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The influence of desk and display design on posture and muscle activity variability whilst performing information technology tasks

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ABSTRACT

Desk design and computer display height can affect posture and muscle activation during computer use. Amplitudes of postural variables and muscle activity during computer use do not explain the results from epidemiological studies of musculoskeletal discomfort and disorders related to computer use. The purpose of this study was to assess variability of posture and muscle activity during work with two computer display heights and book/paper, in conjunction with a curved desk designed to provide forearm support and a traditional, straight desk.

18 male and 18 female participants performed 10-min tasks involving keying, mousing, reading and writing in six desk/display conditions. 3D posture and surface emg were assessed for the final 2 min of each task.

The *curved* desk resulted in greater postural and muscle activity variation, suggesting an advantage of this supportive surface over the straight desk. There was little difference in variability associated with the two display heights. However, greater variability of posture and muscle activity was evident with the book/paper condition. Non-touch typists had greater neck flexion variation.

The design of information technology tasks and workstations can influence the short term variation in posture and muscle activity. Variation is influenced independently of mean postures and muscle amplitudes and therefore needs to be considered to adequately assess the risk of musculoskeletal disorders.

1. Introduction

Computer use is becoming ubiquitous at home and work. The number of personal computers in use worldwide exceeded 900 million in 2005 and if current trends are maintained, the U.S.A. is likely to have more personal computers (PCs) in use than people in five to six years (Computer Industry Almanac, 2006). In Australia 89% of businesses used computers in the year to June 2005 (Australian Bureau of Statistics, 2006) and in the U.K. approximately 13.9 million households could access the Internet from home in early 2006 (National Statistics UK, 2006). Concerns over musculoskeletal disorders related to computer use (Bergqvist et al., 1995; Sillanpää et al., 2003) have led to the development of guidelines for workstation design. A review of guidelines for occupational loading of the musculoskeletal system – primarily the neck and shoulder regions – was conducted by Westgaard and Winkel (1996). It was found that current guidelines for physical workload mainly emphasised a reduction in the level (amplitude) of workload, while few guidelines considered the 'time dimensions' of exposure – i.e. the variability and duration of workload. The authors suggested that all of these components should be addressed in order to assess the risk for musculoskeletal disorders. This need for an accounting of exposure variability is starting to be addressed within the guidelines themselves. For example, one of the stated objectives of the new North American BSR/HFES 100 (a draft update of the ANSI/HFES 100 standard) is to 'maintain user performance by allowing postural changes that minimise static loads'.

In spite of the stated need for variability of loading, and the need for evidence to inform guidelines, most research concerning workstation design has continued to focus primarily on the amplitudes of postural angles and muscle activity. Two critical aspects of workstation design are the display and the desk.

Computer display heights have generally been recommended based on reducing mean head and neck flexion and cervical

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extensor muscle activity. It is generally accepted that a downward gaze angle is beneficial for visual comfort (Mon-Williams et al., 1999; Sommerich et al., 2001). A consideration of postural mechanics, however, dictates that the increase in head tilt required to accommodate lower displays increases the gravitational moment, and therefore the muscular torque required to maintain this flexed posture. In agreement with this mechanical model, an increase in cervical erector spinae activity has been observed with lower display heights (Greig et al., 2005; Sommerich et al., 2001; Straker et al., 2008b; Turville et al., 1998; Villanueva et al., 1997). Greater trapezius activity may also be expected in response to an increase in the gravitational moment about the neck and some studies have reported this (Aaras et al., 1997; Sommerich et al., 2001; Turville et al., 1998; Villanueva et al., 1996) whilst others have reported a decline (Briggs et al., 2004; Turville et al., 1998). However, the relationship between display heights and musculoskeletal loading is more complex than simple gravitational moment considerations would imply (Burgess-Limerick et al., 2000; Straker et al., 2008b).

Reductions in muscular symptoms with lower displays have been reported in field studies by Fostervold et al. (2006) and Marcus et al. (2002). Current knowledge of the effects of display height on muscle activity of the neck and shoulder does not account for the reported benefits of a lower display height – a reduction in the risk of musculoskeletal disorders. It therefore appears that parameters other than EMG amplitude must be of significance for the risk of musculoskeletal disorders with changing display height.

Little is known about the impact of display height upon exposure variability. Ankrum and Nemeth (2000) suggested that a lower display may provide the opportunity to move between a range of postures that were acceptable to both ocular and musculoskeletal systems, thus avoiding postural fixity. Whilst this argument is intuitively appealing, the authors did not provide supporting data. An assessment by Turville et al. (1998) of the number of posture shifts during work with two display heights revealed no difference between conditions, however, the frequency of postural shifts increased across time for both display heights. Fostervold et al. (2006) found no difference in the number of periods during which trapezius activity was below 1% MVC for display positions of 15° and 30° below horizontal.

Desks which provide for forearm support have also been shown to reduce the incidence of musculoskeletal discomfort and disorders (Cook et al., 2004; Marcus et al., 2002; Rempel et al., 2006). However, studies which have examined the effect of forearm support on muscle activity amplitudes have provided mixed results, and therefore cannot adequately explain this protective effect. A reduction in activity of the neck/shoulder muscles with forearm support was reported by Aaras et al. (1997) and Karlqvist et al. (1999). In contrast, the use of a curved desk designed to facilitate forearm support was shown by Straker et al. (2008b) to increase rather than decrease the mean amplitude of upper trapezius activity, when compared to a traditional, straight desk. Cook et al. (2004) found a reduction of trapezius and anterior deltoid activity with the utilisation of wrist support but not forearm support, when compared to a 'floating' posture. In one of the few studies to have considered variables other than EMG amplitude, Aaras et al. (1997) reported that the number of periods and total duration when trapezius activity was below 1% MVC increased when the forearms were supported on the desk.

