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ORIGINAL ARTICLE

The influence of body posture, arm movement, and work stress on trapezius activity during computer work

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Abstract The study aimed to determine the influence of arm posture and movement on trapezius activity of computer workers, considering the full workday. A second aim was to investigate if work periods perceived as stressful were associated with elevated or more sustained muscle activity pattern. Twenty-six computer workers performing call-center ($n = 11$), help desk ($n = 7$), or secretarial ($n = 8$) work tasks participated. Bilateral trapezius surface electromyographic (sEMG) activity and heart rate was recorded throughout the workday. Simultaneous inclinometer recordings from left thigh and upper arms identified periods with sitting, standing, and walking, as well as arm posture and movement. Perceived work stress and tension were recorded on visual analog scales (VAS) every hour. Trapezius sEMG activity was low in seated posture [group median 1.8 and 0.9% of activity at maximal voluntary contraction (%EMG$_{max}$) for dominant and non-dominant side] and was elevated in standing (3.0 and 2.5% EMG$_{max}$) and walking (3.9 and 3.4% EMG$_{max}$). In seated posture (mean duration 79% of workday) arm movement consistently influenced trapezius activity, accounting for ~20% of intra-individual variation in trapezius activity. Arm elevation was on average not associated with trapezius activity when seated; however, considerable individual variation was observed. There was no indication of increase in trapezius activity or more sustained activity pattern, nor in heart rate, in high-stress versus low-stress periods, comparing periods with seated posture for the subjects reporting contrasts of at least two VAS units in stress ($n = 16$) or tension ($n = 14$) score.

Keywords Electromyography · Trapezius · Shoulder and neck pain · Computer work · Posture · Work stress

Introduction

Prolonged computer work is recognized as an occupational hazard with risk of shoulder and neck pain (Blatter and Bongers 2002; Jensen et al. 2002; Nakazawa et al. 2002). Intensive keying or mouse use may exacerbate such risk (Marcus et al. 2002). Means considered to reduce complaints associated with computer work include more variation in work tasks, alternating between seated and standing postures and rest breaks (Carter and Banister 1994). An intervention introducing short breaks with walking activities had positive effect on neck and shoulder discomfort (Galinsky et al. 2000).

Shoulder and neck pain commonly has a location that includes the upper trapezius muscle and may develop at seemingly low muscle activity levels (Jensen et al. 1998). A frequently cited hypothesis to explain such pain is that prolonged computer work in combination with mental stress cause sustained activation of low-threshold motor units in postural neck and shoulder muscles, resulting in metabolic overload (e.g., Melin and Lundberg 1997; Sjøgaard et al. 2000; Lundberg et al. 2002; Larsman et al. 2006). Laboratory studies have demonstrated sustained trapezius motor unit firing in low-level sustained

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contractions (Thorn et al. 2002) and in response to mental stress (e.g., Wærsted et al. 1996); however, at present there is no evidence to show this phenomenon in occupational settings with computer work. It is therefore important to investigate trapezius activity pattern in putative risk-enhancing and risk-reducing postures of computer workers, taking into account the level of perceived stress.

Whole-day trapezius surface electromyographic (sEMG) recordings were recently reported for several occupational groups, including secretaries and computer workers with call-center and help-desk work duties (Mork and Westgaard 2005). The computer workers were shown to have low trapezius activity during the workday (Mork and Westgaard 2006), but activity patterns in presumed health-promoting and risk-associated work activities were not analyzed. Simultaneous inclinometer recordings were, however, used to detect the position of the left thigh, upper and lower back and upper arms. The thigh angle identified periods with sitting, standing and walking activities. For each of the three postures, the influence of arm and trunk elevation and movement on trapezius activity was determined. Upper back and pelvic recordings showed no association to trapezius sEMG activity in neither seated nor upright postures and will be separately reported. The main aim of this study is to determine the influence of arm elevation and movement on trapezius activity pattern in putative risk-enhancing seated and risk-reducing upright postures of subjects performing intensive computer work.

Subjectively assessed mental stress and perceived tension were recorded every hour by visual analog scale (VAS) to identify periods of high and low strain (Holte and Westgaard 2002a, b). A second aim is to quantify trapezius activity pattern in perceived high-strain and low-strain periods while adopting a seated posture.

Methods and materials

Subjects

Twenty-six female subjects (age, mean ± SD 44 ± 11, range 26–61 years) participated in the study. They worked as call-center operators in the sales department of a dairy company ($n = 11$), help-desk workers in a telecommunication firm ($n = 7$), and secretaries in a private safety company ($n = 8$). Body mass ranged from 56 to 86 kg (68 ± 9 kg), body mass index (BMI) ranged from 19.6 to 32.4 kg/m^2 (24.2 ± 2.7 kg/m^2). All subjects had full-time position (7.5 h per day). The length of employment in their present job ranged from 1 to 35 years (13 ± 11 years). Age, body mass, BMI, and length of employment were similar for the three sub-groups of computer workers ($P > 0.15$ for all comparisons). Sixteen subjects (call-center operators $n = 7$, secretaries $n = 4$, and help-desk workers $n = 5$) reported shoulder and neck pain ≥2 on a scale from 0 to 6, taking into account intensity and frequency of pain the last 6 months (Westgaard and Jansen 1992). Nine subjects reported a score of 4 or higher, a score that in the previous study induced 75% to seek medical attention for their complaint. Pain drawings showed locations that included upper trapezius for 15 of 16 subjects with shoulder and neck pain. Five subjects indicated bilateral pain while ten subjects indicated unilateral pain ($n = 6$ dominant side and $n = 4$ non-dominant side). The Regional Ethics Committee approved the study protocol and all subjects signed an informed consent before inclusion. The study was carried out according to the Declaration of Helsinki.

