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The impact of computer display height and desk design on 3D posture during information technology work by young adults

L. Straker [a,*], R. Burgess-Limerick [b], C. Pollock [c], K. Murray [d], K. Netto [a,e], J. Coleman [a], R. Skoss [a]

[a] School of Physiotherapy, Curtin University of Technology, Perth 6845, Australia
[b] School of Human Movement Studies, University of Queensland, Brisbane 4072, Australia
[c] School of Psychology, Curtin University of Technology, Perth 6845, Australia
[d] Rheumatology Department, Princess, Margaret Hospital, Perth 6005, Australia
[e] School of Science and Primary Industries, Charles Darwin University, Darwin 0810, Australia

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Abstract

Computer display height and desk design to allow forearm support are two critical design features of workstations for information technology tasks. However there is currently no 3D description of head and neck posture with different computer display heights and no direct comparison to paper based information technology tasks. There is also inconsistent evidence on the effect of forearm support on posture and no evidence on whether these features interact. This study compared the 3D head, neck and upper limb postures of 18 male and 18 female young adults whilst working with different display and desk design conditions. There was no substantial interaction between display height and desk design. Lower display heights increased head and neck flexion with more spinal asymmetry when working with paper. The curved desk, designed to provide forearm support, increased scapula elevation/protraction and shoulder flexion/abduction.
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1. Introduction

The majority of people in affluent countries now use computers. For example, recent figures showed that 66% of Australian adults and 55% of European Union adults used a computer (Australian Bureau of Statistics, 2000b; Demunter, 2005). Computer use is growing rapidly, for example in the USA 18% of adults used a computer in 1984 compared with 36% in 1993 and 64% in 2003 (Cheeseman-Day et al., 2005). Computers are being used for work tasks but also for activities of daily living including social communication and entertainment. Computer use is now as common at home as at work with 47% of Australian adults using a computer at home and 42% at work in 2000 (Australian Bureau of Statistics, 2000b). Nearly half of all households in affluent countries now have a computer at home (e.g. 47% in Japan in 2004) (Statistics Bureau of Japan, 2005). The prevalence of computer use is related to education level, urbanisation, level of income and sex. Age has a particularly strong effect on computer use, with senior school children having the highest prevalence and use declining with age thereafter (Australian Bureau of Statistics, 2000a,b; Cheeseman-Day et al., 2005; Demunter, 2005).

Following the introduction of microcomputers in the early 1970s there has been concern over the prevalence of musculoskeletal disorders related to computer use. Recent epidemiological studies have found annual musculoskeletal symptom prevalence rates of 76% across a range of

* Corresponding author.
E-mail address: L.Straker@curtin.edu.au (L. Straker).

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industries (Cook et al., 2000) and as high as 86% in intensive data processing workers (Woods, 2005). Whilst the evidence for a causal relationship between computer use and musculoskeletal disorders is inconclusive, there is evidence of a dose response relationship (Marcus et al., 2002). The neck/shoulder region is often the most common location of discomfort with Karlqvist et al. (2002) reporting a neck/shoulder monthly discomfort prevalence of 45% compared with 32% for back and 30% for forearm/hands. With more than two thirds of young adults now using computers, compared with less than one third of people aged over 55 years, young adults are a group at particular risk of computer related musculoskeletal disorders (Australian Bureau of Statistics, 2000b; Demunter, 2005).

Physical and psychosocial, personal and environmental factors have been identified as possible risk factors (Buckle et al., 1999), with workstation design factors such as display height and arm support thought to be important. Posture is an important component of the physical impact of computer use (e.g. Burgess-Limerick et al., 1999; Straker et al., 2000) and is widely used to estimate musculoskeletal stress with evidence that postures away from the vertical result in greater gross moments (e.g. Chaffin, 1973) and that postures nearer the end of available range result in increased tissue stresses (e.g. Dolan et al., 1994). These 'poorer' postures have been associated with musculoskeletal disorder development in epidemiological, human laboratory and animal model studies (Buckle et al., 1999; National Research Council, 1999). This paper reviews available evidence for display height and arm support effects on posture and presents new data on the three dimensional posture effects of these workstation design factors. The focus of this paper is information technology tasks, using either computers or paper.

1.1. Visual display height and posture

Visual display height has an important, though controversial, effect on posture. In early epidemiological studies Hunting et al. (1981) and Starr et al. (1985) found musculoskeletal symptoms tended to increase with lower displays whereas more recently Marcus et al. (2002) found the opposite. We have identified 24 studies (four field, 20 laboratory) reporting the effect of display height on posture in peer reviewed journals. Table 1 provides a summary of the testing scenarios for these studies, including the participants, site of research, input devices used, seat adjustments and desk details. The table also summarises display type (cathode ray tube [CRT] or liquid crystal/thin film transistor [LCD]), size (screen diagonal), angle from eyes (or height if angle not specified), tilt and distance from eyes and the posture variables reported.

One of the major difficulties in summarising the available evidence on the effect of display height on posture is the range of posture measures used. To enable a comparison and encourage more standardised reporting of postures in the future, we developed a taxonomy of the posture measures used (Table 2). We believe reporting angles for each segment with respect to a vertical or horizontal axis (see head flexion in Fig. 1) is essential as this provides information on the effect of gravity and can be used to calculate intersegmental angles. Intersegmental angles (see cranio–cervical angle in Fig. 1) provide information about stresses related to joint range, but can not be used to derive segment angles with respect to gravity. Some studies used angles with respect to a reference posture which provides information on postural deviations away from a 'usual' posture, however without a description of the reference posture these data are of limited use. Another issue with reported postural measures is the variation in the marker set used to define the postural angles.

The postures reported in these studies show considerable variability but an overall relatively linear increase in head and neck flexion (relative to the vertical) as the visual target moves lower than eye height (negative gaze angles relative to the horizontal) as shown in Figs. 2 and 3. Interestingly, as the visual target moves above eye height (positive gaze angles), head flexion decreases on the same linear relationship, but neck flexion appears to change less rapidly. Fig. 4 shows the curvilinear relationship between gaze angle and cranio–cervical angle (intersegmental angle between head and neck, derived from the head and neck angles). The quadratic trend line ($y = 0.004x^2 + 0.460x + 155.2$) more closely matched the data ($r^2 = .70$; $p < .001$) than a linear trend line ($y - 0.296x + 156.2$; $r^2 = .58$;$p < .001$). To aid comparison with real world postures a 'neutral' zone corresponding to gaze angles between 0° and −15° is shown.

Despite the substantial number of studies, most only reported head and neck posture in the sagittal plane and there are no reports of 3D head and neck postures. Further, whilst there are some early reports of head/neck posture during work with paper technology (Bridger, 1988; Freudenthal et al., 1991), no single adult study has evaluated the postural effects of both computer and paper information technology tasks. Therefore there is no adequate comparison of the postural risks of computer and paper information technology.

1.2. Forearm support and posture

In a prospective epidemiological study Marcus et al. (2002) found arm support to be associated with a lower risk of neck/shoulder symptoms and disorders, as Hunting et al. (1981) and Bergqvist et al. (1995) had found previously in cross sectional studies. However there are very few reports of the effect of arm support on actual postures. Table 3 provides a summary of the testing scenarios for the six studies we found reporting a posture effect from forearm support. Various types of wrist or forearm support have been evaluated including support built into a laptop, desk based support and chair or ceiling based support. Lintula et al. (2001) conducted a six week intervention study, whilst the rest of the studies were short term laboratory

Table 1
Summary of studies ($N = 24$) investigating effect of visual display height on posture (see Table 2 for definitions of reported data variables)

