Applied Ergonomics 45 (2014) 1603–1609

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Effects of portable computing devices on posture, muscle activation levels and efficiency

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ARTICLE INFO

Article history:
Received 17 January 2013
Accepted 25 May 2014
Available online 13 June 2014

Keywords:
Portable computing devices
Typing
Performance
Posture

ABSTRACT

Very little research exists on ergonomic exposures when using portable computing devices. This study quantified muscle activity (forearm and neck), posture (wrist, forearm and neck), and performance (gross typing speed and error rates) differences across three portable computing devices (laptop, netbook, and slate computer) and two work settings (desk and computer) during data entry tasks. Twelve participants completed test sessions on a single computer using a test–rest–test protocol (30 min of work at one work setting, 15 min of rest, 30 min of work at the other work setting). The slate computer resulted in significantly more non-neutral wrist, elbow and neck postures, particularly when working on the sofa. Performance on the slate computer was four times less than that of the other computers, though lower muscle activity levels were also found. Potential or injury or illness may be elevated when working on smaller, portable computers in non-traditional work settings.

1. Introduction

Eighteen million slate computers were sold in 2010 and it is estimated that over 290 million slate computers will be sold worldwide from 2010 to 2016 (Melanson, 2011; Rotman Epps, 2012). One of the major advantages of slates is their mobility. This provides a distinct advantage to companies that allow their workers to telecommute. Telecommuting is becoming more prominent in the workforce with 89 of the top 100 US companies allowing their workers to telecommute (Telework Coalition, 2010). The Gartner Group estimates that in the US alone, 36.3 million employees telecommuted at least 8 h/month in 2008, up from 12.4 million in 1998 (Telework Coalition, 2010). Similarly, there was an approximately threefold increase in people telecommuting more than 8 h/week from 1998 to 2008 (4.65 million to 13.65 million, respectively).

These changes in consumer behavior are not just limited to the workforce. Students, at all levels, have become less reliant on desktop computers. In 2006, 71% of undergraduate students owned a desktop, and by 2009 the number decreased to 44% (Smith et al., 2009). A study reported that in 2008, 82% of college students owned a laptop and it was their only computer (Chang et al., 2008). Further, it was found that, on average, students used their computers 21.3 h a week (Smith et al., 2009). Given these numbers and expected continued growth in portable computer use, it is important to understand the ergonomic risks associated with using these types of data entry devices.

Data entry or typing tasks have been the focus of research efforts for a number of years. A number of workstation parameters have been studied including chair design parameters (NIOSH, 1997; Psihogios et al., 1998; Rogers and Thomas, 1990; Sauter et al., 1991; Shute and Starr, 1984; Sommerich et al., 2000), VDT equipment positioning (Psihogios et al., 1998; Rogers and Thomas, 1990; Sauter et al., 1991; Shute and Starr, 1984; Sommerich et al., 2000), and prolonged seating postures (Eklundh, 1967; Kelsey, 1975; Kottke, 1961; Magora, 1972). Results of these studies found implications for low back and neck pain (Psihogios et al., 1998; Rogers and Thomas, 1990; Sauter et al., 1991; Shute and Starr, 1984), carpal tunnel pressure (Gilad and Harel, 2000; Hedge, 1994; Rempel et al., 1997; Weiss et al., 1995), and upper extremity discomfort (Bergqvist et al., 1995; Faucett and Rempel, 1994; Life and Pheasant, 1984; Sauter et al., 1991, among others). Additionally, research shows that participants who typed for two-hour periods experienced low-frequency fatigue (long-term fatigue) in their hands and arms (Lin et al., 2004). While this study was on a desktop computer, it may be indicative of what can be expected from typing on laptop or other mobile computers. Similar literature relating mobile computing devices, particularly newer devices such as slate computers, is extremely limited creating a significant gap in the literature.