Work description

The call-center operators were working in an interactive computer–telephone setting (using telephone headsets) with work tasks mainly consisting of typing numeric input for data encoding of incoming telephone orders. The help-desk workers provided on-line customer support in an interactive computer–telephone setting (using telephone headsets) or by e-mail correspondence. The secretaries performed regular desk and computer work, mainly consisting of word processing and responding to telephone requests by customers. Call-center operators and help-desk workers had limited opportunity to take unscheduled breaks due to customers waiting on the telephone lines. The secretaries were less constrained in performing computer work tasks. All three groups of workers considered their work situation strenuous at times. This was supported by the hourly scoring of shoulder and neck pain, perceived stress, and tension (cf. Methods and material: subjective variables), which all augmented over the workday ($P < 0.05$ for all variables; statistics for pain score valid for both dominant and non-dominant side). A tendency of higher pain score for call-center operators (mean value 2.2) and help-desk workers (2.4) than for secretaries (0.6) was observed (one-way ANOVA, $P = 0.06$).

For all subjects, periods with standing and walking mostly involved conversations with colleagues or superiors, use of copy machine, or handling printouts. The company health services provided individual adjustments of computer workstations, including placement and height of screen, table, arm rests, and chair. Individual adjustments were followed up on a yearly basis or by request from the employees.

Physiological recordings

Postural angles of the upper arms, left thigh, upper back and pelvic, sEMG from both trapezius muscles and electrocardiogram (ECG) were recorded (Physiometer PHY-400, Premed A/S, Norway) throughout the workday. Postural angles were detected by inclinometers (electrolytic liquid sensors), with error margin <3.6° (Hagen et al. 1995). Thigh angle was recorded by an inclinometer attached to the low front of the left thigh, nominally recording thigh angle in the sagittal plane. Inclinometers on the upper arms were attached to the lateral aspect at the mid-point between the shoulder and elbow joint. Neutral posture was defined as relaxed, standing posture with eyes fixed at a distant point at eye-level and with arms hanging along the side of the body. Postural angles were recorded for 45 s in the reference posture before and after work and the average recorded angle was used for calibration. Postural recordings were excluded if the recorded angles in reference posture (flexion/extension or abduction/adduction) deviated by >5° between the two recordings. Five bilateral and seven unilateral recordings (three on dominant and four on non-dominant side) were excluded or failed due to technical problems. Thigh angle was successfully recorded for all subjects.

The procedure for electrophysiological recordings is described in detail elsewhere (Mork and Westgaard 2005). Briefly, ECG and bilateral sEMG activity from upper trapezius and lower back muscles (lumbar multifidus, iliocostalis, and longissimus), were recorded over 24 h. Only work recordings of upper trapezius are reported here. Silver/silver chloride electrodes with diameter 6 mm (Neuroline, Medicotest A/S, Denmark) were used for ECG and sEMG recordings. Bipolar sEMG electrodes (20 mm center-to-center distance) were placed at a point 2/3 of the distance from the spinous process of the C7 vertebra towards the lateral edge of the acromion (Jensen et al. 1993). Electrodes for ECG recording were placed in standard positions across the chest. The QRS complex was detected and instantaneous heart rate determined by inverting beat-to-beat intervals. The sEMG signals were root-mean-square (RMS) detected and stored at a time resolution of 0.1 s, but a resolution of 0.2 s was used in the further analyses of the ECG and sEMG signals.

The sEMG signal was normalized by isometric maximal voluntary contractions (MVCs), repeated three times both at the start and the end (i.e., start of work the next day) of the recording. The MVCs were performed with the subjects placed in an erect seated posture, with arms 90° abducted in the scapular plane and resistance applied just proximal to the elbow joint. The highest sEMG response ($\mathrm{EMG}_{\max}$) was used to normalize the sEMG signal. Mean percentage difference between $\mathrm{EMG}_{\max}$ values obtained at the start and the end of the recording was 5.7 and 6.1% for the dominant and non-dominant trapezius, respectively, with no systematic difference between the two calibration trials (Mork and Westgaard 2005). Three sEMG recordings failed in different subjects due to accidental removal of electrodes, one on the dominant and two on the non-dominant side. Mean duration of sEMG recordings was 6 h (range 4.9–7.0 h).

Posture analyses

Postural angles were quantified by deviation from the reference body posture. The detection of periods with sitting, standing, and walking relied on visual inspection of an amplitude-time display of the thigh angle recording (Fig. 1). The difference between a stationary thigh angle during standing and the cyclical pattern during walking is illustrated by the expanded time plot in Fig. 1.

For recording of arm posture, the inclinometers were positioned to nominally record movements in the sagittal (flexion/extension) and frontal (abduction/adduction) plane. Recordings were transformed to arm elevation by the equation:

$$R = \sqrt{x^2 + y^2}, \tag{1}$$

where x and y are the recorded angle in the sagittal and frontal plane and R is the elevation angle. In the analysis of association between arm posture and trapezius sEMG activity, the sagittal/frontal orientation of arm position was ignored as ergonomic evaluations mainly use arm elevation as a criterion in considering work posture. Maximal and sub-maximal trapezius activity in flexion has been indicated as similar, although somewhat lower relative to abduction (Jensen et al. 1993).

The intra-individual relation between trapezius activity and arm elevation or arm movement was assessed by linear regression analysis. First, the 50th percentile of sEMG activity and arm elevation, and the SD of arm elevation were extracted from successive time intervals of 3 s, i.e., the extracted data points was based on 15 samples (Fig. 2).

