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ORIGINAL ARTICLE

Examining the low, high and range measures of muscle activity amplitudes in symptomatic and asymptomatic computer users performing typing and mousing tasks

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Abstract Past studies on work-related musculoskeletal disorders (WMSD) have reported increased median muscle activities in terms of 50th% of amplitude probability distribution function (APDF), and this was thought to be a manifestation of altered motor control—an important mechanism contributing to WMSD. The present study aimed to examine whether such altered motor control was also present in other parameters of APDF—the 10th and 90th% values, which can be considered indicators of the low and high measures of muscle activity. The difference between 10th and 90th% APDF can be considered an indicator of the variation in muscle activity amplitude (the "APDF range"). Surface electromyography was examined in female office workers as Case ($n = 21$) and Control ($n = 18$) subjects. The APDF variables were measured in cervical erector spinae (CES) and upper trapezius (UT) muscles during typing, mousing and type-and-mouse, for 20 min each. The Case Group had significantly higher CES activity in the 10th, 90th% and APDF range compared to Controls. The UT muscles showed similar trends but the between-group differences were not statistically significant. These results have demonstrated the *robustness* of the APDF variables as sensitive indicators of motor control variations in symptomatic subjects with musculoskeletal disorders.

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Introduction

The relationship between surface electromyography (sEMG) and work-related musculoskeletal disorders (WMSD) has been the focus of considerable research in occupational biomechanics and ergonomics. Among the factors that influence the development of WMSD, sustained activities in major stabilising muscles of the neck and shoulder region associated with prolonged static posture have been found to be important (Aarås and Ro 1999; Bansevicius et al. 1997; Kleine et al. 1999; Szeto et al. 2005a, b, c, d, e). Recent research has provided mounting evidence supporting the important contribution of altered muscle activation patterns in symptomatic computer users (Szeto et al. 2005a, b, c, d, e). These studies found that symptomatic computer users had increased muscle activation which was apparent across a number of different conditions such as typing for a prolonged duration, typing with increased speed and typing with increased force. Other studies have also reported increased muscle activity amplitude and less muscular rest time in single motor units in symptomatic computer users (Hägg and Astrom 1997; Thorn et al. 2007). There is also similar evidence emerging from clinical research on patients with different types of chronic neck pain due to traumatic injuries or work-related problems, with increased muscle activity in symptomatic patients compared to asymptomatic controls (Falla et al. 2004; Madeleine et al. 1999; Nederhand et al. 2003).

A vast amount of research has reported on different aspects of the surface electromyographic (sEMG) activity in the neck and shoulder muscles. The 10th, 50th and 90th percentile (%) values of the amplitude probability distribution function (APDF) have been widely used as indicators of low, middle and high levels of muscle activity amplitude in studies of real or simulated occupational tasks. Jonsson (1982) proposed that different types of work could be characterized by their APDF profiles. He also suggested a set of "acceptable limit values" for performing constrained work for 1 h: that the 10th% APDF should be below 2–5% of Maximum Voluntary Contraction (MVC), the 50th% APDF below 10–14% MVC, and the 90th% APDF below 50–70% MVC (Jonsson 1982; Jonsson et al. 1988). However the evidence for the validity of Jonsson's thresholds is mixed (Aarås et al. 1997; Roe et al. 2001; Vasseljen and Westgaard 1995; Westgaard et al. 2001).

There have been different viewpoints regarding the usefulness of the different levels of muscle activity amplitude as indicators or predictors of musculoskeletal stress. The 10th% APDF has been considered important for risk associated with sedentary work such as computer tasks, as it reflects the near continuous muscle load in postural stabilizing muscles such as the trapezius (Aarås et al. 1997; Holte and Westgaard 2002). Veiersted et al. (1990); Westgaard et al. (2001) reported a correlation between the 10th% level of muscle activity and musculoskeletal symptoms in different occupational groups, but other studies have reported no significant relationship (Roe et al. 2001; Vasseljen and Westgaard 1995; Nordander et al. 2000). Past studies have used 50th% APDF (median) as an indicator of the average muscle activity in performing work tasks throughout the work period (Aarås et al. 1997; Blangsted et al. 2003; Dennerlein and Johnson 2006; Holte and Westgaard 2002; Szeto et al. 2005a, b, c, d, e). Very few studies have examined the 90th% APDF in detail, yet this figure may also be an important risk indicator (Hansson et al. 2000; Nordander et al. 2000; Sandsjo et al. 2000).