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http://dx.doi.org/10.1016/j.apergo.2014.05.008
0003-6870/

Most research related to laptop computer usage has been limited to the use of laptops at traditional workstations. Previous research has indicated that laptop computers result in greater neck flexion angles (Price and Dowell, 1998; Straker et al., 1997; Sommerich et al., 2002; Seghers et al., 2003) and reduced range of movement and stress on the neck which could lead to greater discomfort (Straker et al., 1997). A potential reason for these poorer working postures and increased discomfort is the connected keyboard and monitor in laptop designs, reducing the adjustability of these computing elements. With the introduction of slate and laptop computers, these issues are likely further compounded as the keyboard and monitor are now integrated into a single unit, though little to no research is available in the public domain relating to these issues.

Only a few studies have attempted to assess the ergonomic risk associated with using laptops in non-traditional work environments (e.g. working with the laptop on the lap) (Asundi et al., 2010; Moffett et al., 2002). When using the laptop positioned on the lap, head-neck and wrist postures were found to be more non-neutral, potentially increasing injury risk to these areas (Asundi et al., 2010; Moffett et al., 2002). Interestingly, performance was not affected by computer use location, lap vs. desktop (Moffet et al., 2002), though this slate computers or other devices that use compact or virtual keyboards may have significant performance decrements.

While laptop computers are the most common devices used by the mobile workforce, other, smaller portable computing devices, such as netbooks and slate computers (e.g. iPad), are becoming more popular. Thirty-seven percent of all slate owners take their slate with them to work (Rotman Epps, 2012). Decreases in computer size have led to changes in hardware design features (e.g. smaller key sizes, virtual keyboards, different input methods, etc.) that potentially could impose different demands on the user than other computer designs. A previous study found that slate computers resulted in greater neck flexion than other portable computing devices in common environments (Young et al., 2012), though other literature on ergonomic exposures was not found.

Micro-computers (smaller, lighter-weight versions of laptops, e.g., netbooks) and slate computers (e.g., iPads) may impose unique demands on the user, such as a smaller platform (i.e., small keys and monitor), integrated monitor/keyboard (not just connected), and changes in data entry methods (swiping/gesturing, virtual keyboards), among others. However, little to no data is readily available on ergonomic exposures associated with prolonged usage of these devices, particularly in non-traditional work environments. The objective of this research was to quantify the physiological responses and performance impacts of performing traditional data entry tasks on mobile computers in select non-traditional environments. The specific hypotheses tested were:

Hypothesis 1: muscle activity and joint posture will be negatively affected by portable computing device and workplace setting. As the device becomes more integrated (e.g., slate type computer), these impacts will be more negative, particularly for the neck.

Hypothesis 2: performance on the portable computing devices will be similar to previous studies on typing performance in traditional desk settings, though performance will be degraded on the slate computer.

2. Methodology

2.1. Participants

A total of 12 participants (6 males, 6 females) were recruited from the Mississippi State University student population for this study. Participants' average age was 23.25 years (SD = 2.66) and they had an average net typing speed of 59.33 words per minute (wpm) (SD = 15.08 wpm). All participants were touch typists and meet all inclusion criteria (net typing speed of 40 wpm and limited experience on a netbook or slate computer).

2.2. Experimental design

A repeated measures design was used to compare muscle activity, posture and performance across computing device (3 levels) and workstation (2 levels). A single computing device was tested across both workstations in a test session using a test–rest–test protocol (further details are provided below). Exposure to computing devices was randomized across participants and exposure to workstations was balanced across participants.

2.3. Independent variables

2.3.1. Computing device

Three mobile computing devices were selected for study to span a range of mobile computers: a laptop, a netbook, and a slate computer. The laptop represents a “large” mobile computer with a full sized keyboard. The netbook represents a micro-computer that typically is much smaller in size, lighter weight than a laptop, and typically is used only for basic computing. The netbook as a standard keyboard, though the size of the keyboard and keys are smaller than on a standard keyboard or a full sized laptop. Slate computers have an integrated, virtual keyboard. While any number of mobile computing devices could have been selected, these three devices were chosen to span the current market of what is available in mobile computers. Additionally, these devices represent a significant proportion of the market and were viewed as more likely to be used for work purposes. While smart phones are also common devices used for mobile computing of short durations, for prolonged work (the focus of this application), these devices were not viewed as viable. The three specific devices studied were a Toshiba Satellite M640 (laptop), HP Mini 210-2190NR (netbook), and Adam Laptop running Android 2.2 (slate computer).

