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Children have less variable postures and muscle activities when using new electronic information technology compared with old paper-based information technology

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Abstract

Children now have considerable exposure to new information technologies (IT) such as desktop computers. A reported association between computer use and discomfort in children has prompted concerns about the musculoskeletal stresses associated with computer use. There were no detailed data on children reading and writing, nor any evidence on the variability of postures and muscle activity whilst children use IT.

Twenty-four children (10–12 years old; 12 male) performed a reading and writing task using new IT (computer/keyboard/mouse with high display and mid height display) and old IT (book/paper/pen). Spinal and upper limb 3D posture and muscle activity were recorded and estimates of mean and variation calculated.

The mean postures for children reading and writing with computers were more neutral than when they read and wrote with old IT. Similarly, mean muscle activity levels were lower during computer use than old IT use. However, new IT use also resulted in less variable, more monotonous postures and muscle activities. Moderate di erences in computer display height had little e ect on posture and muscle activity variation.

Variation in musculoskeletal stresses is considered an important component of the risk of musculoskeletal disorders. Children should therefore be encouraged to ensure task variety when using new IT to o set the greater posture and muscle activity monotony.

Keywords: Computer; Musculoskeletal disorder; Variation; Posture; Muscle activity; Children

1. Introduction

Children have significant exposure to information technology (IT), from the paper/book-based technology still used for much of the school day, through to desktop and laptop computers and computer-driven, interactive technology such as electronic games, MP3 players and mobile phones. This new IT accounts for a significant part of many children's leisure time, with children in the USA spending more than an hour on a computer and 49 min playing console games on average each day (Roberts et al., 2005) in addition to school computer use.

Hours of school computer use by children can vary widely. Ramos et al. (2005) found that a sample of 476 New York schoolchildren aged 5–14 years only used computers at school once per week, for 0.5–1 h. In contrast, two Singaporean schools converted a whole year group to tablet computer-based education, with digitized texts, handwriting recognition software, and electronic submission and retrieval of school work providing an almost paperless educational programme (SRI International, 2005). Australian students at schools with mandatory

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laptop computer programmes reportedly spent an average of 3.2 h per school day and 16.9 h per week using their laptop (Harris and Straker, 2000). It is clear that many children are spending considerable amounts of time using computers, at home, school or both.

Children also tend to use computers di erently from adults, adopting a wide variety of postures in addition to desk sitting (Harris and Straker, 2000; Ramos et al., 2005) and using several forms of technology simultaneously (Ramos et al., 2005; Roberts et al., 2005). In common with adult populations however, there is evidence that IT use is associated with musculoskeletal discomfort in children (Harris and Straker, 2000; Ramos et al., 2005).

Early research on children's posture at school focussed on old IT use (books, pen/paper). Danish school children were reported to spend 57% of their seated time interacting with old IT in a forward flexed posture (reading or writing) (Storr-Paulsen and Aagard-Hensen, 1994). Mandal (1982) reported that school furniture appeared to be designed for the backward leaning posture, rather than the forward leaning posture that children adopted during written work. No muscle activity or other variables were measured explicitly, however it was suggested that a forward declined seat would result in a more upright posture. The posture and muscle activity of ten young children performing tracing tasks whilst seated at a traditional workstation and one with a forward declined seat was later studied by Marschall et al. (1995). Latissimus dorsi activity was lower for the new workstation, together with a tendency for a reduction in neck flexion. Based on the standard deviations, the authors stated that the variability of neck flexion was high for both workstations.

More recent research has focussed on posture and muscle activity during new IT use by children. The posture of North American children (8–12 years) working at their usual non-adjustable school workstations was assessed by Oates et al. (1998). All 95 children were found to be working in postures classified as either 'unacceptable' or 'at risk of injury' based on a posture observation rating scale. Laeser et al. (1998) using the same rating scale, determined that children's working postures could be improved with the use of an adjustable workstation with a tiltdown keyboard.

The first detailed comparison of posture and muscle activity of children reading from both old (book) and new (laptop and desktop computers) IT was conducted on Australian children (Briggs et al., 2004; Greig et al., 2005; Straker et al., 2002). The greatest deviation from resting posture occurred when reading from the book, whilst greatest EMG amplitudes were observed whilst using the laptop. Adjustment of the desktop computer workstation to conform to the dimensions of the child actually resulted in higher cervical erector spinae (CES) activity and increases in head tilt and neck flexion, however, the head and neck postures with the adjusted workstation were closest to resting posture and there was a trend for a reduction in upper trapezius activity. A limitation of this study was that children did not interact fully with the IT, as the task involved only reading with no data input. The authors questioned the assumption that a more flexed posture was more stressful for the musculoskeletal system, and proposed that variation of posture may be of importance to minimise postural and visual strain.

The idea that variation in posture and muscle loading may be of importance for the prevention of musculoskeletal disorders is not a recent hypothesis (see review by Westgaard and Winkel, 1996). However, exposure variables other than amplitude, usually have not been considered in studies of workstation e ects. This narrow focus may contribute to the lack of correspondence between epidemiological studies and the predicted e ects of more flexed postures and higher muscle activity amplitudes. Epidemiological studies of computer display height typically show fewer musculoskeletal disorders with a lower display (Fostervold et al., 2006; Marcus et al., 2002) however, a lower display is associated with a more flexed spine and greater CES activity (Sommerich et al., 2001; Straker and Mekhora, 2000; Turville et al., 1998) – factors which may be expected to increase rather than decrease musculoskeletal stress. A reliance on load amplitudes alone is critiqued by Treaster et al. (2006). These authors proposed that traditional ergonomic models, whereby load magnitude predicts injury, are unlikely to apply to computer work because of its sustained, low load level.

Knowledge relating to musculoskeletal stress during use of IT by children is lacking. The di erences between old and new IT are not well understood. The mean amplitudes of posture and muscle activity during computer use have been the subject of considerable research in adults, however, changes in these variables do not correlate well with epidemiological data relating to musculoskeletal disorders. Interventions for adults have emphasised trying to reduce already small muscle activity amplitudes rather than accounting for other exposure parameters which may describe the sustained nature of the activity and variation in load. There is very little evidence regarding posture and muscle variation during IT use by adults, and no reports on children. Children are using computers more frequently and for longer durations, and may use them differently from adults, hence it is important to specifically address the e ects of IT use for this population.

The main aim of the current study was therefore to compare the variation in posture and muscle activity whilst children used new and old IT. The secondary aim was to compare the variation in posture and muscle activity of different computer display heights.