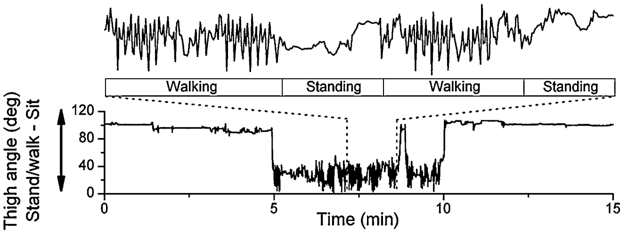

Fig. 1 A 15-min period of thigh angle recording illustrating visually detectable differences for sitting, standing, and walking postures. The stationary signal during seated posture corresponds to a thigh angle close to 90°, which is reduced by >60° in upright postures. The stationary thigh angle during standing and the cyclic pattern during walking is illustrated by the expanded time plot covering a period of ~2 min. Periods with walking was defined by clearly visible alternating pattern in thigh angle, lasting at least three consecutive cycles

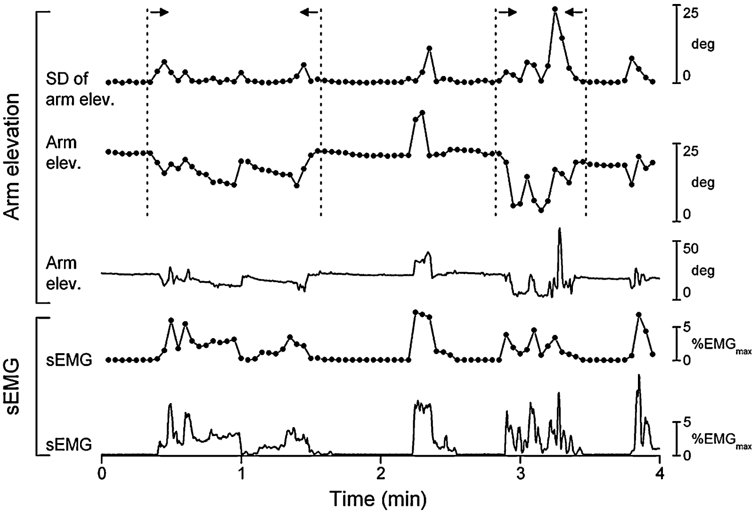

Fig. 2 A 4-min period showing recordings of trapezius sEMG activity and arm elevation from the dominant side during seated posture. *Thin lines* show recordings with 0.2 s time resolution while *filled circles* with *connecting lines* show extracted data points (3-s intervals) for sEMG activity, arm elevation, and SD of arm elevation. *Vertical dotted lines* with *horizontal arrows* demarcate intervals with contrasting time-amplitude variation between arm elevation and SD of arm elevation

In determining arm movement, the first derivative of arm elevation (i.e., arm velocity) was considered used as a variable. However, the first derivative emphasizes movement transients with instantaneous high-velocity peaks. In consideration of the long-duration recordings and the context of studying work activities, it was therefore considered more appropriate to make the comparison between short periods with defined levels of movement and the associated level of trapezius activity.

The possible time shift in arm movement versus trapezius sEMG activity was examined by generating the cross-correlation function in a sub-set of eight recordings (Vasseljen and Westgaard 1997). Analyses with time resolution 3 s showed no time shift in arm posture versus sEMG recordings. Correlation analyses were therefore performed with no time lag. (The peak in the cross-correlation function was time-shifted 0.2–0.4 s for time resolution 0.2 s, showing a moderate increase of 5% (mean) relative to zero time lag for both sitting and upright postures.)

When determining SD of arm elevation, the first order (linear) regression component was removed for each 3 s interval and SD thereafter calculated. Second, periods with sitting, standing, and walking were identified and linear regression analysis performed on the extracted data for each subject. The association between sEMG activity and arm elevation or SD of arm elevation was evaluated by rate of increase or decrease ("slope coefficient"; SC) in linear regressions and by determining the corresponding correlation coefficient. Preliminary analysis (15 recordings from dominant side) showed that intervals of 3, 9, or 30 s were similarly sensitive in showing associations between sEMG activity and arm posture, but a resolution of 3 s was the most sensitive for detecting the effect of arm movement (SD of arm elevation) on sEMG activity. This may be understood in terms of the movement pattern with the typical duration of arm movement being a few seconds (cf. Fig. 2; Table 1: burst duration).

sEMG analyses

Surface electromyographic activity was quantified by median sEMG level (%EMG$_{max}$), defined as the amplitude at which the activity level is below for 50% of the observation time (Jonsson 1978). Trapezius rest time is defined as the overall duration with sEMG activity <0.5% EMG$_{max}$ (% of recording time; Veiersted et al. 1990). In quantifying sEMG responses, sEMG noise level (typically <1 µV; Mork and Westgaard 2004) was first subtracted from the RMS detected EMG signal.

Surface electromyographic activity with amplitude >2% EMG$_{max}$ was quantified by burst analysis as described by Kern et al. (2001). Outcome variables were burst time (% of recording time), mean burst amplitude (%EMG$_{max}$), mean burst duration (s), and burst rate (bursts/s). Temporal pattern of sustained trapezius activity was quantified as fraction of time with un-interrupted activity above 2 and 1% EMG$_{max}$ as a function of the overall duration of sEMG burst activity. For example, a fraction of 20% at 60 s indicates that 20% of time with muscle activity higher than 2 or 1% EMG$_{max}$ consisted of periods with uninterrupted activity of 60-s duration or longer. A threshold of 2% EMG$_{max}$ for detection of EMG bursts is consistent with the observed variation in threshold for repeated recruitment of the same trapezius motor unit (mean difference 1.9% EMG$_{max}$; Westad et al. 2003).

Subjective variables

The subjects scored their level of shoulder and neck pain, perceived tension, and perceived stress every hour throughout the workday. Responses were scored on a

Table 1 Trapezius sEMG activity and heart rate during sitting, standing, and walking (dominant trapezius $n = 25$ and non-dominant trapezius $n = 24$)