2.3.2. Workstations

Two workstations were studied: traditional desk and a sofa. These workstations were selected to represent two of the most common work settings for the working population, though other settings may also have been chosen. The desk workstation consisted of a Generation IV fully adjustable bi-level table. Participants were allowed to adjust the height of the workstation to position the computer at the height that was most comfortable for them. As the devices differed across test sessions, participant workstation measurements were not recorded. Rather they were allowed to adjust the workstation at each test session to fit the device that was being tested. A fully adjustable chair with standard adjustable features was also provided. Participants were encouraged to adjust the chair to their preferences. The sofa used in this study as a two person sofa with a cotton covering. Back cushions were integrated into the sofa, though seat cushions were removable.

2.4. Dependent variables

2.4.1. Muscle activity

Surface electromyography (EMG) of select forearm, shoulder, and neck muscles was used to quantify differences in muscle activation levels during task performance. A Noraxon 1400A system was used to collect all EMG data. EMG measurements of the flexor carpi radialis (FCR), extensor carpi radialis (ECR), sternocleidomastoid (SCM) and upper trapezius were obtained using rectangular Ag/AgCl pregelled bipolar disposable electrodes. Electrodes were applied to muscles on both the right and left sides. Prior to electrode application, the skin surface area was shaved, slightly abraded, and cleansed with alcohol to ensure minimal impedance. Electrodes for the FCR were located three to four fingerbreadths distal to the midpoint of a line connecting the medial epicondyle and biceps tendon (Perotto, 1994). For the ECR, electrodes were located at the lateral epicondyle of humerus, immediately medial to the brachioradialis muscle (Perotto, 1994). Electrodes for the upper trapezius were located at the angle of the neck and the shoulder (Perotto, 1994). Electrodes for the SCM were placed four fingerbreadths from the cephalad to the muscle origin (Perotto, 1994). Interelectrode distance was set to 2.5 cm. Signals were transmitted through leads which were secured to the arm with tape and to the participants clothing to the back belt loop to reduce noise and minimize displacement. EMG signals were hardware amplified, band-pass filtered (10–500 Hz), RMS converted (110 ms time constant), and A/D converted. The amplifier gain was set such that the signals did not exceed 2–3 volts. Input impedance was measured using a standard voltmeter to ensure impedance was within acceptable levels (<10 kΩ).

After stabilization of the electrodes (15 min), maximum voluntary contractions (MVCs) were obtained. MVCs were performed in a representative posture to improve accuracy of MVC readings. Forearm MVCs were collected using a hand dynamometer with the hand in a standard typing position. Trapezius MVCs were collected by having participants grip a handle at hand height connected to a chain secured to the floor while standing and shrugging the shoulders upwards toward the ear, though the design of the structure minimized actual movement. Sternocleidomastoid MVCs were collected by having the participant rest their face against a padded surface and try to turn their head either left or right. A minimum of three trials lasting 5 seconds with a 30-s rest period between exertions were collected. Peak RMS EMG signals were identified for each trial using Noraxon's MyoResearch XP Master Edition software (Noraxon, Scottsdale, Arizona), and the maximum value taken as the MVC for that muscle for normalization of task EMG. Task RMS EMG was sampled at 1000 Hz for the entire test session Mean RMS values were calculated and normalized using MVC data. The first and last 2 min of data were removed to reduce start up and task completion effects. Processed data was expressed in terms of percent MVC.

2.4.2. Posture assessment

Wrist and elbow posture for the left and right sides, and neck postures was quantified using electrogoniometers, and were attached using double sided tape according to the manufacturer's recommendations. A bi-axial electrogoniometer (XM65, Biometrics, Ltd.) was used to capture wrist postures (flexion/extension (FE) and radial/ulnar deviation (RU)). The distal end block of the XM 64 was positioned over the third metacarpal and proximal end block was positioned over the center of the lower forearm. An SG110 electrogonometer (Biometrics, Ltd) placed along the dorsal side of the upper and lower arm spanning the elbow joint captured elbow FE. Neck FE and axial rotation were also quantified using two electrogoniometers SG110 electrogoniometers (Biometrics, Ltd). The distal end block was located along the cervical vertebrae directly below the hair line; and the proximal end block was located along the thoracic vertebrae. Goniometer placement was checked to ensure motion was not inhibited. Data was sampled at 50 Hz using Biometrics DataLog software. Mean, median, minimum, and maximum postures were extracted and the following sign conventions were used: positive angles represented wrist, elbow, and neck flexion; wrist radial deviation; and neck rotation to the left; and negative angles represented wrist, elbow, and neck extension; wrist ulnar deviation; and neck rotation to the right.

