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The impact of computer display height and desk design on muscle activity during information technology work by young adults

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Abstract

Computer display height and desk design are believed to be important workstation features and are included in international standards and guidelines. However, the evidence base for these guidelines is lacking a comparison of neck/shoulder muscle activity during computer and paper tasks and whether forearm support can be provided by desk design. This study measured the spinal and upper limb muscle activity in 36 young adults whilst they worked in different computer display, book and desk conditions. Display height affected spinal muscle activity with paper tasks resulting in greater mean spinal and upper limb muscle activity. A curved desk resulted in increased proximal muscle activity. There was no substantial interaction between display and desk.

Keywords: Computer; Muscle activity; Musculoskeletal disorder; Work-related neck and upper limb disorder

1. Introduction

During the late 1980s, international and national standards and guidelines on computer use were developed in response to the growing reports of musculoskeletal disorders associated with computer use (e.g. AS, 1990; EEC, 1990; ISO, 1997; SCC, 1991). These standards covered workstation tasks (data and word processing, typing, programming, etc.), environment (space, light, noise, heat, etc.), software (usability, dialogues, etc.), hardware (displays, keyboards, non-keyboard input devices, etc.) and workstation (desk, chair, etc.) design in addition to personnel factors (eyesight, physical problems, mental stress, etc.). Many guidelines included information on how the individual should fit the furniture to themselves (e.g. chair height so the knees are >90°, armrests/keyboard height so elbow angle >90°). Some guidelines provided considerable detail on workstation design such as chair seat height, seat pan depth/width/angle, seat back height/width/length; armrest height/width/length; work surface height, width, depth, leg clearances; keyboard height, placement; and display height/gaze angle, distance, tilt.

These standards and guidelines were based on expert and industry opinion, often using available research evidence. Whilst some standards have been updated more recently (e.g. ANSI, 2002) we believe a serious review of standards is required due to: changes in computing technology, changes in how computers are used, changes in who uses computers, and recent laboratory and field research. Examples of potentially important computer technology changes include: shift from keyboard command to mouse input Graphic User Interface as the norm, increasing replacement of cathode ray tube displays with liquid crystal thin film transistor displays and the development of tablet computers where the user writes on the screen similar to writing on paper and reading from a book. Changes in how computers are used include increasing use for activities of daily living, social communication and entertainment. Changes in who uses computers include

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Table 1
Summary of studies investigating effect of visual display height on muscle activity

Reference	Workstation scenario	Visual target	Reported data
1. Aaras et al. (1997)	$n = 20$ (workers), lab, keyboard, mouse. Seat height unspecified. Desk provided forearm support, height unspecified	Unspecified	L/R TRAP, L/R LES
2. Babski-Reeves et al. (2005)	$n = 8$ (students), lab, keyboard. Seat height adjusted for horizontal thigh, vertical leg; backrest upright. Keyboard height at sitting elbow height	17″ monitor, GA-h at +15°, −15°. Tilt 0-5°	L SPLEN*, L LES†
3. Bauer and Wittig (1998)	$n = 8$ (students), lab, keyboard. Seat height adjusted for horizontal thigh, vertical leg; backrest upright. Desk height set 3 cm below elbow height	Monitor unspecified; GA-h at 0°, −17.5°, −35°; tilt perpendicular; distance 74, 82, 105 cm	L CES‡
4. Karlqvist et al. (1999)	$n = 20$ (workers), lab, mouse/ trackball. Seat (45–7 5 cm) and desk height (70–76 cm) self selected	Monitor size unspecified; distance to desk edge 50 cm	L/R TRAP, R DELT, R EDL
5. Kleine et al. (1999)	$n = 9$ (workers), lab, keyboard. Seat height self selected. Desk height unspecified	Unspecified	L/R CES¶, L/R TES¶, L/R LES¶, L/R TRAP¶, L/R SCM¶, L/R DELT¶, L/R DELT POS¶
6. Laursen and Jensen (2000)	$n = 17$ (young/old), lab, mouse. Seat height unspecified. Desk provided forearm support, height unspecified	17″ monitor, distance 65 cm, screen top at eye height	R DELT, L/R TRAP, R CES
7. Saito et al. (1997)	$n = 10$ (students), lab, keyboard; chair height adjusted ‘appropriately’, desk height 70 cm, keyboard position 4 cm from desk edge	Notebook: 10.4″ display, desktop: 14″ display. Distance self selected (32.9(±5.4), 40.6(±4.3) cm)	R CES§, R TRAP§, R DELT§, R TES§
8. Sommerich et al. (2001)	$n = 16$ (eight typists), lab, typing, mousing, reading. Seat pan set for thighs horizontal, legs vertical, feet flat on floor. Keyboard height set at elbow height, distance for vertical forearms and elbows at 90°	(1) 14″ or 19″ monitor; (2) GA-h at 0°, −17.5°, −35°; tilt perpendicular to GA-h; distance self-selected (50–100 cm)	L/R SCM, L/R LEV, L/R TRAP, L/R CES, L/R TES
9. Sommerich et al. (2002)	$n = 10$ (unspecified), lab, mouse, keyboard; chair height adjusted for 90° knee flexion with feet flat, keyboard height at elbow height. Laptop, with and without external keyboard and/or mouse	Laptop with screen size unspecified. Distance and tilt unspecified	R TRAP, R PM, R TMI, R DI1
10. Turville et al. (1998)	$n = 12$ (unspecified), lab, keyboard, mouse. Seat height at popliteal height +2 cm, then adjusted for 90° knee flexion. Keyboard height at elbow height	Monitor unspecified; GA-h at −15°, −40°; tilt perpendicular; distance 75–80 cm	L/R TRAP, L/R CES, L/R TES, L/R SCM, L/R LEV
11. Straker and Mekhora (2000)	$n = 20$ (students), lab, keyboard. Seat height at popliteal height, pan inclined 5° forwards. Desk height at seated elbow height	Monitor unspecified; GA-h at −10° (tilt 5° or −30°) (tilt 25°); distance self-selected 30–75 cm	L/R TRAP, L/R CES‖, L/R TES‖
12. Villanueva et al. (1997)	$n = 10$ (unspecified), lab, mouse. Seat height adjusted so forearm is horizontal when using mouse (43.0 ± 1.8 cm). Desk height 67 cm	14″ monitor; height 80, 100, 120 cm; distance unspecified	R CES, R TRAP
13. Villanueva et al. (1998)	$n = 10$ (unspecified), lab, keyboard; chair adjusted for horizontal forearm when hand over home-key, desk height 70 cm	(1) Desktop: 17″ monitor; (2) Notebook: 13.8″ screen; (3) Notebook: 10.4″ screen; (4) Notebook: 7.2″ screen; (5) Notebook: 6.1″ screen. Monitor height: 96.0, 92.9, 81.1, 80.2, 76.4 cm. Distance, tilt self selected; distance: 50.5(±8.7), 49.3(±7.2), 46.7(±8.0), 43.4(±7.1), 41.2(±6.5) cm. Tilt: 5.5° (±3.0), 22.2°(±5.7), 32.6°(±4.8), 37.3°(±7.1), 41.0°(±6.3)	L CES, L TRAP, L DELT, L ECU

