external shoulder rotation angles were greatest for the RISER configuration. These changes were primarily due to the external input peripherals (mouse and keyboard) required to use the riser. Finally, the RISER configuration also increased viewing distance as a consequence of having to place the riser behind the external keyboard.

A number of studies have evaluated upper extremity postures during notebook computer use in configurations similar to our DESK configuration (Straker et al., 1997; Villanueva et al., 1998; Moffet et al., 2002; Sommerich et al., 2002; Szeto and Lee, 2002; Seghers et al., 2003; Rempel et al., 2007). Median head tilt values reported here are similar to those found by Seghers et al. (2003) and Sommerich et al. (2002), and our median forearm pronation values were similar to those reported by Rempel et al. (2007). Shoulder abduction, flexion and external rotation as well as wrist extension and deviation values measured for the DESK configurations were generally higher than those reported in previous studies while elbow flexion values were lower. The differences in postural outcomes may be due to differences in the horizontal and vertical placement of the notebook relative to the subject as well as the distribution of computing tasks performed factors which have been reported to affect upper extremity posture (Kotani et al., 2007; Dennerlein and Johnson, 2006a).

Consistent with previous studies (Villanueva et al., 1998; Szeto and Lee 2002; Seghers et al., 2003), elevating the notebook, and thus the display screen, with inclines or a riser improved head and neck postures. Previous studies have demonstrated forward head postures are associated with increased compressive loading of the

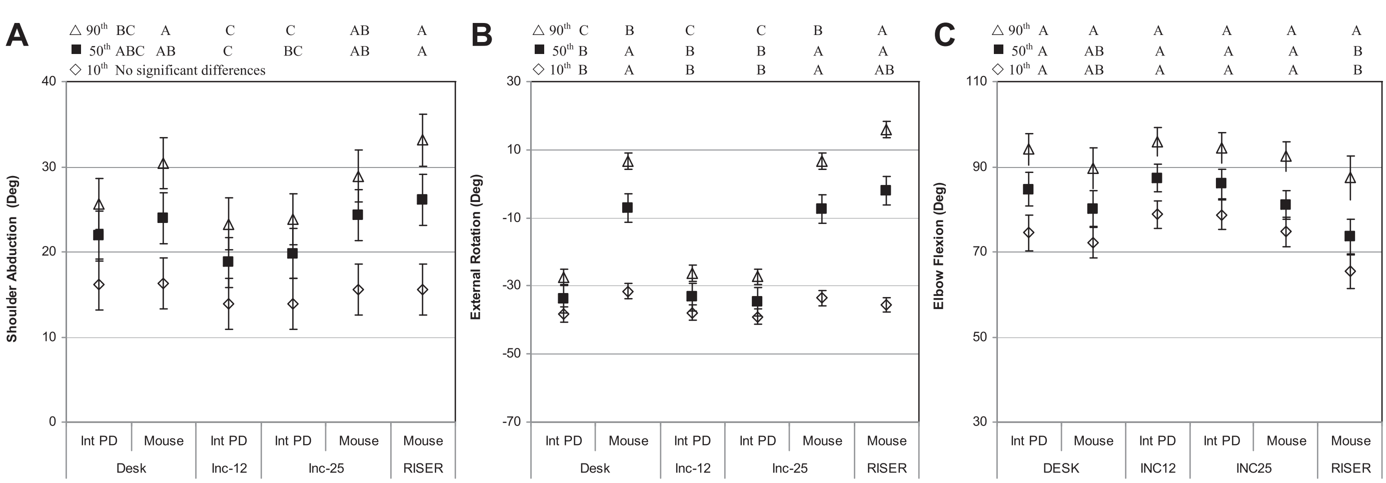

Fig. 3. Shoulder and Elbow Angles. No difference was seen in shoulder flexion angle (not shown). Abduction and external rotation angles varied across condition; however, stratified analysis indicated that most of these differences were due to the use of an external mouse. Small decreases in elbow flexion were seen with use of the riser. Mean 10th, 50th and 90th %ile values with standard errors across conditions are presented. Int PD indicates the internal pointing device (touchpad) was used. The letters above report results from the Tukey post-hoc analysis. Values with the same letter were note significantly different. Values with different letters are ranked such that A > B > C.