Some studies reported both low and median levels of APDF (Blangsted et al. 2003; Holte and Westgaard 2002; Thorn et al. 2007; Westgaard et al. 2001) or all three levels of APDF (Dennerlein and Johnson 2006; Nordander et al. 2000; Sandsjo et al. 2000). Aarås et al. (1996) commented that both the 10th% and median loads of the trapezius muscles were stable and reliable measures of muscle activity which showed appropriate changes to different loading situations such as performing computer work with and without forearm support and on repeated measures on different days. Other researchers also found that the three APDF levels were sensitive measures to express the exposure or load performed by muscles in different tasks. Nordander et al. (2000) reported four different levels of APDF (10th, 50th, 90th and 99th%) values of trapezius activity in cleaners and office workers, and reported consistent patterns of differences between female cleaners and office workers, but the association of EMG measures and pain was weak due to large individual variations. In these earlier studies, the focus of research appeared to be examination of the APDF variables under different task conditions and determining whether these amplitude measures could be used as factors to predict the risk of WMSD.

Only a few studies have examined different levels of APDF comparing symptomatic and asymptomatic individuals. Sandsjo et al. (2000) compared 10, 25, 50, 75, and 90th% APDF between cashiers with and without pain, in the trapezius muscle on both the dominant and non-dominant sides while performing case-register work. The dominant side of the painful group showed consistently higher activity in the low and median measures, but the 75th and 90th% APDF were lower in the painful group. On the non-dominant side, muscle activation was higher in the painful group across all percentiles. Westgaard et al. (2001) reported no difference in low and high amplitude measures between painful and non-painful subjects in a field study of shopping centre assistants and healthcare workers. One reason for the conflicting evidence may have been the lack of control over work tasks performed, which can be a significant factor contributing to the between-subject differences in muscle activation. Dennerlein and Johnson (2006) reported all three levels of APDF measures when subjects performed different computing tasks but they were all painfree healthy subjects. Thorn et al. (2007) compared EMG in female elderly symptomatic and asymptomatic office workers while performing controlled computer tasks, but the focus was on examining the relationship between EMG gaps and the low amplitude measure of 10th% APDF.

While some studies have reported multiple levels of APDF, the relationships between the different levels have not been adequately investigated in comparisons of pain and non-pain subjects. The difference between the 10th% APDF and 90th% APDF may be particularly useful as it represents the extent of variation from low activity to high activity amplitudes—the range in the muscle amplitude that is being employed to control the movement in the task. This factor may be an important component in motor control as lack of variability has been considered a risk factor for WMSDs (Madeleine et al. 2008; Mathiassen 2006). Madeleine et al. (1999, 2008) reported decreased variability in muscle activity in chronically painful subjects performing meat-cutting tasks, with variability measured in terms of standard deviations of the root mean square (RMS) values of EMG. Szeto et al. (2005d) also measured the standard deviations in median muscle activity and keystroke kinetics but found trends for increased variability when symptomatic office workers performed typing tasks with increased speed and force, compared to control subjects.

Past studies have demonstrated increased median amplitudes in symptomatic office workers while performing typing and mousing tasks, it is not clear whether such motor control differences are also present in the low and high amplitude measures or in the range of amplitude. It is hypothesized that symptomatic individuals would also show increased activity at the low and high amplitudes, as well as an increased APDF range (difference between the 90th and 10th% APDF).

Methods

Subjects

The present study recruited 38 female office workers by convenience sampling. Subjects were allocated into Case and Control Groups based on their responses to an initial assessment. All subjects were full-time office workers who performed on the average, at least 4 h of computer work daily, with mainly text reading and editing tasks. An interview questionnaire modified from the Standardized Nordic Questionnaire (Kuorinka et al. 1987) was used to collect information from the subjects and this approach has been reported in several past studies (Szeto et al. 2005a, b, c, d, e). Any person with a significant past traumatic injury or surgical intervention in her neck and upper limb regions was excluded. The Case Group ($n = 21$) consisted of subjects who reported discomfort scores of 4/10 or above in the neck and/or shoulder regions, in the past 12 months (for at least 3 months). For the Control Group, subjects had either no past history of discomforts or discomfort scores of lower than 4/10 and for less than 3 months, and no present musculoskeletal complaints at the time of the experiment. The experimental procedures were explained to each subject and informed consent was obtained before the experiment began. Subjects were free to withdraw from the study if they experienced any undue discomfort anytime during the testing procedures. Prior approval was obtained from the Hong Kong Polytechnic University's Human Research Ethics Committee.

Variables

The independent variables were *group* (Case vs. Control), *task* (typing, mousing, type and mouse), and *time* (five repeated data captures in each task). During each 20 min trial of typing, mousing, and type-and-mouse, 30 s samples were taken at the end of the 1st, 5th, 10th, 15th and 20th min. The dependent variables were (1) the 10th% APDF, (2) the 90th% APDF, (3) APDF range (difference between 90th and 10th%). Other variables such as the 50th% APDF and EMG gap frequencies have been reported elsewhere.

