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Effects of notebook computer configuration and task on user biomechanics, productivity, and comfort

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Abstract

This study took a comprehensive approach to evaluating effects of using a notebook computer stand-alone or along with inexpensive peripheral input devices. The study examined effects on biomechanics, productivity, and discomfort, and considered the impact of both computer configuration and task performed. It was hypothesized that, in general, the stand-alone configuration would induce greater postural fixity and more non-neutral postures than configurations with peripheral input devices. Dependent measures included muscle activity, posture and posture variation/fixity, productivity, and subjective assessments of discomfort and preference. The data were generally consistent with the hypothesis, though some biomechanical advantages were identified for each configuration; specifics and exceptions are discussed, along with reasons for a general recommendation for the use of an external mouse, or mouse and keyboard (without number pad) when using a notebook computer for an extended period of time, as in a desktop replacement scenario.

Relevance to industry

Notebook computer use is rapidly increasing, in industry and schools. Yet the notebook form factor is inconsistent with a number of current design recommendations. Little research concerning physical ergonomics of notebook computer use has been conducted, so recommendations for use are currently limited and not strongly supported by objective evidence. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Portable computer; Laptop computer; Notebook computer; Ergonomics; Biomechanics; Pointing device

1. Introduction

Computer use has increased rapidly over the last quarter century. In 1975 there were fewer than 200,000 computers in the US (Juliussen and

Petska-Juliussen, 1994); 1994 projections for 1995 exceeded 100,000,000 computers. Personal computers (PCs) account for 90% of all computers. Worldwide, the portable PC is a rapidly growing market segment. In 1997 it was estimated that mobile computers would constitute 34% of total US PC shipments in 2000 (almost 10 million units).¹ Portables already constituted 40% of total

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¹Giga, The US Mobile Computer Market Report, 1997.

computer output in Japan (Villanueva et al., 1998); in 1998 they were 20% of the computers sold in the UK (Heasman et al., 2000). Initially, portable PCs were used by mobile workers. More recently, however, portables are being used as replacements for desktop computers (DPC), even for workers who do not require PC mobility.

Work-related exposure to desktop style computers has been associated with musculoskeletal discomfort in workers (Bernard, 1991; Hünting et al., 1981; Sauter et al., 1991). Surveys reveal widespread workplace use of computers: half of the employed adults in the US used a computer for work in 1997 (Newburger, 1997). Statistics from the US and UK show that over 80% of those who use computers for work, also use them at home (Newburger, 1997; Heasman et al., 2000), providing the potential for a high level of exposure among users. The growing use of notebook computers (NPCs) raises concerns for development of discomfort in their users, as well.

In a recent study of 2192 workers, frequencies of symptoms and discomforts were found to be similar across four exclusive computer user classifications (stand-alone portable, portable with external monitor and/or keyboard, DPC, and multiple configurations) (Heasman et al., 2000), although it is unclear how accounting for differences in usage duration might have altered that finding. For the sample as a whole, correlations were found between health effects and weekly hours of computer use. Of the 1197 NPC users interviewed, only 9% used the portable in a stand-alone configuration (defined in the report as using no external keyboard or monitor). By contrast, Diederich and Stewart (1997) reported 60% stand-alone use (defined as using no peripherals) in a group of Australian workers. Diederich and Stewart (1997) concluded, from their survey data and review of the literature, that the workers who used notebook computers in a stand-alone configuration were at increased risk for injury. Preliminary analysis of a survey that included 240 NPC users showed a significant correspondence between stand-alone use (using either of the previous definitions) and discomfort that users associate with their NPC use (Sommerich, 2002).

Concerns about NPC use are related to the design of the computer, as well as expansion and diversification of the user population and use locations (Sommerich, 2000). Issues related to computer design include features that NPCs share with DPCs, such as keyboards that induce ulnar wrist deviation and forearm pronation. Additional NPC features that raise concerns include other keyboard design characteristics (reduced key size and/or spacing, lack of redundant keys, increased thickness), permanent attachment of keyboard and display, and pointing device design (lack of alternative integrated devices and device locations, Kelaher et al., 2001). Each of these features can be cause for concern, because of their potential to increase biomechanical strain in the user and hinder performance.

Only a few lab-based studies have been conducted on NPCs. Results show that NPC use can affect user posture, increase discomfort and muscle activity, and hamper performance in comparison to DPC use. Straker et al. (1997a) found increases in head tilt and neck flexion during text typing on an NPC, compared to using a DPC. In both situations, subjects were free to adjust the workstation to their own preferences. Subjects chose to position the keyboards of the two computers similarly, forcing the location of the NPC screen to be lower than that chosen for the DPC screen. Price and Dowell (1998) found differences in user posture and discomfort associated with NPC placement. Comparing lower (keyboard at elbow height) to higher NPC placement (to optimize arm posture and neck posture, respectively), discomfort in all body parts, including the neck, was greater with the higher placement. Price and Dowell (1998) also found that conditions in which the NPC was used stand-alone showed more discomfort in the right wrist/hand than conditions that employed an external mouse (with or without an external keyboard).

Villanueva et al. (1998) compared use of a DPC to use of four progressively smaller NPCs during text entry. Although keyboard dimensions varied across computers, keyboard height relative to each subject was standardized. The authors still found differences in elbow flexion

and wrist extension. Medial shoulder rotation increased as keyboard size decreased, though abduction was not affected. Keying difficulty was judged greater for the NPCs compared to the DPC, and was greatest for the two smaller keyboards. Keying performance was reduced for the two smaller NPCs. Smaller screen size was associated with visual discomfort, more non-neutral body postures, and increased neck extensor muscle activity.

Musculoskeletal discomfort associated with computer work, in general, has been attributed to assumed postures, postural fixity, and inactivity (Sauter et al., 1991; Grieco, 1986). While the level of muscle activity required to maintain typical computer work postures is generally low (Wærsted and Westgaard, 1997), the static nature of the activation, the lack of variation in it, and potentially most important, the length of time it is sustained, are thought to be reasons underlying the risk associated with computer work and other static tasks. In reviewing low-level static exertions, Sjøgaard (1999) emphasized the importance of duration in elevating the risk of such exertions. Such exertions may result in problems with microcirculation within the muscle, muscle metabolism, and/or overworking of particular fibers (“Cinderella fibers”), as well as inadequate recovery between work periods.

The current study was designed to investigate postural fixity and other indicators of biomechanical strain during use of a stand-alone NPC, and to determine if biomechanical strain would be altered with the use of low cost peripheral devices (mouse or mouse + keyboard). Performance, discomfort, and preference were also examined. This study was unique, in that it explored the effects of task in conjunction with the effects of computer configuration on the various outcome measures. It was expected that the stand-alone configuration would induce more postural fixity and more non-neutral postures than if one or more external input devices were used with the NPC, and that this finding would support the use of peripheral devices when using a NPC, particularly for extended periods of time, as in a desktop replacement scenario.

2. Methods

2.1. Experimental design

Ten participants each experienced ten test conditions. To control for carryover effects, a 10×10 balanced Latin Square was used to determine the order of the test conditions. Each subject experienced the test conditions in a different order, and no condition appeared more than once before or after any other condition.

2.1.1. Independent variable

The independent variable was condition, with 10 levels. Each condition was defined by a combination of task and computer configuration (Table 1).

Statistical testing was limited to seven comparisons (Table 2); these were implemented in the statistical analysis using contrast statements (GLM procedure, SAS, Cary, NC). Comparisons fell into two categories. (1) For a given task, what are the effects of computer configuration? These comparisons explored effects of different computer configurations, given that certain computer-based tasks were performed. They helped to characterize the advantages or disadvantages to any of the three computer configurations, based on consideration of the task performed. For example, it would be of interest to know whether any of the computer configurations tested were more or less beneficial than the others for the task of numeric entry. Also, (2) For a given computer configuration, what are the effects of different types of tasks? These comparisons explored effects that different tasks might produce in someone using a particular computer configuration. For example, it would be of interest to know whether any relief to postural fixity occurs when using a stand-alone NPC, if several different tasks are performed.

