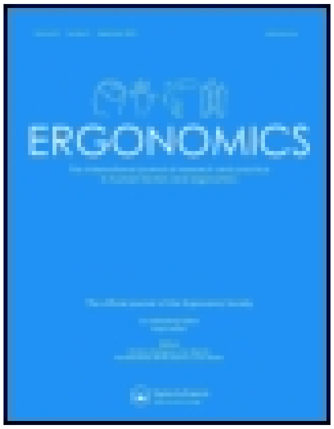

Ergonomics
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/terg20

Notebook computer use on a desk, lap and lap support: Effects on posture, performance and comfort

Krishna Asundi [a] , Dan Odell [b] , Adam Luce [c] & Jack T. Dennerlein [a]
[a] Department of Environmental Health , Harvard School of Public Health , Boston, USA
[b] Microsoft Hardware Corporation , Redmond, USA
[c] Bioengineering Department , Boston University , Boston, USA
Published online: 12 Jan 2010.

Ergonomics
Vol. 53, No. 1, January 2010, 74–82

Notebook computer use on a desk, lap and lap support: Effects on posture, performance and comfort

Krishna Asundi[a], Dan Odell[b], Adam Luce[c] and Jack T. Dennerlein[a]*

[a]*Department of Environmental Health, Harvard School of Public Health, Boston, USA;* [b]*Microsoft Hardware Corporation, Redmond, USA;* [c]*Bioengineering Department, Boston University, Boston, USA*

(*Received 19 January 2009; final version received 1 October 2009*)

This study quantified postures of users working on a notebook computer situated in their lap and tested the effect of using a device designed to increase the height of the notebook when placed on the lap. A motion analysis system measured head, neck and upper extremity postures of 15 adults as they worked on a notebook computer placed on a desk (DESK), the lap (LAP) and a commercially available lapdesk (LAPDESK). Compared with the DESK, the LAP increased downwards head tilt 6° and wrist extension 8°. Shoulder flexion and ulnar deviation decreased 13° and 9°, respectively. Compared with the LAP, the LAPDESK decreased downwards head tilt 4°, neck flexion 2°, and wrist extension 9°. Users reported less discomfort and difficulty in the DESK configuration. Use of the lapdesk improved postures compared with the lap; however, all configurations resulted in high values of wrist extension, wrist deviation and downwards head tilt.

Statement of Relevance: This study quantifies postures of users working with a notebook computer in typical portable configurations. A better understanding of the postures assumed during notebook computer use can improve usage guidelines to reduce the risk of musculoskeletal injuries

Keywords: lapdesk; laptop; musculoskeletal disorder; posture; upper extremity

1. Introduction

As overall computer use grows, more and more people choose notebook computers over the traditional desktops. A recent study (Chang *et al.* 2008) reported over 80% of college students use a notebook computer exclusively as their personal computer and for the first time, quarterly notebook sales have exceeded desktop sales with over 9.5 million units sold in 2008 in the U.S. (Mann 2008). Notebook computers, owing to their compact form factor, integrated monitor, and less than ideal input devices can increase exposure to risk factors for musculoskeletal disorders (MSDs).

Previous studies have shown that, compared with desktop computers, notebook computer use results in greater neck flexion and downwards head tilt (Straker *et al.* 1997, Sommerich *et al.* 2002, Seghers *et al.* 2003), greater neck extensor activity (Saito *et al.* 1997, Villanueva *et al.* 1998), and reduced range of neck movement (Szeto and Lee 2002). Use of the integrated input devices have been shown to decrease external rotation and variability of the shoulder (Sommerich *et al.* 2002) as well as ulnar deviation of the wrist (Rempel *et al.* 2007).

As a result of these findings, most practitioners and researchers recommend using a laptop in a standard desktop configuration with external peripherals, such as a mouse, keyboard, and external monitor in order to avoid exposure to these potentially harmful postures. These recommendations, however, can be difficult to implement for many portable computing environments, such as those that do not provide a desk on which to place the notebook computer. In such environments, users often work with the computer on their lap, effectively lowering the screen and keyboard height.

To date, only Moffet *et al.* (2002) measured posture and muscle activity of the upper extremities while participants completed a simple typewriting task using a laptop placed on the lap or on a desk. They found reduced head bending, backwards trunk inclination and wrist extension but greater shoulder flexion for the desk configuration.