Reference	Workstation scenario	Visual display	Reported data[b]
1. Aaras et al. (1997)	$n = 20$ (VDU operators), lab, keyboard, mouse. Seat height unspecified. Desk provided forearm support, height unspecified	Unspecified	HLB-i, HF-i, TF-f, TF-s, SF, SA
2. 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	Display unspecified; GA-h at 0°, −17.5°, −35°; distance 74, 82, 105 cm; tilt perpendicular to GA-h	HF-h3, HNR
3. Burgess-Limerick et al. (1998)	$n = 12$ (students), lab, mouse. Seat height unspecified. Desk height 69 cm	33 cm display; (1) GA-h at 0°, −15°, −30°; distance unspecified; tilt perpendicular to GA-h; (2) height self-selected (60–130 cm); tilt self-selected (0–40°)	CCA, CTA2, HF-h, GA-eel
4. Burgess-Limerick et al. (1999)	$n = 12$ (staff/students), lab, typing. Self-selected: seat height (43–57 cm), back rest inclination, desk height (65–76 cm)	35.6 cm display: (1) Height[a] ~100 cm; distance 58 cm; tilt 0°; (2) height[a] 88 cm; distance 70 cm; tilt 30°	CTA2, CCA, HF-h
5. Mon-Williams et al. (1999)	$n = 12$ (office workers and students), lab, viewing; chair height and backrest inclination self-selected	7.1 cm display; GA-h at +30°, +15°, 0°, −15°, −30°, −45°, 60°; distance 65 cm	HF-h, CCA, CTA2, TF-c7gt
6. Burgess-Limerick et al. (2000)	$n = 12$ (students), lab, viewing. Seat unspecified except backrest inclination for TF-h of 100° and 110°	7.1 cm display; GA-h at +30°, +15°, 0°, −15°, −30°, −45°, 60°; distance 65 cm	CCA, GA-eel, CTA2, TF-c7gt
7. Delleman and Berndsen (2002)	$n = 8$ (typists), lab, keyboard. Seat height ‘comfortable’, backrest inclination at 0°, −15°. Keyboard height at sitting elbow height	Display unspecified; height (with respect to eye height) +5, −10, −25, −40 cm (eye height not reported)	GA-h, HF-ref, TF-ref, HF-change
8. De Wall et al. (1992)	$n = 10$ (CAD/CAM workers), field, CAD mouse; chair height 47 cm, desk height 80 cm	Display unspecified; GA-h at +15° and −15°; distance unspecified	HLB-i, HF-i, TF-i, TLB-i
9. Grandjean et al. (1984, 1983)	$n = 68$ (VDU operators), field, keyboard; chair height and backrest inclination self-selected	Display unspecified; height (103 ± 4.6cm); distance to desk edge (66 ± 7.9 cm); tilt (5 ± 3.9°) self selected	NF-v, TF-acgt, SF, SA, EA, RUD
10. Karlqvist et al. (1999)	$n = 20$ (VDU operators), lab, mouse/trackball. Seat (45–75 cm) and desk height (70–76 cm) self-selected.	Display unspecified; distance to desk edge 50 cm	NF-ref, SF, SR, SA, EA, WF, RUD
11. Kietrys et al. (1998)	$n = 27$ (workers, >3 h/day VDT use), lab, keyboard. Self-selected seat height (41.9–52.1 cm), desk height 73.7 cm	33 cm display; height 96.5, 109.2 cm; distance unspecified; tilt self-selected 9.6° (±2.8), 3.6° (±2.6)	GA-eel-top, TF-T1SN, NA-h, CTA23, CCA2
12. Kleine et al. (1999)	$n = 9$ (office workers), lab, keyboard. Seat height self-selected. Desk height unspecified	Unspecified	C7E, L/R SE
13. Psihogios et al. (2001)	$n = 20$ (software company workers), field, typing, mousing. Seat and desk unspecified	48.3 cm display; height unspecified; distance unspecified; tilt unspecified	NF-v, TF-c7gt, TB, GA-h, HF-h
14. 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) 35.6 cm or 48.3 cm display; (2) GA-h at 0°, −17.5°, −35°; distance self-selected (50–100 cm); tilt perpendicular to GA-h	HF-h, NF-v, TF-c7gt, TB, TRT1
15. 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 display unspecified; distance unspecified; tilt unspecified	GA-h, HF-h-15, CTA2, TF-c7gt, TB, SF, SR, EA, WF, RUD
16. 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	Display unspecified; GA-h at −15°, −40°; distance 75–80 cm; tilt perpendicular to GA-h	HF-h-15
17. Straker et al. (1997)	$n = 16$ (office workers), lab, keyboard; chair (seat height and angle, backrest height and angle), desk height self-selected	(1) Desktop: CRT Display 35.6 cm; (2) Notebook: LCD display 24.1 cm; height self-selected; tilt self-selected	HF-h, NF-v, TF-v, SF, EA, WF, NPR, SPR2
18. Straker and Mekhora (2000)	$n = 20$ (students), lab, keyboard. Seat height at popliteal height, pan inclined 5° forwards. Desk height at seated elbow height.	Display unspecified; GA-h at −10° (tilt 5°) or −30° (tilt 25°); distance self-selected 30–75 cm	GA-EEL, CCA, CTA-ext, TF-c7gt
19. Szeto and Lee (2002)	$n = 16$ (clerical workers, eight asymptomatic), field, keyboard; chair and desk height self-selected	Display unspecified; distance unspecified; height unspecified; tilt unspecified	HT-v, NF-v, SE2, SPR2
20. Szeto and Lee (2002)	$n = 21$ (students), lab, keyboard. Seat adjusted for ‘comfortable’, desk height 72 cm	(1) Desktop: 35.6 cm display; distance 53.6 cm (±7.4); tilt 9.5° (±3.9); (2) notebook: 29.7 cm display; distance 54.5 cm (±6.6); tilt 28.0° (±6.9); (3) sub-notebook: 22.1 cm display; distance 47.2 cm (±7.3); tilt 37.0° (±9.0); distance self-selected; tilt self-selected	HNF, HNLB, HNR, TF-c7t8, TLB, TR2

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Table 1 (*continued*)

Reference	Workstation scenario	Visual display	Reported data[b]
21. Saito et al. (1997)	$n = 10$ (students), lab, keyboard; chair height adjusted 'appropriately', desk height 70 cm, keyboard position 4 cm from desk edge	(1) Notebook: 26.4 cm LCD display; distance self-selected 32.9 cm (±5.4); (2) desktop: 35.6 cm CRT display; distance self-selected 40.6 cm (±4.3)	GA-h, HF-h2, NF-h2
22 Villanueva et al. (1996)	$n = 10$ (unspecified), lab, mouse. Seat height adjusted so forearm is horizontal when using mouse. Desk height 67 cm	35.6 cm CRT display; height from floor 80, 90, 100, 110, and 120 cm; distance 56 (±7.5) cm	HF-h2, TB, TF-c7gt, TRT2
23. 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	35.6 cm CRT display; height from floor 80, 100, 120 cm; distance unspecified	HF-h2, TB, TF-sic
24. 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: 43.2 cm CRT display; height: 96 cm; distance 50.5 cm (±8.7); tilt 5.5° (±3.0); (2) notebook: 35.1 cm LCD display; height: 92.9 cm; distance 49.3 cm (±7.2); tilt 22.2° (±5.7); (3) notebook: 26.4 cm LCD display; height: 81.1 cm; distance 46.7 cm (±8.0); tilt 32.6° (±4.8); (4) notebook: 18.3 cm LCD display; height: 80.2 cm; distance 43.4 cm (±7.1); tilt 37.3° (±7.1); (5) notebook: 15.5 cm LCD display; height: 76.4 cm; distance 41.2 cm (±6.5); tilt 41.0° (±6.3); distance, tilt self-selected	GA-h, HF-h2, TF-c7ic, SR, SF, SA, EA, WF, RUD, EP

[a] Measurement made to top of screen (else middle of screen).
[b] Posture angles – see Table 2 for definitions.

studies involving a simulation of work tasks. Several studies focussed on the position of the hands while typing, though Aaras et al. (1997) and Moffet et al. (2002) evaluated head/neck posture.

Aaras et al. (1998), found a 'few' degrees increase in head flexion, and up to 10° increase in shoulder flexion and arm abduction with an intervention allowing forearm support on the desk. Cook et al. (2004a) found similar changes in shoulder flexion with forearm support, together with decreased elbow flexion and ulnar deviation. Moffet et al. (2002) found no change in head flexion when using a palm rest and Hedge and Powers (1995) reported no effect of full motion forearm supports on posture. However Lintula et al. (2001) reported reduced wrist extension with arm support. Earlier, Grandjean et al. (1983) had found the majority of office workers used a wrist or forearm support if one was provided and used the desk surface if no specific support was provided. They also reported data showing a trend for slightly higher discomfort when no supports were provided. Whilst not information technology tasks, Feng et al. (1997) reported a change in arm posture with arm supports but no change in head posture. The available evidence is therefore unclear on the impact of a desk design which enables forearm support on spinal and scapula posture and therefore this needs to be more adequately investigated.

1.3. Interaction of display height and forearm support effects on posture

Some studies have investigated the interaction of display height with chair design on posture (Delleman and Berndsen, 2002) and muscle activity (Babski-Reeves et al., 2005), but none have assessed the potential interaction between desk design/forearm support and display height. Aaras et al. (1997) did assess two display heights and forearm support and no forearm support conditions but did not report on any interactions.

In summary, the available evidence for the effect of display height on posture is limited by not including 3D posture assessment and not providing a comparison to a paper based information technology task. Similarly, the available evidence for the posture effect of forearm support by desk design is inconclusive. Finally, there is no clear evidence to determine whether two critical workstation features, display height and desk design/forearm support, will interact in their effect on worker posture. This evidence is needed to inform international standards and guidelines for the appropriate design of workstations for information technology tasks.