2.4.3. Performance data

Performance data was collected and recorded using screen capture software. Gross typing speed, number of errors, and error type were analyzed. The following error types were collected (Cooper, 1983):

- Insertion – defined as an extra letter being inserted into a word.
- Omission – defined as not including a word or letter.
- Shifting errors – defined as either capitalizing a word that was not supposed to be, or not capitalizing a word that should have been.
- Substitution – defined as the wrong letter being typed in the place of the correct letter.
- Transpose – defined as two consecutive letters in a word are interchanged (e.g., the is typed as teh).

2.5. Experimental task

The data entry task consisted of recreating text from a human resources textbook, to minimize familiarization with the material, for a 30-min period on each computing device at each workstation. Text passages were checked to ensure equivalent reading levels across passages.

2.6. Procedures

Participants were provided with a verbal and written description of the research, its objectives, and completed informed consent documents approved by the Mississippi State University IRB prior to any data collection. Participants completed a custom demographic questionnaire, and were given a standard typing test to ensure they met inclusion criteria pertaining to minimum net typing speed (40 wpm).

Participants were asked to complete four, 2-h test sessions. During the first session, participants completed the informed consent process, the demographic questionnaire, and the typing test. Additionally, a familiarization session was completed in which participants typed on each device (in random order) for 30 min with a 15-min rest period between typing bouts. The three remaining sessions were test sessions. Each consisted of typing on a single device for two, 30-min trials with a 15-min rest period between trials (one, 30-min session on each work surface – desk/sofa). Upon arrival, data collection equipment and calibration procedures were completed along with any pre-test data collection (e.g., MVC measurements). Testing was completed for the first condition, the rest period provided during which data were downloaded and saved and the second condition set up, and testing was completed for the second condition. Sessions were separated by a minimum of 48 h to minimize fatigue effects, and sessions were completed at approximately the same time of day to minimize circadian rhythm effects.

2.7. Data analysis

Appropriate descriptive statistics were computed for each dependent variable. Repeated measures ANOVAs were used to quantify differences between computer, workstation, and their interaction for each dependent measure. Additionally, for the EMG results, both muscle and side effects and all two-way interactions were analyzed. Tukey HSD tests were completed for all significant ANOVA results as appropriate. All results were considered significant at alpha = 0.1 as little data currently exists on ergonomic exposure to mobile computing devices in non-traditional work settings.

3. Results

3.1. Muscle activity

In general, muscle activity levels were extremely low for all test conditions (2–6% of Max) (Table 1). Repeated measure ANOVA results indicated that computer, muscle, and their interaction were found to affect muscle activity levels (Table 2). The slate computer was found to result in the lowest muscle activation and these levels differed significantly from laptop and netbook activation levels (Table 3), though no other differences were found. Not surprisingly, all muscles were found to result in differing levels of activation, except for the ECR and the Trapezius which had the highest activation levels (Table 3). Though there was a muscle by workstation interaction effect, Tukey analysis was unable to identify specific differences in factor levels.

3.2. Posture

In general, participants assumed a flexed, ulnar deviated and pronated wrist posture and flexed neck posture when typing regardless of the work setting (Table 4). Separate repeated measures ANOVAs were performed for each joint motion considered. For the upper extremity measures, side was included as a main effect, though no two-way interaction effects were considered with side as one of the variables. Computer was found to significantly affect wrist FE and RU measures (Table 5). In general, the slate computer was found to result in increased wrist flexion, decreased wrist ulnar deviation, and increased maximum neck and elbow flexion compared to the laptop or netbook (Table 6). Workstation was found to significantly affect wrist FE, elbow and neck FE postures (Table 5). The sofa was found to result in significantly increased wrist extension, increased elbow flexion, and increased neck extension (Table 6). Readings between the left and right side were significantly different for wrist RU (Table 5). The left side was found to have higher mean flexion values and larger ulnar deviation values (Table 6).