2. Methods

2.1. Study design

The study used a quasi-experimental, within-subjects design, with the IT type forming the independent variable. IT type comprised three levels that were representative of real world conditions experienced by school children using new (desktop computer) and old (pen and paper) IT: (1) high – centre of electronic display set at participant's eye height, (2) mid – bottom of display was 100 mm above the desk surface, (3) book – a book (285 225 mm) and A4 size paper were placed flat on the desk surface. For the new IT conditions, the keyboard and mouse were placed at the front edge of the desk, central to the child.

For all display conditions a standard, height-adjustable o ce chair with no arm rests (Burgtec, Perth, WA) was adjusted to the individual's popliteal height, using a footrest if required. The rectangular desk (1020 mm wide 450 mm deep) was set at the participant's sitting elbow height. An adjustable height display arm was used to position the thin film transistor display (38 cm, model LM520, AOC, Fremont, CA, USA) at the correct height for the high and mid conditions. The display was turned away during the book condition. The same keyboard (model KM-2601, Turbostar, China) and mouse (optical wheel mouse, Microsoft, Washington, USA) were used for all computer conditions.

2.2. Participants and experimental protocol

Twenty-four children (12 male) aged between 10 and 12 years participated in the study. Participants were recruited through personal contact and advertisements placed in local and community newspapers. Children were excluded from the study if they had a history of neck or shoulder disorders or pain, or were currently experiencing musculoskeletal discomfort. All participants were right-hand dominant and had normal or corrected-to-normal vision. Each child 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 (see Table 1). Level of typing skill and typing style were assessed using a standardised typing test (TypeMaster Pro, TypingMaster Inc., Helsinki, Finland) and hypermobility was assessed using Beighton's scale. Characteristics of the subjects are summarized in Table 1. The study was approved by the Human Research Ethics Committee of Curtin University of Technology.

A 10 min task was completed in each of the three IT conditions. The task required reading from electronic (with navigation by mouse) or paper versions of an 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, during which they performed no set activity and generally socialized with research team. Equivalent forms of the general knowledge activities were developed from CD and book versions of the same history encyclopedia (the Dorling Kindersley History of the World, Plantagenet, Somerset Fry.) A balanced ordering of conditions and activity sheets was utilised. The study was conducted in a climate and lighting controlled motion analysis laboratory.

2.3. Postural variables

Three-dimensional posture of the head, neck, torso and upper limbs was assessed using a 7-camera, infra-red motion analysis system (Peak Motus version 8; Peak Performance Technologies Inc., Centennial, CO, USA). Spherical or semi-spherical retro-reflective markers were placed bilaterally over the following skeletal landmarks: outer canthus, tragus, posterior acromial shelf, lateral humeral epicondyle, midpoint between the radial and ulnar styloid processes, third metacarpal head, femoral greater trochanter, spinous processes of C7 and T3, and the suprasternal notch. Markers were also placed on the four corners of the desk and display. Spinal and upper limb postures were characterised using the angles defined in Table 2. Data were sampled at 50 Hz and smoothed using a Butterworth filter (cut-o frequency 4 Hz). Angles (referenced to the vertical for sagittal and coronal angles, and the anterior sagittal plane for transverse angles) over the last 2 min of data collection were utilized for the current analysis as the PEAK system could only collect this volume of data.

Table 2
Angle definitions

Angle	Angle described by
Gaze angle	Centre of display or desk, cyclops[a] and horizontal axis
Head flexion	Cyclops, OC1[b] and vertical axis
Head lateral bending	Cyclops, OC1 and vertical axis (negative to the left)
Head rotation	Cyclops, OC1 and anterior axis (negative to the left)
Neck flexion	OC1, C7 and vertical axis in the sagittal plane
Neck lateral bending	OC1, C7 and vertical axis in the frontal plane
Cranio-cervical angle	Cyclops, OC1 and C7
Cervico-thoracic angle	OC1, C7 and T3
Trunk flexion	C7, mid-trochanter and vertical axis
Trunk rotation	T3, C7 and anterior axis
Scapula elevation	Acromion, C7 and vertical axis
Scapula protraction	Acromion, C7 and lateral axis
Arm flexion	Lateral humeral epicondyle, acromion and vertical axis
Arm abduction	Lateral humeral epicondyle, acromion and vertical axis in the frontal plane

[a] Cyclops = midpoint of outer canthi, calculated by analysis software.
[b] OC1 = midpoint of the tragi, representing the head/neck joint.

Table 1
Subject characteristics

	Females	Males	All
Age [years, mean (s.d.)]	11.7 (0.7)	11.5 (0.9)	11.6 (0.8)
Height [cm, mean (s.d.)]	154.0 (10.6)	155.7 (8.9)	154.9 (9.5)
Weight [kg, mean (s.d.)]	44.4 (5.7)	43.1 (6.9)	43.7 (6.3)
Hypermobility [Beighton median (range)]	3.7 (0–10)	1.9 (0–6)	2.8 (0–10)
Typing net speed [words/min, mean (s.d.)]	19.5 (7.8)	14.5 (7.3)	16.9 (7.8)
Typing accuracy [%, mean (s.d.)]	91.2 (14.1)	81.0 (13.8)	85.9 (14.6)
Typing style [number of fingers used, mean (s.d.)]	4.4 (1.5)	3.1 (1.2)	3.7 (1.5)
Age started using computers [years, mean (s.d.)]	5.0 (1.8)	5.8 (2.3)	5.4 (2.1)

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. Prior to application of the electrodes the skin was thoroughly prepared by shaving, lightly abrading and cleaning with surgical spirits. Impedances were checked after electrode attachment and only values of <5 kX were deemed acceptable. 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) using standard locations determined by palpation (Straker et al., 2006). The electrodes remained on the skin throughout all task and rest conditions.

In order to permit amplitude normalisation of sEMG data, participants performed three maximum voluntary exertions (MVEs) in a custom-made dynamometer for each of the muscle groups assessed using previously described protocols (Straker et al., 2006). MVE involved isometric contractions for 5 s. The strain gauge and sEMG were connected to a computer display, providing biofeedback for the participant in order to elicit a maximal contraction. Further, verbal encouragement was provided by the tester.

Data acquisition was controlled using a customised software program (LabView V7 , National Instruments, Austin, 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 di erential amplifiers (common mode rejection ratio: 115 dB). The root mean square (RMS) value over the final 2 min of each trial was normalised to the appropriate MVE before being used for statistical analysis. MVE sEMG had good inter-trial reliability (ICCs 0.718–0.920).