The aim of this study was to assess for the first time the independent and interactive effects of display height and forearm support on head, neck and upper limb posture in three dimensions during work with computer and paper information technologies.

2. Methods

2.1. Study design

The independent variables in this study were *display* and *desk* conditions. The first factor, display, comprised 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 with some shoulder flexion. This paper reports on mean postures, with a companion paper reporting on mean muscle activity levels.

Table 2
Taxonomy of posture measures used in studies investigating effect of visual display height on posture

Angle		Name	Definition
Gaze angles			
With respect to (WRT) horizontal	GA-h[a]	Gaze angle WRT horizontal	Centre of visual display, eye and horizontal line through eye
WRT eye–ear line	GA-eel	Gaze angle WRT the ear–eye line	Centre of display, eye and eye–ear line
	GA-eel-top	Gaze angle WRT the ear–eye line	Top of display, eye and eye–ear line
Head angles			
WRT vertical/horizontal	HF-v[a]	Head flexion WRT vertical	Tragus, eye and vertical line through ear
	HF-v2	Head flexion WRT vertical	Tragus–forehead and vertical line through ear
	HF-h	Head flexion WRT horizontal	Eye–ear line and horizontal line through ear
	HF-h2	Head flexion WRT horizontal	Reid's line (infraorbital margin and upper margin of external auditory meatus) and horizontal line
	HF-h3	Head flexion WRT horizontal	Head relative to floor in sagittal plane
	HF-h-15	Head flexion WRT horizontal	Eye–ear line and horizontal line through ear minus 15°
	HF-i	Head flexion WRT vertical	Sagittal plane head position from inclinometer
	HLB[a]	Head lateral bending WRT vertical	Lateral angle between OC1-tragus, and the vertical line through OC1 (negative to left)
	HLB-i	Head lateral bending WRT vertical	Frontal plane head position from inclinometer
	HR[a]	Head rotation	Angle between OC1-cyclops and anterior axis in transverse plane (negative to left)
WRT reference posture	HF-ref	Head flexion with respect to head flexion in reference position	Ear–eye line with respect to ear–eye line in reference posture
WRT neck or trunk	CCA[a]	Cranio–cervical angle	Eye–tragus–C7
	CCA2	Cranio–cervical angle	Eye–ear–T1
head/neck combined	HNF	Head/neck flexion	Head relative to C7 in sagittal plane
	HNLB	Head/neck lateral bending	Head relative to C7 in frontal plane
	HNR	Head/neck axial rotation	Head relative to C7 in transverse plane
Other	HF-change	Head flexion WRT trunk flexion	Change in head flexion versus change in trunk flexion
Neck angles			
WRT vertical/ horizontal	NF-v[a]	Neck flexion WRT vertical	Tragus, C7 and vertical line through C7
	NF-h	Neck flexion WRT horizontal	Tragus, T1 and horizontal line through T1
	NF-h2	Neck flexion WRT horizontal	Tragus, acromion process and horizontal line through acromion process
	NLB[a]	Neck lateral bending	OC1–C7 and vertical axis through C7 in frontal plane
WRT reference posture	NF-ref	Neck flexion relative to a reference posture	Head and neck markers unspecified
WRT trunk	CTA[a]	Cervico–thoracic angle	Tragus–C7–T5
	CTA2	Cervico–thoracic angle	Ear–C7–hip
	CTA-ext	External CTA	Ear–C7–hip
	CTA3	Cervico–thoracic angle	Ear–T1–suprasternal notch
Other	NPR	Neck protraction/retraction	Horizontal distance between ear and C7
Trunk angles			
WRT vertical	TF-v[a]	Trunk flexion	C7-greater trochanter and vertical line through greater trochanter
	TF-v2	Trunk flexion	C7-iliac crest and vertical line
WRT horizontal	TF-c7gt	Trunk flexion	C7-greater trochanter and horizontal line
	TF-c7ic	Trunk flexion	C7-iliac crest and horizontal line
	TF-sic	Trunk flexion	Inferior angle of scapula – iliac crest and horizontal line
	TF-acgt	Trunk flexion	Acromion process – greater trochanter and horizontal line
	TF-i	Trunk flexion	Sagittal plane trunk position from inclinometer
	TF-t1sn	Thoracic trunk angle	T1 – suprasternal notch and horizontal line
	TF-c7t8	Thoracic trunk angle	C7 relative to T8 in sagittal plane
	TLB	Thoracic trunk lateral bending	C7 relative to T8 in frontal plane
	TLB-i	Trunk lateral bending	Frontal plane trunk position from inclinometer
	TR[a]	Thoracic trunk rotation	Angle between sternum–T5 and anterior axis in transverse plane (negative to left)
	TR2	Thoracic trunk rotation	C7 relative to T8 in transverse plane
WRT reference posture	TF-ref	Trunk angle relative to a reference posture	C7–hip with respect to C7–hip in reference postures
Intersegmental angle	TB	Thoracic bend angle	C7, inferior angle of scapula, hip
	TRT1	Trunk relative to thigh	C7, hip, knee
	TRT2	Trunk relative to thigh	C7, iliac crest, knee

(*continued on next page*)

Table 2 (*continued*)

Angle		Name	Definition
Upper limb			
	SPR[a]	Scapula protraction/retraction	Angle between acromion–C7 and lateral axis
	SPR2	Scapula protraction/retraction	Horizontal distance between C7 and acromion process
	SE[a]	Scapula elevation	Angle between acromion–C7 and vertical axis
	SE2	Scapula elevation	vertical displacement of acromion process with respect to C7
	C7E	C7 elevation	Vertical displacement of C7 marker
	SF[a]	Shoulder flexion	Angle between lateral humeral epicondyle, acromion and vertical axis in sagittal plane
	SA[a]	Shoulder abduction	Angle between lateral humeral epicondyle, acromion and vertical axis in frontal plane
	SR	Shoulder rotation	
	EA	Elbow angle	
	EP	Elbow position	Horizontal distance between elbow and desk
	WA[a]	Wrist angle	Conical angle between elbow, wrist and hand
	WF[a]	Wrist flexion	Angle between hand, wrist and vertical axis
	RUD[a]	Radial/ulnar deviation	Angle between hand, wrist and lateral axis

[a] Postural angle definitions used in this study and recommended for future studies. *Note*: for 3-D measures, OC1 – mid way between left and right tragus; Cyclops – mid way between left and right eye.

2.2. Participants

Eighteen males and 18 females aged between 18 and 25 years were recruited by notices in local universities and community newspapers and through personal contacts. This age range was specified to ensure skeletal maturity but limited degenerative changes. These participants had no history of significant chronic musculoskeletal disorder in the neck and upper limb, no current neck and/or upper limb pain and no diagnosed acute or chronic musculoskeletal condition. Participants had no psycho-active prescription medication or diagnosed mental disorder and were required to have normal or normal 'corrected' vision. Participant heights were between 5th and 95th age/gender percentiles to minimise impact from extreme anthropometry. Hypermobility was assessed using Beighton's scale (Beighton et al., 1973). All participants were using computers at least two times per week for a total of at least 2 h per week. Level of typing skill was measured using a standardised typing test (TypeMaster Pro, TypingMaster Inc., Helsinki, Finland). Characteristics of the subjects are summarized in Table 4.

2.3. Variables

Posture was measured using the Peak Motus passive reflector motion analysis system (Chattanooga, USA). Semi-spherical retro-reflective markers were placed bilaterally on the outer canthi, tragii, acromions, posterior mid humeri, lateral humeral epicondyles, midway between radial and ulnar styloid processes and distal end of the 3rd metacarpals and greater trochanters, and on the C7 and T5 spinous processes and suprasternal notch. Markers were also placed on the desk and display. The x, y, z coordinates of the markers were determined from infrared images collected simultaneously by seven cameras for 120 s in the 2nd and 3rd, 5th and 6th and 9th and 10th minutes. Data were compared over the different epochs, and as no differences were observed, the mean value over the final 2 min of each trial was used for analyses. Gaze (eye to visual target), head (flexion/extension, lateral bending, rotation), neck (flexion/extension, lateral bending), cranio–cervical angle, cervico–thoracic angle, trunk (rotation), scapula (protraction, elevation), arm (flexion/extension, abduction), and wrist (conical deviation, flexion/extension, ulnar/radial deviation) angles were calculated from the marker positions (see definitions in Table 2). Mean angles referenced to vertical for sagittal and coronal angles and to the anterior sagittal plane for transverse angles are reported. The reliability and validity of the motion analysis system has been demonstrated (e.g. accuracy in marker determination, estimation of skeletal movement and joint angle estimation) (Salo et al., 1997; Scheirman et al., 1997; Scholz and Millford, 1993) with callibration in our laboratory resulting in <5 mm standard deviation in assessed length of a 916 mm rod. A digital video image was also collected simultaneously to assist quality control of data.