(continued on next page)

Table 1 (*continued*)

Reference	Workstation scenario	Visual target	Reported data
14. Visser et al. (2000)	$n = 10$ (workers), lab, keyboard, mouse. Seat and desk height unspecified	Unspecified	R TRAP#

Notes:
L – left
R – right
DELT – deltoid (assumed anterior)
DELT POS – posterior deltoid
TES – thoracic erector spinae
LES – lumbar erector spinae
SCM – sternocleidomastoid
TRAP – trapezius
CES – cervical erector spinae
LEV – levator scapulae
SPLEN – splenius capitis
EDL – extensor digitorum longus
PM – pectoralis major
TMI – teres minor/infraspinatus
DI1 – first dorsal interosseus
ECU – extensor carpi ulnaris
EMG normalisation details:
EMG normalised to MVE unless otherwise stated.
*The study normalised to a submaximal reference voluntary contraction (RVE) task of resisting neck flexion while wearing mask with 0.91 kg weight attached, looking straight ahead. A correction factor for RVE to MVE was determined by the ratio between CES data at GA = −15° from this study with a mean at the same GA from the literature (Villanueva et al., 1998; Turville et al., 1998; Sommerich et al., 2001).
†Normalised to RVE task of holding 2.27 kg weight in each hand with arms abducted 90° in frontal plane and arms parallel to the floor.
‡Normalised to a reference position. A correction factor for RVE to MVE was determined by the ratio between CES data at GA = 0° from this study with a mean at the same GA from the literature (Villanueva et al., 1998; Laursen and Jensen, 2000; Sommerich et al., 2001).
¶Normalised to RMS of task.
§No normalisation. A correction factor was determined by the ratio between CES data at GA = 0° from this study with a mean at the same GA from the literature (Villanueva et al., 1998; Laursen and Jensen, 2000; Sommerich et al., 2001). The correction factor for TRAP at GA = 0° used data from Villanueva et al. (1998) and Laursen and Jensen (2000).
‖Normalised to RVE task of raising head 20 mm above plinth while prone. Data not converted to relative MVE.
#Normalised to standard isometric contraction holding 2 kg load, position unspecified.

the rapid expansion of computer use from specialist computer and data processing occupations to nearly all occupational sectors.

Computer use continues to become more prevalent in both work and home environments. Recent figures from Japan show computers are being used in 93% of businesses and 47% of households (Statistics Bureau of Japan, 2005). In 2000, home became the more common site for computer use than work for the first time in Western Australia (33% vs. 25%) (Australian Bureau of Statistics, 2000). Within the adult population, young adults are the most prevalent users. For example, two-thirds of Swedes in the 16–24 years age range use computers daily with 90% using them at least weekly (Statistics Sweden, 2003).

Given the changes in technology and work practices it is timely to review the research evidence for important current workstation features such as display height and forearm support. In a companion paper (Straker et al., 2008) we have reported new data and reviewed prior evidence for the effect of display height and forearm support on posture. In this paper, we review the evidence for the effect of display height and forearm support on muscle activity.

1.1. Display height and muscle activity

We found 14 studies reporting the effect of display height on neck/shoulder surface electromyography (sEMG) for adults. Search strategies included searching Pubmed, Medline and AMed databases using keywords EMG, VDU, computer, display height, and posture, crossing-checking reference lists in relevant articles and searches of authors' library of papers. Table 1 provides a summary of the testing scenario for each of these studies and notes adjustments and estimates we made to provide comparable sEMG data across the studies.

In Figs. 1 and 2, we present a summary of the data from these available studies. It was difficult to synthesise the data from the previous studies due to the different manner that data were both collected and reported. For example, normalisation of sEMG data were to a maximum voluntary exertion (MVE) (eight studies), or to a range of submaximal reference voluntary exertions (RVE) exertions (four studies), or not normalised. Data had to be approximated from figures in five studies. Data were also reported relative to a particular condition (two studies). Where