A number of interaction effects were found (Table 5). A significant computer by workstation interaction effect was found for wrist RU, elbow FE, and neck FE. A decrease in wrist ulnar deviation was found when working on the slate computer on the sofa compared to all other combinations (Fig. 1). Working on the netbook on the sofa resulted in significantly more flexed neck postures than when working on the netbook or laptop at the desk (Fig. 1).

Table 1
Descriptive statistics for muscle activity by independent variables. Values are reported in % Max.

Factor	Level	Mean (SD) (%Max)	Range (%Max)
Computer	Laptop	0.0462 (0.0386)	(0.0049, 0.2611)
	Netbook	0.0427 (0.0361)	(0.0038, 0.1737)
	Slate	0.0381 (0.0370)	(0.0028, 0.3075)
Workstation	Desk	0.0432 (0.0379)	(0.0028, 0.3075)
	Sofa	0.0415 (0.0369)	(0.0038, 0.2612)
Side	Left	0.0406 (0.0363)	(0.0047, 0.2612)
	Right	0.0441 (0.0384)	(0.0028, 0.3075)
Muscle	ECR	0.0495 (0.0390)	(0.0093, 0.2612)
	FCR	0.0360 (0.0296)	(0.0073, 0.1940)
	SCM	0.0244 (0.0240)	(0.0028, 0.1579)
	Trapezius	0.0593 (0.0439)	(0.0078, 0.3075)

SCM = sternocleidomastoid; FCR = flexor carpi radialis; ECR = extensor carpi radialis; and Trap = trapezius.

Table 2
ANOVA results for muscle activity. Values are *p*-values.

Factor	*p*-Value	Factor	*p*-Value
Computer	0.0017[a]	Computer × Side	0.9731
Muscle	0.0001[a]	Computer × Workstation	0.8564
Side	0.1572	Muscle × Side	0.4567
Workstation	0.3991	Muscle × Workstation	0.0061[a]
Computer × Muscle	0.9065	Side × Workstation	0.6089

[a] Significant at alpha = 0.05.

Table 3
Tukey results for muscle activity level.

Factor	Level	Mean (%Max)	Grouping	Factor	Level	Mean (%Max)	Grouping
Computer	Slate	0.0381	A	Muscle	SCM	0.0244	A
	Netbook	0.0427	B		FCR	0.0360	B
	Laptop	0.0462	B		ECR	0.0495	C
					Trap	0.0593	C

SCM = sternocleidomastoid; FCR = flexor carpi radialis; ECR = extensor carpi radialis; and Trap = trapezius.

3.3. Typing performance

Typing performance was measured as typing speed (gross) and error frequencies (total errors and error types). Though net typing speed is typically used, gross typing speed was chosen for analysis because performance on the slate computer was so low. Though frequency count data is typically analyzed using contingency table analysis, this was not done for this study. The range of total errors and specific error types was quite large and error totals were not categorized, and contingency table analysis would include every number in the range of the error counts (0–80+). Therefore, error data was treated as continuous and analyzed using repeated measures ANOVA.

Descriptive statistics for typing performance are presented in Table 7. In general, the only difference in performance related to computer, with gross typing speed for the slate computer much lower than the other computers, which was statistically significant (Tables 8 and 9). Computer was also found to affect substitution and transpose errors, with the slate computer having the lowest error rate (Tables 8 and 10).

4. Discussion and conclusions

The objective of this study was to quantify differences in muscle loading, posture, and performance when using three computers (laptop, netbook and slate types computers) on two work surfaces (desk and sofa/lap). It was hypothesized that muscle loading, posture, and performance would be degraded when working on smaller computers and when working on the sofa. These hypotheses were mostly supported by the study findings.

The primary computer differences were related to posture and performance. The slate computer was found to result in more non-neutral wrist, elbow and neck postures and reduced performance. These findings are similar to those found in previous studies comparing desktop computers to laptop computers (Straker et al., 1997; Sommerich et al., 2002; Seghers et al., 2003). These findings indicate that using more compact computers, particularly slate computers, may present increased risk for injury or illness development for the neck and upper extremity.