2.4. Procedure

Participants completed a general history knowledge task in each condition which required reading from an electronic (with navigation by mouse) or paper encyclopedia and completing an activity sheet using either keyboard/mouse or pen and paper input (as relevant for the condition). Six parallel forms of the tasks were developed and the order of form of task was randomly allocated to task condition. The study was conducted in a climate and lighting controlled motion analysis laboratory. Upon arrival at the laboratory, participants signed written informed consent, were fitted with retro-reflective markers and were instructed in the task. 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/curved). 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, California) 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, Turbo-Star, China) and mouse (Optical Wheel Mouse, Microsoft, Redmond, Washington) were used in all computer conditions. Participants were then led by voice and palpation through full head/neck flexion and extension, left and right lateral flexion and rotation and chin protrusion and retraction motions (to measure individual available range). Finally, participants sat in a relaxed 'usual' posture looking at an eye height visual target at 5 m.

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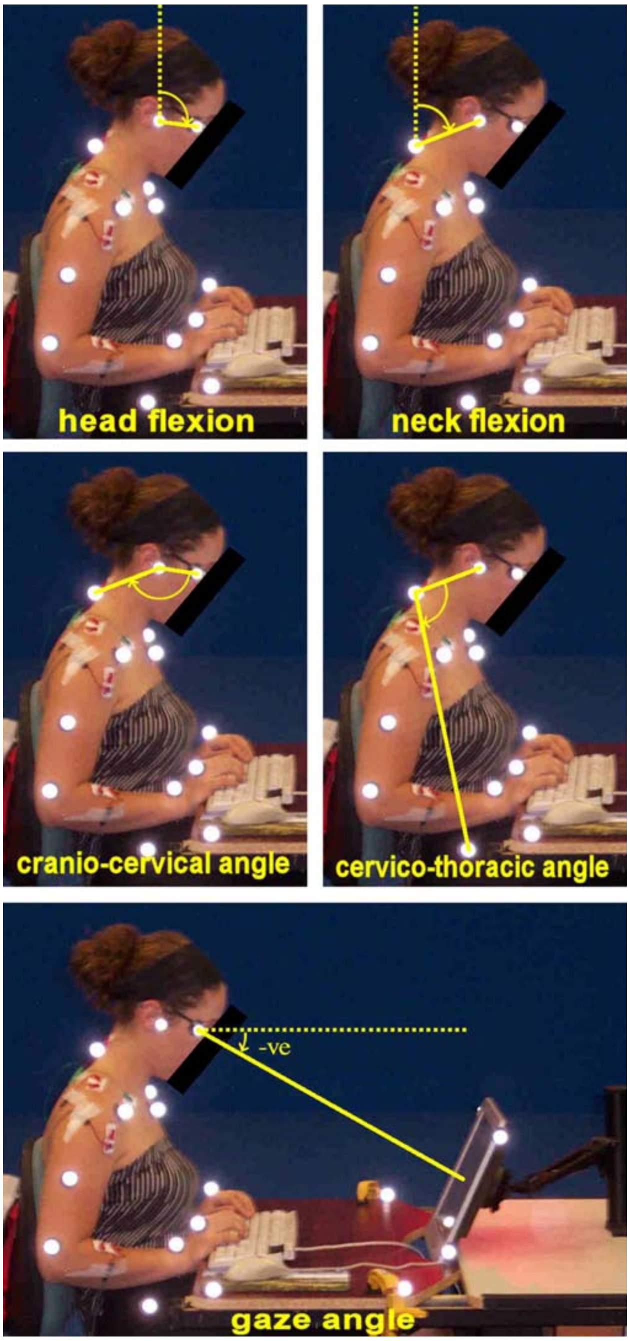

Fig. 1. Examples of angle definitions: (a) head flexion, (b) neck flexion, (c) cranio–cervical angle, (d) cervico–thoracic angle and (e) gaze angle.

Participants performed each task for 10 min. Between tasks, participants moved away from the desk area while the desk and display were adjusted. Participants worked for 10 min in each condition followed by 5 min breaks. A balanced ordering of desk/display conditions and task across genders was used. All participants were right-side dominant for the required tasks. Statistical analysis was conducted using SPSS for Windows® version 13 (SPSS Inc. Chicago, IL). The study was approved by the Human Research Ethics Committee of Curtin University of Technology.

3. Results

Table 5 shows the spinal angles in the different study conditions. Univariate RANOVA with post hoc contrasts were calculated for each dependant variable using a critical alpha level of 0.01 to balance familywise error and power (Table 6). Huynh–Feldt epsilon corrections were used if Mauchly's test indicated lack of sphericity. Table 7 shows the upper limb angles in the different conditions, with RANOVA results summarised in Table 8. Covariate analysis using *gender* had no effect on the pattern of results and so unadjusted results are given. Significant effects of *display* and *desk* were found on spinal and arm postures.

Compared with the *mid* display, the *high* display resulted in 15° less head flexion, 6° less neck flexion, 7° more cranio–cervical angle and 5° more cervico–thoracic angle associated with a 23° less gaze angle. There were no upper limb differences between *high* and *mid* displays. There were even larger differences in head and neck postures between *book* and *high* display. Compared with the *mid* display, the *book* display resulted in marked increases in head (20°) and neck (18°) flexion associated with a 39° lower gaze angle. The *book* display also resulted in more spinal asymmetry, characterised by lateral bending of the head (2° to right) and neck (3° to left), 5° more head rotation to left and 2° more trunk rotation to left than both electronic displays. The *book* also resulted in 5° less right scapula elevation, 6° less left scapula protraction and 4° less left arm abduction. The *mid* display postures lay between *high* and *book* postures.

The *curved* desk resulted in spinal postures essentially similar to the *straight* desk except for 2° less head flexion. In contrast the *curved* desk resulted in quite different arm postures, characterised by scapulae in 4–7° more elevation and 2–3° more protraction, shoulders in 6–13° more flexion and 12–17° more abduction, and left wrist 8° straighter. *Display* × *desk* interactions were only evident for left arm flexion and abduction (greater difference between desks when using *high* display), and left wrist deviation (less difference between desks when using *book*) with a trend for greater cranio–cervical angles in the *high* display with the *curved* desk.

4. Discussion

These data are the most comprehensive description of head and arm postures during information technology use. Most prior studies have only reported posture in a single plane and none have compared computer and paper information technology.

We had anticipated some interaction between the effects of *display* and *desk* design on posture, however the results showed very little interaction. The only prior study to investigate both display height and forearm support, Aaras et al. (1997), did not analyse potential interaction effects. Whilst not tested in their paper, they reported a 4° differ-

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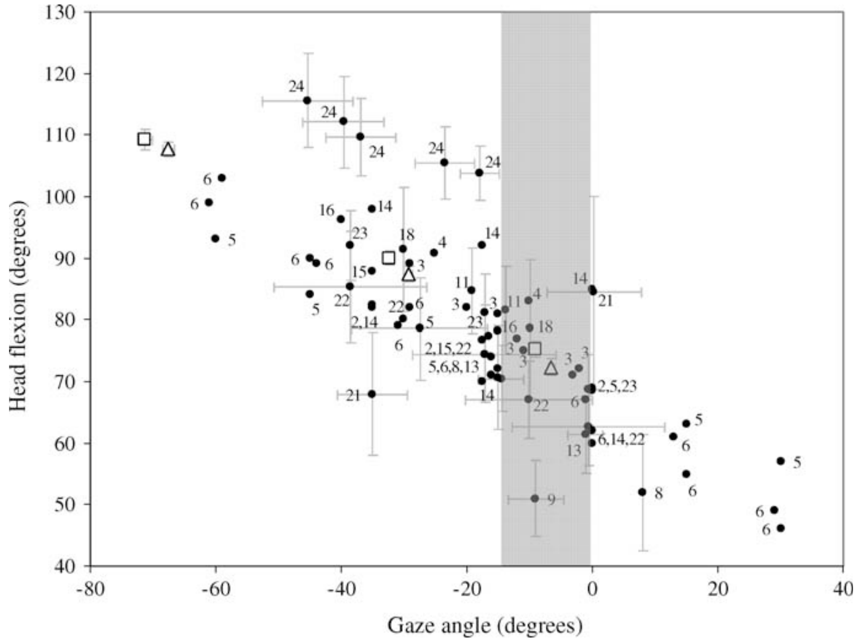

Fig. 2. Head flexion (eye–ear with respect to vertical) postures relative to gaze angle (display-eye with respect to horizontal) reported in 24 studies (data from current study shown with open squares). 'Neutral' zone illustrated in grey. Numbers correspond to references in Table 1. (Data from Aaras, Delleman, Karlqvist, Kleine, Straker and Szeto not included as comparable head and/or gaze angle data not provided.)

ence in head posture with forearm support – suggesting the potential for an interaction. However our data do not support any interaction effect on posture.