2.1.2. Dependent variables

Muscle activity: Static and median (10th and 50th percentile) normalized EMG statistics were calculated for electromyographic (EMG) activity from the first dorsal interosseus (D11), upper trapezius (TRAP), pectoralis major (PM), and teres minor/infraspinatus (TMI) muscles on the right side of the body (by design, all subjects were

Table 1
Test conditions

Test condition designation	Computer configuration	Task
Notebook keying: NK	Stand-alone notebook	Keying letters
Notebook numbering: NN	Stand-alone notebook (using number row)	Keying numbers
Notebook mousing: NM	Stand-alone notebook (using integrated pointing stick)	Editing text styles using pointing device
Notebook combination: NC	Stand-alone notebook	Combination task (a mix of keying letters and numbers, and editing with pointing device)
External mousing: EM	Stand-alone notebook with external mouse	Editing text styles using pointing device
External combination: EC	Stand-alone notebook with external mouse	Combination task (a mix of keying letters and numbers, and editing with pointing device)
Full keying: FK	Notebook with external mouse and full-size external keyboard	Keying letters
Full numbering: FN	Notebook with external mouse and full-size external keyboard (using number pad)	Keying numbers
Full mousing: FM	Notebook with external mouse and full-size external keyboard	Editing text styles using pointing device
Full combination: FC	Notebook with external mouse and full-size external keyboard	Combination task (a mix of keying letters and numbers, and editing with pointing device)

right-handed). The TRAP is a standard muscle to study in computer-related tasks, because it is a primary stabilizer of the shoulder complex. The DII was chosen to reflect potential differences in the index finger load due to pointing device differences. The PM and TMI were chosen to reflect differences in internal/external shoulder rotation. Surface electrodes were Ag–AgCl, 4 mm in diameter. Electrode locations for DII, PM, and TMI muscles were determined by muscle palpation. TRAP electrodes were centered about a point 2 cm lateral to the midpoint of a line between C7 and the acromion (Jensen et al., 1993). For all locations, electrode pairs were aligned with the muscle fibers. A reference electrode was placed over the right clavicle.

EMG signals passed from electrodes to pre-amplifiers ($1000 \times$ gain), then through shielded cables to a second amplification system (gains set individually for each subject and muscle). Signals were low pass filtered at 2000 Hz. EMG data were sampled at 1024 Hz, for 5 s every 30 s during the last 5 min of each 10 min test condition. Post-collection processing included application of a

10 Hz high pass filter, signal rectification, application of a 100 ms moving average window, and normalization to maximum exertions.

Posture: Viewing angle, head tilt, neck angle, thoracic bend, trunk angle, elbow flexion, and shoulder flexion were determined from videotape from a camera positioned to the right of the participant at shoulder height and perpendicular to the sagittal plane. Shoulder rotation was determined from videotape from a camera positioned above the subject. Reflective markers were placed bilaterally over the acromion processes, lateral epicondyles, and ulnar styloids, and unilaterally on the right side over the inferior angle of the scapula, center of rotation of the hip, canthus, and tragus. A marker was also placed over C7, and on the computer to mark the vertical center of the monitor. Coordinates for each marker were determined once each minute throughout each condition, and posture angles were determined from those coordinates. To reduce variability, one analyst digitized all the video data. Posture angles are depicted in Fig. 1. For each condition, a mean value and standard deviation were calculated for

Table 2
Comparisons examined in the statistical analysis

Comparison	Question	Expected effects in dependent measures
NK vs. FK	Is there a difference when text typing (letters and punctuation), between using a stand-alone notebook and a notebook with a standard external keyboard?	Less head and neck flexion with the full keyboard, due to placement of the display. No other effects.
NN vs. FN	Is there a difference when typing numbers, between using a stand-alone notebook and a notebook with a standard external keyboard, using the number pad?	In addition to head and neck posture differences... more neutral shoulder posture using number pad, less muscle activity in shoulder muscles; unpredictable performance differences, based on each individual's familiarity with number row and number pad.
NM vs. EM vs. FM	Is there a difference editing with a pointing device, between using a stand-alone notebook (internal pointing device), a notebook with an external mouse next to it, and a notebook with external keyboard and the external mouse next to the keyboard?	In addition to head and neck posture differences... more neutral shoulder posture in the EM condition than the other two, less muscle activity in shoulder muscles in EM; better performance with the mouse (EM and FM) than the pointing stick (Loricchio, 1992; Card et al., 1978).
NC vs. EC vs. FC	Is there a difference performing a task that requires typing text and numbers, and editing with a pointing device, between using a stand-alone notebook, a notebook with an external mouse, and a notebook with an external mouse and external standard keyboard?	In addition to head and neck posture differences... greater range of shoulder and wrist postures with EC and FC, due to mouse and number pad locations that require movements away from the keyboard.
NK vs. NN vs. NM	When using a stand-alone notebook computer, is there a difference between typing text, typing numbers, and using the pointing device?	None expected. (Concern is that stand-alone configuration induces more postural fixity than even traditional desktop computer.)
NK vs. NN vs. EM	When using a notebook computer with an external mouse, is there a difference between typing text, typing numbers, and using the pointing device?	EM will induce changes in wrist and shoulder posture; changes in shoulder muscle activity, as well.
FK vs. FN vs. FM	When using a notebook computer with an external mouse and external keyboard, is there a difference between typing text, typing numbers, and using the pointing device?	Shoulder and wrist postures will differ among the three conditions, as will muscle activity.

Refer to Table 1 for test condition designs.

each posture angle, for each subject. The standard deviation values were used as a gage of postural variation/fixity.

Radial–ulnar and flexion–extension wrist postures were determined from a pair of electrogoniometers placed over the subject's right wrist, according to procedures described by Marras and Schoenmarklin (1993). Data were collected at 300 Hz for 20 s each minute during the first 5 min of each condition. Mean values and ranges (the latter defined as the difference between 10th

and 90th percentile values, and used as a gage of postural variation/fixity) were examined in the statistical analysis.

Productivity: For number typing, text typing, and the combined task, the number of lines completed defined productivity; for the pointing device task, it was the number of phrases formatted. Participants were instructed to work at a normal pace. A problem affecting productivity assessment for the EM condition was identified and corrected after running the fifth subject. As