2.5. Variability

Variability of posture and muscle activity was analysed using two parameters: the amplitude probability distribution function (APDF, Jonsson, 1978) and exposure variation analysis (EVA, Mathiassen and Winkel, 1991). The di erence between the 90th and 10th percentiles of the APDF provides a measure of the amplitude range ($APDF_{(90–10)}$). A greater variability of posture or muscle activity is associated with a larger $APDF_{(90–10)}$ as this reflects a more substantial change in postural angle or muscle activity. The EVA matrix expresses variation over time for each postural or muscle activity variable as a three-dimensional distribution, with intensity and duration intervals along the x and y axes, respectively, and relative accumulated time along the z axis. There were ten amplitude categories for posture (each representing 10% of the usual range of motion, for example 40–46 , 46–52 , 52–58 , etc. for neck flexion) and seven for EMG (0–1%, 1–3%, 3–7%, 7–15%, 15–31%, 31–63% and >63% MVE). Seven period categories were utilised for both EMG and posture (0–1, 1–3, 3–7, 7–15, 15–31, 31–63 and >63 s). Exposure variation analysis thus describes both the amplitude and duration of variation. A standard deviation of the EVA matrix ($EVA_{(s.d.)}$) was used as a simple summary of variation for statistical analysis (O'Sullivan et al., 2006). A larger $EVA_{(s.d.)}$ indicates that more time was spent within a particular intensity/duration class, and therefore reflects greater monotony of posture or muscle contraction.

2.6. Statistical analysis

Statistical analysis was conducted using SPSS for Windows version 13 (SPSS Inc., Chicago, IL) using data from the last 2 min of each trial. A critical alpha level of 0.01 was used to balance family-wise error and power. The two aims were tested using a repeated measures analysis of variance (ANOVA) with pairwise contrasts. Huynh–Feldt epsilon corrections were used if Mauchly's test indicated lack of sphericity.

3. Results

3.1. Mean posture and muscle amplitudes

Children using new IT sat with more neutral spinal postures and more neutral upper limb postures than when using old IT (Table 3). Head and neck flexion both increased as the gaze was lowered from high to mid to book display. Corresponding reductions were evident in craniocervical and cervicothoracic angles. Trunk angles did not vary significantly as a result of IT type. Right scapula protraction and bilateral arm flexion were markedly greater with old IT.

Mean muscle activity during old IT use also tended to be greater than during computer use (Table 3), with the book condition associated with greater muscle activity than both high and mid displays for bilateral CES and left UT. A nonlinear relationship was evident for right UT and left TES, with the mid display showing lower activity for these muscle groups compared to book, but no di erence evident between book and high displays.

3.2. $APDF_{(90–10)}$

The $APDF_{(90–10)}$ measured during children's use of new and old IT is summarised in Table 4. There were significant di erences in most spinal and upper limb kinematic and muscle activity parameters, with a greater range of posture and muscle activity during old IT use than during new IT use. No $APDF_{(90–10)}$ significant di erences existed between high and mid display conditions.

3.3. $EVA_{(s.d.)}$

The $EVA_{(s.d.)}$ measured during children's use of new and old IT is summarised in Table 5. The significant di erences in most spinal and upper limb kinematic parameters reflected less monotony (more variation) of posture during old IT use than during new IT use. The e ect of IT type on muscle activity $EVA_{(s.d.)}$ was less marked than for $APDF_{(90–10)}$, with a lower monotony of right UT activity evident during book use compared to a high display, and trends for reduced monotony of left TES and RWE with old IT use. As per the APDF results, no di erences in $EVA_{(s.d.)}$ were evident between high and mid displays, suggesting that the monotony of posture is similar across the two new IT conditions.

Table 3
Mean posture ( ) and muscle activity (% maximum voluntary exertion) for three IT conditions

	High	Mid	Book	F	p[A]
Posture					
Gaze angle[B]	10.8 (0.6)[a]	15.7 (0.8)[b]	56.7 (1.4)[c]	2046.7	<.001
Head flexion	69.7 (1.7)[a]	80.3 (1.6)[b]	103.7 (2.4)[c]	108.2	<.001
Head lateral bending[B]	0.3 (0.9)	0.1 (1.0)	0.4 (1.6)	0.2	.796
Head abs. lat. bend	3.4 (0.6)	3.5 (0.6)	5.6 (1.0)	2.9	.068
Head rotation[B]	0.4 (0.9)	1.7 (0.9)	2.0 (2.9)	1.1	.315
Head abs. rotation	2.9 (0.6)[a]	3.8 (0.6)[ab]	9.7 (1.9)[b]	8.9	.003
Neck flexion	48.6 (1.3)[a]	52.2 (1.6)[b]	69.2 (1.9)[c]	96.8	<.001
Neck lateral bending[B]	0.9 (0.9)	0.4 (0.8)	2.2 (2.0)	1.7	.206
Neck abs. lat. bend	3.1 (0.6)	3.0 (0.4)	6.7 (1.4)	5.7	.018
Cranio-cervical angle	158.4 (2.1)[a]	151.8 (2.1)[b]	145.2 (1.9)[c]	21.3	<.001
Cervico-thoracic angle	152.3 (1.2)[a]	149.0 (1.6)[a]	142.8 (1.3)[b]	25.4	<.001
Trunk flexion	22.3 (2.1)	19.2 (1.6)	16.2 (1.4)	1.1	.334
Trunk rotation	2.3 (1.7)	1.7 (0.9)	2.7 (2.1)	3.3	.049
Scapula elevation R[B]	83.4 (2.1)	83.3 (1.2)	84.4 (1.4)	0.2	.763
Scapula elevation L[B]	83.7 (2.0)	85.0 (1.4)	86.7 (1.8)	1.8	.188
Scapula protraction R[B]	11.1 (1.2)[a]	11.5 (1.0)[a]	18.4 (2.3)[b]	13.8	<.001
Scapula protraction L	14.3 (2.1)	14.1 (1.4)	14.2 (1.8)	<0.1	.993
Arm flexion R[B]	0.3 (1.4)[a]	1.0 (2.1)[ab]	10.5 (3.4)[b]	6.4	.009
Arm flexion L	9.9 (3.4)[ab]	4.1 (2.3)[a]	15.5 (2.6)[b]	6.3	.004
Arm abduction R[B]	28.3 (1.4)	28.0 (1.4)	28.4 (1.9)	<0.1	.964
Arm abduction L	24.3 (2.5)	25.5 (2.0)	23.8 (1.9)	0.1	.871
Muscle activity					
Cerv. erector spinae-R	10.6 (1.0)[a]	12.7 (1.4)[a]	18.5 (1.3)[b]	14.6	<.001
Cerv. erector spinae-L	10.3 (0.7)[a]	12.8 (1.1)[a]	21.7 (1.8)[b]	40.2	<.001
Upper trapezius-R	14.8 (1.7)	12.0 (1.4)	14.8 (1.7)	4.3	.019
Upper trapezius-L	12.2 (1.5)[a]	10.6 (1.3)[a]	16.5 (1.9)[b]	10.9	<.001
Thoracic erect. spin.-R[B]	10.0 (2.0)	10.0 (2.1)	9.2 (1.0)	<0.1	.915
Thoracic erect. spin.-L	7.4 (1.0)[ab]	6.7 (0.7)[a]	10.8 (1.2)[b]	7.4	.004
Anterior deltoid-R[B]	4.9 (1.7)	3.7 (0.9)	4.0 (0.6)	0.4	.542
Wrist extensors-R	10.1 (1.2)	9.2 (1.0)	12.3 (1.4)	4.1	.023