In addition to non-neutral postures, another risk factor during notebook use on the lap may be reduced postural variability (Grieco 1986, Sauter *et al.* 1991). When working with the notebook computer on the lap, users must stabilise it with their arms and legs and

*Corresponding author. Email: jax@hsph.harvard.edu

ISSN 0014-0139 print/ISSN 1366-5847 online

DOI: 10.1080/00140130903389043
http://www.informaworld.com

therefore may limit their movement to reduce the risk of dropping the computer.

Users and ergonomic practitioners have several options to alleviate postural stress when working in a portable computing environment. One option is increasing the height of the notebook on the lap by placing pillows or cushions under the notebook. This option may decrease forwards head inclination by raising the position of the screen. Soft devices, however, are often unstable and therefore off-the-shelf devices such as lapdesks provide both an elevated and sturdy support surface. The stable surface may allow postural variability to increase.

Therefore, the aim of this study was to compare postures, postural variability, performance and comfort between notebook computer use on a fixed desk and on the users lap. We also aimed to evaluate the use of a commercially available lapdesk on these measures. We hypothesise that non-neutral postures of the head, neck and wrist will increase while postural variability of the shoulder and elbow will decrease during notebook use on the lap compared with notebook use on top of a fixed desk. Furthermore, we hypothesise the use of a lapdesk will reduce these non-neutral postures and increase postural variability.

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 either owned or had experience working with a laptop and reported no current or previous history of head, neck or upper extremity MSDs. The mean anthropometric measures for the participants were typical of northern American population (Table 1). The Harvard School of Public Health Human Subjects Committee approved all protocols and participant consent forms.

2.2. *Experimental protocol*

Three portable computing configurations tested were, DESK, LAP and LAPDESK (Figure 1). For all configurations participants used a 15 inch notebook computer with built-in touch pad and isometric joystick (Touch Point) pointing devices (Thinkpad T61, Lenovo, Morrisville, NC, USA). The order of configurations was randomised.

The DESK configuration placed the notebook computer on top of a desk 72.4 cm high. Participants sat in an adjustable office chair with seat pan height selected to match popliteal height when the thighs were horizontal (mean chair height = 44.8 cm, std. dev. = 5.2 cm). Seat pan depth was fixed at 44.0 cm and the seat back was at a 90° angle relative to the seat pan. Notebook position on the desk was selected by the participant. The edge of the desk was padded with a thin strip of foam to reduce contact pressure.

The LAP configuration placed the notebook directly on the participants' lap. The LAPDESK configuration placed the computer on a lapdesk

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)

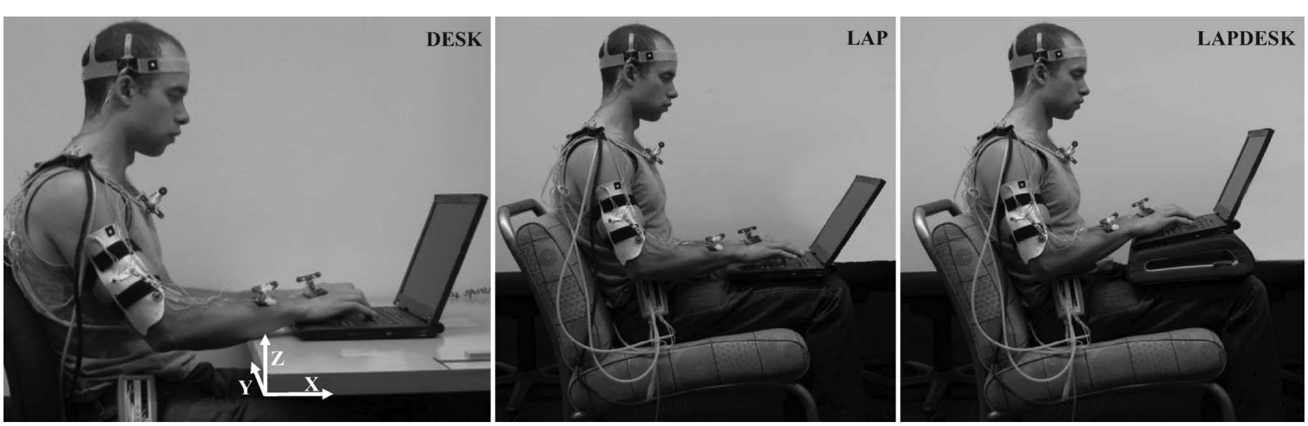

Figure 1. Participant working on a notebook computer at a fixed height desk (left), on the lap (middle) and on a lapdesk (right). Five clusters of three infrared markers tracked the position and orientation of the head, arm, forearm and hand. From the segment orientations, relative joint angles were computed for the head, neck, shoulder, elbow and wrist. Position of the upper arm provided measures of shoulder elevation and protraction. Note the orientation of the global axis system in the DESK image.

