ARTICLE IN PRESS

Available online at www.sciencedirect.com

ScienceDirect

Journal of Electromyography and Kinesiology xxx (2008) xxx–xxx

JOURNAL OF ELECTROMYOGRAPHY AND KINESIOLOGY

www.elsevier.com/locate/jelekin

The effect of forearm support on children's head, neck and upper limb posture and muscle activity during computer use

Leon Straker [a,*], Robin Burgess-Limerick [b], Clare Pollock [c], Barbara Maslen [a]

[a] *School of Physiotherapy, Curtin University of Technology, GPO Box U1987, Perth, WA 6845, Australia*
[b] *School of Human Movement Studies, University of Queensland, Brisbane, Australia*
[c] *School of Psychology, Curtin University of Technology, Perth, Australia*

Received 30 May 2007; received in revised form 12 February 2008; accepted 13 February 2008

Abstract

Use of computers by children has increased rapidly, however few studies have addressed factors which may reduce musculoskeletal stress during computer use by children. This study quantified the postural and muscle activity effects of providing forearm support when children used computers. Twelve male and 12 female children (10–12 years) who regularly used computers were recruited. Activities were completed using a computer with two workstation configurations, one of which provided for forearm support on the desk surface. 3D posture was analysed using an infra-red motion analysis system. Surface EMG was collected from five muscle groups in the neck/shoulder region and right upper limb. Providing a support surface resulted in more elevated and flexed upper limbs. The use of forearm or wrist support was associated with reduced muscle activity for most muscle groups. Muscle activity reductions with support were of sufficient magnitude to be clinically meaningful. The provision of a supporting surface for the arm is therefore likely to be useful for reducing musculoskeletal stresses associated with computing tasks for children.

Keywords: Musculoskeletal disorder; Children; Computer use

1. Introduction

The majority of children in affluent countries now use computers both at school and at home. Data from the Australian Bureau of Statistics (2003) illustrate that in 2002, 94% of children aged between 5 and 14 years used a computer at school, with 84% of these children having access to a home computer. Statistics are similar for many other countries. In 2004 in the USA, 86% of homes with children aged between 8 and 18 years had a computer (Roberts et al., 2005) and 98% of 5–18 year old from the UK used a computer at home and/or school in 2002 (Babb et al., 2003). The duration of computer use by children is also increasing. For example, census data indicate that from 2000 to 2002 Hong Kong children aged between 6 and 12 years more than doubled the time spent on a computer each week, with an increase from 3.5 to 8.3 h (Education and Manpower Bureau, 2003).

With such an exposure of children to computer technology, and given the association between postural factors, workstation set-up and musculoskeletal disorders in adult computer users (Marcus et al., 2002) it is appropriate to evaluate the available ergonomic guidelines for children's computer use. Unfortunately, few such guidelines exist, and those that are available tend not to be evidence-based or up to date with newer advancements in information technology (Straker et al., 2006a).

One factor which has been shown to reduce musculoskeletal loading for adults is the presence of a supporting surface for the forearms or wrists, in the form of either an area on the desk, or chair-based arm rests (Straker et al., 2008). Reductions in muscle activity with the presence of

* Corresponding author. Tel.: +61 8 9266 3634; fax: +61 8 9266 3699.
E-mail address: L.Straker@curtin.edu.au (L. Straker).

1050-6411/$ - see front matter
doi:10.1016/j.jelekin.2008.02.003

Please cite this article in press as: Straker L et al., The effect of forearm support on children's head, neck and upper ..., J Electromyogr Kinesiol (2008), doi:10.1016/j.jelekin.2008.02.003

a supporting surface have been reported by several authors (Aaras et al., 1997; Cook et al., 2004b; Karlqvist et al., 1999). Further evidence for the benefits of forearm support can be inferred from studies of the prevalence of musculoskeletal discomfort and disorders. In a one year field study of 182 call centre operators, the use of an arm board decreased the incidence of neck/shoulder and upper extremity pain, and reduced by 50% the risk of incident neck–shoulder disorders (Rempel et al., 2006). Similarly, a prospective study of 632 newly employed computer users identified a lower risk of neck and shoulder disorders for those operators who had arm rests on their chairs (Marcus et al., 2002), although the effect was not significant after adjusting for covariates. Cook and Burgess-Limerick (2004a) also described fewer reports of discomfort when forearm support was provided to call centre intensive computer users in a randomized and controlled trial. Whilst the evidence for the efficacy of support during computing tasks is fairly convincing, it is complicated by the particular task and workstation design. Cook et al. (2004b) reported muscle loading benefits from wrist but not forearm support, whilst Straker et al. (in press) found that a curved desk designed to provide support actually resulted in increases in muscle activity.

In summary, the use of forearm support during computing tasks by adults has generally shown positive benefits to the musculoskeletal system, however the issue is complicated by the particular task (mousing, keying and reading) and the type of support (wrist support, forearms on the desk surface or resting on chair arms). A further complication is the 'compliance' with the studied conditions, as it appears that computer users may intuitively seek some form of postural support approximately 40–80% of the time (Grandjean et al., 1983; Straker et al., in press).

Few studies have evaluated the effects of workstation set-up on posture and muscle activity for children's computing tasks, and no research papers could be found which directly addressed the effects of forearm support for this population. Straker et al. (2002) compared posture and muscle activity obtained at a typical computer workstation to values recorded when the chair and desk height were adjusted to suit the individual child. The adjusted workstation resulted in postures which were closer to 'resting' alignment. Muscle activity results were not definitive – there was a trend towards a reduction in right UT activity and higher CES activity with the adjusted workstation. For the youngest children, adjustment of the work surface to sitting elbow height required that the desk surface be lowered an average of 33.9 cm and this was expected to substantially reduce the required contribution of UT. Whilst there was a trend towards this pattern the results were not statistically significant. The use of forearm support was postulated to be a mitigating factor, although support was not directly addressed in that study.