Performance differences across computers found that participants were able to type almost 4 times as much on the laptop or netbook than on the slate. Previous research has found no performance differences between desktop and laptop computers (Price

Table 4
Descriptive statistics for posture. Values are in degrees.

	Left				Right	
	Factor	Level	Mean (SD)	Range	Mean (SD)	Range
Elbow FE	Computer	Netbook	4.35 (16.95)	(−27.02, 62.67)	1.42 (20.58)	(−19.83, 58.11)
		Slate	−0.47 (16.02)	(−17.76, 40.20)	−4.78 (15.77)	(−32.19, 37.18)
		Laptop	4.35 (10.26)	(−23.53, 24.53)	1.21 (14.38)	(−26.00, 22.81)
	Workstation	Desk	1.26 (14.79)	(−27.02, 62.67)	−6.53 (17.67)	(−32.19, 58.11)
		Sofa	4.31 (14.62)	(−23.53, 40.20)	5.43 (14.35)	(−22.28, 37.18)
Wrist FE	Computer	Netbook	−2.62 (13.41)	(−28.46, 22.51)	−0.84 (14.72)	(−39.97, 13.19)
		Slate	−12.96 (15.24)	(−41.70, 9.18)	−12.26 (13.09)	(−39.97, 13.19)
		Laptop	1.78 (13.20)	(−19.68, 28.56)	2.33 (11.59)	(−13.42, 28.91)
	Workstation	Desk	0.74 (13.58)	(−28.85, 28.57)	1.46 (14.27)	(−22.76, 30.34)
		Sofa	−10.24 (14.78)	(−41.70 (22.17)	−8.93 (12.80)	(−39.97, 20.03)
Wrist RU	Computer	Netbook	−21.56 (10.23)	(−45.21, −4.85)	−15.26 (11.94)	(−37.10, −0.45)
		Slate	−13.09 (11.32)	(−41.41, 6.24)	−7.00 (14.55)	(−26.35, 31.27)
		Laptop	−21.17 (8.80)	(−40.86, −9.44)	−13.42 (12.69)	(−32.16, 14.59,)
	Workstation	Desk	−20.95 (10.31)	(−45.21, −6.57)	−13.34 (11.93)	(−32.16, 12.08)
		Sofa	−15.79 (10.80)	(−39.93, 6.24)	−1.00 (14.85)	(−37.10, 31.27)
			FE		Rotation	
Neck	Computer	Netbook	6.41 (10.60)	(−18.30, 28.58)	2.10 (8.17)	(−13.44, 17.43)
		Slate	8.03 (9.50)	(−8.45, 36.34)	0.46 (5.89)	(−12.56, 12.66)
		Laptop	4.00 (9.74)	(−13.84, 23.96)	−1.34 (5.55)	(10.09, 8.70)
	Workstation	Desk	3.03 (8.05)	(−13.84, 36.34)	−0.04 (6.09)	(−13.44, 15.91)
		Sofa	9.46 (10.79)	(−18.30, 28.58)	−.88 (7.34)	(−12.56, 17.43)

Table 5
ANOVA results for posture by joint/direction. Values are *p*-values.

Joint/direction	Factor	Mean	Joint/direction	Factor	Mean
Wrist FE	Computer	0.0001[a]	Elbow FE	Computer	0.1724
	Workstation	0.0001[a]		Workstation	0.0021[a]
	Side	0.5855		Side	0.1682
	Computer × Workstation	0.3621		Computer × Workstation	0.0984[b]
	Side × Computer	0.9581		Side × Computer	0.9839
	Side × Workstation	0.8774		Side × Workstation	0.0678[b]
Wrist RU	Computer	0.0002[a]	Neck FE	Computer	0.1880
	Workstation	0.1642		Workstation	0.0005[a]
	Side	0.0001[a]		Computer × Workstation	0.0956[b]
	Computer × Workstation	0.0663[b]	Neck rotation	Computer	0.1965
	Side × Computer	0.8678		Workstation	0.5303
	Side × Workstation	0.5346		Computer × Workstation	0.3556

FE = flexion/extension; RU = radial/ulnar deviation.
[a] Significant at alpha = 0.05.
[b] Significant at alpha = 0.10.

and Dowell, 1998; Straker et al., 1997; Sommerich et al., 2002; Seghers et al., 2003), though no data exists currently for performance on slate computers. These findings indicate that slate computer, while appropriate for gaming or other entertainment uses, are not designed for long-term usage as a device for traditional computer work activities.