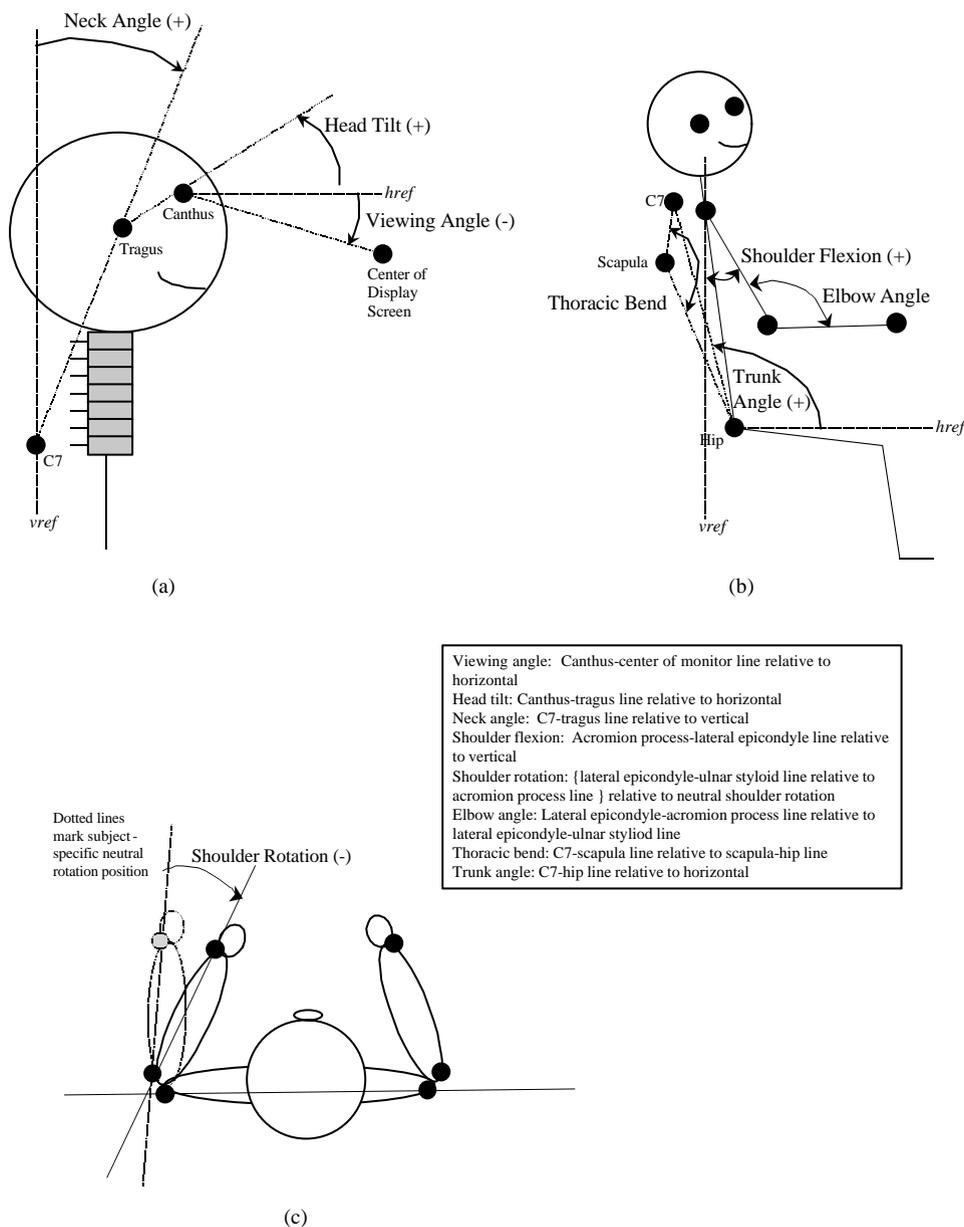


Fig. 1. Joint angles of interest to this study, which were determined from videotape images.

such, productivity assessment for conditions involving the pointing device task were based on data from the last five participants.

Discomfort: Participants completed a discomfort survey before the experiment began and after completing each condition. The Borg CR-10 scale

(Borg, 1982) was used to describe discomfort in the head, neck, left and right shoulders, mid-back, lower back, right forearm, right wrist, and right hand. Differences between baseline ratings and ratings made following each condition were evaluated. No rating above the mildest discomfort

was acceptable for baseline. These data were found to be non-normal, so a log transformation was performed before statistical testing.

Preferences: Following completion of the tenth condition, participants completed a final questionnaire about computer preferences, in general and specific to this study.

2.2. Subjects

Six males and four females, aged 21–44 years, participated in the study, after providing informed consent. Participants were in good health and none wore bifocals. Participants were required to be right-handed, touch typists, and be proficient in using a mouse and a pointing stick. Subjects' demographic and anthropometric data appear in Table 3.

2.3. Experimental conditions

Test conditions were defined by task and computer configuration (Table 1). The four tasks were (1) text typing, (sentences containing words and simple punctuation); (2) number typing; (3) pointing device use (editing font styles of pre-typed text); and (4) a task that combined the three previous tasks (typical of general word processing tasks). Each task was set up in a word processing program in two columns, with the correct text in the left-hand column and space for entry in the right-hand column. Different material from the same source was used for each condition.

The three computer configurations were (1) stand-alone NPC (NPCsa); (2) NPC with external mouse positioned just to the right of the NPC's keyboard (NPCEx); and (3) NPC with standard

keyboard and external mouse positioned just to the right of the keyboard's number pad (FULL).

When performing the number typing task, subjects were required to use the number pad when the external keyboard was in use, and the number row with the stand-alone NPC configuration. During the pointing device tasks, key presses were not allowed. For the combination task, participants could use any keys (number pad or number row) in conjunction with the specified pointing device.

2.4. Workstation configuration

The workstation was set up to conform to each participant's anthropometry. The armless chair's seatpan height was adjusted so that the participant's knees were at 90° with feet resting flat on the floor. Keyboard height was set to elbow height, based on findings of Bergqvist et al. (1995), Price and Dowell (1998), and Straker et al. (1997a, b). When the external keyboard was used, the NPC was positioned above that keyboard with a viewing angle of approximately 17° below horizontal, based on findings of Sommerich et al. (2001) and Psihogios et al. (2001). Each participant was allowed to adjust the distance of the external keyboard from the edge of the support surface. Once the distance was chosen for the keyboard, it remained constant for all tasks. Participants were also allowed to determine their preferred distance from the keyboard support surface. The chair location was then fixed for the duration of the experiment. The participant was also allowed to adjust the tilt of the monitor when using the NPC with and without the external keyboard. These two tilt angles were recorded and remained constant

Table 3
Subject demographic and anthropometric data

	Quantity of subjects	Daily hours of computer use ^a	Age—yrs (S.D.)	Weight—kg (S.D.)	Height—cm (S.D.)	Sitting eye height—cm (S.D.)	Shoulder breadth—cm (S.D.)
Male	6	2–8	31 (7.2)	88.5 (14.6)	178.8 (7.1)	122.6 (2.4)	40.7 (2.3)
Female	4	0.5–6	29 (10.6)	56.8 (12.6)	163.3 (3.8)	114.4 (2.2)	36.1 (1.9)

^a Range of self-reported estimate of daily hours of computer use, across the group.

throughout the experiment. The “G” and “H” keys on each keyboard were aligned with the participant’s mid-sagittal plane. The notebook computer used by subjects was an IBM ThinkPad 560. The external keyboard was made by ALR (Model RT6856TW, NMB Technologies, Inc). Both keyboards measured 11.25 in (28.6 cm) between the outer edges of Caps Lock to Enter keys (width) and 3.75 in (9.6 cm) between the outer edges of number row and space bar (depth). The external mouse was a standard oval shaped 2-button PS-2 mouse (model 13H6690, IBM).

2.5. Procedures

After providing informed consent, participants completed a discomfort survey to assess baseline discomfort. Anthropometric measurements were taken and used to set up the workstation. The participant completed a series of stretches to prepare for performing maximal voluntary exertions (MVEs), data from which were used to normalize the EMG data.

The participant’s skin was prepared for electrode placement and pairs of surface electrodes were attached over the four muscle sites. Participants were taught to perform five different isometric MVEs. For each MVE, the participant was asked to gradually increase exertion effort up to a maximum level over 2 s, continue to exert at maximum for up to 4 s, then rest for at least 2 min before performing another MVE. Participants performed two exertions for the TRAP: (1) pushing upward against resistance with the shoulder abducted 90° and elbow flexed 90°, and (2) shrugging the right shoulder while holding onto a strap with the hand (Jensen et al., 1993). For the TMI, participants exerted in external rotation, with the upper arm at the side and elbow flexed 90°. For the PEC, participants exerted in internal rotation, with the upper arm at the side and elbow flexed 90°. For the DII, participants performed an abduction by pushing with the index finger against resistance applied at the proximal interphalangeal joint (Li et al., 2000).

Following the MVEs, two wrist electrogoniometers and reflective markers were applied. Participants were then seated at the workstation,

and final adjustments were made to position the computer equipment. After resting values were collected for EMG data, and neutral posture data were collected for the wrist and for shoulder rotation, participants performed each of the ten test conditions. After each condition, participants completed a discomfort survey, and took a break of at least 1 min. After the last condition, participants filled out a short questionnaire regarding computer experience and preferences.

3. Results and discussion

Test condition significantly affected muscle activity, posture, body part discomfort, and productivity measures. Results are summarized in Table 4; details are provided in Tables 5–14, Fig. 2, and the text in this section.

3.1. Productivity

Productivity was only assessed for effects of computer configuration. The only differences occurred during the pointing device tasks ($p < 0.0001$; conditions NM, EM, and FM; refer to Table 1 for condition descriptions). Subjects were more productive with the mouse than with the pointing stick (see Fig. 2). This finding is consistent with previous research (Card et al., 1978; Epps, 1986; Loricchio, 1992). For novice users, Card et al. (1978) found positioning time and error rates for text selection were less for a mouse compared to a rate-controlled isometric joystick, step keys, or text keys. Epps (1986) found a mouse was faster for target acquisition than a rate-controlled force joystick. In target acquisition and text selection tasks, Loricchio (1992) also found mouse performance superior to that of a rate-controlled force pushbutton device.

3.2. Posture

Test condition significantly affected mean posture of all measured body angles, as well as viewing angle. Posture variation was also affected by condition, for both planes of the wrist, shoulder flexion, elbow flexion, and shoulder rotation.