(Belkin Cushtop, Belkin, Compton, CA, USA) placed on the participants' lap. For these two lap configurations, participants sat in an office lounge chair with relatively stiff cushions. Seat pan height and depth were 45.0 and 48.0 cm, respectively. The seat back was fixed with a 100° angle relative to the seat pan. The two lap configurations were designed to imitate casual computer use on a comfortable chair or couch.

Participants were free to adjust the position the notebook and the tilt of the screen for each configuration. No external input peripherals were provided for any of the configurations and participants were instructed to use the touchpad rather than the isometric joystick for cursor movement.

For each configuration, participants completed a simulated computer task. The simulated task involved a combination of typing text, pointing and clicking on icons, selecting-dragging-and-dropping of icons, and comprehensive reading exercise. The task was designed to require relatively equal amounts of keyboard and mouse use as well as periods of not using the input devices (e.g. reading text from the screen). Productivity was measured as the time to complete the set of tasks.

An infrared three-dimensional (3D) motion analysis system (Optotrak Certus, Northern Digital, Ontario, Canada) measured upper extremity posture. 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 (Figure 1). An additional three IREDs were placed on the base of the notebook and one on the top, right edge of the notebook screen. Modelling each body segment as a rigid body, specific bony landmarks were tracked based on their location relative to their associated IRED cluster (Table 2). Using a single 3-camera unit, the 3D locations of the 19 IREDs were recorded at 20 samples/s. Data were digitally filtered through a low-pass, fourth-order Butterworth filter with a 5 Hz cutoff frequency. Filtered marker position data were then used to define local coordinate systems for each segment (Table 2).

Relative joint angles were calculated from the Euler angles defined by the rotation matrices describing the orientation of the distal segment relative to the proximal segment (Winter 2005). 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). Note that as the trunk X and Z axes are parallel to the global axes, shoulder abduction and flexion are measured relative to the global coordinate system (i.e. gravity).

Shoulder elevation and protraction were defined as the vertical and horizontal translation, respectively, of the upper arm relative to 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 tragus'. Downwards 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 participants' eyes and the top, centre of the screen. The shoulder IREDS for two participants came loose during the experiments. All shoulder posture, elbow flexion and

Table 2. Bony Landmarks and Local coordinate system for measured body segments.

Segment	Bony Landmarks	Local Coordinate System*
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 towards 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 through the top of the suprasternal notch and parallel to the global Z axis
	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 towards 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 towards 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 towards the dorsal side of the hand
	Dactylion (with fingers extended)	

*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.

wrist pronation data for these participants were excluded from analysis.

Zero degree (0°) reference postures for the head, neck, shoulder and wrist and 90° reference postures for the elbow and forearm were collected by aligning the local coordinate system of each segment with the global reference frame. For the global reference frame, X and Y axes were aligned with the desk and Z was parallel to gravity (Figure 1).

The position of the computer was defined by the vertical, horizontal and lateral position of the J key relative to the participants' trunk. In addition, for the DESK configuration, the distance of the J key to the edge of the desk was measured. The viewing distance for each configuration was calculated as the distance between midpoint of the participants' eyes and the top, centre of the screen. Screen angle was defined as the angle of the screen relative to the base of the computer.

Participants indicated discomfort of the neck, shoulder, upper back, lower back, forearm, wrist or hand on a 10 cm visual analogue scale at the beginning of the experiment and after completing the task in each configuration. Tick mark distances from the left side of the 10 cm line were measured for each body segment and summed to obtain a total discomfort score for each participant. Participants also rated the ease and comfort of each configuration on a 7-point Likert scale.

2.3. *Data analysis and statistics*

Percentiles (10th, 50th, 90th) were calculated for viewing angle, head (tilt), neck (flexion), shoulder (flexion, abduction, rotation, elevation, and protraction), forearm (pronation), elbow (flexion) and wrist (extension and deviation). Standard deviations of these postures during the task were calculated as a measure of postural variability (Sommerich *et al*., 2002). Mean productivity, screen angle, viewing distance and notebook position were also calculated. Metrics were compared using a 1-way repeated measures analysis of variance (RMANOVA) with configuration as the independent variable. If a significant treatment effect was found, pair-wise differences were evaluated using the Tukey-Kramer HSD test.