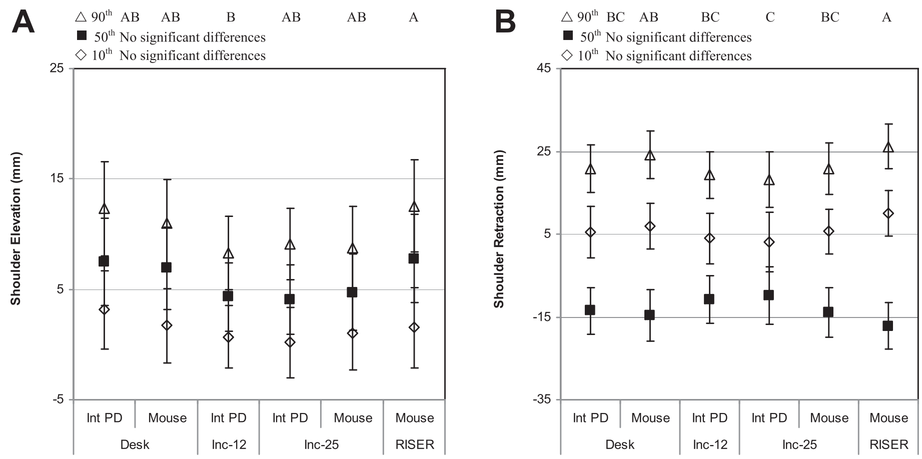

Fig. 4. Shoulder Position. Use of the riser increased shoulder elevation and reduced shoulder retraction. Mean 10th, 50th and 90th %ile values with standard errors across conditions are presented. Int PD indicates the internal pointing device (touchpad) was used. The letters above report results from the Tukey post-hoc analysis. Values with the same letter were note significantly different. Values with different letters are ranked such that A > B > C.

spine (Harms-Ringdahl, 1986; Schuldt et al., 1986; Berkhout et al., 2004) and increased neck extensor muscle activity (Sommerich et al., 2001; Seghers et al., 2003; Turville et al., 1998). Epidemiologic evidence, however, for forward head and neck postures as a risk factor for MDSs is limited. A literature review by Gerr et al. (2006) found no evidence for an association between MSD outcomes and viewing angle or neck posture. Limited and conflicting evidence was found for associations between MSD outcomes and head tilt (Hunting et al., 1981; Starr et al., 1985; Marcus et al., 2002).

With regards to the wrist, postures were relatively poor in the DESK configuration to begin with and were made worse with each incline. Furthermore, use of the external mouse decreased extension while use of the external keyboard increased extension (Comparing DESK + M to RISER). Studies by Rempel et al. (2007) and Sommerich et al. (2002) also reported similar increases in wrist extension for subjects using an external keyboard (without a built in wrist rest) compared to using the internal keyboard of a notebook computer. It is important to point out that the design of the external mouse and keyboard can have a significant impact on postures, particularly for the wrist (Rempel et al., 2007; Oude Hengel et al., 2008). In addition, when a keyboard is higher than the elbow, the inclined slope of the keyboard in the vicinity of 12° provides similar wrist extension postures to lower and flatter keyboard configurations (Simoneau and Marklin, 2001; Asundi et al., 2011).

Configurations that increase non-neutral postures of the wrist may lead to higher risk of injury. Laboratory studies have shown wrist postures beyond 33° extension or 15° ulnar deviation result in carpal tunnel pressures of 30 mmHg (Keir et al., 2007). Pressures at this level, over a period of repeated exposures, may be high enough to cause nerve dysfunction (Rempel et al., 1999). Additionally, limited epidemiologic data suggests these extension values increase the risk of injury (Bergqvist et al., 1995; Liu et al., 2003), with one study reporting an association between carpal tunnel syndrome and wrist extension beyond 20° (Liu et al., 2003).