Table 4
Summary of significant results; consult text, Fig. 2, and Tables 5–14 for details

Parameter area	Dependent variables	Test of configuration effects ^a	Tests of task effects ^b			Detailed results	Primary observed differences ^c
			NPCsa	NPCEx	FULL		
Productivity	Mousing productivity	M				Section 3.1, Fig. 2	FULL, NPCEx: greater productivity using external mouse
Posture	Viewing angle, mean	N,K,M,C				Section 3.2.1	FULL: raising computer provided an appropriate viewing angle
	Head tilt, mean	N,K,M,C	X	X	X	Section 3.2.1, Table 5	FULL: raised computer facilitated more neutral head and neck postures
	Neck angle, mean	N,K,M,C	X	X	X	Section 3.2.2	
	Trunk angle, mean			X			
	Thoracic bend, mean				X	Section 3.2.3	FULL, using number pad, provided only opportunity for neutral posture
	Shoulder flex, mean						
	Shoulder flex, variation	M,C	X			Section 3.2.3, Table 6	More variation when using external mouse. NPCEx, FULL: more variation in combo task
	Shoulder rot., mean	N,M,C		X	X	Section 3.2.3, Table 7	FULL: neutral posture during number pad use. NPCEx: neutral posture during mousing
	Shoulder rot., variation	C				Section 3.2.3	FULL > NPCEx > NPCsa
	Elbow angle, mean	N,K,M	X	X	X	Section 3.2.3, Table 8	FULL, NPCEx: provided more variation during the combo task
Elbow angle, variation	C	X			Section 3.2.3		
Wrist flex./ext., mean	N,K,M,C	X	X		Section 3.2.4, Table 9	NPCsa: less extension; ulnar deviation was non-neutral when using number row; limited variation during pointing device use	
Wrist rad./uln., mean	N	X	X	X			
Wrist flex./ext., variation	N,M	X	X	X	Section 3.2.4, Table 10		
Wrist rad./uln., variation	M	X	X	X			
EMG	Static D11	M	X	X	X	Section 3.3, Table 11	FULL: less PEC activity
	Static TRAP		X	X			
	Static PEC	N,K,C		X		Section 3.3, Table 12	
	Static TMI			X	X		

Table 4 (continued)

Parameter area	Dependent variables	Test of configuration effects ^a	Tests of task effects ^b			Detailed results	Primary observed differences ^c
			NPCsa	NPCEX	FULL		
Discomfort	Total		X	X	X	Section 3.4, Table 13	FULL: less neck discomfort during text keying FULL, NPCEX: less neck discomfort during combo task
	Neck	K,C			X		NPCEX, NPCsa: less upper extremity discomfort in text and number typing tasks
	Rt. forearm	N	X		X	Section 3.4, Table 14	
	Rt. wrist	K	X				

^a Indicates which configuration tests were significant; details are provided in the referenced subsection, table, or figure. N = number typing; K = text keying; M = pointing device use; C = combination task.

^b For a given configuration, indicates where task effects were significant.

^c If blank, none of the differences appeared to be practically significant.

3.2.1. Head and neck postures

Consistent with the intended setup for the FULL configuration, the mean viewing angle for the FULL configuration averaged about 16.5°. For both NPCEX and NPCsa it averaged about 35°. This difference, due to monitor location, affected head and neck postures. Mean head tilt was greater (more upright) by 5–15° and neck angle was less flexed (by about 5°) in the FULL configuration, compared to the other configurations (see Table 5). In all the three configurations, subjects assumed lower head positions when typing numbers than when typing letters.

Neck angles in this study were slightly less pronounced than those reported by Straker et al. (1997a), and are slightly more pronounced than those reported by Harbison and Forrester (1995). Head tilt and neck angle postures were within the ranges reported by Psihogios et al. (2001), in their review of monitor placement VDT studies. Psihogios et al. (2001) also reviewed studies of visual strain and neutral head and neck posture. They concluded that, for full-size monitors, neutral head posture is achieved with monitor placed at mid-level (viewing angle of 10–17.5° below horizontal) or moderate-low (27.5–30° below horizontal). This suggests that the FULL configuration would provide an advantage over the NPCsa and NPCEX with regard to head and neck posture, and, potentially, visual strain, as well.

3.2.2. Trunk angle and thoracic bend

Across the ten conditions, means for trunk angle and thoracic bend ranged from 103.4° to 107.3° and from 120.4° to 125.0°, respectively. Both angles were only affected by task, and only for the NPCEX configuration. Trunk angle was 106–107° for the EM and NK conditions and about 103° for the NN condition ($p = 0.0143$). Thoracic bend was approximately 125° for the NN and NK conditions, and 120° for the EM condition ($p = 0.0012$).

This finding is in contrast to some previous studies that showed subjects sitting more forward or with a more rounded trunk when using an NPC or a lower monitor (Villanueva et al., 1996, 1998), though other studies have also not found those

Table 5
Effects of COMPUTER SETUP and TASK on mean head tilt and neck angle

		Test conditions									
		NK	NN	NM	NC	EM	EC	FK	FN	FM	FC
Mean head tilt, deg	Mean (S.D.)	6.5 (8.4)	-0.1 (6.1)	0.2 (7.6)	2.2 (5.8)	0.6 (7.2)	2.7 (6.8)	15.1 (6.4)	5.4 (4.1)	16.1 (4.6)	13.9 (4.5)
$p < 0.0001$											
Computer configuration effects	<i>p</i> -value										
During number-typing task	0.0052*		B						A		
During word-typing task	<0.0001*	B						A			
During pointing device task	<0.0001*			B		B				A	
During combination task	<0.00011*				B		B				A
Task effects											
Using NPCsa	0.0009*	a	b	b							
Using NPCEX	0.0013*	a	b			b					
Using FULL	<0.0001*							a	b	a	
Mean neck angle, deg	Mean (S.D.)	49.2 (8.5)	53.5 (9.9)	54.8 (10.1)	52.8 (9.2)	53.1 (8.9)	51.6 (8.8)	44.6 (7.0)	48.6 (8.1)	47.4 (8.1)	47.2 (8.0)
$p < 0.0001$											
Computer configuration effects	<i>p</i> -value										
During number-typing task	0.0052*		A						B		
During word-typing task	<0.0001*	A						B			
During pointing device task	<0.0001*			A		A				B	
During combination task	<0.0001*				A		A				B
Task effects											
Using NPCsa	0.0014*	b	a	a							
Using NPCEX	0.0127*	b	a			a					
Using FULL	0.0357*							b	a	a b	

Mean values and standard deviations (in parentheses) are in degrees. Refer to Fig. 2 for posture angles and Tables 1 and 2 for condition abbreviations and contrast explanations.

*indicates $p \leq 0.05$. $A > B > C$; $a > b > c$.

Table 6
Effects of COMPUTER SETUP and TASK on shoulder flexion variation

		Test conditions									
		NK	NN	NM	NC	EM	EC	FK	FN	FM	FC
Shoulder flexion variation, deg	Mean (S.D.)	2.2 (2.1)	3.5 (2.4)	1.7 (1.1)	2.2 (1.0)	2.5 (1.1)	4.4 (2.4)	2.4 (1.4)	3.2 (1.1)	3.2 (2.1)	3.9 (1.9)
$p = 0.0003$											
Computer configuration effects	p -value										
During number-typing task	0.6361										
During word-typing task	0.7738										
During pointing device task	0.0465*			B		A B				A	
During combination task	0.0010*				B		A				A
Task effects											
Using NPCsa	0.0111*	b	a	b							
Using NPCEx	0.0861										
Using FULL	0.2814										

Mean values and standard deviations (in parentheses) are in degrees.

*indicates $p \leq 0.05$. $A > B > C$; $a > b > c$.

Table 7
Effects of COMPUTER SETUP and TASK on mean shoulder rotation

		Test conditions									
		NK	NN	NM	NC	EM	EC	FK	FN	FM	FC
Mean shoulder rotation, deg	Mean (S.D.)	-23.5	-22.6	-27.3	-23.9	0.7 (6.8)	-16.7	-23.5	1.0 (4.6)	13.0	-11.9
$p < 0.0001$		(4.6)	(4.2)	(5.4)	(4.9)		(5.7)	(10.0)		(7.9)	(14.6)
Computer configuration effects	p -value										
During number-typing task	<0.0001*		B						A		
During word-typing task	0.9825										
During pointing device task	<0.0001*			C		B				A	
During combination task	0.0003*				B		A				A
Task effects											
Using NPCsa	0.2971										
Using NPCEx	<0.0001*	b	b			a					
Using FULL	<0.0001*						c	b		a	

Mean values and standard deviations (in parentheses) are in degrees. External rotation is positive. Internal rotation from 0° to -10° and external rotation from 0° to 3° is considered neutral (Drury, 1987). Non-neutral postures are written in italics.