The *high* display had no important effects on upper limb posture, but resulted in substantially less head and neck flexion than the mid display as was expected. However, as we have argued (Burgess-Limerick et al., 2000), whilst less head flexion has been recommended from simple moment modelling, the load on deep sub-capital muscles may be increased. EMG has been used to provide estimates of superficial muscle loading, but deep sub-capital muscle loads are yet to be estimated.

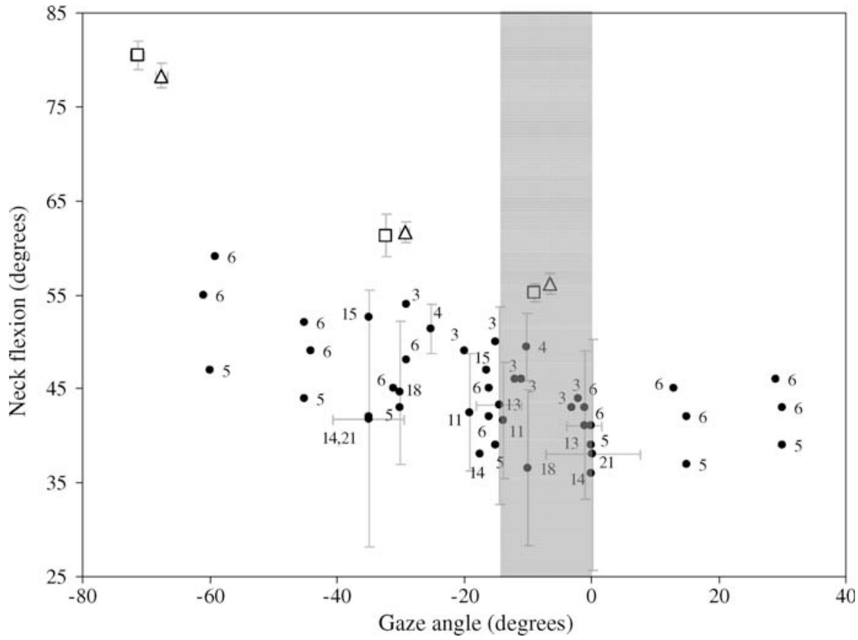

Fig. 3. Neck flexion (ear–C7 with respect to vertical) postures relative to gaze angle reported in 24 studies. (Data from current study shown with open squares. 'Neutral' zone illustrated in grey. Numbers correspond to references in Table 1.)

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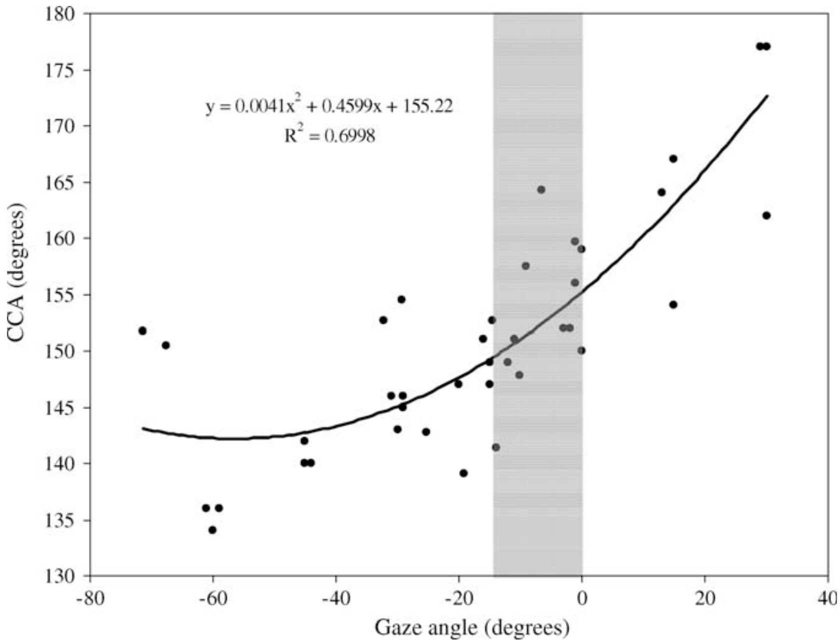

Fig. 4. Cranio–cervical angle (CCA) relative to gaze angle reported in seven studies. (Studies 3, 4, 5, 6, 11, 13 in Table 1 and current study. Each point represents separate data from each study. 'Neutral' zone illustrated in grey. Regression line shows quadratic line of best fit.)

Table 3
Summary of studies investigating effect of arm support on posture

Reference	Workstation scenario	Support type	Reported data[a]
Aaras et al. (1998)	$n = 20$ (workers), lab, keyboard, mouse. Seat height unspecified. Desk height unspecified	Forearm support provided by desk	HLB-i, HF-i, TF-i, TLB-i, SF, SA
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	SF, EA, WF, RUD
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	WF, RUD
Feng et al. (1997)	$n = 12$ (office workers), lab, keyboard. Seat height self-selected. Desk height 68 cm	Forearm support (full motion forearm support); wrist support (negative slope keyboard support); no support	EA, WF, RUD
Lintula et al. (2001)	$n = 21$ (office workers), field (6 week intervention), keyboard, mouse. Seat & 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	WF, RUD
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	HF-v, TF-acgt, SF, SF-v, WF, RUD

[a] Posture angles – see Table 2 for definitions.

Table 4
Summary of participant details

	Females	Males	All
Age years [mean(sd)]	20.8 (2.4)	20.4 (2.1)	20.6 (2.1)
Height, cm [mean(sd)]	168.4 (5.6)	179.5 (6.9)	172.2 (9.7)
Weight, kg [mean(sd)]	61.7 (10.6)	74.8 (10.6)	68.3 (12.4)
Hypermobility [median(range)]	1 (0–8)	0 (0–4)	1 (0–8)
Typing net speed keystrokes/min [mean(sd)]	41.8 (11.5)	36.8 (8.8)	39.3 (10.4)
Typing accuracy % correct [mean(sd)]	95.9 (1.6)	93.2 (5.8)	94.6 (4.4)
Typing style (no. touch typists)	5	6	11
Age started using computers years [mean (sd)]	9.7 (3.6)	10.2 (2.7)	9.9 (3.2)

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Table 5
Mean (standard error) absolute spinal angles (°) in six display (high, mid, book) and desk (curved, straight) conditions

	High display		Mid-display		Book display	
	Curved	Straight	Curved	Straight	Curved	Straight
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)
Head flexion	72.4 (1.3)	75.2 (1.2)	87.4 (1.3)	90.0 (1.2)	107.7 (1.2)	109.3 (1.7)
Head lateral bending	−0.6 (0.7)	−0.9 (0.8)	−1.0 (0.8)	−1.7 (1.0)	−0.4 (1.8)	2.2 (1.5)
Head rotation	−0.9 (0.8)	−3.7 (1.0)	−0.3 (1.0)	−0.7 (1.0)	−5.6 (2.0)	−4.4 (2.4)
Neck flexion	56.2 (1.1)	55.2 (1.0)	61.7 (1.1)	61.3 (2.3)	78.3 (1.3)	80.5 (1.5)
Neck lateral bending	0.0 (0.7)	−0.5 (0.7)	1.0 (0.7)	0.5 (0.7)	−3.4 (2.3)	−3.6 (1.1)
Cranio–cervical angle	164.2 (1.7)	157.5 (2.5)	154.5 (1.2)	152.7 (1.1)	150.5 (1.0)	151.7 (1.6)
Cervico–thoracic angle	153.3 (1.1)	153.4 (1.4)	148.7 (1.1)	147.2 (1.1)	138.8 (1.0)	137.1 (2.3)
Trunk rotation	−0.3 (0.7)	−0.9 (0.7)	0.4 (0.6)	−0.1 (0.7)	−2.5 (1.1)	−2.2 (0.7)

−ve lateral bending = to the left, −ve rotation = to the left.