Other studies of computer workstations for children have generally evaluated workstation set-up in schools. Oates et al. (1998) used the rapid upper limb assessment (RULA) method to evaluate the posture of children in the USA using their usual school computer workstation. This assessment placed all 95 children in either the 'unacceptable' or 'at risk of injury' classifications. Typically the workstation surface and keyboard were too high, the display was too high and/or the chair height was inappropriate. An intervention study by Laeser et al. (1998) showed some improvement in RULA scores when a workstation with a tilt down keyboard system and some adjustability to individual anthropometry was used, however, the scores with the adjusted system were still considered to be outside the optimal range. The adjustability of workstations to suit individuals was also found to be poor in Canadian and Australian schools by Zandvliet and Straker (2001). This lack of optimal workstation set-up and adjustability can be expected to hinder the ability to utilize strategies such as forearm support to reduce musculoskeletal loading and discomfort.

The relationship between reports of discomfort related to computer use and people presenting for treatment at clinics is not well known. Adult computer-related discomfort is known to be most common in the neck and shoulder (45%) followed by the back (32%) and forearm/hand regions (30%) (Karlqvist et al., 2002) and this correlates well with diagnosed musculoskeletal disorders (Marcus et al., 2002). Szeto et al. (2005) have shown differences in muscle activity patterns between adult computer users with symptoms and those without symptoms. Juul-Kristensen et al. (2004) determined that episodes of pain related to computing tasks increased the probability of later pain development, suggesting that the prevention of discomfort during computing is of considerable importance. However there are no reports of posture and muscle activity comparisons between symptomatic and asymptomatic children. The epidemiological studies of computer-related discomfort in children (Harris and Straker, 2000; Jacobs and Baker, 2002; Royster and Yearout, 1999; Sommerich et al., 2007) have not evaluated the health service impact of the discomforts.

From the available research it is clear that computer-related discomfort is experienced by a significant number of children, and that evidence on optimal workstation design for children lags behind evidence for adult workstations. Given the rapid and extensive growth in the duration and prevalence of computer use for even very young children (Straker et al., 2006b), postural considerations and loading during computer use by children need to be rigorously assessed, and guidelines constructed to ensure a minimum of discomfort and disorder during these critical growth years. The aim of this study was to quantify the postural and muscle activity effects of providing forearm support when children use computers at a desktop set-up.

2. Method

2.1. Study design

A mixed model design was used to test the effect of forearm support on head, neck and upper limb posture and muscle activity during computer use by boys and girls.

2.2. Subjects

Twenty-four healthy children (12 male, 12 female) between the ages of 10 and 12 years were recruited through personal contacts and advertisements placed in community newspapers. All participants were right hand dominant, had no history of musculoskeletal disorders or pain and had normal or normal corrected vision. The children regularly used computers (at least twice per week for a total of at least 2 h per week) and had already been using computers for several years. Typing ability and style (number of fingers used) was assessed using a two minute typing test. Characteristics of the participants are summarized in Table 1. The study was approved by the Human Research Ethics Committee of Curtin University.

2.3. Independent variable

The independent variable was support, with two levels: *support* and *no support*.

In this study, the defined *support* condition allowed subjects to rest at least 3/4 of their forearms on the desktop by positioning the keyboard and mouse away from the edge of the desk and moving the subject's chair so their abdomen was close to the desk edge (see Fig. 1). In the *no support* condition, the keyboard and mouse were placed at the near edge of the desk to inhibit use of the desk for forearm support. For both conditions subjects sat in a standard office chair with no arms rests. The chair was adjusted to the subject's popliteal height, using a foot rest if required. Each subject sat at a rectangular desk (1020 mm wide × 450 mm deep) set at the subject's sitting elbow height. An adjustable height display arm was used to adjust the computer display (model LM520, AOC, Fremont, CA, USA) so that the bottom of the display was 100 mm above the desk surface. The same keyboard and mouse were used in both conditions.

Two equivalent general knowledge reading and activity tasks were developed using a CD version of a history encyclopedia. Each task involved searching for and reading information and completing an on-line question and answer sheet. The task required use of both keyboard and mouse. The two different topic activity question and answer sheets were balanced across the support conditions and gender. The study was conducted in a climate and lighting controlled motion analysis laboratory.

Table 1
Subject characteristics

	Females	Males	All
Age [years mean (standard deviation sd)]	11.7 (0.7)	11.5 (0.9)	11.6 (0.8)
Height [cm mean (sd)]	154.0 (10.6)	155.7 (8.9)	154.9 (9.5)
Weight [kg mean (sd)]	44.4 (5.7)	43.1 (6.9)	43.7 (6.3)
Typing net speed [words/min mean (sd)]	19.5 (7.8)	14.5 (7.3)	16.9 (7.8)
Typing accuracy [% mean (sd)]	91.2 (14.1)	81.0 (13.8)	85.9 (14.6)
Typing style [no. fingers used mean (sd)]	4.4 (1.5)	3.1 (1.2)	3.7 (1.5)
Age started using computers [years mean (sd)]	5.0 (1.8)	5.8 (2.3)	5.4 (2.1)

2.4. Dependent variables

Three-dimensional posture of the head, neck, torso and upper limbs was assessed using an eight camera, infra-red motion analysis system (Peak Motus v.8, Peak Performance Technologies, CO,USA). Spherical or semi-spherical, reflective markers were positioned on the skin bilaterally over the following skeletal landmarks: outer canthi, tragi, 7th cervical vertebra, posterior acromial shelf, lateral humeral epicondyle, the midpoint between the radial and ulnar styloid processes, 3rd metacarpal head, suprasternal notch, spinous process of 3rd thoracic vertebra, femoral greater trochanter and the four corners of the desk and the computer display. Locations of the following 'virtual' markers were calculated by the software: midpoint of the outer canthi ('Cyclops'), midpoint of the tragi (representing occiput-cervical joint 'OC1'), mid trochanter, centre of computer display and centre of the desk. Data were sampled at 50 Hz, then filtered and smoothed using a Butterworth filter (cut-off frequency 4 Hz). Output from the kinematic analysis included the three-dimensional orientations of the head, neck, trunk and upper limb segments. Mean angles (referenced to the vertical for sagittal and coronal angles, and the anterior sagittal plane for transverse angles) over the last two minutes of data collection for each 10-min task were utilized for the current analysis.