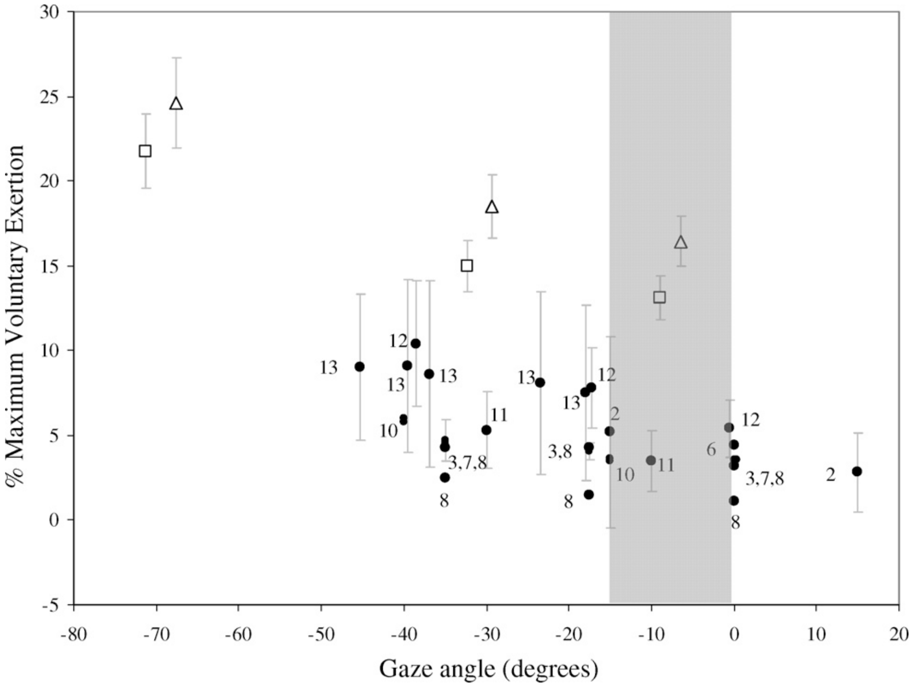

Fig. 1. Cervical erector spinae muscle activity (% maximum voluntary exertion) relative to gaze angle (eye to display with respect to horizontal) reported in nine studies. (Data from current study shown in open squares (straight desk) and open triangles (curved desk). 'Neutral' zone shown in grey. Numbers correspond to references in Table 1.)

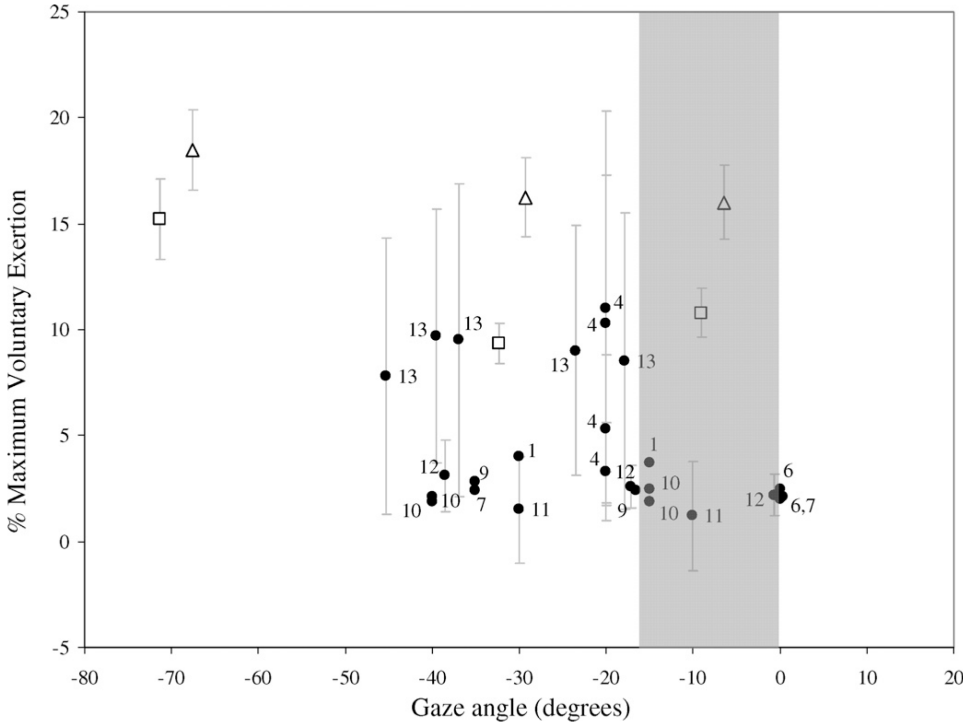

Fig. 2. Upper trapezius muscle activity (% maximum voluntary exertion) relative to gaze angle (eye to display with respect to horizontal) reported in eight studies. (Data from current study shown in open squares (straight desk) and open triangles (curved desk). 'Neutral' zone shown in grey. Numbers correspond to references in Table 1.)

possible, the cervical erector spinae and upper trapezius data from papers not reported as %MVE by gaze angle (Saito et al., 1997; Bauer and Wittig, 1998; Babski-Reeves et al., 2005) were modified using a ratio of the reported RVE to averaged MVE data at a similar gaze angle from other papers (Villanueva et al., 1997, 1998; Turville et al., 1998; Laursen and Jensen, 2000; Sommerich et al., 2001) in order to consistently compare relative results across studies.