Surface electromyography

Surface EMG data were recorded from the muscles of cervical erector spinae (CES) and upper trapezii (UT) bilaterally using a Noraxon Telemyo system (Noraxon USA Inc., USA). The Noraxon system has an intrinsic frequency of 1,000 Hz and a bandwidth of 10–500 Hz. The raw EMG signals first went through an A/D conversion (1,000 Hz) from the transmitter to the receiver of the Noraxon system and captured using a Labview program (National Instruments™, Austin, USA) on a laptop computer.

A standard surface EMG normalisation protocol was followed. The skin was carefully prepared by cleaning the located area with water, fine sand paper and 2% alcohol (and shaved if necessary) before electrode placement and impedance was checked to achieve an acceptable level (<2 k ohms). The electrode application procedures were similar to those reported in previous studies (Szeto et al. 2005a). Surface electrodes were placed on carefully selected and standardised positions on the bilateral CES and UT muscles, with reference to established guidelines (Cram et al. 1998; Hermen et al. 1999). Four pairs of bipolar Ag–AgCl (3M™ Infant Red Dot™) surface electrodes of 15 mm diameter (3M Hong Kong Limited, Hong Kong) were placed on the four muscles with an inter-electrode distance fixed at 20 mm. All the EMG signals were processed with a high-pass filter at 20 Hz, a low-pass filter at 200 Hz and notch filters at 50 and 60 Hz to reduce the noise levels. Then the signals were demeaned, rectified and down-sampled to 10 Hz RMS values. Amplitude was normalized to the value obtained during an isometric maximum voluntary exertion (MVE) using a standardized protocol (Szeto et al. 2005a). The EMG normalisation procedures consisted of three trials of MVEs and one trial of 0–30% ramp contraction. Each contraction lasted for 5 s. A special chair was constructed for this process. For testing the MVE for the CES muscles, the subject had to perform resisted neck extension against a loadcell positioned at the occiput with her maximal effort. The loadcell was fixed on a steel bar which was adjusted to subject's height. For testing the MVE for the UT muscles, the subject had to perform resisted shoulder elevation against a shoulder strap (connected to a loadcell fixed to the floor) with maximal effort. For the CES muscles, both muscles were tested simultaneously; for the UT muscle the two sides were tested separately.

Subjective discomfort

The subject was asked to verbally rate her subjective discomfort in ten upper body regions (left and right neck, upper back, shoulders, elbows, wrists/hands) on a numerical scale of 0–10 with 0 = no discomfort, 1 = minimal discomfort and 10 = extreme/intolerable discomfort. This rating was recorded at the start of each task, after 10 min and at the end of each 20 min task. The boundaries of the various upper body regions were adopted from the Standardized Nordic Questionnaire (Kuorinka et al. 1987). The discomfort data were analyzed in terms of the summed score of all discomfort areas reported in each trial. This method of assessing subjective discomfort was used in previous published studies and the data can be compared directly (Szeto et al. 2005a, b, c, d).

Experimental procedures

Following the initial assessment and EMG normalisation trials, each subject performed 3 experimental tasks of 20 min each, with a 5-min rest period in between. The three tasks were: (1) typing, (2) mousing, (3) type-and-mouse. The nature and content of the three tasks were standardised and the order was randomised. The typing task involved copy-typing the texts displayed in a typing-training program ("Typing Master", Aquarian Technologies, Maldon, Australia). The mousing task involved playing a simple "minesweeper" game on the screen. The type-and-mouse task involved copy-typing a word from a printed list placed on the side, in a word processing document, and then highlighting the word with clicking and dragging the mouse to perform the "copy" and "paste" functions. These tasks were selected as they involved mainly physical actions without significant psychological demands.

The workstation was standardised for all the subjects. It included a standard computer desk with an adjustable slide-out tray for keyboard and mouse and an adjustable height swivel chair with no arm rests. The subject was instructed to adjust the keyboard tray and the chair in order to assume a position of comfort, with hip, knee, and elbow joints approximately at 90°. The display screen height, distance and angle were adjusted to a comfortable level for the subject so that the head–neck region was in a reasonably erect posture.

Data management

The three levels of APDF (10th, 50th, 90th%) were computed using the normalised values of the muscle activity data collected in the three tasks. The variables, the 10th% APDF, 90th% APDF and the APDF range were examined separately for each muscle in three way repeated measures ANOVA analyses. The between-subject factor was *group* (Case vs. Control) and the within-subject factors were *task* (×3 levels) and *side* (×2 levels). Post hoc pairwise *t* tests were used to locate significant task differences. An initial analysis showed no significant effects of *time* (repeated trials) in each task, so mean values were compared. Discomfort scores were analysed with a three way repeated measures ANOVA with group, task and time (before, during and after) factors. The SPSS 14.0 version was used for statistical analysis and the critical alpha level of 0.05 was used in all analysis. No family wise error adjustment of critical level was made, in order to balance the type I and type II errors.