Mean discomfort, ease of use, and comfort ratings were compared using the Kruskal-Wallis test adjusted for participant. If a significant treatment effect was found, pairwise differences were evaluated using a Wilcoxon test with Bonferroni correction for multiple comparisons.

3. Results

3.1. *Notebook position*

The position of the notebook computer varied across the three conditions (Table 3). When working with the notebook computer on the desk, the average distance from the J key to the edge of the desk was 240 mm (47 mm std. dev.). On the lap, compared with the desk, the notebook was approximately 100 mm lower and 25 mm closer to the user. On the lapdesk compared with on the lap, the notebook was 94 mm higher with little to no difference in its horizontal location. For all conditions, the distance between the eyes and the screen was relatively similar.

3.2. *Posture*

Overall, participants lowered their head and brought their arms closer to their body when using the notebook computer on their lap compared with using it on the fixed height desk. Use of the lapdesk elevated head postures while keeping the arms close to the body. Participants flexed at the elbow to compensate for the higher computer position with the lapdesk. In general, the patterns of change in 10th and 90th percentile postures across configurations were similar to those of the 50th percentile and therefore only median values are reported.

Compared with the DESK configuration, use of the notebook computer in the LAP increased downward head tilt and viewing angle approximately 10° and 6°, respectively, (Table 4), while neck flexion was unaffected. Wrist extension was increased

Table 3. Mean (SD) location of the notebook relative to the trunk, viewing distance screen angle and productivity.

Metric	p-value[+]	DESK	LAP	LAPDESK
Horizontal (mm)	**0.009**	440 (69)[a]	414 (54)[b]	411 (47)[b]
Lateral (mm)[#]	0.207	23 (56)	7 (44)	11 (43)
Vertical (mm)	<**0.001**	187 (25)[a]	289 (22)[b]	195 (25)[a]
Viewing Distance (mm)	0.104	557 (68)	593 (60)	559 (88)
Screen Angle (°)	<**0.001**	108 (5)[a]	113 (8)[b]	114 (8)[b]
Productivity (minutes)	0.655	9.81.2	10.42.1	10.42.2

[+]Bold p-values indicate a significant difference across groups (n = 15).

[a]Values with common superscripts were not significantly different based on Tukey HSD pair-wise comparisons.

[#]Lateral values are positive to the left.

approximately 8° while wrist ulnar deviation was reduced by 9°. Shoulder elevation, protraction, flexion and abduction were also significantly reduced when working with the notebook computer on the LAP, compared with the DESK.

3.3. Postural variability

Notebook computer use on the lap led to significant decreases in postural variability in shoulder elevation, shoulder protraction and elbow flexion compared with the DESK configuration (Table 5). The largest decrease was seen in elbow flexion with a 42% reduction in variability. An increase in postural variability was seen in wrist ulnar deviation.

Use of the LAPDESK significantly reduced viewing angle, downward head tilt and neck flexion approximately 10°, 4° and 3°, respectively compared with the LAP (Table 4). In addition, wrist extension was reduced 9°. All other postures were similar between the LAP and LAPDESK configurations.

Compared with the LAP, the LAPDESK did not significantly increase postural variability for any of the joints evaluated; however, values for shoulder protraction and elbow flexion did increase such that they were no longer significantly different from the DESK configuration (Table 5).

3.4. Discomfort, ratings and productivity

Participants found the DESK configuration to be more comfortable and result in less discomfort compared with the LAP configuration (Table 6). The LAPDESK configuration did not significantly change comfort or discomfort scores compared with the LAP, however, comfort scores increased slightly such that they were no longer significantly different compared with the DESK configurations. Participants took an average of

Table 4. Average (SD) median postures.

Segment	Direction	p-value+	DESK	LAP	LAPDESK
Viewing	Angle (°)*	**<.001**	12 (3)[a]	22(3)[b]	12(3)[a]
Head	Tilt (°)*	**<.001**	4 (6)[a]	−2(8)[b]	2(7)[a]
Neck	Flexion (°)	**0.002**	22 (9)[a]	21(10)[a]	19(9)[b]
Shoulder	Flexion (°)	**<.001**	31 (13)[a]	18(11)[b]	19(8)[b]
Shoulder	Adduction (°)	**<.001**	22 (11)[a]	15(7)[b]	14(8)[b]
Shoulder	Rotation (°)	0.670	34 (8)	36(7)	34(6)
Shoulder	Elevation (mm)	**0.003**	7 (14)[a]	−3(4)[b]	0(6)[b]
Shoulder	Protraction (mm)	**<.001**	−13 (20)[a]	13(17)[b]	10(19)[b]
Elbow	Flexion (°)	**0.001**	85 (14)[a,b]	77(11)[a]	91(9)[b]
Forearm	Pronation (°)	**0.038**	60 (5)[a]	57(4)[a,b]	57(4)[b]
Wrist	Extension (°)	**0.004**	28 (11)[a]	36(10)[b]	27(7)[a]
Wrist	Ulnar Dev (°)	**<.001**	16 (9)[a]	7(11)[b]	10(9)[b]