From Fig. 1, it can be seen that when the visual target is below eye height (negative gaze angles), there is a reasonably consistent relationship with cervical erector spinae (CES semispinalis capitus and splenius capitus) activity increasing with lower gaze angle. There is little data on CES activity for positive gaze angles (ultra-high displays) and large negative gaze angles (very low displays). In contrast, upper trapezius (UT) activity remains fairly constant across moderate gaze angles. Again, however, the available UT data are limited in the low range of display heights, making a comparison with reading from a display on the desk level worthwhile. To aid comparison with postures readers may observe, a 'neutral' zone corre-

Table 2
Summary of studies investigating effect of forearm support on muscle activity

Reference	Workstation scenario	Support type	Reported data
Aaras et al. (1998)	$n = 20$ (workers), lab, keyboard, mouse. Seat height unspecified. Desk height unspecified	Forearm support provided by desk	L/R TRAP, L/R LES
Bendix and Jessen (1986)	$n = 12$ (secretaries), lab, typing. Seat height 52 cm (45.5–55.5). Desk height (interspace bar) 78.8 cm	No wrist support provided; wrist support 1 cm below interspace bar, wrist support 0.5 cm above interspace bar, wrist support and typewriter elevated 3 cm with support 0.5 cm above interspace bar	L/R TRAP, L/R WE
Cook et al. (2004a)	$n = 13$ (workers), lab, keyboard. Seat height unspecified. Desk height dependent on condition	Forearm support – provided by desk (elbow at 90°)Wrist support – adjustable wrist rest (Rubbermaid 6800) No support	L/R TRAP*, L/R DELT†, L/R EDC‡, L/R ECU‡
Cook et al. (2004b)	$n = 15$ (workers), lab, keyboard, mouse. Seat height for feet flat on floor. Desk height so forearms supported with no shoulder elevation/depression	Forearm support – provided by desk (elbow at 90°)Wrist support 20 mm high	L/R TRAP*, L/R DELT†
Erdelyi et al. (1988)	$n = 20$ (workers, 12 pain), lab, keyboard. Seat and desk height set to recommendations by Cakir et al. (1980)	No forearm support with forearms horizontal; horizontal forearm support, fixated to desk; horizontal forearm support, fixated to ceiling	R TRAP¶
Feng et al. (1997)	$n = 12$ (unspecified), lab, keyboard. Seat height for thigh horizontal, Desk height set to elbow height	No support; fixed arm support; spring-loaded arm support; horizontal moveable arm support	R TRAP§, R DELT§, R DELT LAT§, ECR‖
Lintula et al. (2001)	$n = 21$ (office workers), field (six week intervention), keyboard, mouse. Seat and desk height unspecified	No support; (1) Ergorest support with mouse pad for preferred hand; (2) Ergorest supports – with mouse pad for preferred hand, basic arm support for non-preferred hand	L/R TRAP. L/R EDC
Moffet et al. (2002)	$n = 8$ (non-experienced laptop users), lab, keyboard. Seat height 46 cm, backrest 100°, Desk height 73 cm. Laptop used on desk or lap	Laptop 1: built in palm rest with keyboard positioned close to screen; laptop 2: no palm rest with keyboard positioned close to front of base	R CES¶, R TRAP¶, DELT¶, WE¶
Tepper et al. (2003)	$n = 38$ (19 healthy, 19 whiplash), lab, keyboard. Seat height for hip and knee at 90°. Desk height set for eye level at 10 cm below upper border of monitor	Forearm and wrist support provided by 'Up-line' tilted 18° from horizontal. Forearm support provided by standard workstation	L/R TRAP#
Visser et al. (2000)	$n = 10$ (workers), lab, keyboard, mouse. Seat and desk height unspecified	No support; two arm supports (ERGOarm, ERGOrest); two wrist supports (TOPtec, TC100/210)	R TRAP|

Notes:
L – left
R – right
DELT – deltoid (assumed anterior)
DELT LAT – lateral deltoid
LES – lumbar erector spinae
TRAP – trapezius
EDC – extensor digitorum communis
ECU – extensor carpi ulnaris
ECR – extensor carpi radialis
WE – wrist extensors
EMG normalisation details:
Note: EMG normalised to MVC unless otherwise stated.
*Normalised to standard isometric contraction holding 1 kg load, arms held at 90° abduction in coronal plane, elbows straight, forearm pronated.
†Normalised to standard isometric contraction holding 1 kg load, arms held at 90° flexion, elbows straight.
‡Normalised to standard isometric contraction holding 1 kg load, wrists held in full extension.
¶No normalisation.
§Normalised to standard reference posture seated with hip, knee and elbow at 90° flexion.
‖Normalised to standard reference posture standing with arm in semi-pronated position, performing an isometric contraction against a vertical surface.
#Normalised to standard isometric contraction while holding arms in position of 90° abduction.
|Normalised to standard isometric contraction holding 2 kg load, position unspecified.

sponding to gaze angles between zero and negative 15° is shown.

1.2. Forearm support and muscle activity

We found 10 studies reported in peer reviewed journals which investigated the effect of forearm support on muscle activity. Table 2 provides a summary of the studies including the workstation details, the type of support provided and the muscle activity variables reported. Aaras et al. (1998) and Visser et al. (2000) report decreased UT activity with the provision of forearm support. However, Cook et al. (2004a,b), Erdelyi et al. (1988) and Tepper et al. (2003) found no difference in UT activity with forearm support. Differences in the nature of the supports and the nature of the tasks performed may have contributed to the differing results. To determine whether a curved desk can provide support, which reduces UT load, further research is required.

1.3. Interaction effects of display height and forearm support on muscle activity

Whilst Babski-Reeves et al. (2005) assessed the interaction of display height and chair design, only Aaras et al. (1997) has reported muscle activity data from both display height and forearm support conditions. Although no interaction effects were tested statistically, the figures in their report suggest the reduction in UT activity with