Mean (standard error) and summary of ANOVA results.
[a] or [b] or [c] Values with the same symbol do not di er statistically based on pairwise contrasts ($p > .01$).
[A] Alpha probability for RANOVA main e ect.
[B] Mauchly's sphericity = 0.

3.4. Examples of variation

Because the assessment of variability estimates is relatively new, it is useful to describe detailed examples of actual variability for individual children. The examples presented in Figs. 1–3 present data for individuals whose variation ($EVA_{(s.d.)}$) was close to the group mean values.

The time history of neck flexion for the last 2 min of the 10 min task is presented for one subject in Fig. 1a for the new (mid display) IT condition, and Fig. 1b for old IT. Corresponding EVA matrices are illustrated in Figs. 1c and d. When using a computer this individual tended to alternate between two postures, which are likely to correspond to viewing the display and the keyboard. All of the columns on the EVA matrix graph (Fig. 1c) are contained in the 40–58 intervals, reflecting the narrow range of neck flexion angles adopted by this participant during new IT use. Neck flexion during use of old IT shows much greater variation over time, both in the frequency of postural changes and the range of postural angles adopted. The EVA matrix for this condition (Fig. 1d) reflects this greater movement range, with columns spread from 52 to more than 100 . The greater amplitude range is also reflected in the corresponding $APDF_{(90–10)}$ values for this subject (7.3 for new IT, 24.6 for old IT). The frequency of postural changes is highlighted by the concentration of columns towards the front of the EVA matrix graph – none of the angular posture intervals was maintained for longer than 15 s at a time. In contrast, the columns for the new IT EVA matrix are concentrated towards the back of the graph and represent postures that were sustained for between 7.0 and 63.0 s. The height of the columns reflects the accumulated time within an intensity/duration class. For the new IT condition this participant maintained the neck at an angle between 46 and 52 for a considerable total accumulated time.

As the shoulder region is a frequent site of discomfort amongst computer users (Bergqvist et al., 1995; Marcus et al., 2002; Sillanpää et al., 2003), scapula elevation and upper trapezius muscle activity are important parameters for the assessment of musculoskeletal risk. Right scapula elevation for one subject is shown in Fig. 2 for both new (mid display) and old IT, together with the corresponding EVA matrices. The very monotonous scapula posture

Table 4
APDF$_{(90–10)}$ (90th–10th percentile of APDF) variability of posture ( ) and muscle activity (% maximum voluntary exertion) for three IT conditions

	High	Mid	Book	F	p[A]
Posture					
Gaze angle[B]	3.7 (0.5)[a]	3.2 (0.6)[a]	13.1 (2.7)[b]	11.5	.002
Head flexion[B]	25.1 (3.6)	16.9 (1.9)	32.6 (5.5)	4.3	.034
Head lateral bending[B]	8.4 (1.3)[a]	8.9 (1.3)[a]	27.1 (3.2)[b]	29.5	<.001
Head rotation[B]	11.9 (2.3)[a]	11.7 (0.8)[a]	53.2 (4.3)[b]	84.8	<.001
Neck flexion[B]	11.1 (1.6)[a]	10.9 (1.2)[a]	22.6 (2.0)[b]	21.9	<.001
Neck lateral bending [B]	7.4 (1.1)[a]	7.8 (1.0)[a]	25.6 (2.6)[b]	41.2	<.001
Cranio-cervical angle	17.0 (2.0)	14.6 (2.2)	14.6 (2.1)	0.6	.536
Cervico-thoracic angle	12.2 (1.7)	11.5 (1.5)	13.9 (1.6)	0.6	.578
Trunk flexion	5.9 (1.8)	8.7 (2.0)	7.3 (0.9)	3.3	.053
Trunk rotation	8.6 (1.6)[a]	10.1 (1.2)[ab]	18.4 (2.6)[b]	9.9	<.001
Scapula elevation-R[B]	7.2 (1.3)	6.0 (0.5)	10.0 (0.7)	5.0	.023
Scapula elevation-L	7.1 (1.2)[a]	6.0 (0.5)[a]	11.0 (1.0)[b]	21.4	<.001
Scapula protraction-R[B]	7.2 (0.7)[a]	8.3 (1.0)[a]	18.6 (2.5)[b]	16.9	<.001
Scapula protraction-L	8.3 (1.1)[a]	10.3 (1.4)[a]	17.7 (2.2)[b]	11.5	<.001
Arm flexion-R[B]	11.4 (1.3)[a]	14.5 (1.6)[a]	27.0 (2.7)[b]	20.0	<.001
Arm flexion-L	16.5 (2.7)[a]	21.5 (3.0)[a]	34.3 (3.5)[b]	12.7	<.001
Arm abduction-R[B]	10.3 (1.2)[ab]	10.6 (1.1)[a]	18.0 (2.7)[b]	7.1	.006
Arm abduction-L	11.6 (2.3)[a]	10.4 (1.6)[a]	20.3 (2.2)[b]	11.4	<.001
Muscle activity					
Cerv. erector spinae-R[B]	6.7 (0.8)	9.0 (2.1)	11.8 (1.1)	3.0	.079
Cerv. erector spinae-L[B]	6.4 (0.8)[a]	6.5 (0.6)[a]	12.3 (1.5)[b]	17.1	<.001
Upper trapezius-R[B]	12.4 (1.6)[ab]	12.3 (1.8)[a]	18.3 (2.5)[b]	7.1	.005
Upper trapezius-L	11.4 (1.8)[a]	9.7 (1.3)[a]	21.3 (2.3)[b]	16.0	<.001
Thoracic erect. spin.-R	9.6 (2.3)	8.3 (1.6)	9.6 (1.2)	0.2	.840
Thoracic erect. spin.-L[B]	5.2 (1.2)[a]	4.4 (0.6)[a]	11.6 (1.9)[b]	10.9	.001
Anterior deltoid-R[B]	5.3 (1.8)	3.9 (1.0)	4.9 (1.0)	0.5	.550
Wrist extensors-R	11.1 (1.2)[a]	9.6 (0.9)[a]	16.1 (2.0)[b]	12.2	<.001