Results

Low, high and range amplitude variables showed differences between the Case and Control Groups and between different tasks.

Low amplitudes of Case and Control Groups

The 10th% APDF of the two muscles ranged from 3 to 12% MVE and showed consistently greater values in the Case Group compared to the Control Group on both sides of CES and UT muscles (see Fig. 1). The between-group difference was statistically significant for CES ($F_{1,37} = 4.62$, $P = 0.038$), but not for UT muscle ($F_{1,37} = 2.16$, $P = 0.150$). There were significant differences between *tasks* for both muscles (CES: $F_{2,74} = 5.94$, $P = 0.004$, UT: $F_{2,74} = 9.582$, $P < 0.001$). In the CES muscles, mousing elicited lower activity than typing and type-and-mouse (mousing vs. typing: $F_{1,37} = 7.08$, $P = 0.011$ in RCES, $F_{1,37} = 10.77$, $P = 0.002$ in LCES; mousing vs. type-and-mouse: $F_{1,37} = 4.01$, $P = 0.053$ in RCES; $F_{1,37} = 6.09$, $P = 0.018$ in LCES), with typing and type-and-mouse equivalent ($F_{1,37} = 1.05$, $P = 0.312$ in RCES; $F_{1,37} = 2.42$, $P = 0.128$ in LCES). In the UT muscles, mousing was significantly lower than typing ($F_{1,37} = 6.78$, $P = 0.013$ in RUT; $F_{1,37} = 12.04$, $P = 0.001$ in LUT). Mousing was also significantly lower than type-and-mouse ($F_{1,37} = 9.83$, $P = 0.003$ in RUT; $F_{1,37} = 6.17$, $P = 0.018$ in LUT) and there was no significant difference between typing and type-and-mouse ($F_{1,37} = 1.58$, $P = 0.217$ in RUT; $F_{1,37} = 7.10$, $P = 0.011$ in LUT). There were no significant interactions.

High amplitudes of Case and Control Groups

The 90th% APDF results followed a similar pattern to 10th%, ranging from 4 to 17% MVE with consistently higher values in the Case Group compared to the Control Group (see Fig. 2). The between-group differences for the 90th% values were again significant for CES ($F_{1,37} = 6.31$, $P = 0.017$), but not significant for UT ($F_{1,37} = 2.47$, $P = 0.124$). Again, there were significant differences between tasks for both muscles in a rather similar pattern to that of 10th% APDF. In the CES muscles, mousing was significantly lower than typing ($F_{1,37} = 15.87$, $P < 0.001$ in

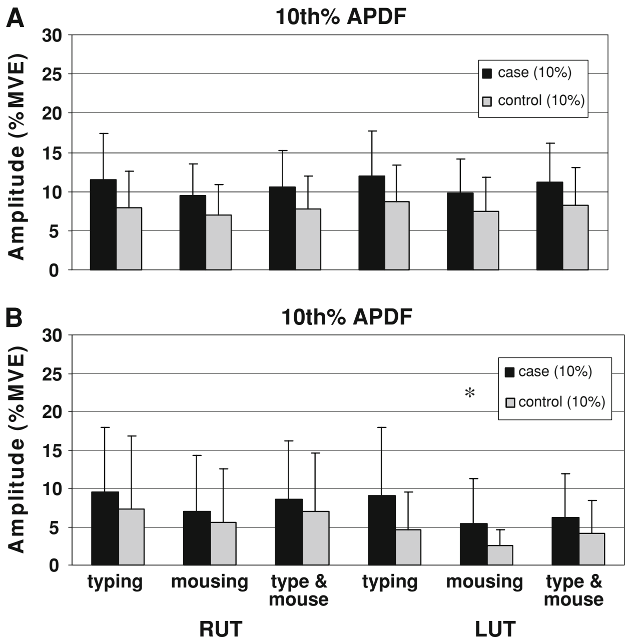

Fig. 1 Comparing low level muscle activities (10th% APDF) in (**a**) CES and (**b**) UT muscles during the three tasks