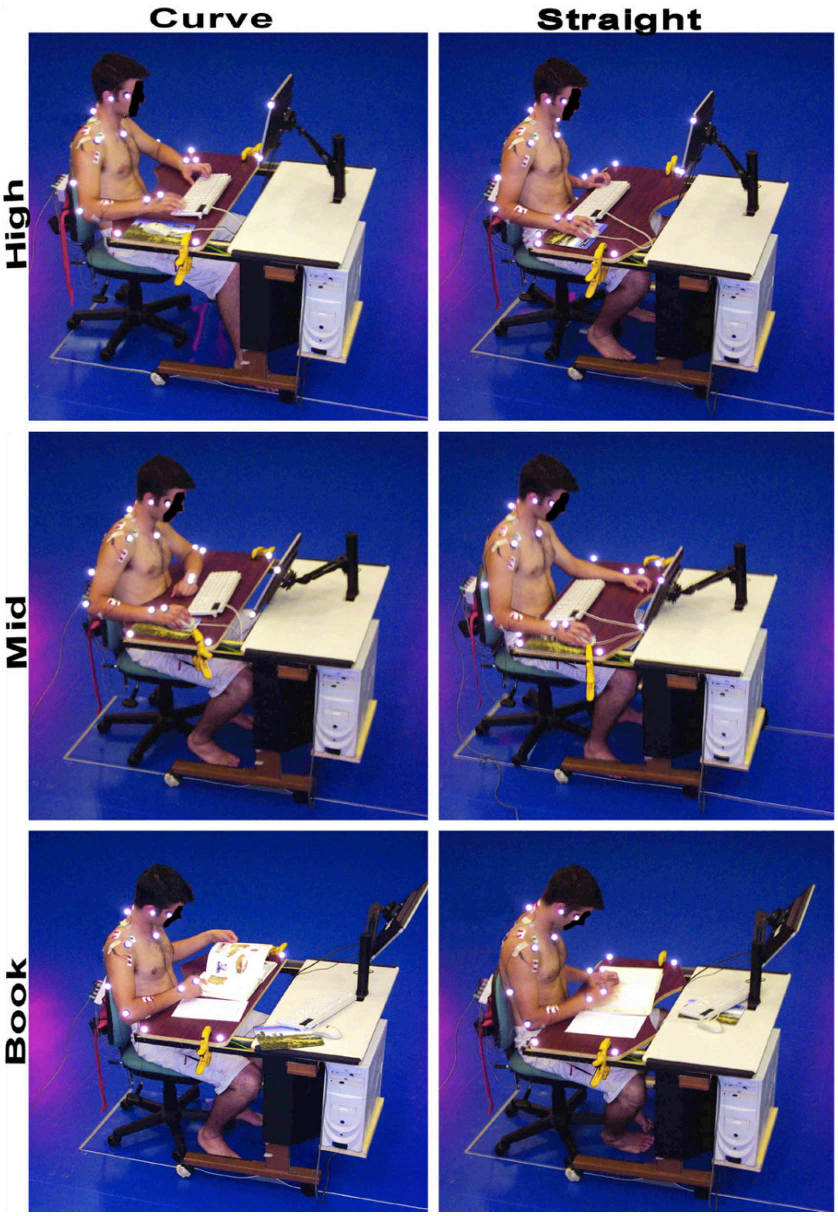

Fig. 3. Photographs of a subject working in the six study conditions – *curve* and *straight* desk and *high*, *mid* computer displays and *book*.

forearm support may be moderated by the display height.

In summary, the available evidence for the effect of display height on upper body muscle activity lacks a comparison with paper based tasks. Similarly, the evidence for the effect of forearm support on muscle activity is inconclusive. Finally, there is no clear evidence on whether display height and desk design features interact. This evidence would help inform workstation design guidelines designed to minimise musculoskeletal disorders associated with information technology tasks. The aim of this study was to assess the independent and interactive effects of display height and forearm support on neck and upper limb muscle activity during work with paper and computer. The results of this study provide complementary evidence to the posture data collected during the study and reported in a companion paper (Straker et al., 2008).

2. Methods

2.1. Study design

The study used a 2×3 within subjects design (see Fig. 3). The first factor, display, had three levels: (1) *high* – top of electronic display set at participant's eye height, (2) *mid* – bottom of electronic display set at desk height, (3) *book* – paper on desk. The second factor, desk, had two levels: (1) 'traditional' *straight* desk set at 3 cm below participant's elbow height with 0° shoulder flexion and forearms unsupported, and (2) 'horseshoe' partly wrapped around *curved* desk set at 3 cm above elbow height enabling full forearm support.

2.2. Participants

Thirty-six participants (18 male) were recruited by notices in local universities and community newspapers and personal contacts. Participants had a mean age of 20.6 (SD 2.1) years with no history of significant chronic musculoskeletal disorder in the neck and upper limb, no current neck and/or upper limb pain and no diagnosed rheumatic or acute or chronic musculoskeletal condition. The mean heights of participants were 164.8 cm (SD 5.6 cm) for females and 179.5 cm (SD 6.9 cm) for males. All participants were using computers at least two times per week for a total of at least 2 h per week, and were right-side dominant for the required tasks.

2.3. Variables

sEMG was collected from bilateral CES, bilateral UT, bilateral thoracic erector spinae/scapula retractors (TES), right anterior deltoid (RAD) and right wrist extensor bundle (RWE). The electrode sites (see Table 3) were prepared by shaving, lightly abrading and cleaning with surgical spirits, before pairs of 12 mm diameter Ag–AgCl disposable surface electrodes (Uni-Patch, Wasbasha, MN, USA) were placed 25 mm centre-to-centre distance. Impedances were checked after electrode attachment and only values of <5 kΩ were deemed acceptable.

Participants performed three MVEs in a custom-made dynamometer. The dynamometer consisted of a wooden frame and a detachable leather cuff (Lafayette Instruments Co., Lafayette, IN, USA) or plastic handle attached to a 50 kgf strain gauge (Bongsing Co., Korea) via an inextensible wire cable. The strain gauge and sEMG were connected to a desktop PC via an A/D board (National Instruments, Austin, TX, USA) allowing the participant biofeedback as they elicited each maximal exertion. The tester gave further, verbal encouragement. sEMG and peak strain readings were recorded for the three contractions and an average of the final two contractions used for normalisation.