From the preceding studies it can be seen that there is growing evidence that a focus on EMG amplitudes does not necessarily capture the risk of musculoskeletal disorders, and that assessment of variation in exposure over time may be required, as discussed by Mathiassen (2006). A recent study by Delisle et al. (2006) highlights the value of considering exposure variability. This study compared support from chair armrests (with and without the use of an adjustable workstation) and support from the desk surface during computer work. There was no difference in the amplitude of trapezius activity, as measured using the Amplitude Probability Distribution Function (APDF). However, parameters of the Exposure Variation Analysis (Mathiassen and Winkel, 1991) proved more sensitive for assessment of the effects of differing forms of support. There was greater variation of muscle activity with the corner workstation (desk-based support) than with the use of armrests. The authors suggested that a single height surface may have afforded greater opportunity for postural changes than the multiple levels provided by chair rests and desk.

Aside from new, computer-based tasks, many adults are exposed to information technology (IT) tasks using old, book/paper-based technology. Prior reports have demonstrated higher mean posture and muscle activity loads using old IT (Straker et al., 2008 a,b). However, it was suggested that old IT may be more variable, which may offset the increased risk associated with higher muscle activity amplitudes.

The aim of this study was to examine the influence of desk and display design on the variability of posture and muscle activity whilst performing IT tasks using new and old technology.

2. Methods

2.1. Study design

The study used a 2 × 3 within-subjects design, with desk and display conditions forming the independent variables. The first factor, desk, had two levels: 1) 'traditional' *straight* desk set at 3 cm below seated participant's elbow height with 0° shoulder flexion and forearms unsupported, and 2) 'horseshoe' partially wrapped around *curved* desk surface located 3 cm above elbow height, enabling full forearm support with some shoulder flexion (see Fig. 1). The second 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 was placed on the desk surface.

2.2. Participants and experimental protocol

36 participants (18 male) aged between 18 and 25 years participated in the study. This age range was specified to ensure skeletal maturity but limited degenerative changes. Participants were excluded from the study if they had a history of neck or shoulder disorders or pain. All participants were right-hand dominant and used 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) and hypermobility was assessed using Beighton et al.'s scale (1983). The study was approved by the Human Research Ethics Committee of Curtin University of Technology. Characteristics of the subjects are summarised in Table 1.

A 10-min task was completed in each of the 6 workstation configurations. This task required reading from an electronic (with navigation by mouse) or paper encyclopedia and completion of an activity sheet using either keyboard/mouse or pen input. Between conditions participants moved away from the desk for a 5-min break. Six equivalent forms of the general knowledge activities were developed and these were allocated randomly to the task conditions for each participant. A balanced ordering of desk/display conditions was utilised.

A standard office chair without armrests was adjusted to the participant's popliteal height. Subjects sat at a customised desk which could be adjusted to either a straight or curved front edge, and was also height-adjustable. The 38 cm LCD display (model LM520, AOC, Fremont, California, USA) was adjusted to the required

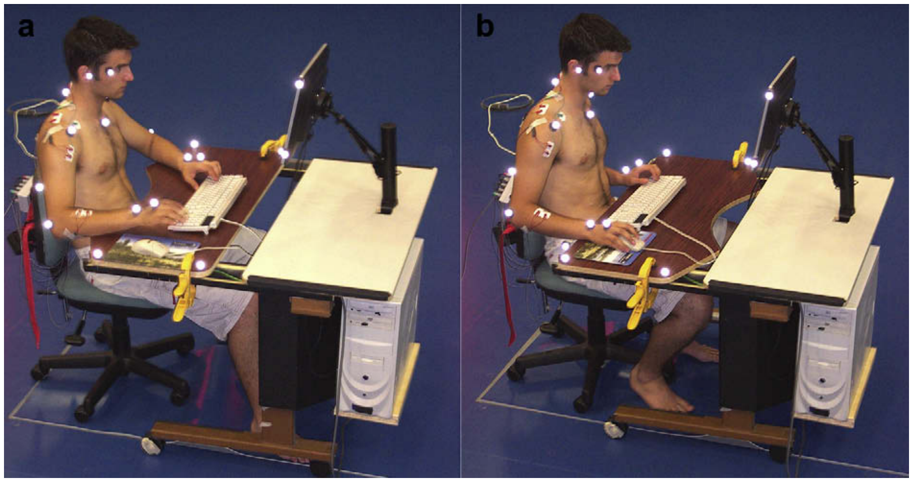

Fig. 1. An example subject working with a) *curved* and b) *straight* desk, both with *high* display.

height or turned away from the desk (for the *book* condition) using a swing arm (Swing Arm Single, Atdec Pty Ltd. Padstow, Australia). The study was conducted in a climate and lighting controlled motion analysis laboratory. Statistical analysis was conducted using SPSS for Windows® version 13 (SPSS Inc., Chicago, Ill, USA.) A critical alpha level of 0.01 was used to balance family-wise error and power.

2.3. Postural variables

A 7-camera, infra-red motion analysis system (Peak Motus version 8; Peak Performance Technologies, Inc., Centennial, CO, USA) was used to assess the three-dimensional posture of the head, neck, torso and upper limbs. Semi-spherical retro-reflective markers were placed bilaterally over the following skeletal landmarks: outer canthus, tragus, posterior acromial shelf, posterior mid humerus, lateral humeral epicondyle, midpoint between the radial and ulnar styloid processes, distal end of the 3rd metacarpal, femoral greater trochanter, spinous processes of C7 and T5, and the suprasternal notch. Markers were also placed on the four corners of the desk and display. Calculation of virtual marker locations was performed by the software, to provide data for the midpoint of the outer canthi ('Cyclops'), mid tragi (representing the occiput-cervical joint 'OC1'), mid trochanter, and the centres of the desk and electronic display. Data were sampled at 50 Hz and smoothed using a Butterworth filter with a cut-off frequency of 4 Hz. Three-dimensional postures of the head, neck, trunk and upper limb segments were derived from these data. Gaze angle from 'Cyclops' to the centre of the desk or electronic display with respect to the horizontal was also calculated.