RCES, $F_{1,37} = 21.14$, $P < 0.001$ in LCES); and lower than type-and-mouse ($F_{1,37} = 13.52$, $P = 0.001$ in RCES; $F_{1,37} = 16.86$, $P < 0.001$ in LCES), while typing and type-and-mouse were equivalent ($F_{1,37} = 0.50$, $P = 0.485$ in RCES; $F_{1,37} = 1.21$, $P = 0.278$ in LCES). In the UT muscles, mousing was significantly lower than typing ($F_{1,37} = 10.25$, $P = 0.003$ in RUT; $F_{1,37} = 16.46$, $P < 0.001$ in LUT). Mousing was also significantly lower than type-and-mouse ($F_{1,37} = 23.04$, $P < 0.001$ in RUT; $F_{1,37} = 11.55$, $P = 0.002$ in LUT). Typing was not significantly different from type-and-mouse in the right UT ($F_{1,37} = 3.29$, $P = 0.078$) but this difference was significant in LUT ($F_{1,37} = 5.27$, $P = 0.028$). This was consistent with the significant *task* x *side* interaction for UT muscle ($F_{2,74} = 6.11$, $P = 0.004$) associated with a comparatively lower left UT activity during type-and-mouse. There were no other significant interactions.

Amplitude range

The amplitude ranges (90th–10th% APDF) were around 2–6% MVE for the two muscles (see Fig. 3). The pattern of response was similar to both 10th and 90th%, with an apparently greater range for Case subjects which was significant for CES ($F_{1,37} = 8.61$, $P = 0.006$) but not for the UT muscle ($F_{1,37} = 2.69$, $P = 0.110$). Like the results for the 90th% APDF, t*ask* had a significant effect for both muscles (CES: $F_{2,74} = 17.81$, $P < 0.001$; UT: $F_{2,74} = 19.76$, $P < 0.001$). The *task* × *side* interaction was also significant for UT muscle ($F_{2,74} = 8.51$, $P < 0.001$), again due to the

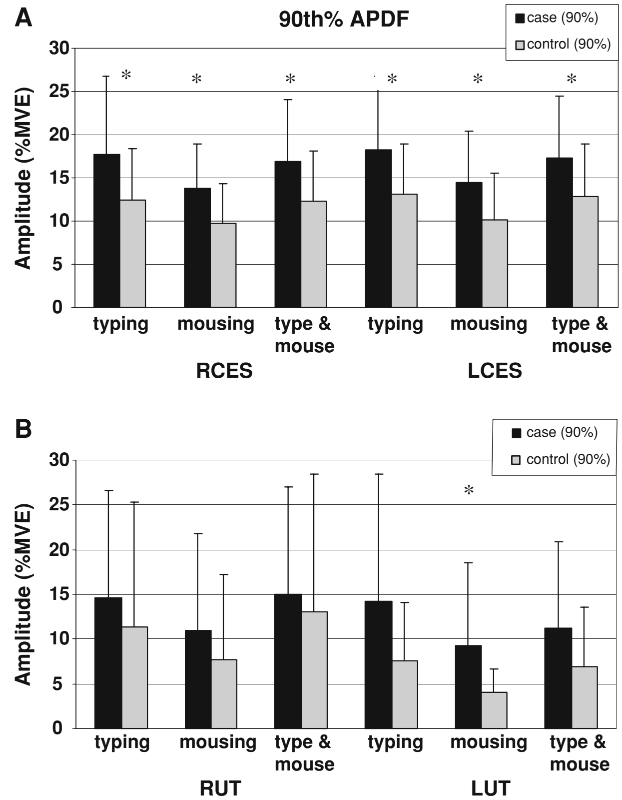

Fig. 2 Comparing 90th% APDF in (**a**) CES and (**b**) UT muscles during the three tasks

different amplitudes in the right and left UT muscles especially during the type-and-mouse task. The range values in the CES muscle showed that mousing was significantly lower than both typing ($F_{1,37} = 21.09$, $P < 0.001$ in RCES; $F_{1,37} = 21.78$, $P < 0.001$ in LCES), and type-and-mouse ($F_{1,37} = 23.38$, $P < 0.001$ in RCES; $F_{1,37} = 21.89$, $P < 0.001$ in LCES); while typing was very similar to type-and-mouse ($F_{1,37} = 0.00$, $P = 0.982$ in RCES; $F_{1,37} = 0.02$, $P = 0.891$ in LCES). In the UT muscle, mousing was significantly lower than both typing ($F_{1,37} = 12.65$, $P = 0.001$ in RUT; $F_{1,37} = 19.96$, $P < 0.001$ in LUT) and type-and-mouse ($F_{1,37} = 18.69$, $P < 0.001$ in RUT; $F_{1,37} = 18.51$, $P < 0.001$ in LUT). The RUT range was significantly higher in the type-and-mouse compared to typing ($F_{1,37} = 15.34$, $P < 0.001$) but these tasks were very similar in the LUT ($F_{1,37} = 0.20$, $P = 0.654$).