Raw sEMG signals were collected via an eight channel AMT-8 EMG cable telemetry system (Bortec Biomedical, Alberta, Canada) with analogue differential amplifiers (frequency response: 10–1000 Hz, common mode rejection ratio: 115 dB). As most of the sEMG signal power was below 500 Hz, data were sampled at 1000 Hz for 120 s in the 2nd and 3rd, 5th and 6th and 9th and 10th minutes, using customised data acquisition software (LabVIEW, National Instruments, Austin, TX, USA). Data were compared over the different epochs, and as no differences were observed, the mean root mean square (RMS) value over the final 2 min of each trial was normalised to the MVE for each muscle.

Motion data were collected in synchrony with sEMG using a seven camera Peak Motus® 3D Optical Capture System (Peak Performance Technologies Inc., Centennial, CO, USA) via a 32 channel A/D interface (Data Translations 3010, Data Translation Inc., Marlboro, MA, USA). Data acquisition was controlled by the Peak Motus® 8 (Peak Performance Technologies Inc., Centennial, CO, USA) software. The method for acquiring kinematic data have been reported in a companion paper (Straker et al.,

Table 3
Description of electrode placements and MVE protocol used

Electrode placement	Description	MVE protocol
Right and left cervical erector spinae	The midpoint between external occipital protruberance and C7. Electrodes placed lateral to the cervical spinal processes on the erector spinae muscle bulk	Head extension against a leather cuff placed around the head over external occipital protruberance and glabella. Participants were seated
Right and left upper trapezius	Just lateral to the midpoint between C7 spinous process and acromion	Scapula elevation with straight arms holding a handle. Participants were standing
Right and left thoracic scapular retractors	Midpoint between T3 and the inferior angle of the scapular. Electrodes were placed along line between landmarks	Scapula retraction against a handle. Participants supported contralateral knee and hand on a chair to have trunk horizontal during vertical pull by scapula
Right anterior deltoid	The midpoint of the fibres of anterior deltoid between the anterior acromion and deltoid insertion	Upper arm flexion against a leather cuff around the distal arm. Participants were seated with the elbow flexed at 90°, trying to punch forward with the arm
Right wrist extensors	1/3 distance between the right lateral humeral epicondyle and radial styloid process. Active wrist extension was encouraged to palpate the muscle bulk before placement	Wrist extension vertically holding handle. Participants were seated with forearm supported on a height adjustable table
Common ground	Mid clavicle	N/A

2008). For the purposes of this study, gaze angle was calculated from the midpoint between markers at the bilateral outer canthi, and the centre of the display, and is reported relative to the sagittal plane with respect to horizontal.

Variability of movement and muscle activity, as well as performance and the psychological experience of flow (Arrowsmith and Pollock, 2001; Webster et al., 1993), were also measured and will be reported separately.

2.4. Procedure

The study was conducted in a climate and lighting controlled motion analysis laboratory. A standard office chair (Burgtec, Perth Western Australia) was adjusted to the participant's popliteal height. A specially designed desk was adjusted to height and shape (straight/horseshoe). An adjustable height display arm (Swing Arm Single, Atdec Pty Ltd. Padstow, New South Wales) was used to adjust the 15″ LCD display (model LM520, AOC, Fremont, CA, USA) so the top of the display was set level at participant eye height, bottom of display at desk height, or turned away from the participant during paper conditions. The same keyboard (model KM-2601, TurboStar, China) and mouse (Optical Wheel Mouse, Microsoft, Redmond, WA, USA) were used in all computer conditions. Six equivalent general knowledge reading and activity sheets were developed and for each participant the six topics were randomly assigned to the six conditions.

Following electrode placement, participants performed MVEs for each muscle using the specially designed rig. Participants then moved to the study workstation and performed the interactive task involving reading and writing on paper or reading from computer display and keyboard and mouse data entry for 10 min. After each task participants moved away from the desk area and reported discomfort and flow. After a 5 min break the participant returned to the now modified workstation and worked in the next condition for 10 min. The study was approved by the Human Research Ethics Committee of Curtin University.

3. Results

Table 4 shows the muscle activities in the different study conditions. Univariate RANOVA with post hoc contrasts were calculated for each dependent variable using a critical alpha level of 0.01 to balance family-wise error and power (Table 5). Huynh–Feldt epsilon corrections were used if Mauchly's test indicated lack of sphericity. Covariate analysis using *gender* had no effect on the pattern of results and so unadjusted results are given. Significant main effects of *display* and *desk* were found on neck and upper limb muscle activities.

Compared with the mid display, the *high* display resulted in 2% less right and left CES activity whilst UT activity was the same. There was no difference in scapula retractor, right anterior deltoid or right wrist extensor activity between *high* and *mid* displays.

Compared with the *mid* display, the *book* display resulted in 5–7% more CES activity, 3–5% more UT activity, 2–3% more TES activity, 1% more RAD activity and 1% more RWE activity.

The *curved* desk resulted in CES muscle activity increasing by 4% (right) to 2% (left). Similarly, UT activity was increased whilst using the *curved* desk by 7% (right) and 4% (left). There was no difference in scapula retractor or right anterior deltoid activity and minimal increase in right wrist extensor activity between desks.

Display × *desk* interactions were not significant except for a trend for right UT to be less different between display heights with the *curved* desk.