*indicates $p \leq 0.05$. $A > B > C$; $a > b > c$.

Table 8
Effects of COMPUTER SETUP and TASK on mean elbow angle

		Test conditions									
		NK	NN	NM	NC	EM	EC	FK	FN	FM	FC
Mean elbow angle, deg	$p < 0.0001$	112.1 (16.1)	105.6 (15.3)	106.6 (13.7)	108.0 (14.1)	113.8 (11.1)	109.9 (12.9)	106.5 (13.9)	98.1 (11.7)	116.3 (7.9)	105.8 (14.8)
Computer configuration effects	<i>p</i> -value		A						B		
During number-typing task	0.0067*										
During word-typing task	0.0404*	A		B	A			B		A	
During pointing device task	0.0015*										
During combination task	0.3158										
Task effects											
Using NPCsa	0.0393*	a	b	b							
Using NPCEx	0.0077*	a	b		a						
Using FULL	< 0.0001*							b	c	a	a

Mean values and standard deviations (in parentheses) are in degrees. 80–120° is considered neutral (McAtamney and Corlett, 1993), therefore all means in the table are considered neutral.

*indicates $p \leq 0.05$. A > B > C; a > b > c.

effects (Straker et al., 1997a; Sommerich et al., 2001).

3.2.3. Shoulder and elbow angles

Shoulder flexion during FN differed from the other conditions. Using the number pad in FN, mean shoulder flexion was 10.5°. This was significantly different from the NN condition mean of 24.8° ($p < 0.0001$). Within the FULL configuration, differences were seen between the number typing task and the other two tasks ($p < 0.0001$), with angles of 22.7° and 23.7° for FM and FK, respectively. Across the remaining conditions, shoulder flexion ranged from 21.5° to 26.7°. Shoulder flexion has been shown to be associated with shoulder discomfort in VDT users in the lab (Straker et al., 1997b) and the field (Sauter et al., 1991). With the exception of FN, mean shoulder flexion exhibited in this study exceeded neutral ranges ($\geq 20^\circ$) in at least two published evaluation systems (McAtamney and Corlett, 1993; Drury, 1987).

Shoulder flexion variation was reduced when using the pointing stick, compared to the mouse. This was seen as differences due to task for the NPCsa configuration, and differences due to computer configuration for the pointing device and combination tasks (Table 6).

Mean shoulder rotation was affected by computer configuration and task (Table 7). Exceptions to this were the keying task, which was unaffected by computer configuration, and the NPCsa configuration in which shoulder rotation remained the same across all three tasks. For the number typing task, use of the number pad with the FULL configuration induced a neutral shoulder rotation, compared to internal rotation observed when using the NPC keyboard. For the pointing device task, the NPCEx configuration induced neutral shoulder rotation, compared to pronounced internal rotation with the NPCsa and pronounced external rotation with the FULL configuration.

Shoulder rotation posture variation was only affected by computer configuration during the combination task. In the other seven conditions, variation ranged from 1.7° to 2.8°. Variation in the NC condition was similar, at 2.7°. By contrast, shoulder rotation posture variations for the EC

Table 9
Effects of COMPUTER SETUP and TASK on mean wrist postures

		Test conditions									
		NK	NN	NM	NC	EM	EC	FK	FN	FM	FC
Mean flexion/extension posture, deg	Mean (S.D.)	-11.7 (11.6)	-6.2 (11.2)	-10.8 (9.4)	-10.7 (9.9)	-19.0 (6.1)	-12.2 (9.6)	-20.1 (10.2)	-19.0 (9.1)	-20.2 (4.9)	-18.5 (10.3)
Computer configuration effects	<i>p</i> -value										
During number-typing task	<0.0001*		A						B		
During word-typing task	<0.0001*	A						B			
During pointing device task	<0.0001*			A		B				B	
During combination task	0.0001*				A		A				B
Task effects											
Using NPCsa	0.0101*	b	a	b							
Using NPCEX	<0.0001*	b	a			c					
Using FULL	0.7763										
Mean rad./uln. posture, deg	Mean (S.D.)	-13.2 (6.0)	-15.3 (6.2)	-10.9 (6.8)	-13.1 (7.2)	-9.0 (5.5)	-13.3 (6.1)	-12.1 (6.6)	-2.5 (4.3)	-7.5 (6.4)	-11.7 (7.4)
Computer configuration effects	<i>p</i> -value										
During number-typing task	<.0001*		B						A		
During word-typing task	0.4829										
During pointing device task	0.1074										
During combination task	0.5841										
Task effects											
Using NPCsa	0.0285*	a b	b	a							
Using NPCEX	0.0007*	b	b			a					
Using FULL	<0.0001*							c	a	b	

Mean values and standard deviations (in parentheses) are in degrees. Flexion and radial deviation are positive. Flexion from 0° to 15° and extension from 0° to -25° is considered neutral (Moore and Garg, 1995). Radial/ulnar deviation between 15° and -15° is considered neutral (Moore and Garg, 1995). Non-neutral postures are written in italics.

*indicates $p \leq 0.05$. A > B > C; a > b > c.

Table 10
Effects of COMPUTER SETUP and TASK on wrist posture variation

		Test conditions									
		NK	NN	NM	NC	EM	EC	FK	FN	FM	FC
Mean flexion/extension variation, deg	Mean (S.D.)	5.8 (1.2)	7.1 (1.8)	0.3 (0.3)	7.4 (2.1)	2.2 (1.6)	9.0 (4.5)	6.5 (2.5)	9.4 (2.7)	2.8 (1.5)	9.4 (3.6)
Computer configuration effects	<i>p</i> -value										
During number typing task	0.0188*		B						A		
During word typing task	0.5038										
During pointing device task	0.0338*			B		A B				A	
During combination task	0.0954										
Task effects											
Using NPCsa	<0.0001*	A	a	b							
Using NPCEX	<0.0001*	A	a			b					
Using FULL	<0.0001*							b	a	c	
Mean radial/ulnar variation, deg	Mean (S.D.)	5.5 (1.3)	6.5 (3.5)	0.5 (0.4)	6.9 (2.7)	2.7 (0.8)	6.7 (2.1)	5.9 (2.3)	6.4 (1.9)	2.8 (1.6)	8.8 (5.7)
Computer configuration effects	<i>p</i> -value										
During number typing task	0.9265										
During word typing task	0.6579										
During pointing device task	0.0384*			B		A				A	
During combination task	0.0823										
Task effects											
Using NPCsa	<0.0001*	A	a	b							
Using NPCEX	0.0013*	A	a			b					
Using FULL	0.0010*							a	a	b	

Mean values and standard deviations (in parentheses) are in degrees.

*indicates $p \leq 0.05$. A > B > C; a > b > c.

Table 11
Effects of COMPUTER SETUP and TASK on static muscle activity in the first dorsal interosseus and the upper fibers of the middle trapezius

		Test conditions									
		NK	NN	NM	NC	EM	EC	FK	FN	FM	FC
Static EMG—DI1, %MVC, $p < 0.0001$	Mean (S.D.)	0.84 (0.29)	0.75 (0.36)	1.34 (1.03)	0.95 (0.49)	1.97 (1.02)	1.14 (0.55)	0.72 (0.23)	0.55 (0.25)	2.06 (0.98)	0.96 (0.36)
Computer configuration effects	p -value										
During number-typing task	0.3806										
During word-typing task	0.5877										
During pointing device task	0.0034*			B		A				A	
During combination task	0.6218										
Task effects											
Using NPCsa	0.0207*	b	b	a							
Using NPCEX	<0.0001*	b	b			a					
Using FULL	<0.0001*							b	b	a	
Static EMG—TRAP, %MVC, $p < 0.0001$	Mean (S.D.)	2.75 (1.71)	3.10 (1.62)	1.80 (1.06)	3.38 (1.51)	1.80 (1.19)	3.19 (1.44)	2.20 (1.59)	2.49 (1.30)	2.13 (1.30)	2.71 (1.54)
Computer configuration effects	p -value										
During number-typing task	0.0817										
During word-typing task	0.1182										
During pointing device task	0.5435										
During combination task	0.1344										
Task effects											
Using NPCsa	0.0010*	a	a	b							
Using NPCEX	0.0010*	a	a			b					
Using FULL	0.5350										

Mean values and standard deviations (in parentheses) are presented as percentage of MVC. Static muscle activity is considered excessive if it exceeds 2–5% MVC (Jonsson, 1978).