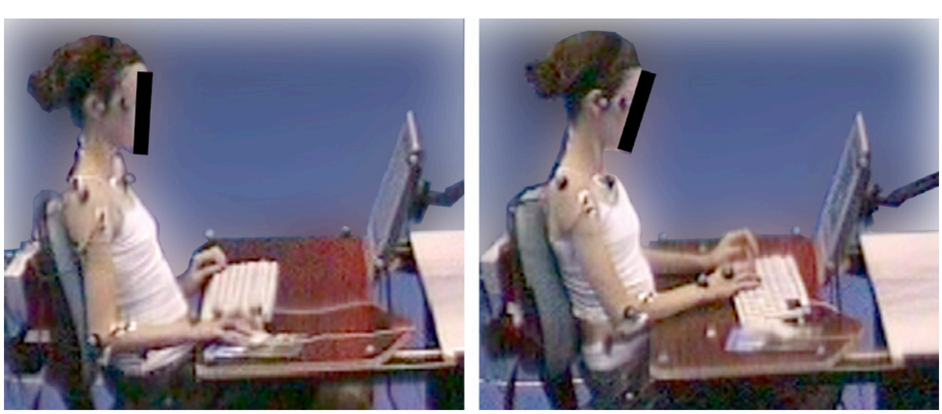

Fig. 1. Workstation setup showing no support and support conditions.

Please cite this article in press as: Straker L et al., The effect of forearm support on children's head, neck and upper ..., J Electromyogr Kinesiol (2008), doi:10.1016/j.jelekin.2008.02.003

Surface myoelectric activity (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). Details of electrode placements are provided in Table 2. Prior to placement of the electrodes the skin was shaved, lightly abraded and cleaned with surgical spirits. Pairs of 12 mm Ag–AgCl disposable surface electrodes were applied to the cleaned sites with a 25 mm centre-to-centre distance. The electrodes remained on the skin throughout the different task conditions and rest periods. Impedances were checked after electrode attachment and only values of <5 kΩ were deemed acceptable.

Participants performed three maximal voluntary exertions (MVEs) for each muscle group assessed, using a custom-made dynamometer. A leather cuff or plastic handle was attached to a 50 kgF strain gauge via an inextensible wire cable. The strain gauge and sEMG were connected to a computer display such that biofeedback was available to the participant during performance of the MVE. Further verbal encouragement was provided by the tester. Muscle actions were as utilized in prior research (Straker et al., in press). MVE sEMG had good inter-trial reliability (ICCs 0.718–.920). Data acquisition were controlled using a customized software program (LabView v.7: National Instruments, TX, USA). 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 (common mode rejection ratio: 115 dB). The mean RMS value over the final 2 min of each trial was normalized to the appropriate MVE before being used for statistical analysis. Task performance was measured by the number of answers attempted.

2.5. Procedure

Following electrode placement, subjects performed MVEs for each muscle using the specially designed rig. Subjects then moved to the study workstation and performed the interactive task involving reading from computer display and keyboard and mouse data entry for 10 min. A sagittal view digital video at 50 Hz was recorded for the whole time in each condition to supplement the coordinate data stored by the motion analysis system. Between tasks, subjects had a 5 min break away from the workstation. Condition order was balanced across genders so that equal numbers of both males and females started with each condition.

Table 2
Sites for electrode placement

Electrode placement	Description
Right and left cervical erector spinae	The midpoint between the external occipital protuberance and C7. Electrodes were placed lateral to the cervical spinal processes on the erector spinae muscle bulk
Right and left upper trapezius	Just lateral to the midpoint between C7 spinous process and acromion
Right and left thoracic scapular retractors	Midpoint between T3 and the inferior angle of the scapular. Electrodes were placed along line between landmarks
Right anterior deltoid	The midpoint of the fibers of anterior deltoid between the anterior acromion and deltoid insertion
Right wrist extensors	1/3 distance between the right lateral humeral epicondyle and radial styloid process. Active wrist extension was encouraged to palpate the muscle bulk before placement
Common ground	Mid clavicle

2.6. Statistical analysis

Univariate mixed model analyses of variance (ANOVA) with *support* as the within subjects factor and *gender* as the between subjects factors were performed. A critical α level of 0.002 for posture and 0.006 for muscle activity analysis was used to balance family-wise error and power. Huynh–Feldt epsilon corrections were used if Mauchly's test indicated lack of sphericity. All analyses were performed with SPSS v13.0 (SPSS Inc. Chicago).

3. Results

The presence of forearm support was associated with an altered upper limb posture, but minimal postural changes of the head and neck and trunk. Initial analysis of the effect of forearm support on muscle activity showed some reductions in muscle activity with forearm support in males but not females. When the data were classified according to the actual use of support, forearm support did reduce the muscle activity for most muscle groups for both genders.

Table 3 shows the mean (standard error) postures for the support conditions and the pair-wise comparison results for spinal and upper limb postures. There were no significant *gender* main effects for posture variables, nor were there any significant *gender* by *support* interaction effects, hence only *support* effects are presented. Providing support resulted in no change in spinal flexion, but significantly more elevated and flexed upper limbs. There were minor differences in trunk asymmetry, with a trend for slightly more trunk rotation and neck lateral bending evident in the *support* condition. There were no main or interaction effects for task performance (data not shown).

The assessment of muscle activation patterns revealed no significant *gender* effect nor *support* effect for any muscle, but trends ($p < .05$) for *gender* by *support* interactions for RCES, LUT and RTES. Males and females were therefore analyzed separately. Table 4 shows the mean (standard error) sEMG for the *support* conditions, with a summary of the statistical analysis. The general activation patterns for the *support* conditions are also presented graphically by *gender* in Fig. 2, graphs a and b. With the exception of the RWE muscle group, the males consistently exhibited an apparent trend for a reduction in muscle activity levels with the presence of forearm support (Table 4, Fig. 2a). The pattern for females did not exhibit such consistency; there was little overall change in the level of muscle activity with the availability of forearm support. The only consistent trend for females was an increase in RWE activity under the *support* condition (Table 4).