2.4. Electromyography

Pairs of 12 mm diameter Ag–AgCl disposable surface electrodes (Uni-Patch, Wabasha, MN, USA) placed 25 mm centre-to-centre distance apart were used to collect surface myoelectric activity (sEMG) signals. The skin was thoroughly prepared by shaving, lightly abrading and cleaning prior to application of the electrodes. sEMG was collected from bilateral cervical erector spinae (CES), bilateral upper trapezius (UT), bilateral thoracic erector spinae/scapular retractors (TES), right anterior deltoid (RAD) and right wrist extensor bundle (RWE). Impedances were checked after electrode attachment and only values of <5 kΩ were deemed acceptable. In order to permit normalisation of EMG data, participants performed three MVEs in a custom-made dynamometer for each of the muscle groups assessed. Muscle actions for each MVE have been described previously (Straker et al., 2008b). The EMG signal was visible on a computer display, providing biofeedback for the participant in order to elicit a maximal contraction. Verbal encouragement was also provided by the tester. A customised LabView V7® (National Instruments, Austin, TX, USA) software program was used to control data acquisition and display. MVE sEMG had good inter-trial reliability (ICCs 0.797–0.961).

Raw EMG signals were sampled at 1000 Hz 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). Posture and sEMG were collected at three separate intervals (minutes 2–3, 5–6, and 9–10) throughout the 10-min task. As no differences were observed between epochs, the sEMG over the final 2 min of each trial was used for analysis.

2.5. Variability

Two parameters were used to characterise the posture and muscle activity variability. The difference between the 90th and 10th percentiles of the Amplitude Probability Distribution Function (Jonsson, 1982) provided a measure of the amplitude range (APDFrange). A greater APDFrange reflects a more substantial change in postural angle or muscle activity, thus reflecting greater variability

Table 1
Subject characteristics

	Females	Males	All
Age [years; mean (sd)]	20.8 (2.2)	20.4 (2.1)	20.6 (2.1)
Height [cm; mean (sd)]	164.8 (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 [Beighton; median (range)]	2.4 (0–8)	0.9 (0–4)	1.7 (0–8)
Typing net speed [words/min; mean (sd)]	41.8 (11.5)	36.8 (8.8)	39.3 (10.4)
Typing accuracy [%; mean (sd)]	95.9 (1.6)	93.2 (5.8)	93.2 (5.8)

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of movement. Exposure Variation Analysis (Mathiassen and Winkel, 1991) was used to capture both amplitude and duration variations. A standard deviation of the EVA matrix (EVAsd) was used as a simple summary of variation for statistical analysis (O'Sullivan et al., 2006). A larger EVAsd indicates that more time was spent within a particular intensity/duration class, and therefore reflects greater monotony of posture or muscle contraction.

3. Results

3D spinal and upper limb postural angles and muscle activity mean amplitudes for the *desk* × *display* conditions have been described previously (Straker et al., 2008a,b). Mean gaze angles for the six *desk* × *display* conditions are recorded in Table 2.

3.1. Amplitude range

Table 3 summarises the APDFrange for the upper body postures and muscle activities in the 6 study conditions, with Table 4 summarising the repeated measures analysis of variance (RANOVA) results. The *curved desk* resulted in a significantly greater amplitude range (more variability) for right scapula elevation, right arm flexion and bilateral CES and UT muscle activity. There was a significant effect of *display* for all posture and muscle activity variables except right anterior deltoid activity. Pre-specified contrasts showed that the *book* display resulted in significantly greater amplitude ranges than *high* and *mid* displays. The only difference between *high* and *mid* displays was greater head flexion with the *high* display. There were no significant *desk* by *display* interaction effects except for RWE, where there was a greater increase in range in the *book* condition with the *curved* desk.

3.2. EVAsd

Table 5 summarises the EVAsd for the upper body postures and muscle activities in the 6 study conditions, with Table 6 summarising the RANOVA results. The *curved* desk resulted in significantly less monotony for right scapula elevation, right CES (left CES $p = 0.026$) and left UT (right UT $p = 0.089$). There was a significant effect of *display* for all posture and muscle activity variables except right anterior deltoid. Pre-specified contrasts showed that *book* display resulted in significantly less monotony than *high* and *mid* displays. There were no significant differences between *high* and *mid* displays, nor any significant *desk* by *display* interaction effects.

4. Discussion

4.1. Desk

As previously reported, the *curved* desk was associated with greater mean scapula elevation (4–7°) and protraction (2–3°), together with more arm flexion (6–13°) and abduction (12–17°) (Straker et al., 2008a) and small increases in CES (2–4%) and UT (4–7%) mean muscle activity (Straker et al., 2008b). Based on mean amplitudes alone, the *straight* desk would be recommended over the *curved* desk. However, the *curved* desk was designed to provide support and there is evidence to show that support is beneficial for the reduction of disorders/discomfort (Cook et al., 2004; Marcus et al., 2002; Rempel et al., 2006). An analysis of the video record confirmed that the *curved* desk did provide support. Full forearm support was used for 84% of the time with the *curved* desk. In contrast, wrist support (42%) was the primary form of support for the *straight* desk, followed by forearm support (36%) and no support (22%). There was some prior concern that providing support would *reduce* movement around the shoulder, due to the constraint of an additional fixed point. However, the reverse was observed, with the right scapula showing more variability of movement, as reflected by a greater APDFrange and reduced EVAsd for scapula elevation. Therefore, postural variability data would suggest some benefit of the *curved* desk over the *straight*.