	Sitting	Standing	Walking
Heart rate (bpm)	77 (72–86)	88 (77–97)*	97 (86–103)**
Median EMG level (%EMG$_{max}$)			
Dominant trapezius	1.8 (1.0–2.0)	3.0 (2.1–3.6)*	3.9 (2.7–5.7)**
Non-dominant trapezius	0.9 (0.9–1.2)	2.5 (1.4–3.5)*	3.4 (2.5–4.7)**
P	0.01	ns	ns
Rest time (%)			
Dominant trapezius	29 (24–38)	13 (7.9–22)*	4.8 (2.1–7.0)**
Non-dominant trapezius	45 (32–49)	17 (8.6–29)*	4.5 (1.6–6.3)**
P	0.05	ns	ns
Burst time (%)			
Dominant trapezius	47 (39–50)	61 (51–70)*	75 (62–84)**
Non-dominant trapezius	33 (27–39)	58 (42–67)*	71 (60–88)**
P	0.005	ns	ns
Burst amplitude (%EMG$_{max}$)			
Dominant trapezius	3.4 (3.3–3.7)	4.2 (3.6–4.4)	4.9 (4.2–5.6)***
Non-dominant trapezius	3.5 (3.2–3.8)	3.8 (3.5–4.2)	4.5 (3.7–5.0)***
P	ns	ns	ns
Burst duration (s)			
Dominant trapezius	1.5 (1.3–2.0)	2.0 (1.6–2.5)	1.1 (0.8–1.9)†
Non-dominant trapezius	1.8 (1.2–2.1)	1.9 (1.5–2.3)	1.3 (0.6–1.9)†
P	ns	ns	ns
Burst rate (bursts/s)			
Dominant trapezius	0.25 (0.22–0.29)	0.27 (0.23–0.31)	0.54 (0.44–0.70)**
Non-dominant trapezius	0.20 (0.16–0.24)	0.28 (0.23–0.31)	0.58 (0.41–0.82)**
P	0.004	ns	ns

Values are median with 95% CI in parentheses

*Different from sitting, $P < 0.001$

**Different from sitting and standing, $P < 0.001$

***Different from sitting, $P < 0.001$

† Different from standing, $P < 0.006$

10 cm VAS with end points *very low* and *very high*; but with pain intensity scored only after subjects had indicated whether they at all felt pain (yes/no).

Statistical analysis

The Shapiro–Wilk *W*-test for normality was performed on all dependent variables before statistical analysis. All posture variables were normally distributed, while 23 of 36 sEMG variables and all subjective variables showed non-normal distribution. Non-parametric tests were therefore used in all group comparisons. A Wilcoxon paired signed rank test was used for paired comparisons. A one-way ANOVA on ranks (Kruskal–Wallis) with a Kruskal–Wallis *z*-score post hoc test was used to test the hypotheses that posture variables, subjective variables and sEMG activity did not differ between call-center operators, help-desk workers, and secretaries. Multilinear regression analysis was performed on all individual data sets (i.e., intra-subject comparisons) to assess the combined influence of arm elevation and SD of arm elevation on trapezius sEMG activity. Partial correlation coefficients were calculated to determine whether sEMG was differentially associated with arm elevation and SD of arm elevation, i.e., correlation coefficients after eliminating the effect of the other posture variable. All variables are reported as mean with SD if not otherwise stated. The software package NCSS 2000 was used for the statistical analyses.

Results

Body posture

The time (% of workday) spent sitting, standing, and walking was 79 ± 9% (range 46–92%), 12 ± 7% (range 4.9–33%), and 5.6 ± 2.9% (range 2.1–16%), respectively. A small fraction of the recordings (2.9 ± 2.8%, range 0.1–11%) could not be classified into any of the three postures. Time spent in upright posture (standing and walking) was longer for secretaries (24 ± 12%) than for call-center operators (14 ± 2.9%, $P < 0.02$) but not significantly different to help-desk workers (17 ± 11%, $P = 0.12$). Mean duration of periods with seated posture was shorter for secretaries (8.0 ± 4.5 min) than for call-center operators (14.8 ± 3.4 min, $P < 0.01$) and help-desk workers (25.5 ± 19.2 min, $P < 0.003$). Mean duration of periods with upright posture was similar for all work groups (call-center operators: 2.2 ± 1.0 min, help-desk workers: 2.8 ± 0.5 min, secretaries: 2.3 ± 0.7 min; one-way ANOVA, $P > 0.13$).

sEMG activity and heart rate versus body posture

Table 1 presents heart rate and sEMG activity (median activity level, rest time, and sEMG burst variables) of the dominant and non-dominant trapezius during sitting, standing, and walking. Heart rate differed significantly between postures, increasing with 20 beats per min (bpm) from sitting to walking. Median sEMG level, rest time and burst time differed significantly from sitting to standing and from standing to walking. Burst amplitude (walking different to sitting) and burst rate (walking different to sitting and standing) showed a similar pattern. Burst duration was most extended for standing (significantly different to walking). Call-center operators, help-desk workers, and secretaries were not distinguished by their sEMG responses during sitting, standing and walking (one-way ANOVA, $P > 0.07$ for all comparisons); however, the sensitivity of this comparison is low due to few subjects in each group and considerable within-group variation in responses.

sEMG activity versus arm posture

Figure 3 shows individual (thin lines) and mean (heavy line) regression lines for trapezius activity versus arm elevation (upper panels) and trapezius activity versus SD of arm elevation (lower panels) in sitting, standing, and walking. Dominant and non-dominant sides were not differentiated by the respective mean regressions ($P > 0.10$ for all comparisons), and data from both sides was therefore pooled in determining mean regressions ($n = 18$ dominant side and $n = 16$ non-dominant side).

In contrast to standing and walking, trapezius activity was weakly associated with arm elevation in sitting; both positive and negative associations were observed for individuals, but on group basis an increase of only 0.1% $\mathrm{EMG_{max}}$ for 10° increase in arm elevation was found (not significant). Significant positive associations were found for trapezius activity versus SD of arm elevation (i.e., arm movement), most marked for sitting. Arm movement, visualized by the length of regression lines, was much less in sitting than in standing and walking.