Table 3
Mean (standard error) posture (degrees) and *support* effect statistics in two support conditions

Variable	*Support*	*No support*	Support effect	
			F_{df}	*p*
Gaze angle	−16.4 (0.9)	−15.7 (0.8)	$2.3_{1,21}$	.146
Head flexion	81.6 (1.3)	80.3 (1.6)	$0.4_{1,20}$	.522
Lateral bending[a]	0.7 (0.7)	−0.1 (1.0)	$<0.1_{1,20}$	.973
Rotation[a]	2.7 (1.2)	1.7 (0.9)	$1.4_{1,20}$	.244
Neck flexion	52.1 (1.6)	52.2 (1.6)	$<0.1_{1,20}$	.994
Lateral bending[a]	1.8 (0.9)	0.4 (0.8)	$4.7_{1,20}$	.043
Craniocervical angle	150.3 (2.1)	151.8 (2.1)	$0.5_{1,20}$	.486
Cervicothoracic angle	151.0 (1.6)	149.0 (1.6)	$3.1_{1,19}$	.093
Trunk flexion	19.3 (2.0)	19.2 (1.6)	$0.1_{1,13}$	.709
Rotation[a]	4.0 (1.2)	1.7 (0.9)	$4.7_{1,19}$	.043
Scapular elevation – right	86.2 (1.2)	83.3 (1.2)	$7.4_{1,21}$	.013
Elevation – left	88.5 (1.5)	85.0 (1.4)	$12.6_{1,21}$	.002
Protraction – right	12.9 (1.3)	11.5 (1.0)	$2.7_{1,21}$	.114
Protraction – left	17.2 (1.9)	14.1 (1.4)	$5.8_{1,21}$	.025
Shoulder flexion – right	20.4 (2.1)	1.0 (2.1)	$85.0_{1,21}$	<.001
Flexion – left	27.3 (2.8)	4.1 (2.3)	$118.4_{1,21}$	<.001
Abduction – right	34.3 (1.5)	28.0 (1.4)	$17.7_{1,21}$	<.001
Abduction – left	23.3 (2.5)	25.9 (2.0)	$0.8_{1,21}$	.369
Wrist angle[b] – right	159.1 (1.4)	159.8 (1.4)	$0.5_{1,21}$	.483
Angle – left	164.2 (1.3)	151.6 (2.8)	$18.7_{1,19}$	<.001
Flexion – right	9.8 (1.5)	5.4 (1.9)	$5.4_{1,20}$	.031
Flexion – left	6.2 (4.9)	17.4 (4.9)	$11.9_{1,18}$	.003
Deviation – right[a]	16.5 (1.7)	16.8 (1.5)	$0.3_{1,21}$	.584
Deviation – left[a]	0.6 (3.0)	8.0 (4.9)	$2.2_{1,18}$	.157

[a] Lateral bending, rotation and deviation to the rig.
[b] Wrist angle was defined as the conical angle between the elbow, wrist and hand.

The potential presence of *gender* by *support* interactions for muscle activity was unexpected, especially in the absence of gender-related changes in the postural variables. Consequently, a post hoc analysis of the video data was performed to assess the actual amount (time) and nature (not supported, wrist supported or forearm supported) of support achieved under each condition The mean muscle activity (and posture) for each subject in each condition were calculated for intervals corresponding to no actual support, actual wrist support and actual forearm support.

Overall, participants used the provided forearm support for 92% of the time in the *support* condition, with no support employed for the remaining 8% of the time, hence they did largely follow the anticipated support pattern for this condition. However, both males and females appeared to intuitively seek support even when the workstation was configured to inhibit support. On average during the *no support* condition, participants were actually wrist supported for 81% of the time, and not supported for only the remaining 19%. When support utilization was described by gender it appeared as though there may have been some difference in the way males and females used support, with females adopting support for a greater percentage of the time during the *no support* condition and a lower proportion of the time during the *support* condition. Paired *t*-tests found that the proportion of time actually spent in support did change when moving from *no support* to *support* condition for males, but not for females (males $t_{11} = 3.1$, $p = .010$ 77% vs. 95% of the time; females $t_{10} = 0.4$, $p = .683$ 86% vs. 89% of the time).

In order to assess whether the differences in muscle activation were a result of true gender differences, or whether they were a consequence of differences in support utilization, data were further subdivided to reflect muscle activation levels during actually forearm supported, actually wrist supported and not actually supported intervals, within each of the two experimental support conditions. For example, within the *no support* condition muscle activity whilst actually wrist supported was compared to that present during the not actually supported periods. For the repeated measures factor of actual support, data from subjects who were 100% actually forearm or wrist supported or 100% not actually supported were excluded, as there were no pair-wise comparative data available within the particular *support* condition for these cases. The sample size was therefore reduced to five females and seven males for the *support* condition (the remaining 12 subjects employed support for the full time period for this condition) and 10 females and 11 males for the *no support* condition (the remaining subjects were actually wrist supported for the full period, in spite of no specific support surface being provided). Muscle activation levels during the actually forearm supported and actually unsupported

Table 4
Mean (standard error) muscle activation (% maximum voluntary exertion) and *support* effect statistics for males and females during the experimental *support* and *no support* conditions

Muscle group	Male		Female		Support effect		Gender × support	
	Support	*No support*	*Support*	*No support*	F_{df}	*p*	F_{df}	*p*
RCES	8.8 (1.03)	13.7 (2.58)	12.2 (1.28)	11.6 (1.14)	$3.2_{1,21}$	.086	$5.1_{1,21}$	.035
LCES	10.2 (1.29)	12.2 (1.39)	12.6 (0.87)	13.5 (1.87)	$2.1_{1,21}$	.159	$0.2_{1,21}$	.646
RUT	9.9 (1.89)	12.5 (2.25)	12.3 (1.77)	11.4 (1.69)	$0.7_{1,21}$	.412	$2.9_{1,21}$	.105
LUT	6.5 (1.06)	10.0 (1.66)	11.7 (2.18)	11.2 (2.00)	$2.9_{1,21}$	.100	$5.4_{1,21}$	.030
RTES	8.6 (3.11)	12.0 (3.96)	8.6 (0.83)	7.8 (1.02)	$1.8_{1,21}$	.191	$5.3_{1,21}$	.032
LTES	6.4 (0.95)	7.4 (1.06)	7.9 (2.05)	6.0 (1.04)	$0.2_{1,20}$	.649	$2.3_{1,21}$	.147
RAD	2.2 (0.33)	4.1 (1.64)	3.9 (0.77)	3.3 (0.63)	$0.6_{1,21}$	.442	$2.7_{1,21}$	.118
RWE	11.2 (2.76)	9.0 (1.51)	11.8 (1.93)	9.4 (1.37)	$2.0_{1,21}$	.170	$0.0_{1,21}$	.947