Subjective discomforts in the Case and Control Groups

The Case subjects reported significantly greater discomforts compared to the Control Group. At the baseline before the start of the experiment, mean discomfort scores in the Case Group was 8.0 (±8.9) and 1.6 (±4.4) in the Control Group. At the end of the typing task, Case Group had a mean score of 13.4 (±10.7) which was significantly greater

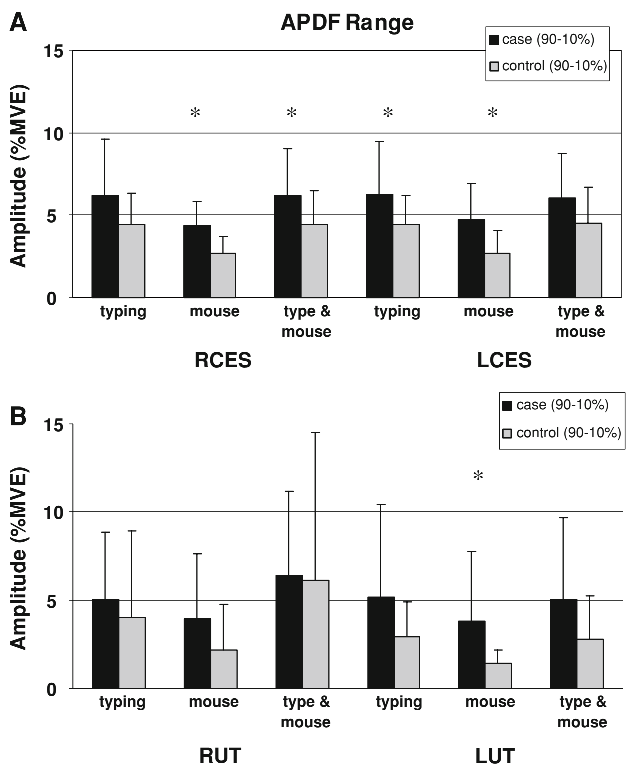

Fig. 3 Comparing APDF range in (**a**) CES and (**b**) UT muscles in Case and Control Groups during the three tasks

than for Control Group 0.6 (±1.6). A significant three-way interaction effect for *group*, *task* and *time* ($F_{4,148} = 3.51$, $P = 0.022$) was found in addition to a *group* main effect ($F_{1,37} = 26.39$, $P < 0.001$). Case discomfort was always greater than Control, but increased more rapidly over typing and type-and-mouse tasks compared with mousing (see Table 1). Mousing showed a trend for lower discomfort scores compared to typing and type-and-mouse, and there was a drop in the discomfort scores in mid-session compared to the beginning and the end. Controls showed minimal discomforts throughout all tasks.

Discussion

Low and high amplitudes of muscle activity

Previous studies have suggested that low levels of muscle activity are closely related to muscular rest, which is considered important to allow the muscles to recover from the sustained workload (Hägg and Astrom 1997; Veiersted et al. 1993). The present results showed that CES muscles were consistently working at higher levels in the symptomatic group, suggesting a relationship between higher muscle loads and the presence of neck and arm symptoms. We also found the median muscle activities in the CES muscles showed a consistent Case-Control difference of about 5% MVE in all three tasks on both sides (data not shown).

The high measure of amplitude is considered an indicator of the “peak” levels of muscle activity involved in performing a task. The present results have demonstrated significant Case-Control differences in the high measures of muscle activities (90th% APDF) for CES. As the present tasks of typing, mousing and type-and-mouse are fairly light in nature, the consistent pattern for higher CES activity for Case subjects across different APDF level measures may suggest that the muscles were being over worked. Previous studies have tended to focus more on the low and median amplitude measures as it was thought that these measures were more important for postural muscles such as the trapezius and CES. Yet, the present study has demonstrated that the high end of EMG amplitude is also a meaningful measure of muscle effort, with significant differences between symptomatic and asymptomatic persons. Nevertheless, this phenomenon can be either an adaptive response to pain or a mechanism contributing to pain. As the study is cross sectional, it is not possible to draw any conclusion about the cause-effect relationship between muscle activity and MSD.

A further limitation is that low and high measures of APDF provided information in the amplitude domain of EMG, with no temporal information. In the present study, EMG gaps (defined as short periods of very low levels of muscle activities, i.e. less than 1% MEMG for more than 0.1 s) also showed a consistent pattern of lower gap frequencies in the Case Group compared to the Control Group (data not shown).

As reviewed in the Introduction, previous studies comparing symptomatic and asymptomatic groups using different levels of APDF have been mainly field studies and yielded conflicting results (Sandsjo et al. 2000; Westgaard et al. 2001). The consistent pattern observed in the current study may be due to the better control of tasks possible in a laboratory study.