Table 6
Summary of RANOVA results for spinal posture variables

	Display		Desk		Display × desk	
	F_{df}	p	F_{df}	p	F_{df}	p
Gaze angle	$3895.6_{2,62}$	**<.001**	$48.1_{1,31}$	**<.001**	$0.9_{2,62}$	.394
Head flexion	$466.6_{2,58}$	**<.001**	$10.8_{1,29}$	**.003**	$0.3_{2,58}$	.766
Head lateral bending	$3.7_{2,60}$	.031	$0.5_{1,30}$	.475	$1.5_{2,60}$	.238
Head rotation	$5.3_{2,60}$	.019	$0.5_{1,30}$	.491	$1.2_{2,60}$	.289
Neck flexion	$214.4_{2,60}$	**<.001**	$0.1_{1,30}$	.725	$1.5_{2,60}$	.242
Neck lateral bending	$9.6_{2,60}$	**.003**	$0.2_{1,30}$	.651	$0.0_{2,60}$	.933
Cranio–cervical angle	$35.5_{2,58}$	**<.001**	$5.6_{1,29}$	.025	$4.5_{2,58}$	.015
Cervico–thoracic angle	$94.8_{2,58}$	**<.001**	$2.4_{1,29}$	.131	$0.1_{2,58}$	.855
Trunk rotation	$9.7_{2,66}$	**<.001**	$0.5_{1,33}$	.500	$0.5_{2,66}$	.632

Table 7
Mean (standard error) absolute upper limb angles (°) in six *display* and *desk* conditions

	High display		Mid-display		Book display	
	Curved	Straight	Curved	Straight	Curved	Straight
Right scapula elevation	101.2 (1.4)	109.5 (0.6)	103.7 (1.1)	111.1 (0.9)	109.8 (0.8)	115.5 (0.7)
Left scapula elevation	105.6 (1.2)	110.2 (0.9)	107.7 (0.9)	111.6 (0.8)	109.8 (0.9)	113.6 (0.9)
Right scapula protraction	26.5 (1.2)	25.1 (0.9)	24.2 (1.1)	23.1 (0.9)	24.3 (1.4)	21.9 (1.3)
Left scapula protraction	22.5 (1.1)	22.4 (1.2)	25.0 (1.3)	22.0 (1.4)	17.5 (1.4)	16.4 (1.1)
Right arm flexion	−3.7 (1.8)	−12.2 (1.5)	−5.4 (2.3)	−11.6 (1.3)	−8.0 (1.9)	−10.7 (1.8)
Left arm flexion	11.6 (2.5)	−7.9 (2.5)	8.9 (2.3)	−4.6 (3.3)	6.6 (3.2)	0.2 (2.5)
Right arm abduction	34.7 (0.8)	20.4 (1.3)	33.3 (0.9)	23.2 (1.0)	35.1 (1.5)	23.4 (1.0)
Left arm abduction	38.6 (2.6)	20.8 (1.1)	40.7 (1.3)	18.3 (2.0)	30.4 (1.9)	20.6 (1.8)
Right wrist angle	159.7 (0.8)	156.2 (4.1)	159.1 (0.6)	160.3 (0.9)	158.1 (1.2)	158.0 (1.7)
Left wrist angle	163.0 (1.0)	148.6 (5.6)	162.7 (1.0)	156.9 (1.9)	161.5 (1.9)	158.4 (2.0)
Right wrist flexion	77.4 (0.7)	76.1 (0.5)	78.3 (0.9)	75.9 (0.6)	81.2 (1.6)	81.0 (1.8)
Left wrist flexion	79.7 (1.2)	73.5 (2.4)	82.1 (1.6)	74.8 (2.5)	86.1 (1.8)	83.0 (1.9)
Right wrist deviation	99.0 (2.9)	104.4 (2.9)	99.4 (2.2)	107.2 (2.2)	83.7 (2.9)	86.5 (1.8)
Left wrist deviation	124.8 (2.8)	97.5 (2.4)	126.0 (3.5)	104.2 (3.0)	124.1 (3.9)	115.2 (3.7)

The *book* display had a substantial effect on head and neck flexion as expected. Whilst a number of studies have reported postures during reading and writing with paper (e.g. Bridger, 1988; Freudenthal et al., 1991), we were unable to find any other study comparing adult postures during computer and paper use. Bridger (1988) reported marked head/neck flexion when writing on paper placed on a flat desk which was reduced slightly with a sloping desk surface. Freudenthal et al. (1991) reported similar findings for reading and writing on a flat surface and slightly inclined desk surface. The actual head and neck flexion values from both studies are difficult to compare with our findings due to their angle definitions.

The increased head and neck flexion when working with paper suggests increased moment around both the lower and upper cervical spine and thus a higher level of tissue stress and musculoskeletal disorder risk. Participants may not have experienced more discomfort after the *book* conditions if there was increased postural variability (Mathiassen, 2006), however this is yet to be determined.

Table 8
Summary of RANOVA results for upper limb posture variables

	Display		Desk		Desk × display	
	F_{df}	*p*	F_{df}	*p*	F_{df}	*p*
Right scapula elevation	$78.3_{2,66}$	**<.001**	$145.5_{1,33}$	**<.001**	$2.3_{2,66}$	.110
Left scapula elevation	$30.6_{2,64}$	**<.001**	$110.6_{1,32}$	**<.001**	$0.3_{2,64}$	.715
Right scapula protraction	$10.7_{2,66}$	**<.001**	$5.7_{1,33}$	.022	$0.6_{2,66}$	.557
Left scapula protraction	$79.4_{2,64}$	**<.001**	$21.7_{1,32}$	**<.001**	$2.5_{2,64}$	.086
Right arm flexion	$0.4_{2,66}$	.645	$41.8_{1,33}$	**<.001**	$2.9_{2,66}$	.064
Left arm flexion	$0.3_{2,64}$	.687	$36.6_{1,32}$	**<.001**	$6.8_{2,64}$	**.002**
Right arm abduction	$1.5_{2,68}$	.220	$252.2_{1,34}$	**<.001**	$2.7_{2,68}$	.072
Left arm abduction	$6.1_{2,66}$	**.004**	$87.8_{1,33}$	**<.001**	$9.0_{2,66}$	**<.001**
Right wrist angle	$0.52_{2,68}$	.544	$0.4_{1,34}$	.549	$1.0_{2,68}$	.362
Left wrist angle	$1.5_{2,64}$	.224	$12.9_{1,32}$	**.001**	$2.2_{2,64}$	.119
Right wrist flexion	$11.5_{2,66}$	**.001**	$2.2_{1,33}$	.143	$0.7_{2,66}$	.435
Left wrist flexion	$8.1_{2,60}$	**.001**	$11.7_{1,30}$	**.002**	$1.0_{2,60}$	.371
Right wrist deviation	$38.4_{2,68}$	**<.001**	$10.8_{1,34}$	**.002**	$0.8_{2,68}$	.448
Left wrist deviation	$3.5_{2,66}$	.053	$48.7_{1,33}$	**<.001**	$5.2_{2,66}$	**.008**

Interestingly the possibility that working with paper could be a greater musculoskeletal risk than computer work has not been widely accepted.

An important new finding was the increased spinal asymmetry in the *book* condition compared to the computer conditions. Asymmetry is often considered a risk factor and there is some evidence to support this belief. For example, Hunting et al. (1981) and Faucet and Rempel (1994) found increased symptoms with increased head rotation in cross sectional studies of office workers. Our research clearly shows the increased head and neck asymmetry associated with the use of paper information technology, compounding the potential increased risk associated with greater head and neck flexion.

The *curved* desk had minimal effect on spinal posture. The 2° less head flexion was probably due to the slightly higher and further away visual target when participants were looking at the book or the keyboard in the *curved* conditions. This is reflected in the 3° less gaze angle and in greater *curved* versus *straight* differences during active keying (when non touch typists were looking at the keyboard frequently, data not shown). Whilst an increase in head extension may increase sub-capital muscle load, the small change observed suggests the effect of desk design on head posture may be of little practical importance.

Scapula and arm differences when using the curved desk were more significant. The decreased shoulder extension was expected as part of the *curved* desk condition, indeed the desk height increase of 6cm was based on modelling the increase in sitting elbow height with 35° shoulder flexion (50th percentile female shoulder–elbow length 330 mm). However participants chose to sit with less extension, rather than more flexion as anticipated, which meant the change in desk height was not needed. Therefore the increased shoulder abduction and scapula elevation may have resulted from an alternate posture strategy in response to the raised *curved* desk. Faucet and Rempel (1994) found a higher keyboard to be associated with more symptoms, suggesting the raised scapula in the *curved* desk condition could lead to increased symptoms. An increase in shoulder flexion and abduction is usually considered to increase musculoskeletal risk as anti-gravity moment increases (Takala and Viikari-Juntura, 1991), but this is only when the arm is unsupported. During this study the *curved* desk provided an opportunity for support. Whether participants utilised the desk support or maintained higher muscular loads to stabilise the shoulder and counter the gravity moment can be determined with sEMG (surface electromyography) (Straker et al., in press). There was some prior concern that the *curved* desk position could encourage habitually protracted scapulae, which could lead to scapulae retractor lengthening and weakening. Whilst a significant increase in protraction was found, its size (2–3°) is such that it may be of little practical importance.