*indicates $p \leq 0.05$. $A > B > C$; $a > b > c$.

Table 12
Effects of COMPUTER SETUP and TASK on static muscle activity in pectoralis major and teres minor/infraspinatus muscles

		Test conditions									
		NK	NN	NM	NC	EM	EC	FK	FN	FM	FC
Static EMG—PEC, %MVC, $p = 0.0014$	Mean (S.D.)	3.33 (1.72)	3.12 (1.65)	2.76 (1.59)	3.27 (1.78)	2.66 (1.50)	3.20 (1.70)	2.79 (1.49)	2.48 (1.43)	2.60 (1.50)	2.69 (1.52)
Computer configuration effects	p -value										
During number-typing task	0.0074*		A						B		
During word-typing task	0.0254*	A						B			
During pointing device task	0.7777										
During combination task	0.0328*				A		A				B
Task effects											
Using NPCsa	0.0578										
Using NPCEX	0.0183*	a	a b			b					
Using FULL	0.4015										
Static EMG—TMI, %MVC, $p = 0.0003$	Mean (S.D.)	2.57 (1.74)	2.53 (1.72)	2.39 (1.66)	2.59 (1.76)	2.37 (1.60)	2.53 (1.74)	2.64 (1.73)	2.66 (1.79)	2.35 (1.56)	2.56 (1.66)
Computer configuration effects	p -value										
During number-typing task	0.1049										
During word-typing task	0.4361										
During pointing device task	0.8939										
During combination task	0.7719										
Task effects											
Using NPCsa	0.0516										
Using NPCEX	0.0261*	a	a			b					
Using FULL	0.0002*							a	a	b	

Mean values and standard deviations (in parentheses) are presented as percentage of MVC. Static muscle activity is considered excessive if it exceeds 2–5% MVC (Jonsson, 1978).

*indicates $p \leq 0.05$. $A > B > C$; $a > b > c$.

Table 13
Effects of COMPUTER SETUP and TASK on total discomfort and neck discomfort^a

		Test conditions									
		NK	NN	NM	NC	EM	EC	FK	FN	FM	FC
Total discomfort, $p < 0.0172$	Mean = (S.D.)	2.90 (3.89)	5.70 (5.94)	6.40 (8.40)	5.40 (5.64)	3.85 (4.67)	4.60 (4.12)	3.70 (5.74)	6.85 (8.11)	4.40 (6.42)	3.70 (5.13)
Computer configuration effects	p -value										
During number-typing task	0.7481										
During word-typing task	0.5738										
During pointing device task	0.1372										
During combination task	0.1694										
Task effects											
Using NPCsa	0.0070*	b	a	a							
Using NPCEx	0.0263*	b	a			a b					
Using FULL	0.0436*							b	a	a b	
Neck discomfort, $p < 0.0002$	Mean = (S.D.)	1.25 (1.27)	1.65 (1.20)	1.00 (0.62)	1.70 (1.25)	1.35 (1.18)	1.25 (1.18)	0.30 (0.35)	1.15 (1.31)	0.80 (0.59)	0.75 (0.68)
Computer configuration effects	p -value										
During number-typing task	0.0724										
During word-typing task	0.0017*	A						B			
During pointing device task	0.253										
During combination task	0.0111*				A		A B				B
Task effects											
Using NPCsa	0.1290										
Using NPCEx	0.3237										
Using FULL	0.0147*							b	a	a	

^aStatistical determinations were based on log transformations of these data.

*indicates $p \leq 0.05$. A > B > C; a > b > c.

Table 14
Effects of COMPUTER SETUP and TASK on right forearm discomfort and right wrist discomfort^a

		Test conditions									
		NK	NN	NM	NC	EM	EC	FK	FN	FM	FC
Right forearm discomfort, $p = 0.0011$	Mean (S.D.)	0.10 (0.32)	0.35 (0.94)	0.85 (1.29)	0.30 (0.63)	0.35 (0.67)	0.40 (0.70)	0.45 (0.93)	1.30 (1.64)	0.40 (1.26)	0.50 (0.94)
Computer configuration effects	p -value										
During number-typing task	0.0004*		B						A		
During word-typing task	0.1432										
During pointing device task	0.0711										
During combination task	0.7250										
Task effects											
Using NPCsa	0.0099*	b	b	a							
Using NPCEx	0.4798										
Using FULL	0.0006*							b	a	b	
Right wrist discomfort, $p = 0.0435$	Mean (S.D.)	-0.10 (0.32)	0.45 (1.01)	1.10 (1.91)	0.55 (1.17)	0.45 (1.07)	0.50 (0.85)	0.85 (1.45)	0.80 (1.55)	0.50 (1.29)	0.35 (1.03)
Computer configuration effects	p -value										
During number-typing task	0.3125										
During word-typing task	0.0020*		B					A			
During pointing device task	0.1469										
During combination task	0.7170										
Task effects											
Using NPCsa	0.0020*	b	a	a							
Using NPCEx	0.0848										
Using FULL	0.4534										

Mean values and standard deviations (in parentheses) are presented. Values for each condition_{*i*} are mean values of (condition_{*i*}–baseline).

*indicates $p \leq 0.05$. A > B > C; a > b > c.

^aStatistical determinations were based on log transformations of these data.

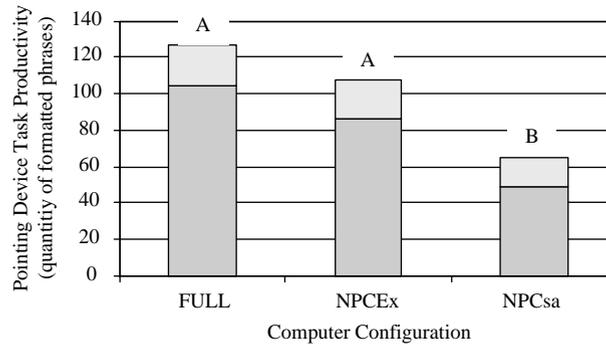


Fig. 2. Effects of computer configuration on pointing device task productivity. The top of the darker part of the bar indicates the mean value, while the lighter region at the top indicates the standard deviation. FULL = NPC + external keyboard + external mouse; NPCEX = NPC + external mouse; NPCsa = NPC only.

and FC conditions were 10.9° and 17.7° , respectively. Based on assessments of mean shoulder rotation posture and variation in that posture, the NPCsa seems to be the more restrictive alternative of the three configurations, which is not even alleviated by varying tasks performed with the computer. It is likely that the effects of posture variation follow a U-shape, with too much or too little variation as potential risk factors for musculoskeletal discomfort. However, the correct amount is unknown, and may differ across individuals. So, at this point in time, it is not known where on that U-curve the three values of shoulder rotation posture variation, which were seen in the combination task, might fall.

Mean elbow angle was affected by computer configuration and by task (Table 8). For each computer configuration, elbow angle differed as a function of task. Elbow angle variation was affected by computer configuration when subjects performed the combination task ($p = 0.0115$). The FULL and NPCEX configurations (4.8°) offered more variation than did the NPCsa configuration (2.9°). There was some difference in variation of elbow angle due to task when subjects used the NPCsa ($p = 0.0051$), though only NN and NM were significantly different from each other. Variations associated with NN, NK, and NM conditions were 4.5° , 3.3° , and 2.5° , respectively.

Mean elbow angles for all conditions were within the 80 – 120° range identified as neutral by

McAtamney and Corlett (1993). Therefore, based on mean elbow angle, use of one computer configuration or another does not seem to offer any advantage. However, for general use (as in the combination task) the NPCsa configuration provided less variation (greater postural fixity) in elbow angle than the other two configurations.

3.2.4. Wrist posture

Subjects adopted extended and ulnarly deviated wrist postures in all the ten conditions, though postures differed as a function of computer configuration and task. In all conditions, wrist extension was within the neutral range (Moore and Garg, 1995). Ulnar deviation exceeded neutral only for the NN condition. For each task, the FULL configuration elicited similar or greater extension than the other configurations, while the NPCsa configuration elicited similar or less extension than the other configurations (Table 9). When using the FULL configuration, task had no effect on wrist extension, whereas with the NPCEX, each task elicited a different extension angle.