Greater variability of the CES and UT was also evident with the *curved* desk. The slightly higher mean muscle amplitudes observed for the *curved* desk may therefore be offset by the potential for greater variability of movement and muscle contractions. This result highlights the importance of considering parameters which reflect the variation of muscle activity in conjunction with the mean amplitudes of activation.

In summary, the *curved* desk resulted in greater postural and muscle activity variation, perhaps by providing more postural options than the *straight* desk. The increase in variation may be important in reducing associated risk by allowing stresses to be shared amongst different structures and by allowing recovery time for stressed structures.

4.2. High vs mid display

As previously reported, the *high* display was associated with lower mean head (15°, eye–ear-vertical) and neck (6°, ear-C7-vertical) flexion, less scapula elevation (1–3°) and more right scapula protraction (6–13°) (Straker et al., 2008a) together with small reductions in CES (2%) mean muscle activity (Straker et al., 2008b) compared with the *mid* display. Based on mean amplitudes alone, the *high* display would be recommended over the *mid* display. The *high* and *mid* displays were found to be equivalent in posture and muscle activity variability, except for head flexion. The *high* display resulted in a greater amplitude range (mean [95% confidence interval]; 15.6° [12.2–19.1]) compared with the *mid* display (10.6° [8.8–12.4]) but there was no difference in EVAsd monotony (high 4.5 [4.0–4.9]; mid 4.6 [4.2–5.0]). The lack of consistency between the two measures may have been due to different levels of sensitivity, or to the measures capturing different aspects of variation. Examination of the raw data suggests the latter. Fig. 2a shows an example of the pattern of head flexion over 2 min using a *high* display, with Fig. 2b showing the head flexion pattern for *mid* display. Head flexion in the *high* display condition was characterised by periods at around 70° (associated with viewing the display) alternating to around 90° (associated with looking at the keyboard). Whilst the reason for the large amplitude range is clear, it is also clear that head flexion posture was fairly stereotypical. This is demonstrated in the bimodal distribution of the EVA matrix (Fig. 3a) with the greatest proportion of time spent in the 66–72° and 84–90° amplitude intervals. In contrast the corresponding EVA matrix plot for the *mid* display (Fig. 3b) shows a unimodal distribution.

Prior research has shown that use of a *high* display tends to result in less head and neck flexion (Straker et al., 2008a) although

Table 2
Mean (standard error) gaze angles for each *desk* × *display* condition. Angles are referenced to the horizontal, with negative angles representing a downward gaze

	Curved desk			Straight desk		
	High display	Mid display	Low paper	High display	Mid display	Low paper
Gaze angle	−6.5 (0.5)	−29.3 (0.7)	−67.6 (0.9)	−9.0 (0.4)	−32.3 (0.5)	−71.3 (1.1)

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Table 3
Mean (standard error) posture (°) and muscle activity (%MVE) 90–10th percentile range in 6 desk and display conditions

	Curved desk			Straight desk		
	High display	Mid display	Low paper	High display	Mid display	Low paper
Head flexion	12.4 (1.4)	10.2 (0.7)	19.3 (1.6)	18.5 (2.2)	11.3 (1.3)	17.5 (1.2)
Lateral bending	6.2 (0.6)	6.2 (0.7)	26.7 (1.8)	5.2 (0.5)	5.7 (0.7)	26.1 (1.7)
Rotation	8.9 (0.8)	8.8 (0.6)	40.6 (2.6)	8.1 (0.7)	10.6 (1.4)	32.9 (2.3)
Neck flexion	6.7 (0.7)	6.5 (0.6)	17.6 (2.1)	9.4 (1.2)	6.8 (0.8)	15.8 (1.6)
Lateral bending	5.9 (0.6)	5.4 (0.6)	20.1 (1.4)	5.2 (0.4)	5.7 (0.6)	15.6 (1.7)
Cranio-cervical angle	9.8 (1.0)	7.1 (0.6)	12.8 (1.3)	12.4 (1.2)	8.1 (1.2)	9.1 (0.7)
Cervico-thoracic angle	7.1 (0.8)	6.5 (0.7)	10.5 (0.9)	8.7 (1.2)	6.8 (0.8)	9.7 (1.2)
Scapula elevation - right	4.3 (0.4)	4.4 (0.4)	7.5 (0.7)	2.9 (0.3)	2.7 (0.2)	6.7 (0.6)
Scapula elevation - left	3.1 (0.3)	3.1 (0.3)	7.3 (0.7)	3.3 (0.3)	2.9 (0.3)	7.1 (0.7)
Protraction - right	4.4 (0.4)	5.6 (0.5)	8.9 (0.7)	3.4 (0.3)	3.6 (0.4)	8.7 (0.7)
Protraction - left	4.2 (0.4)	4.3 (0.4)	10.7 (0.9)	5.0 (0.6)	4.7 (0.6)	11.2 (1.1)
Arm flexion - right	13.8 (1.7)	15.9 (2.0)	20.2 (1.9)	7.9 (0.9)	8.0 (1.1)	16.7 (1.7)
Arm flexion - left	6.4 (0.7)	8.9 (1.5)	30.2 (3.3)	11.4 (1.9)	11.1 (2.0)	26.6 (2.8)
Abduction - right	4.9 (0.6)	6.3 (0.8)	11.3 (1.4)	5.7 (0.6)	5.9 (0.6)	10.0 (0.8)
Abduction - left	4.1 (0.6)	5.4 (1.1)	15.4 (1.5)	4.6 (1.0)	5.8 (1.0)	10.9 (1.3)
Cerv. erect. spin. - right	11.4 (1.7)	10.3 (1.5)	14.0 (1.7)	5.7 (0.8)	5.6 (0.6)	10.8 (1.5)
Cerv. erect. spin. - left	8.2 (1.0)	8.5 (1.3)	13.0 (1.6)	5.9 (0.9)	5.0 (0.5)	10.4 (1.0)
Upper trapezius - right	17.6 (2.9)	17.2 (2.5)	21.5 (2.7)	8.9 (1.0)	8.6 (1.1)	15.9 (2.1)
Upper trapezius - left	10.9 (1.6)	12.7 (2.5)	22.4 (2.7)	7.9 (1.1)	7.2 (1.1)	16.1 (2.4)
Thorac. erect. spin - right	2.4 (0.6)	2.7 (0.6)	5.0 (0.7)	2.2 (0.4)	2.0 (0.3)	5.0 (0.7)
Thorac. erect. spin - left	2.0 (0.3)	2.1 (0.3)	5.3 (0.8)	2.5 (0.3)	2.7 (0.4)	5.5 (0.7)
Anterior deltoid - right	1.3 (0.3)	1.4 (0.3)	1.8 (0.4)	1.0 (0.2)	1.2 (0.2)	1.4 (0.3)
Wrist extensors - right	6.8 (0.8)	6.6 (0.6)	12.1 (1.5)	7.3 (0.8)	7.3 (0.8)	9.5 (1.2)