Table 1 Mean discomfort scores of three trials comparing the three tasks

	Typing			Mousing			Type-and-mouse		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
Case	9.33	11.81	13.45	12.88	10.88	11.79	7.17	9.52	11.10
Control	0.00	0.00	0.56	0.00	0.00	0.33	0.00	0.11	0.00

Amplitude range as a measure of exposure variability

The difference between the 10th and the 90th% APDF is defined as the amplitude range in the present study. It provides valuable information about the variability of the muscle activity amplitudes, more than simply examining the low and high ends of the EMG amplitudes alone.

In the original research by Jonsson (1982) who first proposed the concept of APDF, the APDF distribution for a "light" task was presented as typically a curved line that was close to the *y*-axis, due to low values at 10th, 50th and 90th% APDF. More physically demanding tasks would show lines that curved more towards the right side, with higher values for 50th and 90th% APDF (Jonsson 1982; Jonsson et al. 1988). However, few studies have examined the shape or slope of this curve in relation to pain or musculoskeletal disorders. In the present study, it was observed that the symptomatic subjects tended to have a more slanted APDF distribution due to the greater difference between 10th and 90th% (see Fig. 4).

Variation of load is commonly considered desirable (Mathiassen 2006). However, there are many different aspects of exposure variability, including between subjects, within subjects, between tasks and within tasks (Loomis and Kromhout 2004; Mathiassen et al. 2003). How variability is measured has contributed to discrepancies in results reported in different studies. Past studies have used standard deviations of muscle activity and coefficient of variance (CV) to compare within-subject and between-subject variability (Madeleine et al. 2008; Mathiassen et al. 2003). These measures reflect the consistency of muscle efforts when repeating the same tasks or comparing between different persons. The present measure of APDF range is more an indication of what extent of muscle effort (from the low to the high end) is being employed to complete the same task. For rapid fine motor tasks such as typing and mousing, the range would not be expected to be large. Hence, the findings that the Control Group demonstrated smaller muscle activity variation (APDF range) may be considered a more efficient motor control strategy. In contrast, the symptomatic subjects demonstrating a greater APDF range may suggest that greater variability in muscle activity amplitude is actually a less efficient motor control strategy and is associated with the presence of symptoms. This would also explain the discrepancy between the present results (increased range with symptoms) compared to those reported by Madeleine et al. (1999, 2008) (decreased variability with symptoms). Their meat-cutting tasks involved more forceful actions and more dynamic movements of the whole arm, hence, with increased symptoms, workers may have chosen to limit force and thus had a reduced variation in motor pattern. Both forms of changes in motor variation may be adaptive responses to the pain disorder.

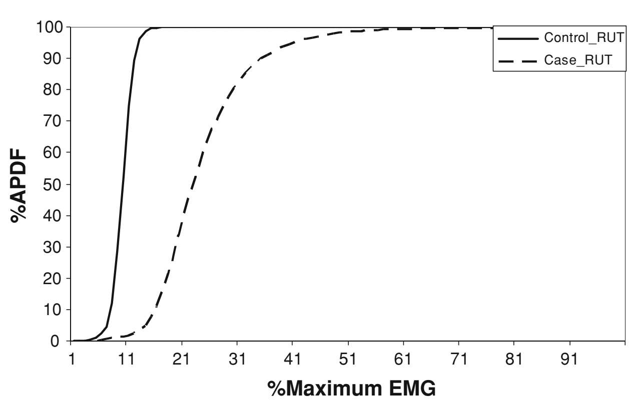

Fig. 4 Illustrations of the typical APDF lines for the Case and Control subjects in the right UT muscle

A limitation of the APDF range measure is that it does not consider time periods, and cannot reveal the temporal component of exposure variation (Mathiassen 2006). The Exposure Variance Analysis (EVA) (Mathiassen and Winkel 1991) is a comprehensive measure that can show different combinations of muscle activities and time periods. However EVA output is rather complex and involves multiple parameters which are difficult to interpret compared with APDF range. However the lack of consideration of time periods may be the reason greater variation (characterised by greater range) was related with symptoms in this study (Fig. 5).

The EMG normalisation procedure, which used maximum voluntary contractions (MVC) may also have influenced the results. Research in EMG has commonly employed either the MVC approach or normalised to some submaximal reference contraction such as an anti-gravity task (Hansson et al. 2000). MVC are usually subject to large individual variations and if symptomatic subjects had decreased strength or force output, then the normalised task data could be artificially inflated. However, the present study has adopted a consistent and reliable approach to ensure that maximal efforts were produced by all subjects, and post-hoc analysis revealed no significant differences between groups in either the force output or the EMG values during MVC. Hence the results are valid and can truly reflect the motor control differences between the two groups.