Muscle loading of two forearm muscles and two neck muscles was not found to differ across computers or work surfaces. The forearm muscles selected for this study are those that have been identified as primary muscles in previous computer usage studies (Martin et al., 1998). However, not all participants used a touch typing operation for the slate computer. Many used a single finger operation. Therefore, the muscles that are primary operators may differ, particularly for the slate computer. The neck muscles studied here are similar to those used in other studies comparing desktop computers to laptop computers (Asundi et al., 2010; Moffet et al., 2002) and other data entry studies (Bauer and Wittig, 1998; Szeto et al., 2009). However, since all of the computers studied in this research were of similar or even more compact design, it is likely that the neck muscle studied (the sternocleidomastoid) would not be affected as little neck rotation was observed, though other neck muscles, such as those primarily responsible for neck flexion and

Table 6
Tukey results for posture.

Wrist flexion/extension				Wrist radial/ulnar deviation			
Factor	Level	Mean	Grouping	Factor	Level	Mean	Grouping
Computer	Slate	−12.61	A	Computer	Laptop	−17.30	A
	Netbook	- 1.73	A		Netbook	−18.41	A
	Laptop	2.06	B		Slate	−10.04	B

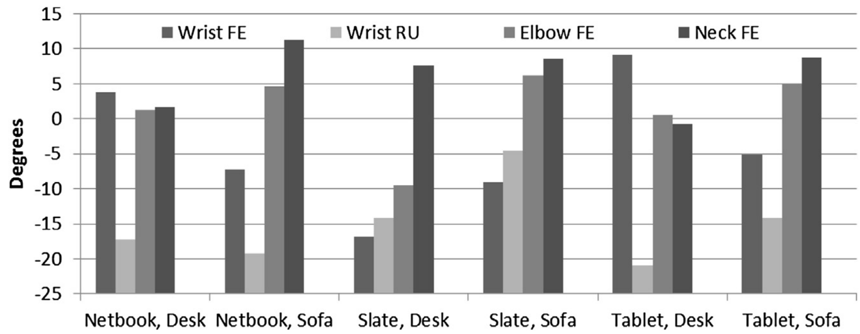

Fig. 1. Computer by workstation interaction effects for posture.

extension, may be impacted. A reason that the forearm muscle activity may not have been different across computers is that performance on the slate computer was almost 4 times less than that observed on the netbook and the laptop. Given the increase in resting activity for the forearm muscles, the loading on the forearms during active cycles may actually be much higher than for laptops, so this hypothesis will need to be confirmed in future studies.

There were a number of computer by work surface interaction, though not as many as expected. Posture was found to be most significantly affected by this interaction. The slate computer was the primary driver in these interaction effects, with poorer postures associated with the conditions containing the slate computer. This finding is likely due to the integrated monitor/keyboard.

Table 7
Descriptive statistics for typing performance.