the upper cervical spine may be in extension relative to a resting head position. Earlier research has also shown that a *high* display results in slightly less cervical extensor activity with little impact on upper trapezius activity (Straker et al., 2008b). The current variability data suggest little advantage for either display height, as although the *high* display resulted in a greater amplitude range, the pattern of postures was more stereotypical. These results support prior studies which found no difference in the number of posture shifts [31] or frequency/duration of <1% UT activity [15] between display heights.

One reason for the lack of variation difference between display heights is that both are quite moderate positions, with the *high* display only slightly higher than the preferred range for visual preference (−9 to −15°). Some of the reasons previous authors have suggested for the desirability of *mid* displays (oculomotor, length tension considerations and reduced discomfort/disorders), probably apply to some extent to both *high* and *mid* levels in the current study. A related reason for the lack of variation difference between display heights is that there may be a range of suitable display heights which varies with individual preference (Bauer and Wittig, 1998; Burgess-Limerick et al., 1998; Straker and Mekhora, 2000; Turville et al., 1998). Our results do not support the suggestion by Ankrum and Nemeth (2000) that lower displays might give more opportunity to move, though our study only observed for a short time period.

Table 4
Summary of RANOVA results for posture and muscle activity range variables

	Desk		Display		Desk × display	
	F_{df}	p	F_{df}	p	F_{df}	p
Head flexion	$1.5_{1,28}$	0.236	$15.7_{2,56}$	<0.001	$2.5_{2,56}$	0.095
Lateral bending	$0.0_{1,28}$	0.887	$217.9_{2,56}$	<0.001	$0.4_{2,56}$	0.575
Rotation	$4.2_{1,28}$	0.049	$169.6_{2,56}$	<0.001	$2.4_{2,56}$	0.118
Neck flexion	$2.0_{1,29}$	0.170	$41.0_{2,58}$	<0.001	$1.3_{2,58}$	0.279
Lateral bending	$5.2_{1,29}$	0.030	$71.7_{2,58}$	<0.001	$3.0_{2,58}$	0.085
Cranio-cervical angle	$0.3_{1,28}$	0.554	$7.0_{2,56}$	0.006	$0.5_{2,56}$	0.592
Cervico-thoracic angle	$0.0_{1,26}$	0.927	$4.6_{2,52}$	0.015	$2.5_{2,52}$	0.094
Scapula elevation - right	$8.4_{1,33}$	0.007	$45.1_{2,66}$	<0.001	$1.6_{2,66}$	0.202
Scapula elevation - left	$0.0_{1,32}$	0.985	$49.0_{2,64}$	<0.001	$0.1_{2,64}$	0.825
Protraction - right	$5.1_{1,33}$	0.031	$55.6_{2,66}$	<0.001	$3.1_{2,66}$	0.053
Protraction - left	$1.2_{1,32}$	0.284	$67.7_{2,64}$	<0.001	$0.1_{2,64}$	0.912
Arm flexion - right	$14.5_{1,33}$	0.001	$15.5_{2,66}$	<0.001	$1.3_{2,66}$	0.270
Arm flexion - left	$0.3_{1,31}$	0.580	$46.4_{2,62}$	<0.001	$1.3_{2,62}$	0.269
Abduction - right	$0.0_{1,34}$	0.846	$30.6_{2,68}$	<0.001	$1.0_{2,68}$	0.384
Abduction - left	$1.3_{1,33}$	0.262	$39.3_{2,66}$	<0.001	$4.4_{2,66}$	0.016
Cerv. erect. spin. - right	$29.0_{1,32}$	<0.001	$11.8_{2,64}$	<0.001	$0.5_{2,64}$	0.593
Cerv. erect. spin. - left	$16.3_{1,31}$	<0.001	$25.7_{2,62}$	<0.001	$0.3_{2,62}$	0.757
Upper trapezius - right	$14.1_{1,34}$	0.001	$6.5_{2,68}$	0.003	$0.7_{2,68}$	0.487
Upper trapezius - left	$8.3_{1,35}$	0.007	$23.2_{2,70}$	<0.001	$0.6_{2,70}$	0.488
Thorac. erect. spin - right	$0.4_{1,35}$	0.523	$16.5_{2,70}$	<0.001	$0.4_{2,70}$	0.596
Thorac. erect. spin - left	$1.7_{1,35}$	0.203	$19.6_{2,70}$	<0.001	$0.1_{2,70}$	0.900
Anterior deltoid - right	$2.1_{1,35}$	0.157	$2.1_{2,70}$	0.152	$0.1_{2,70}$	0.882
Wrist extensors - right	$0.6_{1,35}$	0.457	$15.7_{2,70}$	<0.001	$6.2_{2,70}$	0.003