*Viewing angle is positive below the horizontal, downward head tilt is positive above the horizontal.
+Bold p-values indicate a significant difference across groups (n = 15 for all values except for shoulder, elbow and forearm postures where n = 13).
[a]Values with common superscripts were not significantly different based on Tukey HSD pair-wise comparisons.

Table 5. Mean (SD) standard deviations in postures as a measure of postural variability.

Segment	Direction	p-value+	DESK	LAP	LAPDESK
Viewing	Angle (°)	0.525	1 (0)	1 (0)	1 (0)
Head	Tilt (°)	0.785	3 (1)	3 (1)	3 (1)
Neck	Flexion (°)	0.456	4 (2)	3 (1)	3 (1)
Shoulder	Flexion (°)	0.101	5 (3)	4 (1)	5 (1)
Shoulder	Adduction (°)	**0.001**	4 (2)[a]	3 (2)[a,b]	2 (1)[b]
Shoulder	Rotation (°)	0.815	5 (1)	4 (2)	5 (3)
Shoulder	Elevation (°)	**0.016**	4 (2)[a]	3 (1)[b]	3 (2)[b]
Shoulder	Protraction (°)	**0.038**	6 (4)[a]	4 (2)[b]	5 (2)[a,b]
Elbow	Flexion (°)	**0.020**	7 (3)[a]	4 (2)[b]	5 (4)[a,b]
Forearm	Pronation (°)	0.515	8 (2)	9 (2)	9 (3)
Wrist	Extension (°)	0.621	10 (4)	9 (2)	10 (2)
Wrist	Deviation (°)	**0.010**	7 (2)[a]	8 (3)[b]	9 (3)[b]

+Bold p-values indicate a significant difference across groups (n = 15 for all values except for shoulder, elbow and forearm postures, where n = 13).
[a]Values with common superscripts were not significantly different based on Tukey HSD pair-wise comparisons.

Table 6. Mean (SD) ratings of ease, comfort and discomfort.

Metric	p-value+	DESK	LAP	LAPDESK
Ease (1–7 where 7 = Best)	0.082	5.6 (1.2)	4.4 (2.0)	5.1 (1.5)
Comfort (1–7 where 7 = Best)	**0.025**	5.3 (1.3)[a]	3.9 (1.8)[b]	4.5 (1.8)[a,b]
Discomfort (cm)	**0.003**	0.9 (1.6)[a]	3.2 (3.8)[b]	3.1 (5.7)[b]

+Bold p-values indicate a significant difference across groups (n = 15).
[a]Values with common superscripts were not significantly different based on Tukey HSD pair-wise comparisons.

10.2 minutes to complete the task, which did not differ across tasks.

4. Discussion

In this study we assessed upper extremity posture during notebook computer use in three common portable computing configurations: with the notebook placed on a desk and with the notebook placed on the lap with and without a device to raise the height of the notebook. Consistent with our first hypothesis, non-neutral postures of the head and wrist were increased during notebook computer use on the lap compared with a desk; however, wrist deviation and pronation were reduced and neck flexion was not affected. Furthermore, postural variability of the, shoulder and elbow decreased. Consistent with our second hypothesis, the LAPDESK configuration reduced downwards head tilt, neck flexion and wrist extension compared with the using the computer on the lap. Contrary to our hypothesis however, postural variability was not significantly affected.

The changes in downwards head tilt and viewing angle were expected as a number of studies have shown head posture and viewing angle to be influenced by screen height (Villanueva *et al.* 1998, Psihogios *et al.* 2001, Moffet *et al.* 2002, Seghers *et al.* 2003). Unexpectedly, neck flexion, did not change between DESK and LAP configurations despite the screen being an average of 100 mm lower in the LAP configuration. This may have been due to the fact that the notebook was also 25 mm further away in the DESK configuration resulting in users flexing their neck to bring their eyes closer to the screen. Further evidence for this is the reduction in both downwards head tilt and neck flexion in the LAPDESK configuration where the notebook was elevated to approximately the same level as the DESK with no change in horizontal distance.