Shoulder posture was relatively unaffected by use of the inclines. Similar to the findings by Sommerich et al. (2002), use of the external mouse had a large effect on external rotation (compare DESK to DESK + M and INC25 to INC25 + M). The RISER

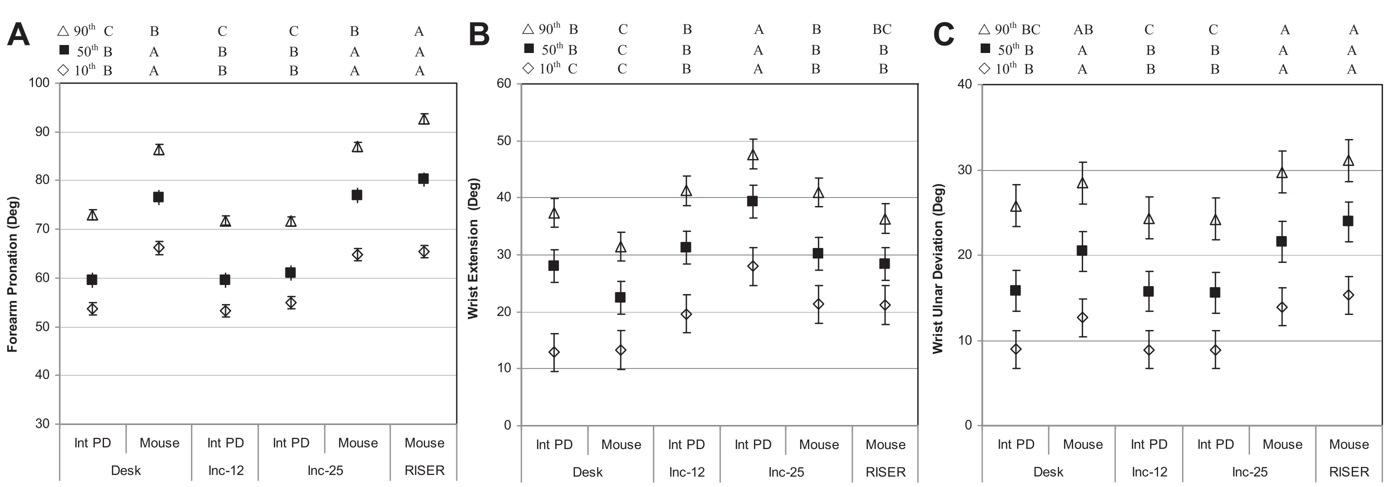

Fig. 5. Forearm and Wrist Angles. Forearm pronation was unaffected by inclines and increased with external mouse use. Extension increased with incline and decreased with mouse use while ulnar deviation increased with mouse use. Mean 10th, 50th and 90th %ile values with standard errors across conditions are presented. Int PD indicates the internal pointing device (touchpad) was used. The letters above report results from the Tukey post-hoc analysis. Values with the same letter were note significantly different. Values with different letters are ranked such that A > B > C.

Table 4
Mean (SD) self-reported ratings of ease, comfort and discomfort.

Metric	p-Value[a]	DESK		INC12	INC25		RISER
		Int PD	Mouse	Int PD	Int PD	Mouse	Mouse
Ease (7 = Best)	**<0.001**	5.6 (1.2)[A]	6.2 (1.1)[A]	5.1 (1.5)[A]	3.6 (2.2)[B]	4.5 (1.8)[A]	5.6 (1.4)[A]
Comfort (7 = Best)	**<0.001**	5.3 (1.3)[B]	6.0 (0.8)[A]	4.8 (1.3)[B]	3.3 (2.1)[C]	4.2 (2.0)[B]	5.4 (1.4)[B]
Discomfort (cm)	**<0.001**	0.9 (1.6)[B]	0.9 (1.4)[B]	1.1 (1.3)[B]	3.3 (4.3)[A]	2.6 (4.1)[A]	0.4 (0.7)[C]

DESK – notebook placed directly on desk, INC12 – notebook placed on a 12° incline, INC25 – notebook placed on a 25° incline, RISER – notebook placed on a riser, Int PD – Internal Pointing Device, Mouse – External Mouse.
[A]Values with common superscripts were not significantly different based on Student-Newman–Keuls follow up tests.
[a] Bolded p-values indicate a significant difference across groups ($n = 15$).