Radial/ulnar deviation was only affected by computer configuration during the number typing tasks. Ulnar deviation was close to zero in the FN condition (using the number pad), while it exceeded the neutral range in the NN condition. Ulnar deviation differed for each task, for each computer configuration. For each configuration, using the pointing device elicited less ulnar

deviation than typing letters. For the FULL configuration, number typing was the task in which wrists were ulnarly deviated the least, whereas in the NPCsa and NPCEX configurations, number typing elicited the most pronounced ulnar deviation.

Wrist extension variation was not affected by configuration for either the letter typing or combination tasks (Table 10). For the other two tasks, the greatest variation occurred with the FULL configuration. When working with each configuration, extension variation was determined by task, with number typing and letter typing associated with greater variation than pointing device use. Radial/ulnar deviation was only affected by computer setup for the pointing device task, during which ulnar wrist posture variation was much less in NM than in EM or FM conditions. In both planes of motion, for each computer configuration, the amount of variation when using either pointing device was markedly less than the posture variation that occurred with the other tasks, and use of the pointing stick compounded that impact. Wrist posture variation, in both planes, was an order of magnitude less in the NM condition than in the other conditions.

Wrist postures were found to be within neutral ranges, with the exception of ulnar deviation in the NN condition. If a less conservative range was chosen, such as from 0° to -20° (Hünting et al., 1981), then postures in all test conditions would be categorized as neutral. As long as number typing was not a primary task of the user, overall, the NPCEX might be considered the better of the three configurations, based on reduced wrist extension and differences in postures in both planes that are afforded when users perform different tasks with that configuration.

3.3. Muscle activity

Static muscle activity was generally low across the conditions with means for muscles within, but none exceeding, the 2–5% MVC recommendation of Jonsson (1978). Statistics and effects are provided in Tables 11 and 12.

No effects of computer configuration were seen in the TRAP or TMI muscles. While these findings

for the TRAP are consistent with those of Cook and Kothiyal (1998) in their investigation of different mouse use locations, they are in contrast to findings of reduced bilateral TRAP activity when comparing use of a pointing stick to a mouse (Fernström and Ericson, 1997). The former group of authors did find reduced deltoid activity when the mouse was placed next to a keyboard without a number pad, compared to more lateral placement when a number pad was present. The latter group of authors found increased activity in the extensor carpi ulnaris and flexor digitorum superficialis when using the pointing stick compared to the mouse. In the current study, intrinsic hand muscle activity (DII) was lowest when using the pointing stick, during the pointing device task. The only effect of computer configuration on DII was seen during that task. For the PEC, no configuration effects were seen for the pointing device task. However, for the other three tasks, the FULL configuration elicited less PEC activity than the other setups.

For particular computer configurations, task had significant effects on static activity of each muscle. For the DII muscle, the pattern was the same within each computer configuration: number and letter typing elicited less muscle activity than use of the pointing device. For the TRAP, no variation due to task was seen in static activity when using the FULL configuration; for the other two configurations, the pointing device task was associated with less muscle activity than the letter or number typing tasks. For the PEC, static activity was similar across tasks for the FULL and NPCsa configurations; for the NPCEX, the pointing device task elicited least activity and the letter typing the most activity. For the TMI, there was no difference due to task for the NPCsa configuration, but for both the FULL and NPCEX configurations the pointing device task elicited less muscle activity than the number or letter typing tasks.

To summarize the muscle activity findings, in terms of lower amplitude of activity, the NPCsa configuration seemed to offer some advantage to the DII muscle in the case of exclusive pointing device use. However, the reduction in productivity would mean that the muscle would be active,

though at a lower level, for at least twice as long, so on balance, the NPCsa may not actually offer a benefit to the DII, especially considering Sjøgaard's concerns for *duration* of muscle activity (Sjøgaard, 1999). For the PEC, the FULL configuration offers lower activity compared to the other two configurations for text typing, number typing, and the combination tasks. In terms of variation in activity, the FULL configuration provides variation in static EMG activity to the DII and TMI, the NPCsa to DII and the TRAP, while the NPCEX offers variation to all four muscles.

3.4. Body part discomfort

Discomfort was generally low, with 1.7 the highest average discomfort in any body part (Neck, NC condition). Total discomfort (the summation of individual discomfort ratings), Neck, Forearm, and Wrist discomfort were all significantly affected by condition (Tables 13 and 14). Regarding Neck discomfort, for the keying task, the FULL setup rated less discomfort than the other two configurations; for the combination task, the FULL or the NPCEX rated less discomfort than the NPCsa. However, the NPCsa rated less discomfort in the forearm when typing numbers and in the wrist when typing letters, than the other two configurations. In examining the effects of Task for each computer configuration, in general typing numbers and using the pointing device rated higher discomfort than typing letters. For the FULL setup, number typing elicited more total, neck, and forearm discomfort; pointing device activity also rated higher total and higher neck discomfort. For the NPCEX, number typing elicited higher total discomfort; pointing device use was also somewhat higher, though not significantly different from typing letters. For the NPCsa, pointing device use elicited more total, forearm, and wrist discomfort than did keying letters; typing numbers also rated higher total and wrist discomfort.

Regarding body part discomfort, there is no clear indication as to which computer configuration was better overall. Neck discomfort seemed to benefit from the FULL configuration, in which the

viewing angle was only about half as steep as in the NPCsa or NPCEX configurations. Other studies have shown reduced neck extensor muscle activity and user preference for displays that are placed at moderate or higher viewing angles rather than deeper angles (Sommerich et al., 2001; Villanueva et al., 1997; Straker and Mekhora, 2000). Based on task comparisons, and contrary to expectations, indications are that using the number pad in the FULL setup was not beneficial, in terms of reduced discomfort, compared to typing on the number row, although postural benefits were realized, as discussed in Sections 3.2.3 and 3.2.4. This may be due, in part, to a lack of practice or expertise in typing numbers, in general, or specifically with the number pad. Performing the pointing device task resulted in increased discomfort over other tasks while using the NPCsa. However, across computer configurations, there was only a trend towards increased discomfort in the forearm and wrist associated with using the pointing stick, compared to using the external mouse, so no clear indications regarding the better pointing device come from this discomfort data.

3.5. Subjective preference

Responses to questions on customary computer use and preferences are presented in Table 15, as a point of interest, and to provide additional background information on the subjects. Responses are not inconsistent with discomfort reports, in that subjects preferred to work with the raised monitor (FULL), nor with the productivity results, in that most subjects preferred to use the mouse rather than the pointing stick, in the study and in practice.

4. Summary and conclusions

This study took a comprehensive approach to evaluating effects of using a notebook computer stand-alone or along with inexpensive peripheral input devices. The study examined effects on posture, postural fixity, muscle activity, productivity, and discomfort, and considered the impact

Table 15
Questions and responses from subject experience and preference survey

Question	Responses
Which setup made you feel least confined?	FULL—7 NPCsa—0 NPCEX—3
While using the NPC, which pointing device did you prefer?	Pointing stick—1 Mouse—9
Which screen height did you prefer?	Table height—0 Shelf height—10
What type of keyboard(s) do you usually use?	FULL size std—7 FULL size alt—3 Notebook—2
What type of pointing device(s) do you usually use?	External mouse—8 Pointing stick—2 Trackball—1 Touchpad—0 Other—0
What type of keyboard do you prefer?	FULL size std—5 FULL size alt—5 Notebook—0
What type of pointing device do you prefer?	External mouse—8 Pointing stick—0 Trackball—2 Touchpad—0 Other—0

of both computer configuration and task performed. Consistent with the original hypothesis, this study demonstrated that use of a stand-alone notebook computer (NPCsa) resulted in significantly more postural fixity in several joints compared to the other two computer configurations used in the study (notebook PC with an external mouse (NPCEX), and notebook PC with an external mouse and external keyboard (FULL)). The stand-alone configuration also induced more non-neutral postures, in certain tasks, than did the other two configurations. Neck posture and discomfort benefited from use of the two external input devices. However, while using the number pad on the external keyboard produced postural benefits, right fore-

arm discomfort was higher during the number typing task with that configuration, compared to when the number row was used on the notebook PC's keyboard. Additionally, muscle activity measures indicated some benefit to the first dorsal interosseous m. from using the built-in pointing stick in the notebook PC, while the pectoralis major m. was less active when both external devices were used. However, the former positive finding might be offset by the reduction in productivity found with the built-in pointing stick in comparison to use of the external mouse.