Downward head tilt angles during notebook use on a desk found in this study are similar to those reported in the literature. Both Sommerich *et al.* (2002) and Seghers *et al.* (2003) evaluated postures during notebook computer work placed on a desk and found downward head tilt values of 2° and 4°, respectively. Neck flexion values reported here however, were considerably lower compared with previously reported values (Straker *et al.* 1997, Sommerich *et al.* 2002). This is likely attributable to the difference in methods used. Previous studies used the C7 as the point of rotation for the neck, whereas our study used the midpoint between the acromions. This point is more anterior to the C7 and hence our values are shifted lower. In a study similar to ours, Moffet *et al.* (2002) compared upper extremity posture during notebook computer use. They had participants perform a simple typing task on a notebook computer placed on a desk or on a lap while monitoring head bending, shoulder flexion, and wrist extension and deviation. For head bending, they reported angles of 17° and 23° for the desk and lap working positions, respectively. Moffet *et al.* (2002) did not consider downwards head tilt and neck flexion separately and therefore the values are difficult to compare directly to our results. However, the difference they report in head bending between conditions (6°) is similar to the difference we found in downward head tilt and neck flexion combined (7°).

While the changes in downward head tilt and neck flexion between configurations are small, due to the static nature of computer work, even small differences can lead to large health effects when the duration of exposure is taken into account (Winkel and Mathiassen 1994). A comprehensive literature review by Gerr *et al.* (2006) found no evidence for an association between MSD outcomes and viewing angle or neck posture while limited and conflicting epidemiological evidence was found for associations between downward head tilt and MSD outcomes (Hunting *et al.* 1981, Starr *et al.* 1985, Marcus *et al.* 2002). The reviewed studies focused on desktop computer configurations where participants may not have been exposed to the head and neck postures seen during notebook computer use, particularly in the LAP configuration.

Changes in shoulder posture were similar to the finding by Moffet *et al.* (2002), moving the notebook to the lap reduced shoulder flexion. Kinematics would predict the reduction in shoulder flexion, as well as abduction in the LAP configuration as the keyboard is brought closer and lower. Use of the lapdesk did not alter shoulder posture, as participants increased elbow flexion to compensate for the increase in keyboard height. Interestingly, while participants elevated their shoulder in the DESK configuration, they also retracted them, even though the keyboard was further away compared with the LAP and LAPDESK configurations. Shoulder flexion, abduction and internal rotation values measured during notebook use on the desk are higher than those reported in previous studies (Straker *et al*. 1997, Moffet *et al*. 2002, Sommerich *et al*. 2002) while elbow angles are slightly lower (94°–108°) (Straker *et al*. 1997, Sommerich *et al*. 2002). The differences in shoulder angles may be attributable to differences in postural measurements techniques, that is relative to gravity versus relative to the trunk.

Shoulder postures deviated further from neutral in the DESK configuration with median shoulder flexion values approaching those reported by Marcus *et al*., (2002) to increase risk of neck and shoulder MSD symptoms (35°–44°). The DESK configuration however provided support for the forearms. Previous studies have demonstrated that different upper arm postures do not necessarily alter shoulder muscle activity if forearm support is provided (Delisle *et al*. 2006, Kotani *et al*. 2007, Nag *et al*. 2008) and some epidemiologic studies have found support can reduce risk of adverse neck and shoulder outcomes (Hunting *et al*. 1981, Marcus *et al*. 2002). Moffet *et al*. (2002) did measure muscle activity and found differences in trapezius and deltoid muscle activity between lap and desk working positions. It is unclear however, whether they placed the notebook computer far enough away from the edge of the desk to allow for forearm support.

The changes in wrist extension between the DESK and LAP configurations is similar to the findings reported by Moffet *et al*. (2002), however the decrease in ulnar deviation is contrary to their findings. Again, differences in the task performed (ours included touch pad use, theirs did not) may explain the differences in deviation values. When the notebook was elevated by use of the lapdesk, the wrist extension was reduced and the lower ulnar deviation posture was maintained. This suggests that the changes in ulnar deviation between the DESK and LAP conditions are attributable to the differences in horizontal keyboard location and availability of forearm support while changes in wrist extension are due to the differences in keyboard height. Wrist extension and deviation values measured during notebook use on the desk are higher than those reported in previous studies (Straker *et al*. 1997, Moffet *et al*. 2002, Sommerich *et al*. 2002, Rempel *et al*., 2007). These differences may be due to the different computing tasks each study employed (Dennerlein and Johnson 2006). In addition, the desk was a standard fixed height of 72 cm (29.5 inches) and was not adjusted to the participants' anthropometry. Forearm pronation values are similar to those found by Rempel *et al*. (2007) in participants performing a typing task on a notebook computer.