configuration further increased 90th percentile external rotation compared to the DESK + M and INC12 + M configurations. The increase in external shoulder rotation may be explained by the mouse being placed more laterally (to the right) in the RISER configuration due to the wider external keyboard compared to the internal notebook keyboard (Dennerlein and Johnson, 2006b). Use of a narrower external keyboard, perhaps without a number pad, would likely reduce the differences in shoulder postures between the DESK + M and RISER configurations. However, the effects of differences in shoulder postures on muscular load are difficult to discern, as subjects could support their forearms on the desk surface. Previous studies have shown forearm support can alter the relationship between sustained postures and muscle load (Delisle et al., 2006; Kotani et al., 2007).

The upper extremities are complex kinematic chains with several degrees-of-freedom (Winter, 2000). In this study we found each configuration generally led to changes across several joints. For example, configurations with an external mouse (DESK + M, INC25 + M and RISER) not only affected the wrist, increasing ulnar deviation and reducing extension compared to configurations without a mouse (DESK, INC12 and INC25), they also affected joints further up, increasing forearm pronation and external rotation. These results highlight the importance of evaluating the entire system when assessing the effects of computer workstations and peripherals on a user's posture.

This study found several small but statistically significant differences in postures across each of the six configurations evaluated. It is difficult to assess the practical implication of these small differences as the literature is limited regarding the dose-response relationship between postures and risk of musculoskeletal (MSK) disorders. However, small changes in posture, particularly those of the head and neck which tend to be more static (as shown by the small difference between 90th and 10th percentiles), can have a significant impact on comfort (Lindegard et al., 2005) and the risk of MSDs over long periods of exposure (Winkel and Mathiassen, 1994), such as those seen during extended computer use (Tornqvist et al., 2009; Wahlstrom et al., 2004).

Of interest was the fact that, while use of the riser led to the lowest discomfort scores, use of the notebook directly on the desk with an external mouse received the highest ease and comfort ratings. This may be explained by the fact that when using the riser, the screen was further back; a factor which some subjects indicated made text and images difficult to see. This issue could be addressed through the use of a riser design that allows the laptop keyboard to float over the external keyboard, allowing the screen to be moved closer to the user. The DESK configuration may also have received a more favorable rating as it was the configuration with which subjects were most familiar.

A potential limitation to our study is the foam padding added to the front edge of the desk which was done to reduce the effects of contact pressure. Desks in portable environments are not likely to have padded surfaces, and therefore, if use of the inclines or riser affects the contact area of the forearm, it may impact a user's discomfort beyond that due to the postural changes observed in this study.

The findings of this study are also limited to postural changes and the self-reported measures. Evaluating other physical outcomes, such as joint torques and muscle activity, would provide further insight into the biomechanical loads associated with each configuration. Another limitation was the short duration of this study (approximately 10 min per trial). During longer sessions users may adjust their posture which could be constrained by the configuration they are working in. It is also important to note that this study only examined the right upper extremities and therefore conclusions cannot be made with regards to the effects of each configuration on the left upper extremities.

Finally, the generalizability of our results may be limited by the use of a 72 cm fixed height desk and height adjustable chair. We chose this configuration as a large majority of fixed height desks have a 72 cm high working surface, while there is no "common" chair height and we did not wish to arbitrarily choose one. Furthermore, our experience suggests height adjustable chairs are common in hotels, a targeted location of this study.

5. Conclusions

Based on these findings, users of notebook computers in mobile computing environments (e.g. hotels, conferences, and conference rooms) may find improved head and neck postures with increasing the angle of the notebook support surface with simple improvised methods (such as a small three ring binder or even the transformer of the power supply); however, there is a tradeoff with wrist extension associated with use of the notebooks internal input devices, which increases with increased angle. The improvements and tradeoffs for the 12° incline appear to be acceptable, given the limitations of the study. Similar to other studies, these results also indicate that users of notebook computers may find improved postures with the use of an external mouse and, if the workspace is available, a riser and external keyboard.

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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 experimental and study design, including the selection of the specific configurations and input devices; 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.

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