Mean (standard error) and summary of ANOVA results.
[a] or [b] Values with the same symbol do not di er statistically based on pairwise contrasts ($p > .01$).
[A] Alpha probability for RANOVA main e ect.
[B] Denotes Mauchly's sphericity = 0.

during computer work by this individual is clearly evident for the 2 min period illustrated in Fig. 2a. As per neck flexion, a limited angular range over time is reflected by the narrow concentration of columns along the x-axis of the EVA matrix (Fig. 2c). Whilst the total range of scapula elevation was slightly greater during old IT use (a wider spread along the x-axis) the most striking di erence between the two conditions is the frequency of postural shifts. In contrast to the sustained scapula postures during new IT use (Fig. 2a: columns are towards the back of the EVA matrix graph, with a large accumulated time spent in one amplitude and the long, 30–60 s duration category), rapid changes of scapula angle are evident during old IT use (Fig. 2b). The concentration of the columns towards the front of the EVA matrix (Fig. 2d) reflects postures which were sustained for only brief intervals.

Exposure variation analysis provides a useful tool for muscle activity in addition to posture analysis. Variation of RUT muscle activity is illustrated in Fig. 3 for one individual. Due to the high sampling rate, only the first 30 s of data is shown for the sEMG time histories (Figs. 3a and b) however, data for the full 2 min were used in the analysis and the complete 2 min period is illustrated in the EVA matrices (Figs. 3c and d). The less monotonous muscle activity during the old IT condition is clearly evident. A greater relative amplitude of muscle activity for old IT is also apparent, as reported in the mean data (Table 3). However, the variability in muscle activity over time may help to o set any adverse e ects of this higher load. Muscle activity during new IT use is very sustained (Fig. 3a) and this is reflected in the EVA matrix (Fig. 3c) by a narrow range of amplitudes (primarily between 1% and 7% of MVE – note that this full range is not apparent in Fig. 3a because only a portion of the time history is presented, as described previously). The highest columns are concentrated towards the back of the EVA matrix (Fig. 3c), reflecting the sustained intensity of muscle activity. The EVA matrix for the old IT condition is more uniform, with variation in both amplitude range and the duration for which each intensity is maintained.

4. Discussion

4.1. Old versus new IT

Given the increasing usage of new IT by children it is important to understand any associated repercussions for the musculoskeletal system. More neutral postures and lower muscle loads occurred when using new IT compared

Table 5
$EVA_{s.d.}$ (exposure variation analysis matrix standard deviation) variability of posture ( ) and muscle activity (% maximum voluntary exertion) for three IT conditions

	High	Mid	Book	F	p[A]
Posture					
Gaze angle	7.7 (0.5)[a]	8.6 (0.4)[a]	10.9 (0.2)[b]	16.1	<.001
Head flexion	4.3 (0.3)	3.9 (0.2)	3.4 (0.2)	2.6	.087
Head lateral bending	4.5 (0.2)[a]	4.5 (0.2)[a]	3.0 (0.1)[b]	29.5	<.001
Head rotation	4.1 (0.2)[a]	3.9 (0.1)[a]	3.1 (0.2)[b]	13.4	<.001
Neck flexion	4.9 (0.4)[a]	4.8 (0.3)[a]	3.5 (0.2)[b]	9.4	<.001
Neck lateral bending[B]	5.2 (0.4)[a]	4.6 (0.2)[a]	3.0 (0.1)[b]	25.8	<.001
Cranio-cervical angle	3.6 (0.2)	4.0 (0.4)	3.9 (0.3)	0.7	.516
Cervico-thoracic angle	5.0 (0.4)	4.6 (0.3)	3.8 (0.1)	4.3	.020
Trunk flexion	7.8 (0.6)	8.1 (0.6)	7.0 (0.6)	1.8	.185
Trunk rotation	5.4 (0.4)[a]	4.7 (0.4)[a]	3.4 (0.1)[b]	8.4	.001
Scapula elevation-R	6.1 (0.3)[a]	5.4 (0.2)[a]	4.4 (0.2)[b]	13.4	<.001
Scapula elevation-L	6.0 (0.4)[a]	5.9 (0.4)[a]	4.4 (0.2)[b]	9.4	.001
Scapula protraction-R	5.6 (0.4)[a]	5.2 (0.2)[a]	4.0 (0.3)[b]	11.0	<.001
Scapula protraction-L	5.5 (0.4)[a]	4.8 (0.3)[ab]	4.0 (0.3)[b]	9.0	.001
Arm flexion-R	5.3 (0.4)	5.0 (0.4)	4.1 (0.3)	3.9	.028
Arm flexion-L	5.7 (0.4)	5.2 (0.4)	4.2 (0.4)	4.4	.019
Arm abduction-R	5.1 (0.4)[a]	4.6 (0.2)[ab]	3.8 (0.2)[b]	5.9	.005
Arm abduction-L	5.7 (0.4)[a]	5.4 (0.3)[a]	3.8 (0.2)[b]	15.3	<.001
Muscle activity					
Cerv. erector spinae-R	5.9 (0.3)	5.7 (0.2)	5.8 (0.3)	0.1	.920
Cerv. erector spinae-L	6.2 (0.3)	6.1 (0.3)	6.2 (0.4)	0.3	.779
Upper trapezius-R	5.5 (0.3)[a]	5.0 (0.2)[ab]	4.5 (0.1)[b]	6.1	.005
Upper trapezius-L	5.4 (0.3)	5.2 (0.2)	4.8 (0.3)	2.0	.153
Thoracic erect. spin.-R	5.5 (0.2)	5.2 (0.2)	5.0 (0.2)	2.2	.132
Thoracic erect. spin.-L	7.2 (0.4)	6.5 (0.3)	6.0 (0.3)	3.7	.033
Anterior deltoid-R	5.9 (0.3)	6.1 (0.4)	5.7 (0.3)	0.4	.663
Wrist extensors-R	5.2 (0.1)	5.2 (0.1)	4.8 (0.1)	5.1	.010

Mean (standard error) and summary of ANOVA results.
[a] or [b] Values with the same symbol do not di er statistically based on pairwise contrasts ($p > .01$).
[A] Alpha probability for RANOVA main e ect.
[B] Denotes Mauchly's sphericity = 0.

to old (pen and paper) IT in the current study. Based on amplitudes alone, a change to new IT may therefore be viewed as beneficial to the musculoskeletal system. However, any advantage may be o set by di erences in the variability. Considerably greater variation of spinal postures, upper limb postures and muscle activity was associated with the use of old IT in comparison to both of the new IT conditions. This is reflected in higher $APDF_{(90–10)}$ and lower $EVA_{(s.d.)}$ values for most variables (Tables 4 and 5).