Configurations that affect wrist posture can have a significant effect on the likelihood of injury. Keir *et al*. (2007) found wrist extension beyond 33° and ulnar deviation beyond 15° results in carpal tunnel pressures of 30 mmHg. This pressure is high enough to cause nerve dysfunction (Rempel *et al*. 1999). For the LAP configuration median wrist extension exceeded the 33° limit, however, in the DESK configuration median ulnar deviation exceeded the 15° limit. The LAPDESK configuration brought both median extension and ulnar deviation values below the recommended limits. Peak (90th) extension and deviation values exceeded the limits in all configurations. The median ulnar deviation values we report for the DESK configuration are near the 20° value reported by Hunting *et al*. (1981) to be associated with hand and arm abnormalities upon physical examination. A cross-sectional study by Liu *et al*. (2003) reported workers who maintained wrist extension above 20° were at greater risk of developing carpal tunnel syndrome. In this study, median wrist extension in all configurations exceeded this value; and for the LAP configuration even 10th percentile values are greater.

Working with the notebook computer on the lap decreased postural variability for a number of joints and these were not significantly affected by the use of a lapdesk. The variability in wrist deviation during notebook use on the desk found in this study is similar to the variability reported by Sommerich *et al*. (2002). However, their values of variability for shoulder and wrist extension are moderately lower. While the lapdesk may provide a larger surface for users to rest the notebook on, it may not improve stability enough to alter their postural dynamics. The variability measured here may not be related to stability of the device but rather that simply supporting something on the lap requires the reduced postural variability.

Ratings of comfort and discomfort were best for the DESK configuration. with no notable differences between the LAP and LAPDESK configurations even though the LAPDESK reduced non-neutral postures relative to LAP. Most participants were unfamiliar with the LAPDESK configuration and this may have affected their ratings. In addition, trials only lasted approximately 10 min, which may not have been enough time to affect discomfort. Other factors not measured may also have contributed to greater discomfort in the LAP and LAPDESK configurations.

One of the limitations to this study was that the only biomechanical parameter measured was posture. While sustained non-neutral postures can result in higher static muscle activity, previous studies have demonstrated that providing support alters the relationship between sustained postures and muscle activity (Delisle *et al.* 2006, Kotani *et al.* 2007). In addition, the study only examined a single device to raise the notebook. Other devices include self-improvised options such as pillows and cushions at hand as well as other commercially available devices. The device tested was designed specifically to raise the notebook to a similar height as a desk configuration and improve stability of the support surface. Most likely, the evaluation of other devices would most likely follow similar trends with different amount of change depending on the thickness and shape of the devices. Finally, the short duration of this study (approximately 10 min per trial) may have not been long enough for participants to reach steady-state performance. During longer sessions users may alter their posture which may be constrained by the configuration they are working in.

Overall, wrist, neck and head postures were relatively poor in all the portable computing configurations tested and therefore, it is recommended that users limit the use of notebook computers in the portable environment, change posture frequently to reduce the risk of injury, and/or take frequent breaks. For these portable configurations the desk configuration allowed for more postural variability and provided some neutral postures for the head. When configured on the lap, devices that raise the computer improve some postures.

In conclusion, use of the notebook on the lap improved some postures while making others worse compared with use of the computer on the desk. A device to increase notebook height, e.g. a lapdesk, improved postures negatively impacted by use of the notebook directly on the lap, nearing those when using the notebook on the desk and overall, improved postures associated with using a notebook in a portable computing configuration. However, based on data reported in the literature many of these postures are still less neutral than those associated with using a desktop computer configuration, that is, with an external monitor, keyboard, and pointing device.

Acknowledgements

This study was supported in part by the National Institute for Occupational Safety (R01 OH008373, and R01 OH003997) and the Microsoft Corporation.

References

Chang, C., *et al.*, 2008. Where and how college students use their laptop computers. *In*: *Proceedings of the 52nd Annual Meeting of the Human Factors and Ergonomics Society*.