4. Discussion

These data are the first description of adult head and arm muscle activity during computer and paper IT (information technology) use in the same study, enabling comparison without assumptions related to sEMG technique differences. Our study included data input by keying and mouse use in addition to writing with a pen. The study also included reading from an electronic screen (involving

Table 5
Summary of RANOVA results for neck and upper limb muscle activity variables

	Display		Desk		Display × desk	
	F_{df}	p	F_{df}	p	F_{df}	p
Right CES	$33.1_{2,66}$	**<0.001**	$34.8_{1,33}$	**<0.001**	$0.2_{2,66}$	0.853
Left CES	$41.7_{2,62}$	**<0.001**	$13.2_{1,31}$	**0.001**	$0.3_{2,62}$	0.767
Right UT	$2.0_{2,68}$	0.143	$31.3_{1,34}$	**<0.001**	$3.1_{2,68}$	0.050
Left UT	$13.5_{2,70}$	**<0.001**	$13.4_{1,35}$	**0.001**	$1.3_{2,70}$	0.270
Right TES	$21.5_{2,70}$	**<0.001**	$0.0_{1,35}$	0.894	$0.4_{2,70}$	0.616
Left TES	$24.8_{2,70}$	**<0.001**	$11.2_{1,35}$	0.065	$0.4_{2,70}$	0.645
Right AD	$6.5_{2,70}$	**0.007**	$2.1_{1,35}$	0.157	$0.2_{2,70}$	0.804
Right WE	$4.0_{2,70}$	0.043	$4.5_{1,35}$	0.042	$2.2_{2,70}$	0.117

Table 4
Mean (standard error) muscle activity (%MVE) in six display and desk conditions

	High display		*Mid* display		*Book* display	
	Curved	Straight	Curved	Straight	Curved	Straight
Right CES	18.1 (1.6)	13.4 (1.3)	20.1 (2.0)	15.4 (1.5)	25.4 (2.7)	21.4 (2.0)
Left CES	14.8 (1.4)	12.8 (1.3)	16.9 (1.8)	14.6 (1.5)	23.8 (2.6)	22.1 (2.4)
Right UT	18.7 (1.9)	10.9 (1.0)	18.7 (1.8)	10.4 (1.1)	18.6 (1.9)	15.1 (1.7)
Left UT	13.3 (1.6)	10.7 (1.3)	13.8 (1.9)	8.3 (0.8)	18.4 (1.9)	15.3 (2.1)
Right TES	3.8 (0.6)	4.0 (0.6)	4.2 (0.7)	4.0 (0.6)	6.0 (0.8)	6.1 (0.8)
Left TES	3.9 (0.5)	4.6 (0.6)	4.2 (0.5)	4.6 (0.6)	6.6 (0.8)	6.8 (0.7)
Right AD	2.5 (0.3)	2.3 (0.3)	2.6 (0.3)	2.5 (0.3)	3.0 (0.4)	2.8 (0.3)
Right WE	8.0 (0.8)	7.6 (0.7)	7.7 (0.6)	7.5 (0.7)	9.9 (1.1)	8.3 (1.0)
Gaze angle	−6.5 (0.5)	−9.0 (0.4)	−29.3 (0.7)	−32.3 (0.5)	−67.6 (0.9)	−71.3 (1.1)

mouse use for navigation) and from a book (involving page turning). The results therefore apply to the common office work situation involving both computer and paper IT work. In comparison with other display height studies our sEMG data follow the same trend for increasing CES activity with lower gaze angles and no change in UT activity across different gaze angles. Sommerich et al. (2000) also noted the differential effects on CES and UT. The inclusion of working with books/paper on the desk in the current study extends the evidence to lower gaze angles and suggests no change in the relationships seen over mid to high display heights.

However, means in our data are substantially greater than most prior reports. We believe these differences are likely to be due to differences in amplitude normalisation. As indicated in Table 1, some studies conducted no amplitude normalisation (Saito et al., 1997), some normalised to a reference position (Bauer and Wittig, 1998), and some normalised to a submaximal exertion (Babski-Reeves et al., 2005; Kleine et al., 1999; Straker and Mekhora, 2000; Visser et al., 2000). Some studies conducted normalisation procedures in a functional seated position, whilst others used a supine or prone position (Straker and Mekhora, 2000). Of the studies which normalised to MVE some used manual resistance (Karlqvist et al., 1999; Sommerich et al., 2001; Villanueva et al., 1997, 1998) and others a dynamometer (Aaras et al., 1997; Turville et al., 1998).

Given the variation in past procedures we chose a protocol aimed at a high level of consistency. The protocol involved taking the mean of the best two of three trials where each trial consisted of a one second ramp up, 3 s hold of maximum exertion and one second ramp down. The ramped activity was supported with visual feedback to the participant and verbal encouragement and instruction. The mean RMS over the highest one second period was taken as the MVE value for each trial. This protocol, whilst providing good reliability, would provide a lower MVE value than other protocols using a peak rectified sEMG value. The effect of a lower magnitude MVE value is to increase the task amplitudes. Therefore, our higher task amplitudes may be due to the conservative MVE protocol. The consistency in amplitude in prior research is exaggerated in Figs. 1 and 2 as we needed to use group mean data to provide a comparison reference point for all the studies which did not use MVE normalisation. Gathering data from different studies using different protocols (eg inter-electrode distance) is problematic. We would not claim that the amplitudes in Figs. 1 and 2 are accurate. However, we believe the figures are useful in showing relative amplitudes and the overall trends in the available evidence.

In our study, the *high* display condition resulted in surprisingly small reductions in CES (−2%) muscle activity from the *mid* display condition despite substantial reductions in head (15°) and neck (6°) flexion and gaze angle (23°) (Straker et al., 2008). Fig. 1 shows that prior research has found a similar small reduction. As we have argued, whilst less head flexion has been recommended from simple moment modelling, the load on muscles may be increased with upper cervical extension. Cranio-cervical angle (upper cervical intersegmental angle) increased by 7° in the *high* display as a result of a greater reduction in head flexion than in neck flexion. Simple modelling of anti-gravity moment suggests CES activity should be more substantially reduced in the *high* display condition (e.g. Harms-Ringdahl et al., 1986; Snijders et al., 1990; Svensson and Svensson, 2001). In the current study, sEMG has been used to provide estimates of superficial muscle loading, but deep tissue loads are yet to be estimated and these may help explain the failure of simple anti-gravity modelling to account for observed CES sEMG changes. Together with the UT results (no difference to 2% more with high display) these results suggest a high display probably provides no significant advantage to CES and UT.