Right and left cervical erector spinae RCES, LCES; right and left upper trapezius RUT, LUT; right and left thoracic erector spinae RTES, LTES; right anterior deltoid RAD; right wrist extensor bundle RWE.

Please cite this article in press as: Straker L et al., The effect of forearm support on children's head, neck and upper ..., J Electromyogr Kinesiol (2008), doi:10.1016/j.jelekin.2008.02.003

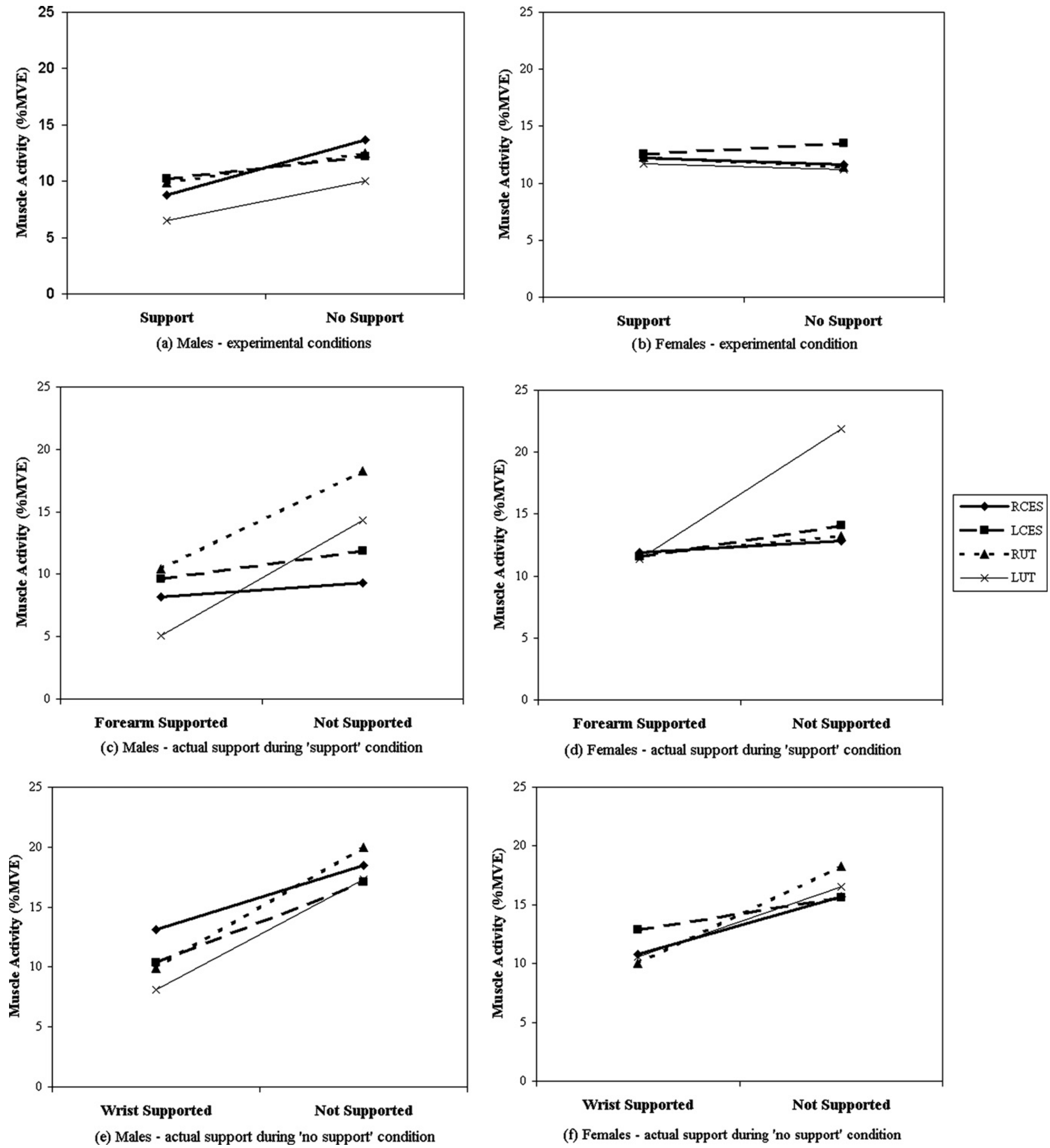

Fig. 2. Effect of support condition and actual support on activity of left and right cervical erector spinae and upper trapezius muscles.

periods are presented in Table 5 for the *support* condition and during actually wrist supported and actually unsupported periods for the *no support* condition in Table 6. These data are also presented graphically in Fig. 2, graphs c–f.