The curved desk was expected to result in reduced ulnar deviation, as the keyboard was further away from the participant. The *curved* desk was observed to result in hand positions of 5° less ulnar deviation on the right and 19° less on the left. However these hand angles were relative to the lateral axis. When an intersegmental (hand–forearm) wrist angle was used, there was no significant desk effect on the right hand, though the left wrist was straighter with the *curved* desk. This suggests the observed increase in shoulder abduction and smaller than expected increase in shoulder flexion may have minimised the effect of the *curved* condition on wrist posture.

The clear implication of these results is that display and desk design can affect working postures. However these results are insufficient to determine the least-risk display and desk design. The relationship between posture and musculoskeletal disorder risk is fuzzy and multifactorial. Risk can arise from: increased gravity resisting moment with increased angulation away from vertical, increased pressure/tension on tissues at more extreme postures, and also from repetition and monotony. The mean posture results presented here give insight into the risks associated with gravity and posture extremes, however measures of postural variability are also needed. These posture results also need to be combined with sEMG data to provide a better understanding of loading. Further insight could also be provided by modelling deeper structure stresses.

An important limitation of this study is the single short duration of the use of each condition. When participants have worked with a different desk and display set up for a period of weeks they may develop different posture responses. This could be investigated with long duration field studies. The posture results reported here were the average postures for each participant during the final 2 min of working in each condition. The computing tasks involved active use of the keyboard, active use of the mouse and postures where the hand(s) were held over the keyboard or mouse but were not active. Similarly, the book tasks involved book page turning and writing with a pen and postures where the hand(s) were holding the book or pen but were not active. The postures and muscle activity differences during these sub-tasks may well have been obscured in the current whole-task analysis.

The postural effects of desk and display designs reported here were for young adults. It remains to be tested whether children and older adults (with musculoskeletal degeneration) have similar postural responses. Similarly, our sample included young adults with a variety of typing skills and there may be differential postural effects on people with touch typing skills compared to those who need to look at the keyboard more frequently. A further limitation of this study was that the display position factor was potentially confounded by a different display mechanism for the flat condition (paper vs. electronic). Tablet computers were not available at the time of designing this study. In an attempt to account for some of the display technology differences we measured psychological flow (attentional absorption – see (Arrowsmith et al., 2001; Webster et al., 1993). No differences were found in the participants' experiences of flow between conditions therefore we have not adjusted the posture analysis for flow. The use of the book condition also provided an important comparison between typical computer display postures and paper based information technology task postures. Finally, different users may require different workstation arrangements to suit their particular postural characteristics.

5. Conclusion

Display and desk design features are critical to the minimisation of musculoskeletal risk as they clearly affect head and arm posture. The study results suggest the potential benefits of reduced head and neck flexion with a *high* display may be offset by an increase in upper cervical extension. The increased head and neck flexion and asymmetry suggest an increased risk of musculoskeletal disorder when working with paper. Whilst sEMG will assist in the interpretation of risk, information on deeper cervical structures and movement variation is needed prior to determining a recommended display position. The study results also suggest that a higher *curved* desk facilitates slightly less head flexion and more scapula elevation and protraction and more shoulder flexion and abduction. Whilst these results show the desk created reasonable postural responses, the potential benefit of supporting the forearms with a higher *curved* desk needs to be evaluated with muscle activity.

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References

Aaras A, Fostervold KI, Ro O, Thoresen M, Larsen S. Postural load during VDU work: a comparison between various work postures. Ergonomics 1997;40(11):1255–68.

Aaras A, Horgen G, Bjorset H, Ro O, Thoresen M. Musculoskeletal, visual and psychosocial stress in VDU operators before and after multidisciplinary ergonomic interventions. Appl Ergonom 1998;29(5):335–54.

Arrowsmith M, Pollock C. The occurrence of flow in year six children's use of computers. Perth, Western Australia; 3/12/2001.

Australian Bureau of Statistics. Children's participation in cultural and leisure activities. Report number: 4901.0, Australian Bureau of Statistics, Canberra; 2000a.

Australian Bureau of Statistics. Use of the internet by householders, Australia. Report Number: 8147.0, Australian Bureau of Statistics, Canberra; 2000b.

Babski-Reeves K, Stanfield J, Hughes L. Assessment of video display workstation set up on risk factors associated with the development of low back and neck discomfort. Int J Ind Ergonom 2005;35:593–604.

Bauer W, Wittig T. Influence of screen and copy holder positions on head posture, muscle activity and user judgement. Appl Ergon 1998;29(3): 185–192.

Beighton P, Solomon L, Soskolne CL. Articular mobility in an African population. Ann Rheum Diseases 1973;32(5):413–8.

Bergqvist U, Wolgast E, Nilsson B, Voss M. The influence of VDT work on musculoskeletal disorders. Ergonomics 1995;38(4):754–62.

Bridger RS. Postural adaptations to a sloping chair and work surface. Human Factors 1988;30(2):237–47.

Buckle P, Devereux J. Work-related neck and upper limb musculoskeletal disorders. Report number: The Robens Centre for Health Ergonomics. Surrey UK: European Institute of Health and Medical Sciences; 1999.

Burgess-Limerick R, Mon-Williams M, Coppard VL. Visual display height. Human Factors 2000;42(1):140–50.

Burgess-Limerick R, Plooy A, Ankrum DR. The effect of imposed and self-selected computer monitor height on posture and gaze angle. Clin Biomech 1998;13(8):584–92.

Burgess-Limerick R, Plooy A, Fraser K, Ankrum DR. The influence of computer monitor height on head and neck posture. Int J Ind Ergon 1999;23(3):171–9.

Chaffin DB. Localized muscle fatigue-definition and measurement. J Occup Med 1973;15(4):346–54.

Cheeseman-Day J, Janus A, Davis J. Computer and internet use in the United States: 2003. Report Number: US Census Bureau, Washington; 2005.

Cook C, Burgess-Limerick R, Chang S. The prevalence of neck and upper extremity musculoskeletal symptoms in computer mouse users. Int J Ind Ergon 2000;26(3):347–56.

Cook C, Burgess-Limerick R, Papalia S. The effect of upper extremity support on upper extremity posture and muscle activity during keyboard use. Appl Ergon 2004a;35:285–92.

Cook C, Burgess-Limerick R, Papalia S. The effect of wrist rests and forearm support during keyboard and mouse use. Int J Ind Ergon 2004b;33:463–72.

De Wall M, Van Riel MPJ, Aghina JCFM, Burdorf A, Snijders CJ. Improving the sitting posture of CAD/CAM workers by increasing VDU monitor working height. Ergonomics 1992;35(4):427–36.

Delleman NJ, Berndsen MB. Touch-typing VDU operation: workstation adjustment, working posture and workers' perceptions. Ergonomics 2002;45(7):514–35.

Demunter C. The digital divide in Europe. Report number: 38/2005, Statistical Office of the European Communities, Luxembourg; 2005.

Dolan P, Mannion AF, Adams MS. Passive tissues help the back muscles to generate extensor moments during lifting. Biomechanics 1994;27:1077–85.

Faucet J, Rempel D. VDT-related musculoskeletal symptoms: interactions between work posture and psychosocial work factors. Am J Ind Med 1994;26:597–612.

Feng Y, Grooten W, Wretenberg P, Arborelius UP. Effects of arm support on shoulder and arm muscle activity during sedentary work. Ergonomics 1997;40(8):834–48.

Freudenthal A, van Riel MP, Molenbroek JF, Snijders CJ. The effect on sitting posture of a desk with a ten-degree inclination using an adjustable chair and table. Appl Ergon 1991;22(5):329–36.

Grandjean E, Hunting W, Nishiyama K. Preferred VDT workstation settings, body posture and physical impairments. Appl Ergon 1984;5(2):99–104.

Grandjean E, Hunting W, Pidermann. VDT work station design: preferred settings and their effects. Human Factors 1983;25(2):161–75.

Hedge A, Powers JR. Wrist postures while keyboarding: effects of a negative slope keyboard system and full motion forearm supports. Ergonomics 1995;38(3):508–17.

Hunting W, Laubli TH, Grandjean E. Postural and visual loads at VDT workplaces I. Constrained postures. Ergonomics 1981;24(12):917–31.

Karlqvist L, Bernmark E, Ekenvall L, Hagberg M, Isaksson A, Rosto T. Computer mouse and track-ball operation: similarities and differences in posture, muscular load and perceived exertion. Int J Ind Ergon 1999;23:157–69.

Karlqvist L, Wigaeus-Tornqvist E, Hagberg M, Hagman M, Toomingas A. Self-reported working conditions of VDU operators and associations with musculoskeletal symptoms: a cross-sectional study focussing on gender differences. Int J Ind Ergon 2002;30:277–94.