Delisle, A., *et al.*, 2006. Comparison of three computer office workstations offering forearm support: impact on upper limb posture and muscle activation. *Ergonomics*, 49 (2), 139–160.

Dennerlein, J.T. and Johnson, P.W., 2006. Different computer tasks affect the exposure of the upper extremity to biomechanical risk factors. *Ergonomics*, 49 (1), 45–61.

Gerr, F., *et al.*, 2006. Keyboard use and musculoskeletal outcomes among computer users. *Journal of Occupational Rehabilitation*, 16 (3), 265–277.

Grieco, A., 1986. Sitting posture: an old problem and a new one. *Ergonomics*, 29 (3), 345–362.

Hunting, W., *et al.*, 1981. Postural and visual loads at VDT workplaces. I. Constrained postures. *Ergonomics*, 24 (12), 917–931.

Keir, P.J., *et al.*, 2007. Guidelines for wrist posture based on carpal tunnel pressure thresholds. *Human Factors*, 49 (1), 88–99.

Kotani, K., *et al.*, 2007. Effect of horizontal position of the computer keyboard on upper extremity posture and muscular load during computer work. *Ergonomics*, 50 (9), 1419–1132.

Liu, C.W., *et al.*, 2003. Relationship between carpal tunnel syndrome and wrist angle in computer workers. *Kaohsiung Journal of Medicine Science*, 19 (12), 617–623.

Mann, J., 2008. *Notebook sales exceed PC sales says IDC* [online]. TechSpot.com. Available from http://www.techspot.com/news/32269-notebook-sales-exceed-pc-sales-says-idc.html [Accessed in: October 2008].

Marcus, M., *et al.*, 2002. A prospective study of computer users: II. Postural risk factors for musculoskeletal symptoms and disorders. *American Journal of Industrial Medicine*, 41 (4), 236–249.

Moffet, H., *et al.*, 2002. Influence of laptop computer design and working position on physical exposure variables. *Clinical Biomechanics*, 17 (5), 368–375.

Nag, P.K., *et al.*, 2008. Influence of arm and wrist support on forearm and back muscle activity in computer keyboard operation. *Applied Ergonomics*, 40 (2), 286–291.

Psihogios, J.P., *et al.*, 2001. A field evaluation of monitor placement effects in VDT users. *Applied Ergonomics*, 32 (4), 313–325.

Rempel, D., *et al.*, 2007. The effect of six keyboard designs on wrist and forearm postures. *Applied Ergonomics*, 38 (3), 293–298.

Rempel, D., *et al.*, 1999. Pathophysiology of nerve compression syndromes: response of peripheral nerves to loading. *Journal of Bone Joint Surgery America*, 81 (11), 1600–1610.

Saito, S., *et al.*, 1997. Ergonomic evaluation of working posture of VDT operation using personal computer with flat panel display. *Industrial Health*, 35 (2), 264–270.

Sauter, S.L., *et al.*, 1991. Work posture, workstation design, and musculoskeletal discomfort in a VDT data entry task. *Human Factors*, 33 (2), 151–167.

Seghers, J., *et al.*, 2003. Posture, muscle activity and muscle fatigue in prolonged VDT work at different screen height settings. *Ergonomics*, 46 (7), 714–730.

Sommerich, C.M., *et al.*, 2002. Effects of notebook computer configuration and task on user biomechanics, productivity, and comfort. *International Journal of Industrial Ergonomics*, 30, 7–31.

Starr, S.J., *et al.*, 1985. Relating posture to discomfort in VDT use. *Journal of Occupational Medicine*, 27 (4), 269–271.

Straker, L., *et al.*, 1997. A comparison of the postures assumed when using laptop computers and desktop computers. *Applied Ergonomics*, 28 (4), 263–268.

Szeto, G.P. and Lee, R., 2002. An ergonomic evaluation comparing desktop, notebook, and subnotebook computers. *Archives of Physical and Medical Rehabilitation*, 83 (4), 527–532.

Villanueva, M.B., *et al.*, 1998. Ergonomic aspects of portable personal computers with flat panel displays (PC-FPDs): evaluation of posture, muscle activities, discomfort and performance. *Industrial Health*, 36 (3), 282–289.

Winkel, J. and Mathiassen, S.E., 1994. Assessment of physical work load in epidemiologic studies: concepts, issues and operational considerations. *Ergonomics*, 37 (6), 979988.

Winter, D.A., 2005. *Biomechanics and motor control of human movement*. John Wiley, Hoboken, NJ.