A primary weakness of the current study is the limited time subjects had to experience each condition. This was necessary in order to ensure subjects would not become fatigued, and that the study would require only one day's worth of time from each subject. This restricts our ability to extrapolate our findings to working with these three configurations for entire work days, as many people do. That said, with the shortened work cycles used for each condition, it is more likely that measured posture variation was indeed due to test condition (task and/or computer configuration), and less likely to have been due to subject fatigue or discomfort.

Based on these results, then, a recommendation is made for use of either the NPCEX or FULL configurations, over the NPCsa configuration, when working for an extended period of time, such as when a notebook is used in a desktop replacement scenario. The primary benefit of adding the external keyboard is the ability to elevate the computer's display. If an external keyboard is used, it is generally recommended that it does not have a built-in number pad, so that the external mouse can be placed directly next to the primary keyboard. Although not tested in this study, a stand-alone number pad would seem to be appropriate for someone who performed a lot of numeric entry. This would provide more flexibility, in terms of mouse and number pad placement (either exchanging one for the other depending on task, or placing one on either side of the keyboard if the individual is willing/able to learn to work with both hands, as he/she already must do in typing text).

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References

- Bergqvist, U., Wolgast, E., Nilsson, B., Voss, M., 1995. Musculoskeletal disorders among visual display terminal workers: individual, ergonomic, and work organizational factors. *Ergonomics* 38, 763–776.
- Bernard, B., 1991. Los Angeles Times (HETA 90-013-2277). Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety & Health.
- Borg, G.A.V., 1982. Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise* 14, 377–381.
- Card, S.K., English, W.K., Burr, B.J., 1978. Evaluation of mouse, rate-controlled isometric joystick, step keys, and text keys for text selection on a CRT. *Ergonomics* 21, 601–613.
- Cook, C.J., Kothiyal, K., 1998. Influence of mouse position on muscular activity in the neck, shoulder and arm in computer users. *Applied Ergonomics* 29, 439–443.
- Diederich, J., Stewart, M., 1997. Laptop computers: flexibility v's disability. In: *Proceedings of the Occupational Therapy Australia, 19th National Conference*, pp. 211–214.
- Drury, C.G., 1987. A biomechanical evaluation of the repetitive motion injury potential of industrial jobs. *Seminars in Occupational Medicine* 2, 41–50.
- Epps, B.W., 1986. Comparison of six cursor control devices based on Fitts' Law model. In: *Proceedings of The Human Factors Society 30th Annual Meeting*. The Human Factors Society, Santa Monica, pp. 327–331.
- Fernström, E., Ericson, M.O., 1997. Computer mouse or Trackpoint—effects on muscular load and operator experience. *Applied Ergonomics* 28, 347–354.
- Grieco, A., 1986. Sitting posture: an old problem and a new one. *Ergonomics* 29, 345–362.
- Harbison, S., Forrester, C., 1995. The ergonomics of notebook computers: problems or just progress. *Journal of Occupational Health and Safety* 11, 481–487.
- Heasman, T., Brooks, A., Stewart, T., 2000. Health and safety of portable display screen equipment (304/2000). Health & Safety Executive, United Kingdom.
- Hünting, W., Laubli, T., Grandjean, E., 1981. Postural and visual loads at VDT workplaces. I. Constrained postures. *Ergonomics* 24, 917–931.
- Jensen, C., Vasseljen, O., Westgaard, R.H., 1993. The influence of electrode position on bipolar surface electromyogram recordings of the upper trapezius muscle. *International Archives of Occupational and Environmental Health* 67, 266–273.
- Jonsson, B., 1978. Kinesiology, with special reference to electromyographic kinesiology. In: Cobb, W.A., Van Duijn, H. (Eds.), *Contemporary Clinical Neurophysiology*. Elsevier, Amsterdam, pp. 417–428.
- Juliussen, E., Petska-Juliussen, K., 1994. 7th Annual Computer Industry Almanac. Computer Industry Almanac, Inc., Austin.
- Kelahr, D., Nay, T., Lawrence, B., Lamar, S., Sommerich, C.M., 2001. An investigation of the effects of touchpad location within a notebook computer. *Applied Ergonomics* 32, 101–110.
- Li, Z.M., Zatsiorsky, V.M., Latash, M.L., 2000. Contribution of the extrinsic and intrinsic hand muscles to the moments in finger joints. *Clinical Biomechanics* 15, 203–211.
- Loricchio, D.F., 1992. A comparison of three pointing devices: mouse, cursor keys, and a keyboard-integrated pushbutton. In: *Proceedings of the Human Factors Society 36th Annual Meeting*. The Human Factors Society, Santa Monica, pp. 303–305.
- Marras, W.S., Schoenmarklin, R.W., 1993. Wrist motions in industry. *Ergonomics* 36, 341–351.
- McAtamney, L., Corlett, E.N., 1993. RULA: a survey method for the investigation of work-related upper limb disorders. *Applied Ergonomics* 24, 91–99.
- Moore, J.S., Garg, A., 1995. The strain index: a proposed method to analyze jobs for risk of distal upper extremity disorders. *American Industrial Hygiene Association Journal* 56, 443–458.
- Newburger, E., 1997. Computer use in the United States (P20-522). US Census Bureau.
- Price, J.A., Dowell, W.R., 1998. Laptop configurations in offices: effects on posture and discomfort. In: *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting*, pp. 629–633.
- Psihogios, J.P., Sommerich, C.M., Mirka, G.M., Moon, S.D., 2001. A field evaluation of monitor placement effects in VDT users. *Applied Ergonomics* 32, 313–325.
- Sauter, S.L., Schleifer, L.M., Knutson, S.J., 1991. Work posture, workstation design, and musculoskeletal discomfort in a VDT data entry task. *Human Factors* 33, 151–167.
- Sjøgaard, G., 1999. Low-level static exertions. In: Karwowski, W., Marras, W. (Eds.), *The Occupational Ergonomics Handbook*. CRC Press, Boca Raton, FL, pp. 247–259.
- Sommerich, C.M., 2000. Inputting to a notebook computer. In: *Proceedings of the IEA 2000/HFES 2000 Congress*. The Human Factors and Ergonomics Society, San Diego, CA, pp. 671–674.
- Sommerich, C.M., 2002. Working with Computers, Part 1: A survey of professionals who use desktop &/or notebook

- style computers for work-related purposes, preliminary analyses. Marconi Research Conference, Marshall, CA.
- Sommerich, C.M., Joines, S.M.B., Psihogios, J.P., 2001. Effects of computer monitor viewing angle and related factors on strain, performance, and preference outcomes. *Human Factors* 43, 39–55.
- Straker, L., Mekhora, K., 2000. An evaluation of visual display unit placement by electromyography, posture, discomfort and preference. *International Journal of Industrial Ergonomics* 26, 389–398.
- Straker, L., Jones, K.J., Miller, J., 1997a. A comparison of the postures assumed when using laptop computers and desktop computers. *Applied Ergonomics* 28, 263–268.
- Straker, L.M., Pollock, C.M., Mangharam, J.E., 1997b. The effect of shoulder posture on performance, discomfort, and muscle fatigue whilst working on a visual display unit. *International Journal of Industrial Ergonomics* 20, 1–10.
- Villanueva, M.B., Sotoyama, M., Jonai, H., Takeuchi, Y., Saito, S., 1996. Adjustments of posture and viewing parameters of the eye to changes in the screen height of the visual display terminal. *Ergonomics* 39, 933–945.
- Villanueva, M.B., Jonai, H., Sotoyama, M., Hisanaga, N., Takeuchi, Y., Saito, S., 1997. Sitting posture and neck and shoulder muscle activities at different screen height settings of the visual display terminal. *Industrial Health* 35, 330–336.
- Villanueva, M.B., Jonai, H., Saito, S., 1998. Ergonomic aspects of portable personal computers with flat panel displays (PC-FPDs): evaluation of posture, muscle activities, discomfort and performance. *Industrial Health* 36, 282–289.
- Wørsted, M., Westgaard, T., 1997. An experimental study of shoulder muscle activity and posture in a paper version versus a VDU version of a monotonous work task. *International Journal of Industrial Ergonomics* 19, 175–185.