The monotonous posture and muscle activity associated with new IT use may contribute to an increased musculoskeletal risk. The 'Cinderella hypothesis' proposed by Hagg (1991) postulates that continuous activation of certain motor units can occur during low-level muscle contraction, and recent research provides experimental support for this theory (Forsman et al., 2002; Zennaro et al., 2003). The development of 'trigger points' (areas of high irritability in muscle) has been shown to occur during computer work, suggesting that even low level static muscular exertions can damage muscle (Treaster et al., 2006). The lower amplitudes of muscle activity during new IT use may therefore be insu cient for o setting the monotonous posture and muscle activity associated with this task.

It should be noted that in many cases the muscle activity amplitudes during old IT use (Table 3) exceeded the limit of 10–14% MVE suggested by Jonsson (1978) for continuous work. Amplitudes during new IT use were also higher than those reported by previous researchers (Aaras et al., 1997; Sommerich et al., 2001; Turville et al., 1998). However the normalisation protocol employed in this study results in a conservative estimate of MVE, hence the task amplitudes appear to be high, as discussed in an earlier report (Straker et al., 2006). Further, as data was collected for only 2 min, some important aspects of variation may not have been detected in the current study. Whilst $EVA_{s.d.}$ and $APDF_{90–10}$ appear to be useful in characterising some aspects of variation, precisely which aspects of variation have important clinical implications are currently unknown. Further study could also investigate whether EMG indications of fatigue, such as median frequency and amplitude shift, are related to variability indices.

Previous researchers have tended to focus on the mean amplitudes of posture and muscle activity, with little attention being devoted to the monotony of the activity. However, the consideration of variation may have important clinical implications. Variation may o set poorer posture

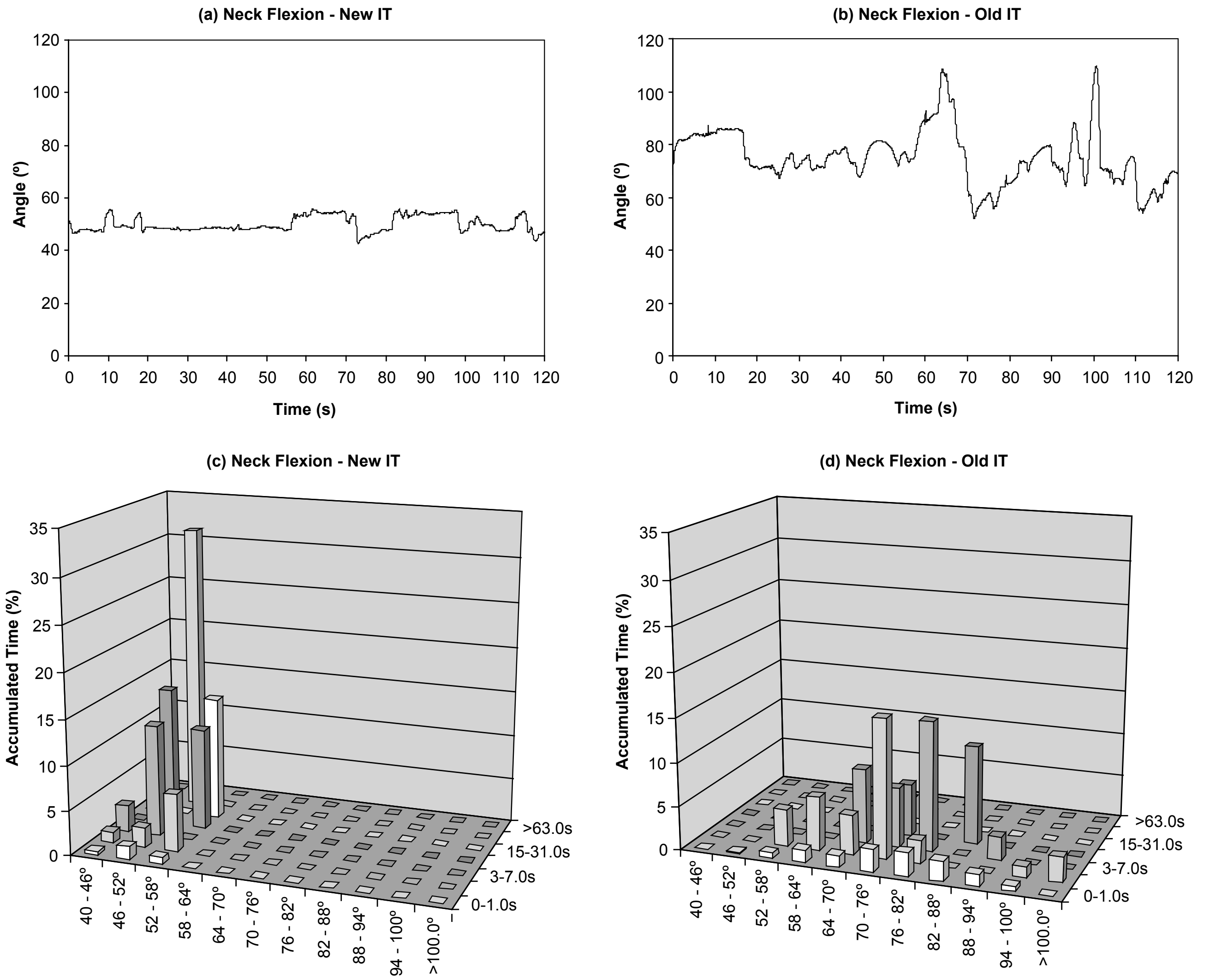

Fig. 1. Example of neck flexion during 2 min of using a computer with mid height display and book, paper and pen. Line graph shows neck flexion at 50 Hz and bar graph shows exposure variation analysis matrix with proportion of time spent in di erent amplitude and duration bands. Mean EVA standard deviations for this subject were 4.6 for computer and 3.1 for book and $APDF_{(90–10)}$ values were 7.3 and 24.6 , respectively.

and greater muscle activity and this may result in a lower risk of musculoskeletal disorder development.