Multilinear regressions were constructed for each individual, with sEMG activity as dependent and arm elevation and SD of arm elevation as independent variables, for each

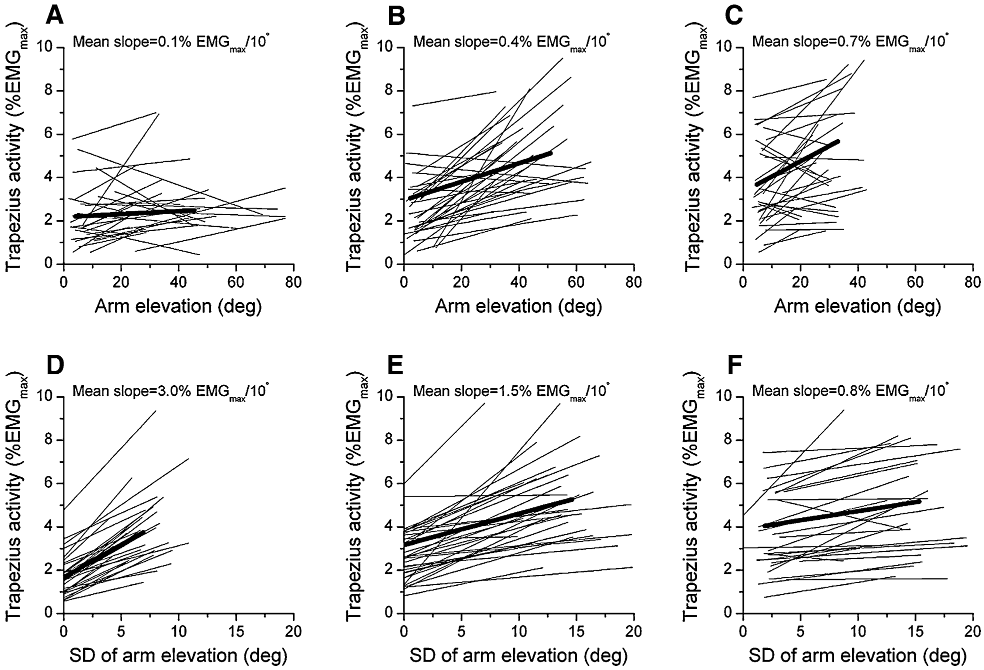

Fig. 3 Trapezius activity as a function of arm elevation (**a**–**c**) and SD of arm elevation (**d**–**f**) in sitting (**a**, **d**), standing (**b**, **e**), and walking (**c**, **f**). Individual (*thin lines*) and mean (*heavy line*) *regression lines* are shown. The extent of the *regression lines* delineates 10th to 90th percentile of arm elevation and SD of arm elevation. Mean increase in sEMG activity per 10° increase in arm elevation or SD of arm elevation ($\%\mathrm{EMG_{max}}/10°$) is indicated. Regression analysis was performed on data points extracted from time intervals of 3 s. On average, individual regression lines are based on 5,553 (range 3,397–8,274) extracted time intervals for the seated posture, 846 (range 318–1,631) for the standing posture, and 389 (range 145–753) for the walking posture. Note that regressions and residual activity (i.e., sEMG at zero arm elevation and SD of arm elevation) is higher than median sEMG level in Table 1 as *linear regression* shows mean rather than median values

posture (Table 2). The table also shows partial correlations of trapezius activity with either of the two posture variables. Arm posture and movement accounted for about 20% of trapezius sEMG variation in seated posture, mainly due to arm movement. This association was a little reduced in standing and was still lower (about 10%) in walking. The multilinear regressions were used to determine sEMG activity for arm elevation and movement at zero (i.e., multivariate intercept). The intercept value was (group median with 95% CI) 1.4% EMG_{max} (0.9–1.9% EMG_{max}) for sitting, 1.6% EMG_{max} (0.9–2.5% EMG_{max}) for standing, and 2.8% EMG_{max} (2.1–5.1% EMG_{max}) for walking ($P < 0.006$, walking versus standing and sitting postures). The multivariate intercept in standing correlated to sEMG activity in standing reference posture ($r = 0.80$ for dominant and $r = 0.77$ for non-dominant side), but with sEMG amplitude in the field recording about 1% EMG_{max} higher than in the calibration recordings. The regression results were much influenced by 4–5 subjects with relatively high level of trapezius activity in both situations.

Inter-individual variation in arm posture and movement was considerable with the exception of seated posture, when all subjects showed little arm movement (Fig. 4). No relation between median trapezius activity and median arm posture or movement was found in inter-subject comparisons, except for trapezius activity and arm movement in seated posture ($P = 0.01$). Call-center operators, help-desk workers, and secretaries were not differentiated by arm elevation or arm movement in neither sitting nor upright posture (one-way ANOVA, $P > 0.12$ for all comparisons).

Work periods with high versus low perceived stress

Trapezius activity and heart rate in seated posture during periods with high and low perceived stress, high and low tension, and during lunch break were determined for subjects with high and low scores distinguished by two or more VAS units (Table 3). Trapezius activity was very low for the non-dominant trapezius, median level about 1% EMG_{max} and rest time 30–40%. Trapezius activity was examined in paired comparisons between periods with high and low perceived stress ($n = 16$) and high and low tension ($n = 14$), and between these work periods and lunch break. No significant difference in sEMG activity or pattern was detected. Time distribution of burst periods with burst amplitude exceeding 2 and 1% EMG_{max}, respectively, was determined as a function of burst duration (Fig. 5). Bursts of long duration were more common in low stress and lunch periods than in high stress periods.

The comparison of periods with high and low perceived stress was further examined by use of scatter plots (Fig. 6). Heart rate tended to increase in high stress periods if perceived stress increased by more than four VAS units ($R = 0.52$ and $P = 0.10$). This association was significant if excluding the outlier marked by arrow ($R = 0.82$ and $P = 0.004$; Fig. 6a). There was no similar tendency of increase in sEMG variables for subjects with marked increase in subjective stress level (scatter plot of Δ median sEMG versus Δ work stress in Fig. 6b). If perceived tension instead of perceived stress was used as independent variable, there was less increase in heart rate with increase in tension and no tendency to change in sEMG variables. Four subjects had markedly more arm movement in low stress than in high stress periods (Fig. 6c), all recording higher sEMG levels in the low stress period. Regression analysis was used to determine sEMG level at no arm movement (i.e., Residual sEMG; Fig. 6d). A scatter plot of median sEMG level in high and low stress periods, after controlling for arm movement, did not indicate higher sEMG level in high-stress periods by this analysis.