The *book display* resulted in a more substantial effect on CES as predicted by a simple anti-gravity model given the increase in head and neck flexion. However, the increased CES activity may have been due to increased stabilisation requirements associated with the increased head and neck asymmetry observed during book/paper use and/or it may have been due to more movement of the neck (and arms) during use of a book/paper. Other studies (Greig et al., 2005) have found a non-linear increase in CES with moderately marked head/neck flexion when reading from a *book*. Interestingly, the reduction in CES activity reported at extreme flexion by Harms-Ringdahl et al. (1986) was not observed, suggesting participants were not working at end of range and substantially loading passive connective tissue.

Although left UT was consistently higher during *book* use than *mid* display computer use, right was only higher in the *straight* desk condition. This suggests the increased stabilisation required for handling book/pen was not greater than the increased stabilisation used with greater scapula elevation and shoulder abduction when working with a computer at the *curved* desk. Bendix and Hagberg (1984) had earlier found median UT activity increased with a desk inclined at 22° compared with a flat desk when writing, but not with just reading. This complements our data showing the importance of task rather than display height for UT activity.

The book display also resulted in small increases in scapula retractor, right anterior deltoid and right wrist extensor activity. Assuming a higher load represents higher risk would suggest using paper presents a higher risk. However, paper based tasks may also encourage more variation in posture and muscle activity. Therefore, the higher loads observed may have been due to more dynamic and variable muscle loading which could indicate lower risk. Evaluation of muscle activity variation should therefore be conducted.

The *curved* desk resulted in a moderate increase in CES activity. The *curved* desk had resulted in a small (2°) decrease in head flexion (Straker et al., 2008), which would usually be expected to be accompanied by a decrease in CES activity as gross flexion moment would be slightly reduced. However, the small decrease in head flexion resulted in an increase in upper cervical extension (as the neck posture was unchanged), which may have created an increased CES load. The increase in UT activity with the curved desk was logically associated with an increase in scapula elevation (4–7°) and shoulder abduction (12–17°).

It was anticipated that the increased forearm support provided by the *curved* desk would result in reduced CES/UT activity as per Aaras et al. (1998). The current results suggest that providing a *curved* desk does not necessarily provide more support and in fact can lead to increased activity. The desk may have influenced the type of arm support participants chose to use. The previous descriptions of the effect of forearm support and wrist only support have had inconsistent results. Tepper et al. (2003) found a trend for a small increase in UT activity when pain free and neck pain participants worked with elevated full forearm support compared with a floating position. Similarly, Visser et al. (2000) found an increase in UT activity with wrist support, and no real effect of chair arm support. In contrast Cook et al. (2004a) found a reduction in UT and anterior deltoid activity with forearm support provided by a straight desk (as well as with wrist support provided by a wrist rest) compared to a free floating arm position during keying. However, their other study (Cook et al., 2004b) found no differences between free floating and wrist rest conditions for both keying and mouse use tasks. One possible reason for the conflicting results could be the extent to which participants actually used the support provided and the nature of the support they gained (full forearm support or only wrist support). The different desk designs in the current study differentially encouraged different types of support. Regardless of desk type, participants were able to gain full forearm support for 60% of the time, and some form of support for 82% of the time (data from post hoc analysis of digital video of participants performing in each condition). Full forearm support was achieved 84% of the time using the curved desk but only 36% of the time with the straight desk. However, participants used wrist support for 42% of the time with the straight desk. The *curved* desk condition was also novel to participants and the elevated scapula, abducted arm and increased CES and UT activity may have been due to participants not being settled in the new set up. Monitoring posture and muscle activity over a number of weeks would be required to determine if the effect observed in this study was only transient. The randomised and controlled trial in call centres by Rempel et al. (2006) provides the best evidence on the efficacy of forearm support to reduce neck/shoulder musculoskeletal disorders. They reported a 50% reduction in diagnosed neck/shoulder incidents over 12 months when using a forearm support, though no change in the risk for right upper limb disorders was found.

As indicated in the companion paper (Straker et al., 2008), there was concern that the curved desk could result in weakening of the scapula retractors due to increased protraction. The lack of difference in sEMG activity together with the very small postural change (2–3°) suggest this concern may not be a problem.

The limitations of this study include those highlighted in the companion posture paper (Straker et al., 2008) – young people, short time periods, typing skill differences, display technology differences and sub-task differences. The limitation of unaccustomed use of a *curved* desk and the need for longer field trials to determine long term benefit or cost is also acknowledged. Finally, the muscle activity assessed in this paper was only surface EMG and then only some extensor muscles. More information on deeper structure stresses could be usefully gained from biomechanical modelling. As previously indicated this paper only reported mean muscle activity. There is some concern that forearm support may inhibit movement and increase muscle activity monotony so this should be investigated.

5. Conclusion

Display and desk design features are critical to the minimisation of musculoskeletal risk as they clearly affect neck and upper limb muscle activities. The study results showed that the expected potential benefits of reduced CES and UT activity associated with less head and neck flexion with a *high* display were not realised. There was no muscle activity advantage to a *high* display. The increased head and neck flexion and asymmetry recorded during book use did result in increased CES and UT activity further supporting an increased risk of musculoskeletal disorder when working with paper. The study results also suggest that a higher *curved* desk resulted in higher CES and UT activity associated with scapula elevation and shoulder abduction. Thus the intended potential benefit of supporting the forearms with a higher *curved* desk also did not occur. Whilst sEMG assisted in the interpretation of risk related to postural responses to display and desk designs, information on deeper cervical structures and movement variation is needed prior to determining a recommended display position.

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