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Table 5
Mean (standard error) EVA postural and muscle activity matrix standard deviations in 6 desk and display conditions. Negative values for lateral bending are to the left, negative rotation angles are also to the left

	Curved desk			Straight desk		
	High display	Mid display	Low paper	High display	Mid display	Low paper
Head flexion	4.3 (0.2)	4.3 (0.1)	3.6 (0.1)	4.5 (0.3)	4.9 (0.3)	3.9 (0.2)
Lateral bending	5.6 (0.3)	5.2 (0.2)	3.1 (0.1)	6.1 (0.3)	6.0 (0.3)	3.3 (0.1)
Rotation	4.5 (0.2)	4.3 (0.1)	3.0 (0.1)	4.9 (0.3)	4.9 (0.3)	3.2 (0.1)
Neck flexion	5.8 (0.3)	5.5 (0.2)	4.0 (0.2)	5.5 (0.3)	5.7 (0.3)	4.1 (0.2)
Lateral bending	5.3 (0.2)	5.4 (0.2)	3.7 (0.2)	5.7 (0.3)	5.9 (0.3)	3.9 (0.1)
Cranio-cervical angle	4.4 (0.3)	3.8 (0.1)	3.4 (0.2)	4.1 (0.3)	4.0 (0.2)	3.5 (0.1)
Cervico-thoracic angle	5.8 (0.4)	6.3 (0.3)	4.5 (0.2)	5.9 (0.4)	5.9 (0.3)	4.8 (0.2)
Trunk rotation	7.3 (0.3)	6.8 (0.3)	5.4 (0.3)	7.7 (0.4)	7.2 (0.4)	5.3 (0.3)
Scapula elevation - right	6.4 (0.4)	6.5 (0.4)	5.4 (0.2)	7.4 (0.3)	8.2 (0.4)	6.1 (0.3)
Scapula elevation - left	5.2 (0.4)	7.1 (0.4)	5.7 (0.2)	7.1 (0.4)	7.3 (0.4)	5.4 (0.2)
Protraction - right	6.4 (0.3)	6.4 (0.4)	4.7 (0.2)	7.2 (0.4)	6.7 (0.4)	5.1 (0.2)
Protraction - left	6.5 (0.3)	6.9 (0.4)	4.9 (0.2)	6.5 (0.4)	7.2 (0.3)	4.6 (0.2)
Arm flexion - right	6.0 (0.3)	6.2 (0.3)	5.2 (0.3)	6.2 (0.3)	6.7 (0.3)	5.0 (0.3)
Arm flexion - left	6.7 (0.3)	6.3 (0.3)	5.5 (0.4)	6.6 (0.4)	7.2 (0.4)	5.3 (0.3)
Abduction - right	6.5 (0.3)	6.3 (0.4)	4.9 (0.2)	6.6 (0.4)	6.6 (0.3)	5.0 (0.2)
Abduction - left	7.1 (0.3)	7.2 (0.3)	5.9 (0.4)	7.3 (0.5)	7.4 (0.4)	5.3 (0.3)
Cerv. erect. spin. - right	6.5 (0.3)	6.7 (0.3)	6.3 (0.2)	7.9 (0.4)	7.9 (0.4)	6.5 (0.3)
Cerv. erect. spin. - left	7.6 (0.4)	7.3 (0.4)	6.1 (0.2)	8.0 (0.4)	8.0 (0.4)	6.7 (0.2)
Upper trapezius - right	5.7 (0.2)	6.0 (0.3)	4.8 (0.1)	6.2 (0.4)	6.1 (0.3)	5.3 (0.2)
Upper trapezius - left	5.8 (0.2)	6.0 (0.3)	5.1 (0.2)	5.9 (0.2)	7.0 (0.4)	5.8 (0.3)
Thorac. erect. spin - right	7.6 (0.4)	7.3 (0.3)	6.0 (0.2)	7.6 (0.4)	7.7 (0.4)	6.1 (0.2)
Thorac. erect. spin - left	8.3 (0.4)	8.5 (0.4)	6.6 (0.2)	7.8 (0.4)	7.9 (0.4)	6.3 (0.3)
Anterior deltoid - right	8.8 (0.5)	8.8 (0.4)	7.7 (0.4)	9.3 (0.6)	9.1 (0.5)	8.7 (0.5)
Wrist extensors - right	5.9 (0.2)	5.9 (0.1)	5.0 (0.1)	5.5 (0.1)	5.5 (0.1)	5.1 (0.2)

4.3. *Touch-typing*

In post hoc analysis we explored the influence of touch-typing skill on head flexion. We found that non-touch typists had about 6° greater mean head flexion, 9° greater APDF amplitude range and 1.1 less EVAsd monotony. These results are consistent with the need for non-touch typists to look at both keyboard and display. These results may also explain the greater neck flexion observed with keyboard use compared with mouse use in the recent study by Delisle et al. (2006). However, lack of touch-typing skill may not be desirable as although there was a reduction in monotony, as characterised by EVAsd, the increase in APDFrange was from the stereotypical movements shown in Fig. 1. Brandis and Straker (2002) reported reduced head and neck discomfort when office workers were taught to touch type and suggested the reduction in discomfort may have been due to a reduction in the frequency of repetitive head flexion movements associated with viewing the keyboard. They also reviewed earlier research which suggested

Table 6
Summary of RANOVA results for postural and muscle activity EVA matrix standard deviations variables