In summary, the use of new IT was associated with more neutral mean postures and lower mean sEMG activity, but also less postural and muscle activity variation.

4.2. New IT display height

The e ect of display height on mean postures and muscle activity in adults has been recently reviewed (Straker et al., 2006; Straker et al., 2006). In the current study, results for children working with high and mid displays were consistent with adult results, with a more flexed head and neck posture with the lower display but limited alteration of trunk and upper limb postures. Muscle activity responses to changes in display height have been varied in previous research. An increase in CES activity has frequently been associated with viewing a lower display (Hagg, 1991; Sommerich et al., 2001; Turville et al., 1998; Villanueva et al., 1997) and a trend for this (p = .017) was evident for the left CES in the current study. Responses of the upper trapezius have been less consistent for both adults and children, with some studies reporting a reduction in upper trapezius activity with a lower display (Greig et al., 2005; Turville et al., 1998) and others no change (Fostervold et al., 2006; Straker et al., 2006). Our data show a trend for lower UT activity on right side (p = .017) with the mid display.

Based on musculoskeletal considerations the mean amplitude data from this and previous studies do not permit recommendation of one display height over the other, although visual preferences suggest some advantage for a lower display (Ankrum and Nemeth, 2000; Burgess-Limerick et al., 2000). It was hoped that the assessment of

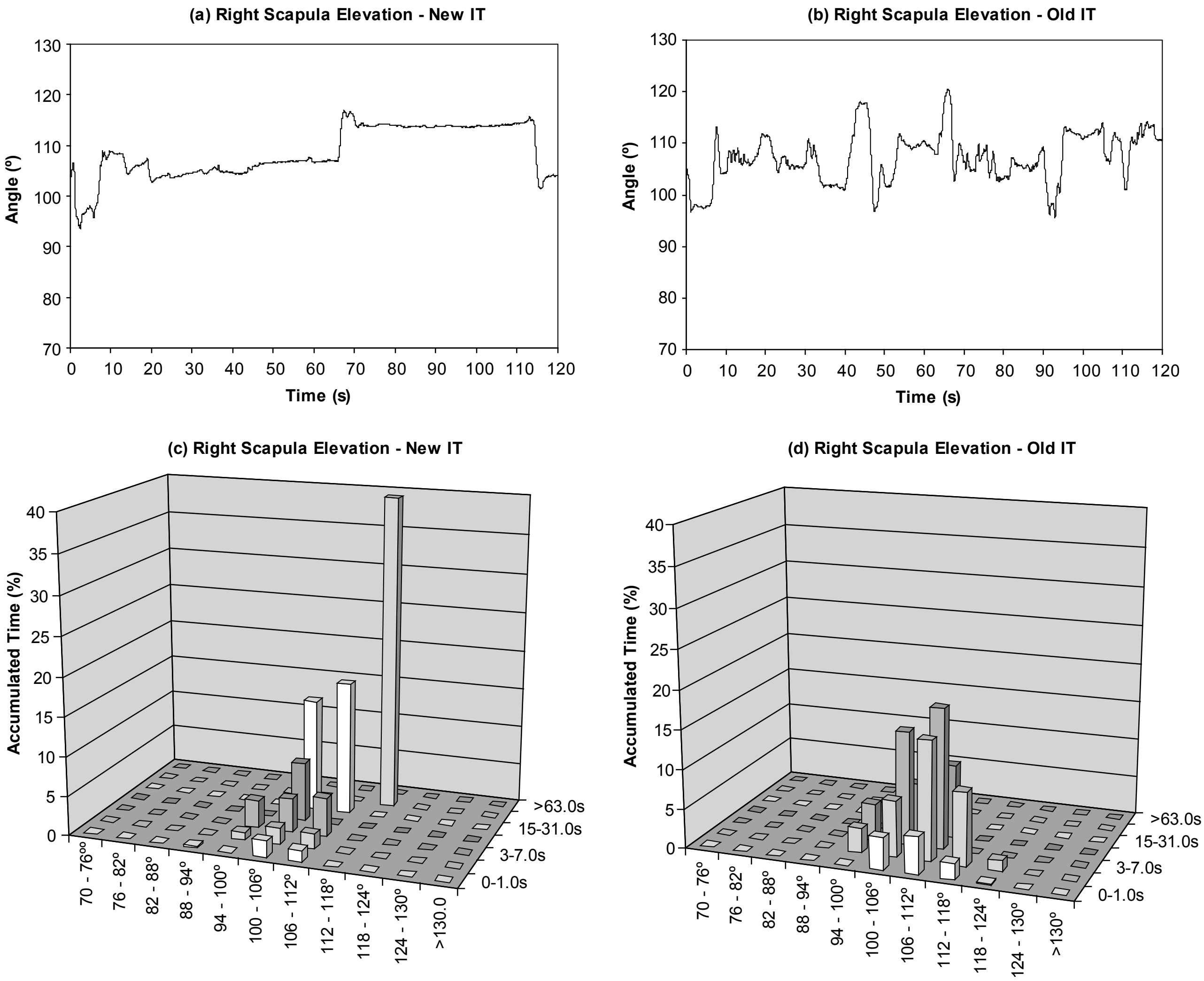

Fig. 2. Example of right scapula elevation during 2 min of using a computer with mid height display and book, paper and pen. Line graph shows scapula elevation at 50 Hz and bar graph shows exposure variation analysis matrix with proportion of time spent in di erent amplitude and duration bands. EVA standard deviations for this subject were 5.9 for computer and 4.1 for book and $APDF_{(90–10)}$ values were 10.4 and 11.2 , respectively.

exposure variation would di erentiate between conditions and assist with guidelines for workstation setup. However, the two new IT conditions were very similar for posture and muscle activity variability. There was a trend for a greater head flexion amplitude range with the higher display (Table 4; p = .016), which is consistent with the greater angular range between viewing the keyboard and display for this condition. A recent report on adults (Straker et al., 2006) found greater variability with the higher display also, but the postures were stereotypical and associated with looking either at the keyboard or the display. The similarity of exposure variation across most variables is consistent with previous adult research using di erent measures of variability. Turville et al. (1998) recorded no di erence in the number of posture shifts for display heights with gaze angles of 15 and 40 below horizontal and Fostervold et al. (2006) found no di erences in the number of periods where muscle amplitude was below 1% MVE for two display heights. It has been suggested that a lower display may provide the opportunity to move between a range of postures that were acceptable to both the musculoskeletal and visual systems (Ankrum and Nemeth, 2000) but current evidence, within our small range of display heights, does not support this hypothesis.