It is apparent from Tables 5 and 6 and Fig. 2 that being either actually forearm supported or actually wrist supported tended to reduce muscle loading. The univariate mixed model (gender and actual support factors) analyses of variance found no significant *gender* or *gender* by *support* interaction effects in either the *no support* or *support* experimental conditions. There were statistically significant *support* effects for all muscles except right TES ($p = .053$) in the *no support* condition (Table 6) with trends for the LCES ($p = .052$), LUT ($p = .011$) and LTES ($p = .049$) muscle groups in the *support* condition (Table 5; the analysis for

Table 5
Mean (standard error) muscle activation (% maximum voluntary exertion) during actually not supported and actually forearm supported periods for the *support* condition (right and left cervical erector spinae RCES, LCES; right and left upper trapezius RUT, LUT; right and left thoracic erector spinae RTES, LTES; right anterior deltoid RAD; right wrist extensor bundle RWE)

Muscle group	Female		Male		Support effect	
	Not supported	Forearm supported	Not supported	Forearm supported	F_{df}	p
RCES	12.8 (2.9)	11.9 (2.0)	9.3 (3.9)	8.2 (1.7)	$1.0_{1,10}$	.341
LCES	14.1 (2.0)	11.6 (2.1)	11.9 (1.7)	9.6 (1.8)	$4.8_{1,10}$	.052
RUT	13.2 (6.4)	11.7 (2.5)	18.3 (5.4)	10.4 (2.2)	$2.6_{1,10}$	.136
LUT	21.9 (5.6)	11.4 (2.0)	14.3 (4.7)	5.1 (1.6)	$9.8_{1,10}$	.011
RTES	6.8 (3.1)	8.5 (1.0)	7.5 (2.6)	3.7 (0.9)	$0.3_{1,10}$	.569
LTES	14.1 (6.4)	4.8 (1.0)	14.6 (4.8)	5.1 (0.7)	$5.2_{1,9}$	.049
RAD	4.8 (1.9)	4.9 (0.8)	5.1 (1.6)	2.1 (0.7)	$1.5_{1,10}$	.256
RWE	7.9 (3.4)	9.8 (4.6)	11.2 (2.9)	12.0 (3.9)	$0.8_{1,10}$	.405

Table 6
Mean (standard error) muscle activation (% maximum voluntary exertion) during actually not supported and actually wrist supported periods for the *no support* condition (right and left cervical erector spinae RCES, LCES; right and left upper trapezius RUT, LUT; right and left thoracic erector spinae RTES, LTES; right anterior deltoid RAD; right wrist extensor bundle RWE)

Muscle group	Female		Male		Support effect	
	Not supported	Wrist supported	Not supported	Wrist supported	F_{df}	p
RCES	15.7 (2.5)	10.8 (2.2)	18.5 (2.4)	13.1 (2.1)	$32.2_{1,19}$	<.001
LCES	15.6 (2.7)	12.9 (1.8)	17.1 (2.6)	10.4 (1.7)	$10.8_{1,19}$	.004
RUT	18.3 (2.5)	10.0 (1.4)	20.0 (2.4)	9.9 (1.3)	$58.0_{1,19}$	<.001
LUT	16.5 (2.4)	10.6 (1.5)	17.3 (2.3)	8.1 (1.5)	$64.2_{1,19}$	<.001
RTES	11.3 (5.5)	7.4 (3.4)	19.5 (5.2)	11.0 (3.3)	$4.3_{1,19}$	.053
LTES	9.0 (3.0)	4.8 (1.0)	13.8 (2.7)	5.9 (0.9)	$8.9_{1,18}$	.008
RAD	6.5 (2.0)	2.2 (1.1)	6.2 (1.9)	3.5 (1.1)	$18.6_{1,19}$	<.001
RWE	12.8 (2.0)	8.7 (1.7)	10.7 (1.9)	8.7 (1.6)	$12.8_{1,19}$	.002

the *support* condition was based on a reduced sample size, as approximately half of the sample actually used support for the full period and were therefore eliminated from this analysis).

As a final check, similar post hoc analyses were also conducted on the posture data. There were no significant differences for any posture during actual forearm support and no actual support in the *support* experimental condition (data not shown). In the *no support* experimental conditions there were no significant posture differences between actual wrist support and no actual support except for head flexion and wrist flexion (data not shown). However these differences could not have accounted for the CES, UT and RWE differences observed.

In summary, the presence of forearm support was associated with an altered upper limb posture (greater left scapula elevation, bilateral arm flexion and right arm abduction), but minimal postural changes of the head and neck and trunk. The effect of forearm support on muscle activity was more complex. Initial analysis showed some reductions in muscle activity with forearm support in males but not females. Further analysis identified that females did not change their average time of actual support use from the *no support* to the *support* condition, although the type of support changed from wrist to forearm supported, potentially explaining their lack of difference in muscle activity between support conditions. When the data were further classified according to the actual use of support, it was apparent that the use of support did reduce the muscle activity for most muscle groups.

4. Discussion

The use of forearm or wrist support during computer use has been shown to be effective for reducing the muscle loads which occur in adults (Aaras et al., 1997; Cook et al., 2004b; Karlqvist et al., 1999), and also for decreasing the incidence of musculoskeletal disorder and discomfort in adults (Cook and Burgess-Limerick, 2004a; Marcus et al., 2002; Rempel et al., 2006). The current study provides the first description of the effect of such support for children's computer use.

4.1. Forearm support and posture

The provision of a surface for forearm support did not result in a significant alteration of spinal flexion, hence there was no evidence to suggest that children 'slumped' onto the support, however only a limited time period was employed in the current study. This is in accordance with previous adult research, which tends to show much greater alteration of upper limb rather than spinal postures with support. Straker et al. (2008) recorded equivalent spinal postures when using either a straight, traditional desk or a curved desk designed to provide greater forearm support. Aaras et al. (1997) did report an increase in spinal flexion when adults supported their forearms on the tabletop, however the corresponding decrease in lumbar erector spinae muscle activity suggested a reduction of the spinal loading in spite of the increased flexion.

The increase in arm flexion was anticipated for the *support* condition, as the arms were required to move forward in order to support the forearms on the desktop. The increase in flexion (19°) would be expected to increase the moment about the shoulder joint, and therefore the required muscle activation. Straker et al. (1997) have previously reported an increase in discomfort and an EMG based muscle fatigue index with a similar change in shoulder flexion in a laboratory study of young adult computer users when no support was used. Both discomfort and muscle fatigue have been suggested to be etiological indicators of disorder risk (Westgaard and Winkel, 1996), suggesting the change in posture is of sufficient magnitude to be of clinical importance. The lack of any change in anterior deltoid activity suggests the desk provided sufficient support to counter the increased moment. Associated increases in scapular elevation and a trend for greater scapular protraction and arm abduction were also observed. Observation of the task video recordings suggests wrist posture differences were associated with some subjects resting their heads in their left hand on occasions. Participants had not been instructed what postures to use, as posture was a dependent variable. Participants usually had postures similar to those depicted in Fig. 1, with only a few showing any significant variation on this posture.