	Desk		Display		Desk × display	
	F_{df}	p	F_{df}	p	F_{df}	p
Head flexion	$1.9_{1,29}$	0.175	$10.5_{2,58}$	<0.001	$0.5_{2,58}$	0.627
Lateral bending	$4.9_{1,30}$	0.034	$83.3_{2,60}$	<0.001	$0.7_{2,60}$	0.500
Rotation	$3.1_{1,30}$	0.088	$46.5_{2,60}$	<0.001	$0.7_{2,60}$	0.499
Neck flexion	$0.0_{1,30}$	0.874	$34.0_{2,60}$	<0.001	$0.4_{2,60}$	0.649
Lateral bending	$3.6_{1,30}$	0.068	$30.2_{2,60}$	<0.001	$0.6_{2,60}$	0.528
Cranio-cervical angle	$0.0_{1,29}$	0.969	$5.8_{2,58}$	0.016	$0.6_{2,58}$	0.571
Cervico-thoracic angle	$0.0_{1,29}$	0.886	$18.1_{2,58}$	<0.001	$0.6_{2,58}$	0.572
Trunk rotation	$0.9_{1,33}$	0.355	$28.2_{2,66}$	<0.001	$0.4_{2,66}$	0.661
Scapula elevation - right	$13.9_{1,33}$	0.001	$17.1_{2,66}$	<0.001	$1.3_{2,66}$	0.287
Scapula elevation - left	$1.0_{1,32}$	0.312	$27.7_{2,64}$	<0.001	$1.9_{2,64}$	0.160
Protraction - right	$3.2_{1,33}$	0.084	$27.3_{2,66}$	<0.001	$0.4_{2,66}$	0.647
Protraction - left	$0.0_{1,32}$	0.932	$27.9_{2,64}$	<0.001	$1.2_{2,64}$	0.302
Arm flexion - right	$0.0_{1,33}$	0.839	$13.8_{2,66}$	<0.001	$0.3_{2,66}$	0.710
Arm flexion - left	$0.8_{1,32}$	0.378	$10.0_{2,64}$	<0.001	$1.4_{2,64}$	0.246
Abduction - right	$0.3_{1,34}$	0.600	$25.8_{2,68}$	<0.001	$0.0_{2,68}$	0.968
Abduction - left	$0.0_{1,33}$	0.884	$16.1_{2,66}$	<0.001	$0.4_{2,66}$	0.643
Cerv. erect. spin. - right	$19.4_{1,33}$	<0.001	$5.0_{2,66}$	0.009	$2.4_{2,66}$	0.094
Cerv. erect. spin. - left	$5.5_{1,31}$	0.026	$8.8_{2,62}$	<0.001	$0.1_{2,62}$	0.898
Upper trapezius - right	$3.0_{1,34}$	0.089	$8.9_{2,68}$	<0.001	$0.5_{2,68}$	0.621
Upper trapezius - left	$9.3_{1,35}$	0.004	$9.2_{2,70}$	<0.001	$1.1_{2,70}$	0.344
Thorac. erect. spin - right	$0.3_{1,35}$	0.580	$13.5_{2,70}$	<0.001	$0.3_{2,70}$	0.747
Thorac. erect. spin - left	$2.1_{1,35}$	0.152	$18.1_{2,70}$	<0.001	$0.1_{2,70}$	0.869
Anterior deltoid - right	$4.3_{1,35}$	0.045	$3.4_{2,70}$	0.037	$0.4_{2,70}$	0.680
Wrist extensors - right	$5.8_{1,35}$	0.022	$15.1_{2,70}$	<0.001	$2.2_{2,70}$	0.122

increased likelihood of discomfort in the non-touch typist and very proficient touch typists. This may be due to a trade-off at high levels of skills, with greater movement efficiency bringing greater monotony and potentially greater exposure also. Future research could attempt to characterise the effect of high levels of touch-typing skill on postural and muscle activity variability.

4.4. Book vs computer

In contrast to the lack of consistency between amplitude range and EVAsd monotony measures for *high* and *mid* displays, the *book* display had consistent results. The amplitude range for head flexion in the *book* condition (18.6° [16.2–21.0]) was as great as for the *high* display, and the EVAsd monotony index was smaller (3.7 [3.5–4.0]). Examination of raw data in Fig. 1c suggests that whilst the range for *book* was similar to *high* display, the pattern was more varied (compared with Fig. 1a). The EVA matrix plot for *book* (Fig. 2c) demonstrates this, with a more even spread of time in 3 amplitude intervals (90–96°, 96–102°, 102–108°).

We have previously reported that the use of old (paper-based) IT tends to result in greater mean spinal flexion and mean neck/shoulder muscle activity in adults (Straker et al., 2008a,b) and children (Briggs et al., 2004; Greig et al., 2005). This suggested a greater risk of musculoskeletal disorders with old IT compared with new, computer-based IT. However, the greater variation in both posture and muscle activations found in the current study may be critical in offsetting the risk from greater mean loads.