Discussion

Trapezius activity was not significantly related to arm elevation in this occupational-based study with no experimental control of posture and movement. Regressions were significant for each worker, in consideration of the large

Table 2 Correlation coefficients for the multilinear regression analysis (left column) and the corresponding partial correlation coefficients (right columns)

	R	Partial correlation	
		sEMG versus elevation	sEMG versus SD of elevation
Sitting			
Dominant trapezius	0.45 (0.27–0.56)	–0.02 (–0.31–0.23)	0.41 (0.25–0.54)
Non-dominant trapezius	0.47 (0.36–0.59)	0.04 (–0.16–0.26)	0.43 (0.36–0.49)
Standing			
Dominant trapezius	0.42 (0.13–0.59)	0.25 (–0.07–0.44)	0.23 (–0.06–0.39)
Non-dominant trapezius	0.37 (0.04–0.63)	0.19 (–0.11–0.45)	0.24 (–0.03–0.60)
Walking			
Dominant trapezius	0.33 (0.02–0.63)	0.13 (–0.18–0.55)	0.10 (–0.11–0.50)
Non-dominant trapezius	0.31 (0.03–0.56)	0.15 (–0.24–0.47)	0.02 (–0.11–0.20)

Values are mean with range in parentheses

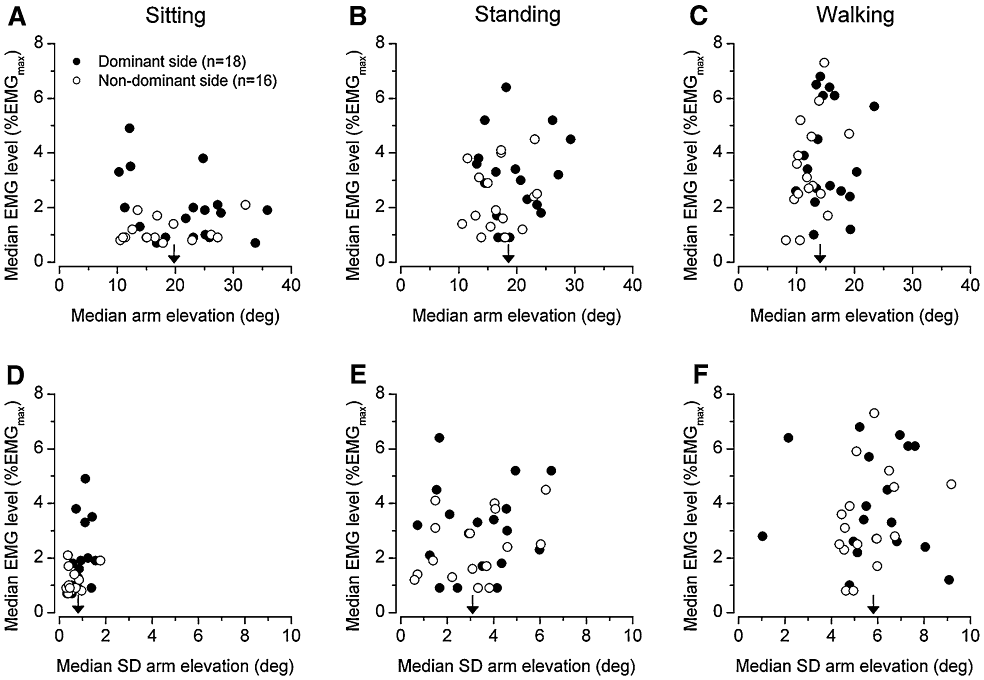

Fig. 4 *Scatter plots* showing inter-individual variation in arm posture and movement, and trapezius sEMG activity. Median sEMG level is shown as a function of median arm elevation (**a**–**c**) and median SD of arm elevation (**d**–**f**) for sitting (**a**, **d**), standing (**b**, **e**), and walking (**c**, **f**) postures. Dominant (*filled circles*; $n = 18$) and non-dominant (*open circles*; $n = 16$) are distinguished by *symbols*. Group mean values of median arm elevation and SD of median arm elevation are indicated by *vertical arrow* on *x*-axis

Table 3 Trapezius sEMG responses during periods with high and low stress, high and low tension, and during lunch break

	High stress ($n = 16$)	Low stress ($n = 16$)	High tension ($n = 14$)	Low tension ($n = 14$)	Lunch break ($n = 19$)
Heart rate	79 (63–87)	78 (72–90)	82 (75–89)	77 (71–87)	84 (74–93)
Median EMG level (%EMG$_{max}$)					
Dominant trapezus	1.6 (0.8–2.2)	1.8 (0.9–2.7)	1.5 (0.7–2.9)	1.3 (0.8–2.4)	2.2 (0.8–3.1)
Non-dominant trapezus	0.8 (0.7–1.4)	1.1 (0.8–1.3)	1.5 (0.7–1.9)	1.0 (0.7–1.5)	0.9 (0.8–2.4)
Rest (%)					
Dominant trapezus	31 (14–36)	20 (7.3–34)	30 (12–57)	24 (7.6–46)	23 (14–44)
Non-dominant trapezus	46 (22–57)	35 (20–52)	28 (8.7–46)	38 (20–63)	38 (23–52)

Only periods with seated posture are included in statistics. Statistics shown in table (median with 95% CI in parentheses) are based on subjects with contrasting stress and tension scores, and with recorded lunch break (*n* in columns)

number of data points, but there was no significant association for the group due to roughly equal number of positive and negative associations. A positive association between arm elevation and trapezius activity when seated is shown in laboratory studies (Mathiassen and Winkel 1990), but factors such as variation in the use of arm support appear to make this association less clear in these real-life work situations. Computer work with elevated arms may represent a risk of shoulder and neck pain, but the explanatory rationale of elevated arms causing an increase in shoulder muscle activity is not generally supported by this study. Arm movement was consistently associated with an increase in trapezius activity.

Trapezius activity was consistently associated with arm elevation and arm movement in standing and walking. It is therefore surprising that median trapezius activity was not significantly related to median arm posture and movement in inter-subject comparisons. This may be due to differences in work technique, idiosyncratic motor patterns, materials handling, etc., contributing to inter-subject differences in trapezius activity pattern.