Kietrys DM, McClure PW, Fitzgerald GK. The relationship between head and neck posture and VDT screen height in keyboard operators. Phys Therapy 1998;78(4):395–403.

Kleine BU, Schumann NP, Bradl I, Grieshaber R, Scholle HC. Surface EMG of shoulder and back muscles and posture analysis in secretaries typing at visual display units. Int Archives Occup Environ Health 1999;72(6):387–94.

Lintula M, Nevala-Puranen N, Louhevaara V. Effects of Ergorest arm supports on muscle strain and wrist positions during the use of the mouse and keyboard in work with visual display units: a work site intervention. Int J Occup Safety Ergon 2001;7(1):103–16.

Marcus M, Gerr F, Monteilh C, Ortiz DJ, Gentry E, Cohen S, Edwards A, Ensor C, Kleinbaum D. A prospective study of computer users: II. Postural risk factors for musculoskeletal symptoms and disorders. Am J Ind Med 2002;41(4):236–49.

Mathiassen SE. Diversity and variation in biomechanical exposure: What is it, and why would we like to know?. Appl Ergon 2006;37(4):419–27.

Moffet H, Hagberg M, Hansson-Risberg E, Karlqvist L. Influence of laptop computer design and working position on physical exposure variables. Clin Biomech 2002;17(5):368–75.

Mon-Williams M, Burgess-Limerick R, Plooy A, Wann J. Vertical gaze direction and postural adjustment: an extension of the Heurer model. J Exp Psychol: Appl 1999;5(1):35–53.

National Research Council. Work-related musculoskeletal disorders: report, workshop summary, and workshop papers. Report number: National Research Council, Washington; 1999.

Psihogios JP, Sommerich CM, Mirka GA, Moon SD. A field evaluation of monitor placement effects in VDT users. Appl Ergon 2001;32(4):313–25.

Saito S, Miyao M, Kondo T, Sakakibara H, Toyoshima H. Ergonomic evaluation of working posture of VDT operation using personal computer with flat panel display. Ind Health 1997;35:264–70.

Salo A, Grimshaw PN, Viitasalo JT. Reliability of variables in the kinematic analysis of spring hurdles. Med Sci Sports Exercise 1997;29(3):383–9.

Scheirman GL, Schrag DR, Olney SJ. Clinical analysis using the Peak Motus measurement system. Orthopaed Phys Therapy Clin North America 1997;6(1):17–42.

Scholz JP, Millford JP. Accuracy and precision of the PEAK performance technologies measurement system. J Motor Behav 1993;25:2–7.

Sommerich CM, Joines SM, Psihogios JP. Effects of computer monitor viewing angle and related factors on strain, performance, and preference outcomes. Human Factors 2001;43(1):39–55.

Sommerich CM, Starr H, Smith CA, Shivers C. Effects of notebook computer configuration and task on user biomechanics, productivity, and comfort. Int J Ind Ergon 2002;30:7–31.

Starr SJ, Shute SJ, Thompson CR. Relating posture to discomfort in VDT use. J Occup Med: Official Publication Ind Med Assoc 1985;27(4):269–71.

Statistics Bureau of Japan. Ownership and utilization of equipments and services related to information technology (IT). Available from: http://www.stat.go.jp/english/data/joukyou/2004ni/index.htm. Last accessed: 26/12/05.

Straker L, Jones KJ, Miller J. A comparison of the postures assumed when using laptop computers and desktop computers. Appl Ergon 1997;28(4):263–8.

Straker L, Mekhora K. An evaluation of visual display unit placement by electromyography, posture, discomfort and preference. Int J Ind Ergon 2000;26(3):389–98.

Straker L, Pollock C, Burgess-Limerick R, Skoss R, Coleman J. Computer display height and desk design impact on muscle activity during IT work by young adults. J Electromyogr Kinesiology, in press.

Szeto GP, Lee R. An ergonomic evaluation comparing desktop, notebook, and subnotebook computers. Arch Phys Med Rehab 2002;83(4):527–32.

Takala EP, Viikari-Juntura E. Loading of shoulder muscles in a simulated work cycle: comparison between sedentary workers with and without neck–shoulder symptoms. Clin Biomech 1991;6:145–52.

Turville KL, Psihogis JP, Ulmer TR, Mirka GA. The effects of video display terminal height on the operator: a comparison of the 15 degree and 40 degree recommendations. Appl Ergon 1998;29(4):239–46.

Villanueva MBG, Jonai H, Saito S. Ergonomic aspects of portable personal computers with flat panel displays (PC-FPDs): evaluation of posture, muscle activities, discomfort and performance. Ind Health 1998;36:282–9.

Villanueva MBG, Jonai H, Sotoyama M, Hisanaga N, Takeuchi Y, Saito S. Sitting posture and neck and shoulder muscle activities at different screen height settings of the visual display terminal. Ind Health 1997;35:330–6.

Villanueva MBG, Sotoyama M, Jonai H, Takeuchi Y, Saito S. Adjustments of posture and viewing parameters of the eye to changes in the screen height of the visual display terminal. Ergonomics 1996;39(7):933–45.

Webster J, Trevino L, Ryan L. The dimensionality and correlates of flow in human–computer interactions. Comput Human Behav 1993;9:411–26.

Woods V. Musculoskeletal disorders and visual strain in intensive data processing workers. Occup Med 2005;55(2):121–7.

Leon Straker earned a Bachelor of Applied Science in Physiotherapy from the Western Australian Institute of Technology, a Master of Science in Ergonomics from University College London and a PhD in the area of Occupational Medicine from the University of Sydney. He is an Associate Professor in the School of Physiotherapy, Curtin University of Technology and is Director of their research and higher degrees by research programs. Dr. Straker's research interests focus on the prevention of musculoskeletal disorders and include the impact of computer use on children, office ergonomics and participative ergonomics.

Robin Burgess-Limerick received his PhD from the University of Queensland. He is an Associate Professor in Occupational Biomechanics in the School of Human Movement Studies, The University of Queensland, Australia, where he coordinates postgraduate programs in ergonomics. Dr. Burgess-Limerick's research interests encompass laboratory and field investigations of topics in office ergonomics, participative ergonomics for the prevention of manual tasks related injuries, and reducing injury risks associated with coal mining equipment.

Professor Clare Pollock is the Head of the School of Psychology, Curtin University of technology. She is a graduate of Oxford University (BA(Hons) Experimental Psychology)and did her PhD in the Ergonomics Unit, University College London. Since gaining her doctorate she has worked in academia as a teacher and researcher. Her research has focussed on the psychological and human factors issues related to safety, complex systems, and technology use. She is a member of Editorial Board for the International Journal of Industrial Ergonomics and was a Member of the Board of the Civil Aviation Safety Authority in her capacity as human factors expert.

Kevin J. Murray received his medical degree (MB.BS.) from the University of Western Australia (WA), and subsequently trained in paediatrics at the Princess Margaret Hospital for Children in Perth WA. He went on to train in the subspecialty of paediatric rheumatology at the Children's Hospital, Cincinnati, Ohio in the US. In 1998, he was appointed as Consultant in Paediatric Rheumatology at the Great Ormond St Hospital in London and Senior Lecturer, Department of Medicine, University College of London. Currently he is a Consultant in Paediatric Rheumatology at the Princess Margaret Hospital for Children in Perth WA and Senior Lecturer in the School of Paediatrics and Child Health, University of WA. His primary research interests include, hypermobility disorders in childhood, paediatric origins of adult mechanical and soft tissue disorders including spinal pain.

Kevin Netto obtained a Diploma in Mechanical Engineering from the Singapore Polytechnic in 1992. He completed a B.Sc. in Sports Science with Honours' in 1999 at Edith Cowan University where he is currently completing his PhD in Biomechanics. His work on this paper was whilst employed as a research officer at Curtin University of Technology. He is currently a lecturer in Exercise and Sports Science at Charles Darwin University in the Northern Territory. His research interests lie in the areas of cervical spine biomechanics and modelling, neck injuries sustained in unique ergonomic settings and sports biomechanics.

Jemma Coleman holds a Bachelor of Sports Science from Edith Cowan University, Western Australia. She is currently completing in a Masters in Ergonomics at The University of Queensland and works fulltime at Curtin University of Technology in Western Australia. Jemma's research interests include upper quadrant muscle activation with different postures, tasks and rehabilitation regimens.

Rachel Skoss is a postdoctoral fellow in the School of Physiotherapy at Curtin University of Technology. She received her PhD in neuromuscular biomechanics from the University of Western Australia. Her research focus is on the coordination of movement, with particular interest in how best to transfer neuromuscular training exercises into habitual muscle activation strategies.

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