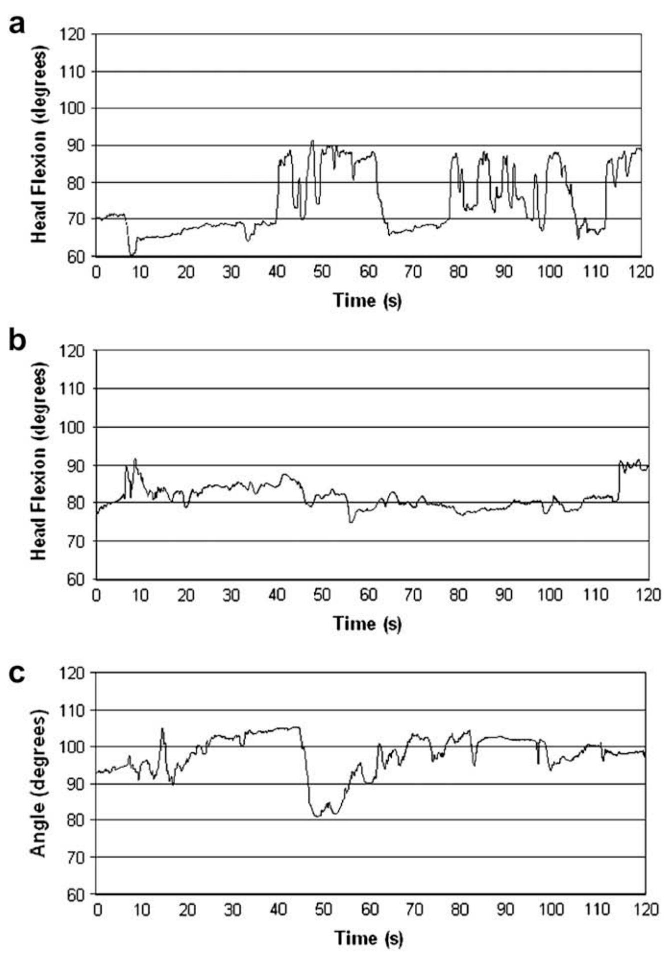

Fig. 2. An example of the pattern of head flexion over 2 min using a) *high* display, b) *mid* display and c) book/paper.

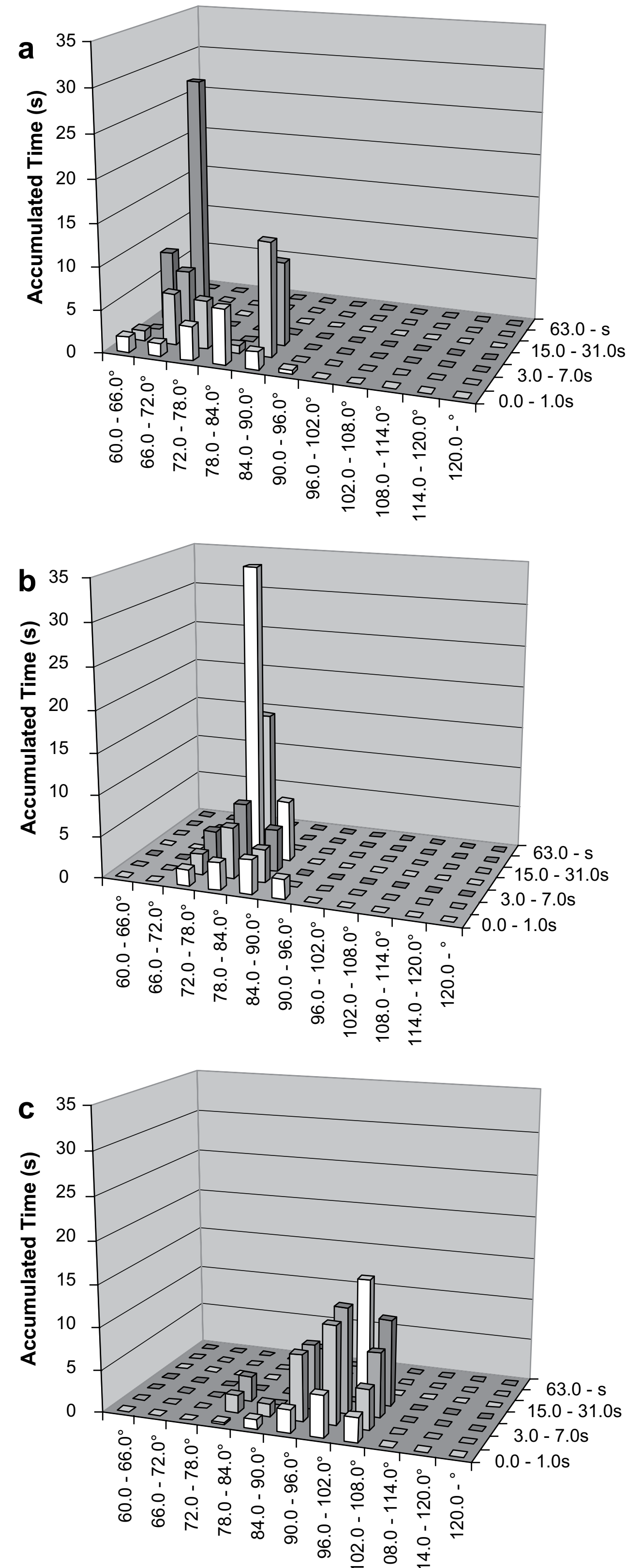

Fig. 3. The EVA matrix plots for the head flexion data shown in Fig. 1 with the a) *high* display, b) *mid* display and c) book/paper.

4.5. Limitations

Only the short term laboratory effects of workstation and task design were examined in this study. Whilst differences in variability were found, indicating the importance of workstation and task design, longer term field studies should examine variability over whole days, from day-to-day, and over longer time periods. Only young asymptomatic people were examined, to minimise the potentially confounding effects of symptoms and age-related degenerative changes. We have reported that the presence of symptoms does affect muscle activity and posture (Szeto et al., 2005a,b) and the effect on variation is currently being investigated. Future work should also investigate whether the variation found in young people is similar to that found in older workers.

5. Conclusion

Prior guidelines for IT workstation design have been largely based on mean exposure amplitudes. The evidence from studies of mean amplitudes associated with desk and display designs has not been able to explain the associations with musculoskeletal disorders identified in epidemiological studies. This suggested that measures of variation may be critical to adequately characterise risk. This paper reports the influence of desk and display designs on posture and muscle activity variation. A *curved* desk designed to provide forearm support not only provided more full forearm support, but resulted in greater variability of posture and muscle activity. A *high* display resulted in a greater amplitude of neck flexion movement, but the movement was stereotypical suggesting little difference between moderate height computer displays. Working with book/paper resulted in greater variability than working with computers, which may explain the perceptions of lower risk despite higher mean amplitudes. Together these findings provide unique information to guide more evidence-based guidelines.

6. Conflict of interest

The authors had no conflicts of interest.

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