Trapezius activity was lower in this study than in some studies of computer users (median activity levels >3% EMG$_{max}$; Wahlström et al. 2002; Blangsted et al. 2003, 2004), but comparable to a study of computer users performing computer assisted drawing work (Byström et al. 2002). There are differences in determining maximal sEMG amplitude, by time interval used (Blangsted et al. 2003, 2004) or by estimate made from a sub-maximal reference contraction (Wahlström et al. 2002). However, the effect of methodological differences in the calibration procedure is scaled down in proportion to the amplitude of

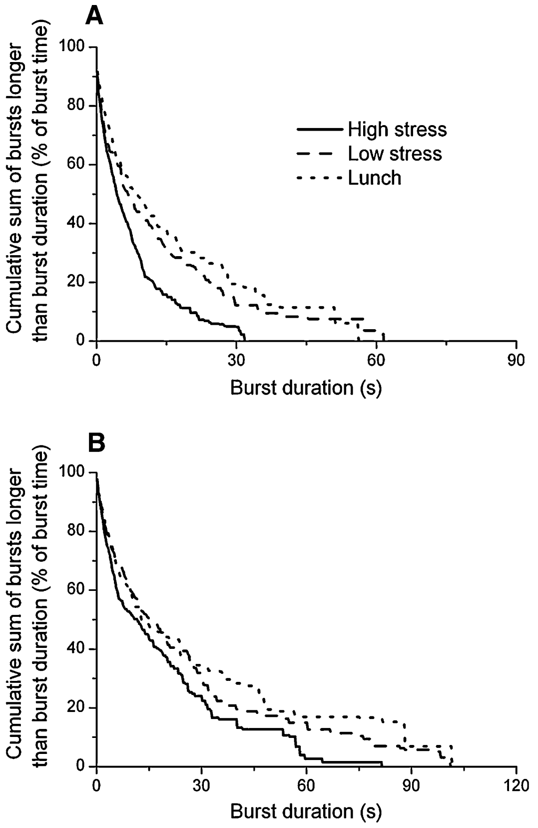

Fig. 5 Fraction of burst time by bursts of equal or longer duration than burst duration shown on abscissa for burst amplitude of 2 (**a**) and 1% EMG_{max} (**b**). *Panels* show group median values of right and left trapezius combined. The *graphs* should be read as showing that, e.g., about 15% of burst time consists of bursts with longer duration than 30 s in low stress and lunch periods, while the comparable result for high stress periods is about 2%. Median value of longest duration burst is about 30 s for high stress and 60 s for low stress and lunch periods, all values referred to burst amplitude 2% EMG_{max} (**a**). There was a tendency of longer bursts for dominant versus non-dominant trapezius in low stress and lunch periods, but not in high stress periods

the sEMG response and is therefore small. Differences in, e.g., arm movement pattern may account for the different results.

A low level of trapezius activity makes especially the left sEMG recording sensitive to the QRS complex of the heartbeat. The level of contamination varies (Mork and Westgaard 2004). In case of significant contamination, a heartbeat of 60 bpm will influence every fourth to fifth sEMG value at 0.2 s resolution, which may cause an underestimate of sEMG rest time, but should have minor influence on median activity level and burst pattern. The findings of lower activity levels in non-dominant (left) trapezius and more sustained activity pattern in work situations with low perceived stress should not be invalidated be this error source.

Secretaries were distinguished by shorter duration of periods with seated posture. Pain scores for the shoulder and neck region tended to be lower for the secretaries and the impression was that the work activities of the secretaries were less stressful than for the other two groups. However, sub-group comparison was not a purpose of this study, which focused within-subject contrasts determined by posture, movement and subjectively reported variables. Inclusion of subjects was based on availability within the general category of computer workers, intended to provide contrasting work activities to other workers with predominant upright posture (Mork and Westgaard 2006).

It may be argued that statistical testing of, e.g., sEMG activity in different postures represents multiple comparisons (by using several variables to quantify sEMG activity) and therefore should be qualified by use of Bonferroni corrections. However, this correction is meant to guard against spurious positive statistical significance. In this study, all sEMG variables showed higher or more sustained trapezius activity for upright postures. Bonferroni corrections were therefore not performed.

Additional to quantification of muscle activity by median activity level and rest time, burst analysis were performed (Kern et al. 2001). The rationale for using this analysis is based on the Henneman size principle of orderly recruitment of motor units: the lowest-threshold motor units are likely to be active for sEMG levels higher than 2% EMG_{max} and, potentially, also at levels higher than 1% EMG_{max}. However, recruitment threshold varies with time in sustained (Nordstrom and Miles 1991) and repeat contractions (Romaiguére et al. 1993). Trapezius motor units showed variation in recruitment threshold close to 2% EMG_{max} upon re-recruitment following a sustained contraction (Westad et al. 2003). Thus, quantification by burst analysis provides an indication of the duration of activity for low-threshold motor units, but results should not be over-interpreted. The lower threshold used to determine rest periods (0.5% EMG_{max}) corresponds to fewer than 2–3 motor units active underneath the surface electrode (Westad and Westgaard 2005).

Level or pattern of trapezius activity did not distinguish high-strain (i.e., high perceived stress or tension work periods) from low-strain (i.e., low stress or tension work periods and lunch break) periods with seated posture. This was still the case after controlling for arm movement. Rest time of the non-dominant trapezius was typically 30–40% in both high-strain and low-strain periods. It is well known that imposed mental stress trigger trapezius activity in laboratory studies (e.g., Wærsted et al. 1994), prompting the suggestion that sustained motor unit activity is a possible mechanism to explain the association between stress at work and shoulder and neck pain (Melin and Lundberg 1997; Sjøgaard et al. 2000). Possible reasons for the discrepant results of the present study are that (1) the relatively few subjects with differential VAS scores for stress