4.2. Forearm support and muscle activity

There was a general tendency towards lower muscle activity with *support* for males but not females, with some variability for right and left muscle groups (Table 4, Fig. 2). These lateral differences were not unexpected, as the tasks involved a mixture of keying, mousing and reading, and all participants in the study were right hand dominant. The reduction in muscle activity follows the pattern reported previously for adults (Aaras et al., 1997; Cook et al., 2004b; Karlqvist et al., 1999), which suggests that the provision of support alleviates loading of the musculoskeletal system during computer tasks. Female participants in the study showed greater average speed and accuracy of typing, used more fingers in typing and on average had started using computers at a younger age (Table 1). These factors may play some part in the gender differences in muscle activity which were observed in the study. In view of these gender differences it was also considered of importance to analyze actual use of support in order to assess whether differences in the actual use of support between genders for each condition also contributed to the observed gender differences in muscle activity. Analysis of the video records provided temporal data which was used to delineate actual supported and not supported periods for each participant for the dominant (right) hand.

It was evident from the video analysis that three forms of actual support were used in the current tasks. During the *support* condition, full forearm support was used by all subjects for the majority of the time studied. 55% of participants were forearm supported for the full period and for all tasks – reading, mousing and keying. On average, participants were forearm supported for 92% of the time for this condition. For the remainder of the time, no forearm or wrist support was actually used. Under the *no support* condition there was no provision for supporting the forearms on the desktop, as the keyboard was placed close to the edge of the desk. However, as reported in Table 6, all subjects managed to obtain support for the majority of this *no support* condition, with no actual support occurring for only 19% of the time. Although no forearm support could occur due to spatial constraints, the subjects were wrist supported for the remaining 81% of the time assessed. On average, females were actually supported for a similar proportion of the time for both support (88.5%) and no support (85.7%) conditions, however there was a switch from forearm to wrist support. For males, this change of the form of support was also observed, but there was also a difference in the proportional support between conditions. A greater relative supported period occurred in the *support* condition (95.4%) when compared to the *no support* condition (77.2%). Hence, it did appear likely that some of the gender difference in muscle activity reduction with support could be explained by differences in actual support utilization.

Mean muscle activity levels were calculated separately for the not supported, wrist supported and forearm supported intervals and it was clear that the actual utilization of support was associated with a reduction in muscle activity (Tables 5 and 6, Fig. 2). This was particularly evident in the *no support* condition, although trends for this to occur within the *support* condition were also recorded. Statistical power was reduced somewhat for the *support* condition because it was necessary to eliminate those participants who used support for the full time period, as they had no comparative pair-wise data.

Although participants tried to gain support in both conditions, the nature of the support was different. Prior studies have found full forearm support and wrist only support to provide different effects on UT activity (Cook et al., 2004b). Further, wrist only support has been associated with greater ulnar deviation (Cook et al., 2004b). Thus, a workstation design which encourages full forearm support is preferable to one which encourages wrist only support.

The muscle activity reductions associated with support are likely to be of sufficient magnitude to be clinically meaningful. For example, the UT activity was reduced from ~17% to ~10% MVE with support. Prior epidemiological studies have found a 5% change in UT activity levels to be sufficient to alter the risk of musculoskeletal disorders (Aaras, 1994).

5. Limitations

The results of this study should be interpreted in view of the limitations of the research design. The tasks employed were of relatively short duration, and postural alterations may vary over a longer duration. Discomfort, whilst not reported by children in this study, may have become apparent with longer task duration. Postural variability may be important for reducing musculoskeletal stress (Mathiassen, 2006) and no assessment of variability was included in the current analysis. Similarly, deep muscle loading may play a part in reducing stress on the musculoskeletal system, however the limitations of the non-invasive, surface electromyography prevent any accounting of deep muscle (e.g. Rectus Capitus Major and Minor) loads in this study. Children probably assume a wide range of postures whilst interacting with desktop computers, only some of which were captured in this short term laboratory study.

A conservative MVE protocol was utilized in the current study, to ensure a high degree of reliability. The muscle activity levels recorded in this study were higher than those previously reported for adult populations (Aaras et al., 1997;

Blangsted et al., 2004; Sommerich et al., 2001), however, comparable levels have previously been reported for children interacting with information technology (Grieg et al., 2005). The relatively high levels of muscle activity in the current study may therefore reflect the normalisation protocol, differences due to maturity, or a combination of the two.

The failure of participants to abide by the support condition set in the study was unexpected and suggests prior studies reporting differences without assessing actual support may need to be reconsidered. Although participants sought support when the workstation was not designed to provide it, the support was likely to be of a poorer quality, with the edge of the desk likely to cause tissue compression and discomfort. Future studies could measure support forces to model the amount of load reduced and record the nature of the support (full forearm or just wrist).

The current results may be representative for many children of similar age, but younger children may respond differently. Children with musculoskeletal discomfort may also respond differently as symptomatic adults have been shown to have different motor control responses to computer tasks (Szeto et al., 2005).

6. Conclusion

Data from this study suggest providing forearm support for children probably reduces neck/shoulder muscle loads. This is broadly consistent with adult results. It appears that both adults and children act intuitively to reduce loading, by finding support where they can. In the *no support* condition, organization of the workstation set-up precluded full forearm support, however participants supported their wrists on the edge of the table for 81% of the time. Such support may lead to discomfort following longer task durations, due to local tissue compression. In the *support* condition, full forearm support was utilized for 92% of the time, across the different tasks (reading, mousing and keying). Subjects who did change their level of support did have reduced muscle activity consistent with adult patterns. Children, and those responsible for their health and safety, can therefore be informed that the provision of a supporting surface for the arm is likely to be useful for reducing musculoskeletal stresses associated with computing tasks for children.