Implications for motor control mechanisms contributing to WMSD

The present results have demonstrated that the low and high measures of APDF are sensitive and robust measures for examining muscle activation patterns in symptomatic individuals. The amplitude range is also demonstrated to be a measure sensitive to symptom status. These results suggested

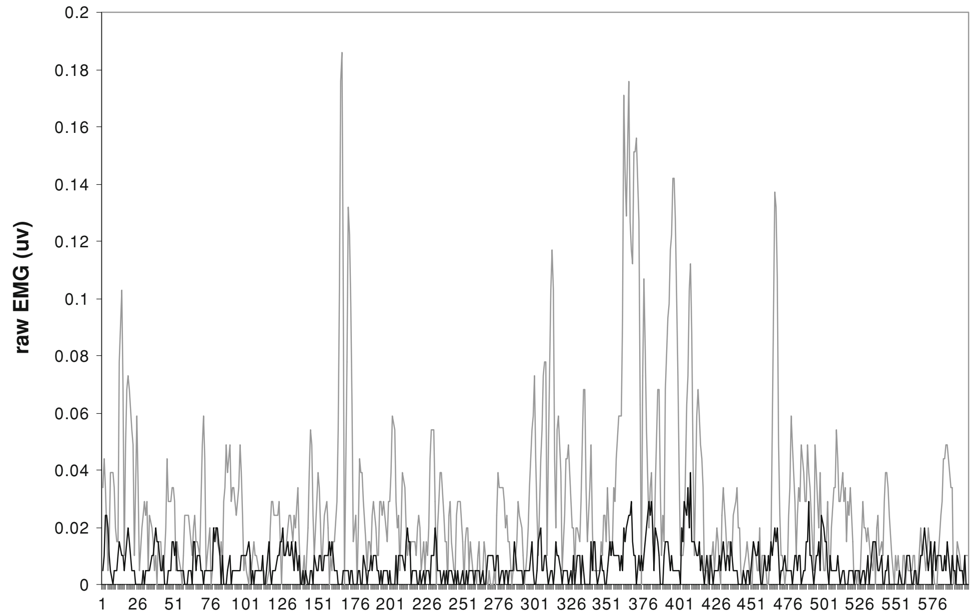

Fig. 5 Graphic illustration to show the typical muscle activity patterns for Case and Control Group subjects in the right UT muscle. The *grey line* represents the typical Case subject while the *black line* represents the typical Control subject

that the symptomatic individuals generally worked with higher activity levels and greater extent of variation in these muscle activity levels. The present results support the previously proposed "altered motor control" model associated with WMSD (Szeto et al. 2005a, b, c, d).

The results are also consistent with the Cinderella Hypothesis, which proposed that certain motor units worked with sustained activities for excessive periods without rest (Hägg 1991), as a mechanism for WMSD development. Recent studies on single motor unit activities have also provided evidence to support this hypothesis (Thorn et al. 2007; Zannaro et al. 2003).

In the present study, the Case subjects reported significantly increased discomfort at the end of each task yet their APDF lines were quite consistent throughout the tasks. This would suggest that their motor control patterns were already pre-programmed and were not directly influenced by current task discomfort. Recent studies on patients with different kinds of mechanical neck pain, had also reported that pain subjects have difficulty in relaxing their postural muscles in the neck region (Nederhand et al. 2003; Falla et al. 2004). Besides symptoms, productivity in terms of typing or mousing performance could also be another manifestation of motor performance differences between the two groups and should be investigated in future research.

The present results have demonstrated that symptomatic subjects performed stressful tasks with increased variation in their muscle activity amplitudes. This may suggest a less refined or less efficient motor control strategy. It is possible that such altered motor control mechanisms were associated with performing lighter motor tasks such as typing and mousing. In contrast, Madeleine et al. (2008) reported decreased motor variability suggestive of a "joint or muscle stiffening" phenomenon, when painful individuals performed meat cutting tasks. Hence there could be different altered motor control strategies in different individuals associated with different types of tasks.

Conclusion

The present study has examined both the low (10th%) and high (90th%) measures of EMG amplitudes and the amplitude range when Case and Control Group subjects performed typing, mousing and type-and-mouse tasks. Consistently the Case Group subjects displayed higher EMG amplitudes in all three tasks and at both high and low measures of amplitudes, with significant differences for the CES muscles. These results helped clarify the earlier field studies comparing muscle activity in symptomatic and asymptomatic workers which had produced conflicting results. The variable of amplitude range is a novel concept and has not been reported in Case-Control studies before. The amplitude range results also highlighted motor control differences between symptomatic and asymptomatic office workers. However, it is not known whether such differences were mainly applicable to such fine motor tasks like typing and mousing, and further investigations should examine the same EMG parameters in a variety of different functional tasks and in different occupational groups.

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