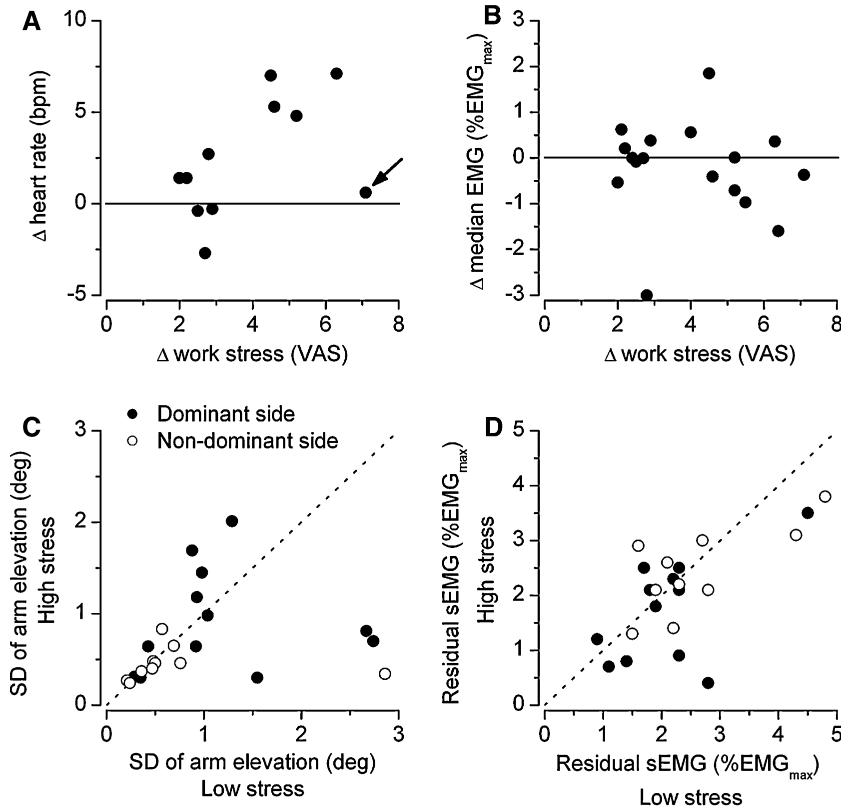

Fig. 6 **a** and **b** *Scatter plots* showing difference in heart rate and median sEMG level (mean of dominant and non-dominant trapezius) versus difference in work stress ≥2 units on VAS. **c** Scatter plot of arm movement in high stress versus low stress periods. **d** Scatter plot of median sEMG level in high stress versus low stress periods, after controlling for arm movement. *Dotted lines* indicate line of identity (**c, d**)

≥2 are not representative for the response pattern in the larger group (i.e., a type-2 error) and (2) the high-stress periods are not of sufficient intensity to trigger a physiological response.

Type-2 error is not likely. With the relatively even distribution of increasing and decreasing sEMG responses in high stress periods (six increasing, seven decreasing, and four unchanged responses), the next 18 subjects in a hypothetical, expanded material must show increased responses to generate a distribution with statistically significant increased response in high stress periods by use of the sign test.

Elevated heart rate in high stress periods was indicated only when there was a substantial difference in subjectively scored work stress. However, there was no indication of higher sEMG level for subjects with markedly elevated stress scores. Higher sEMG level in low stress periods may be due to differences in movement pattern for some subjects, but also after correcting for arm movement there was no indication of increased sEMG activity in high stress periods. To conclude, no indication was found in the present study of higher or more sustained trapezius activity in work periods indicated as stressful. These findings supplement the finding of little or no difference in trapezius activity between work and leisure for workers with habitual low level of trapezius activity (Mork and Westgaard 2006). Work situations with powerful stress elements provoking heart rate and muscle responses similar to those observed in the laboratory probably exist, but it may be queried whether this is a dominant cause of occupational, stress-associated shoulder and neck pain. Work situations in this study were perceived as generally stressful, with reported increase in shoulder and neck pain over the workday and with high prevalence of shoulder and neck pain among all three sub-groups of computer workers.

In an earlier study with a similar analytic approach high stress periods were associated with elevated muscle activity when work tasks included a biomechanical component, but not when a biomechanical component was unlikely (Holte and Westgaard 2002a). A graded increase in differential sEMG activity with increase in perceived tension was indicated, but this included high stress activities with a biomechanical component (Holte et al. 2003).

Firing rates of low-threshold motor units are similar, whether activated by experimental stress or voluntary contraction, for same recruitment threshold and sEMG activity level (Westad et al. 2004). Altogether, these results do not indicate higher metabolic demand on individual motor units in periods with elevated stress, as experienced in the occupational situations of the present study, even though relatively high risk of shoulder and neck pain is indicated (see also Ferreira et al. 1997; Norman et al. 2004).

The motor unit overexertion hypothesis may be an operative mechanism for shoulder and neck pain development at higher trapezius activity levels, but hypotheses for pain causation postulating physiological effects by the sympathetic nervous system should also be investigated (Simons 2004; Knardahl 2002; Eriksen 2004). Physiological phenomena that relate to pain development without influencing the sEMG signal have been reported (Hubbard and Berkoff 1993; McNulty et al. 1994). Stress-induced trapezius activity may thus be a phenomenon in parallel, but not necessarily causal to shoulder and neck pain development following work stress.

Interestingly, the recommended risk-reducing measure of leaving the workplace and performing alternative work activities (Juul-Kristensen et al. 2004) represented periods with increased physical activity and higher trapezius activity level. The potential beneficial health effect of periods with elevated muscle activity, presumably effective whether pain is related to low-threshold motor unit activity or due to other mechanisms, is a promising theme for future studies. It may further be assumed that ergonomic measures aimed at reducing trapezius activity are unlikely to alleviate shoulder and neck pain for the workers in this study.

Individual differences in tolerance to sustained muscle activity are likely: muscle fiber metabolism adapts to habitual usage (Saltin and Gollnick 1983) and the ability of individuals to sustain muscle load may in part be determined by the habitual usage of low-threshold motor units in daily living. If this is the case, the determination of acceptable muscle load by physiological measurement becomes even more difficult. With the uncertain determination of threshold for acceptable muscle load and muscle pain developing at seemingly very low muscle activity levels, the assessment of risk of occupational pain may alternatively be assessed by verbal reports, indicating whether the workload feels undue high (shown to have predictive value in a longitudinal study; Veiersted and Westgaard 1994) or the worker feels stressed or perceive high tension over extended periods (Holte et al. 2003; Wahlström et al. 2004).

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