Acknowledgements

The authors would like to acknowledge funding from the Australian National Health and Medical Research Council (Project #229011) and data and manuscript assistance from Jemma Coleman, Kevin Netto and Paul Davey.

References

Aaras A. The impact of ergonomic intervention on individual health and corporate prosperity in a telecommunications environment. Ergonomics 1994;37(10):1679–96.

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.

Australian Bureau of Statistics. Children's participation in cultural and leisure activities, Australia. Report Number: 4901.0, Canberra, ACT: Australian Bureau of Statistics; 2003.

Babb P, Bird C, Bradford B, Burtenshaw S, Gardener D, Howell S, et al. Social focus in brief: children 2002. Report Number, Newport, UK: National Statistics UK; 2003.

Blangsted AK, Sogaard K, Christensen H, Sjogaard G. The effect of physical and psychosocial loads on the trapezius muscle activity during computer keying tasks and rest periods. Eur J Appl Physiol 2004;91:253–8.

Cook C, Burgess-Limerick R. The effect of forearm support on musculoskeletal discomfort during call centre work. Appl Ergon 2004a;35(4):337–42.

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 2004b;35:285–92.

Education and Manpower Bureau. Education statistics. Report Number, Hong Kong Special Administrative Region of The People's Republic of China, Hong Kong; 2003.

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

Grieg AM, Straker LM, Briggs A. Cervical erector spinae and upper trapezius muscle activity in children using different information technologies. Physiotherapy 2005;91:119–26.

Harris C, Straker L. Survey of physical ergonomics issues associated with school children's use of laptop computers. Int J Indus Ergon 2000;26(3):337–46.

Jacobs K, Baker NA. The association between children's computer use and musculoskeletal discomfort. Work 2002;18(3):221–6.

Juul-Kristensen B, Sogaard K, Stroyer J, Jensen C. Computer users' risk factors for developing shoulder, elbow and back symptoms. Scand J Work Environ Health 2004;30:390–8.

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 Indus Ergon 1999;23:157–69.

Karlqvist L, Tornqvist EW, 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 Indus Ergon 2002;30:277–94.

Laeser K, Maxwell L, Hedge A. The effect of computer workstation design on student posture. J Res Comput Educ 1998;31(2):173–88.

Marcus M, Gerr F, Monteilh C, Ortiz DJ, Gentry E, Cohen S, et al. A prospective study of computer users: II. Postural risk factors for musculoskeletal symptoms and disorders. Am J Indus Med 2002;41:236–49.

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

Oates S, Evans GW, Hedge A. An anthropometric and postural risk assessment of children's school computer work environments. Computer School 1998;14(3):55–63.

Rempel DM, Krause N, Goldberg R, Benner D, Hurdes M, Goldner GU. A randomised controlled trial evaluating the effects of workstation interventions on upper body pain and incident musculoskeletal disorders among computer operators. Occup Environ Med 2006;63:300–6.

Roberts DL, Foehr UG, Rideout V. Generation M. Media in the lives of 8–18 year olds. Report Number: 7521, Menlo Park (CA): The Henry J. Kaiser Family Foundation; 2005.

Royster L, Yearout R. A computer in every classroom – are schoolchildren at risk for repetitive stress injuries (RSIs)?. In: Lee GCH editor. Advances in occupational ergonomics and safety. Amsterdam: IOS Press; 1999. p. 407–12.

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

Sommerich CM, Ward R, Sikdar K, Payne J, Herman L. A survey of high school students with ubiquitous access to tablet PCs. Ergonomics 2007;50(5):706–27.
Straker L, Briggs A, Greig A. The effect of individually adjusted workstations on upper quadrant posture and muscle activity in school children. Work 2002;18(3):239–48.
Straker L, Burgess-Limerick R, Pollock C, Coleman J, Skoss R. The impact of computer display height and desk design on muscle activity during information technology work by young adults. J Electromyogr Kinesiol, in press. doi:10.1016/j.jelekin.2006.09.015.
Straker L, Burgess-Limerick R, Pollock C, Murray K, Netto K, Coleman J, et al. The impact of computer display height and desk design on 3D posture during information technology work by young adults. J Electromyogr Kinesiol 2008;18(2):336–49.
Straker L, Pollock C, Burgess-Limerick R. Towards evidence-based guidelines for wise use of computers by children. Int J Indus Ergon 2006a;36(12):1045–53.
Straker LM, Pollock CM, Mangharam JE. The effect of shoulder posture on performance, discomfort and muscle fatigue whilst working on a visual display unit. Int J Indus Ergon 1997;20:1–10.
Straker LM, Pollock CM, Zubrick SR, Kurinczuk JJ. The association between information and communication technology exposure and physical activity, musculoskeletal and visual symptoms and socio-economic status in 5-year-olds. Child Care Health Dev 2006b;32(3):343–51.
Szeto GPY, Straker LM, O'Sullivan PB. EMG median frequency changes in the neck-shoulder stabilizers of symptomatic office workers when challenged by different physical stressors. J Electromyogr Kinesiol 2005;13:544–55.
Westgaard RH, Winkel J. Guidelines for occupational musculoskeletal load as a basis for intervention: a critical review. Appl Ergon 1996;27(2):79–88.
Zandvliet DB, Straker LM. Physical and psychosocial ergonomic aspects of the learning environment in information technology rich classrooms. Ergonomics 2001;44(9):838–57.

Leon Straker is Director of Research at the School of Physiotherapy, Curtin University of Technology, Australia. He holds a BAppSc in Physiotherapy from the Western Australian Institute of Technology, a MSc in Ergonomics from University College London and a PhD in the area of occupational medicine from Sydney University. Professor 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 for manual task risk reduction.

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, Australia. 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 journal Ergonomics and was a Member of the Board of the Civil Aviation Safety Authority in her capacity as human factors expert.

Barbara Maslen is a post-doctoral researcher at the School of Physiotherapy, Curtin University of Technology. She has a MSc and a PhD in biomechanics from the University of Western Australia. Barbara's research currently includes the prevention of musculoskeletal disorders in children related to the use of computers.