4.3. Comparison with adult data

A preliminary comparison of data from the 10–12-year-old children in this study with an earlier adult population performing the same tasks (Straker et al., 2006; Straker et al., 2006) suggests that children may have more variable postures and muscle activity whilst interacting with IT. For example, children had amplitude ranges of 17 and 33 for head flexion whilst using new (mid display) and old IT, respectively, with corresponding values of only

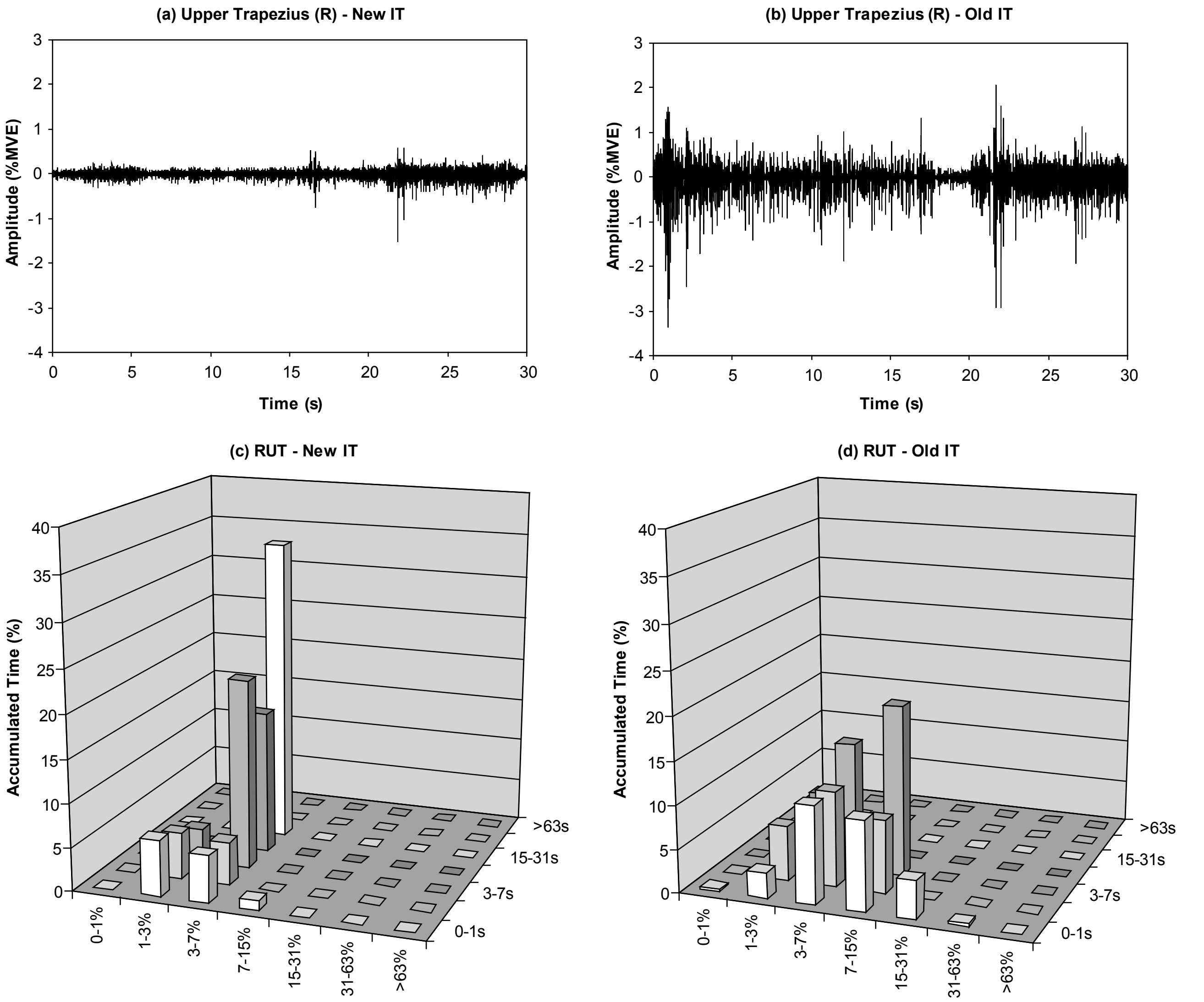

Fig. 3. Example of right upper trapezius activity during 2 min of using a computer with high display height and book, paper and pen. Line graph shows trapezius activity for 30 s at 1000 Hz and bar graph shows exposure variation analysis matrix for 2 min with proportion of time spent in di erent amplitude and duration bands. EVA standard deviations for this subject were 6.2 for computer and 4.4 for book and $APDF_{(90–10)}$ values were 2.7% and 10.7% MVE, respectively.

11 and 18 for adults. Right scapula elevation APDF ranges were 6 for children and 3 for adults with the mid display. Muscle activity followed a similar trend, with children having higher mean values for bilateral CES and UT with both old and new IT. For example, RUT activity amplitude ranges were 18% MVE for children and 16% MVE for adults during old IT use and 12/9% MVE with new IT. The $EVA_{(s.d.)}$ values followed a similar pattern, with children showing lower mean values (greater variability) for many postural and muscle activity variables.

A limitation of this comparison is that while the tasks for the adults and children were identical, di erent actual display heights were used in the two studies. At least part of the di erence in exposure variation between the two groups could therefore be related to these gaze angle di erences. Further investigation is clearly warranted. Task variation is certainly something that should be encouraged in children, as there is evidence to suggest that many children continue to use technology in situations that are causing discomfort (Harris and Straker, 2000).

5. Conclusion

Children in a uent communities now have considerable exposure to new IT such as desktop computers. A reported association between computer use and discomfort in children has prompted concerns about the musculoskeletal stresses associated with computer use.

This study found mean postures for children reading and writing with computers to be more neutral than when they read and wrote with old paper-based IT. Similarly, mean muscle activity levels were lower during computer use than old IT use. However, new IT use also resulted in less variable, more monotonous postures and muscle activities. Moderate di erences in computer display heights appeared to have little e ect on posture and muscle activity variation. Children appear to show more variation in posture and muscle activity when performing the same IT tasks as adults.

Variation in musculoskeletal stresses is considered an important component of the risk of musculoskeletal disorders. Children should therefore be encouraged to maintain their greater variation, and be especially vigilant in ensuring task variety when using new IT, to o set the greater posture and muscle activity monotony.

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