Measure	Factor	Level	Mean (SD)
Gross typing speed (WPM)	Computer	Netbook	43.46 (13.94)
		Slate	12.81 (2.77)
		Laptop	42.36 (14.71)
	Workstation	Desk	32.48 (18.77)
		Sofa	32.73 (18.42)
Total errors (*n*)	Computer	Netbook	2.36 (3.93)
		Slate	2.47 (3.96)
		Laptop	2.51 (3.98)
	Workstation	Desk	2.31 (3.71)
		Sofa	2.57 (4.16)
Error type: insertion	Computer	Netbook	3.88 (6.06)
		Slate	4.83 (5.30)
		Laptop	3.10 (3.85)
	Workstation	Desk	4.09 (5.24)
		Sofa	3.69 (5.16)
Error type: omission	Computer	Netbook	3.39 (3.41)
		Slate	5.30 (3.81)
		Laptop	4.57 (5.10)
	Workstation	Desk	3.91 (3.65)
		Sofa	4.94 (4.61)
Error type: shifting	Computer	Netbook	1.67 (1.92)
		Slate	1.63 (1.93)
		Laptop	1.82 (3.22)
	Workstation	Desk	1.38 (3.38)
		Sofa	1.67 (2.85)
Error type: substitution	Computer	Netbook	2.13 (3.47)
		Slate	0.79 (0.98)
		Laptop	1.64 (3.17)
	Workstation	Desk	1.24 (1.95)
		Sofa	1.78 (3.38)
Error type: transpose	Computer	Netbook	0.21 (0.59)
		Slate	1.21 (3.01)
		Laptop	1.55 (3.76)
	Workstation	Desk	0.88 (2.01)
		Sofa	1.06 (3.39)

4.1. Limitations

Several limitations were part of this research. First, the assessment period was short (30 min of typing). As typing efforts are typically significantly longer, it is of interest to quantify differences between computers and work settings for longer periods. Though muscle activation levels may not practically differ across the study period, localized muscle fatigue development may differ significantly for various muscles. Similarly, the muscles studied were selected because these were commonly assessed muscles in previous studies of computer usage. However, as computers continue to decrease in size and change in functionality (i.e., virtual keyboards) other muscles may be more appropriate for study. A small study is currently underway in the researcher's laboratory to quantify forearm muscles that are primary for slate and netbook computer use.

Table 8
Statistical test results for typing performance.

Performance measure	Factor	*p*-Value
Gross typing speed	Computer	0.0001[a]
	Workstation	0.7527
	Computer × Workstation	0.9098
Total errors	Computer	0.5468
	Workstation	0.4795
	Computer × Workstation	0.8949
Error type: insertion	Computer	0.7917
	Workstation	0.6423
	Computer × Workstation	0.6002
Error type: omission	Computer	0.2480
	Workstation	0.2076
	Computer × Workstation	0.5239
Error type: shifting	Computer	0.6162
	Workstation	0.7601
	Computer × Workstation	0.5638
Error type: substitution	Computer	0.0681[b]
	Workstation	0.4034
	Computer × Workstation	0.9569
Error type: transpose	Computer	0.0415[a]
	Workstation	0.9983
	Computer × Workstation	0.5900

[a] Significant at alpha = 0.05.
[b] Significant at alpha = 0.10.

Table 9
Tukey results for gross typing speed.

Factor	Level	Mean	Grouping
Computer	Slate	12.82	A
	Laptop	42.36	B
	Netbook	43.46	B

Table 10
Tukey results for substitution and transpose errors.

Substitution errors				Transpose errors			
Factor	Level	Mean	Grouping	Factor	Level	Mean	Grouping
Computer	Slate	0.79	A	Computer	Slate	0.21	A
	Laptop	1.80	A B		Netbook	1.21	A B
	Netbook	2.06	B		Laptop	1.75	B

The researchers expected postures to be more dynamic, particularly for the sofa setting. It was expected that participants may assume a lotus position (seated cross-legged position) and/or a mermaid position (seated with both legs supported on the couch to one side). However, these postures were not observed. Again, this may be due to the short assessment period, and may be observed in studies in which longer observation periods are used. These postures may result in significant changes in muscle activity, postures, and performance.

Non-traditional work settings are becoming more commonplace with a large portion of the working population telecommuting. Therefore, other non-traditional settings should also be studied (including working in beds and airports). Other non-traditional settings may also be appropriate. Further, using a less homogenous participant population may be of interest. Though students do represent a primary user population of laptops, netbooks, and slate computers, they represent at most half of the target population. Future studies that include a more diverse participant population are warranted.

4.2. Final conclusions

Ergonomic exposures when using compact and slate type computers are increased, particularly when used in non-traditional work settings. Potential for injury or illness development may be increased with prolonged usage of such computing devices in non-traditional work settings. Exposures may be further compounded when using slate computers, given that performance on these computers are significantly lower than on other portable computers.

Acknowledgments

This study was funded by the Office Ergonomics Research Committee (OERC) grant number 1101045.

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