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Trapezius muscle activity variation during computer work performed by individuals with and without neck-shoulder pain

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ABSTRACT

This study aimed at determining the extent to which individuals with neck-shoulder pain and non-symptomatic individuals differ in muscle activation patterns, when performing computer work, as quantified by exposure variation analysis (EVA). As a secondary aim, we also aimed to quantify the day-to-day reliability of EVA variables describing trapezius muscle activation in a non-symptomatic control group. Thirteen touch-typing computer users (pain: n = 5, non-symptomatic: n = 8) completed three pre-selected computer tasks in the laboratory. Upper trapezius muscle activity was recorded using electromyography and analyzed using EVA with five amplitude and five duration categories. Individuals with neck-shoulder pain spent less time at low amplitudes and exhibited longer uninterrupted periods of muscle activation compared to their non-symptomatic counterparts. Thus, non-symptomatic workers tended to switch between exposure levels more often than individuals with pain. For a majority of EVA variables, ICCs ranged from 0.6 to 0.9, and between-days coefficients of variation were between 0.4 and 2.2.

1. Introduction

Office workers show a higher risk of developing neck and shoulder pain relative to the general population (Ariëns et al., 2001; Chiu et al., 2002; Côté et al., 2009); and several studies have shown that the risk of upper-extremity MSDs increases with duration of computer work (Blatter and Bongers, 2002; Gerr et al., 2006; Jensen, 2003; Marcus et al., 2002). Computer workers have a higher annual prevalence rate (27.1–47.8%) and incidence rate (41–67 cases per 100 person years, depending on symptom case definitions) of pain in the neck and shoulders compared to workers in other occupations (Côté et al., 2009; Wigaeus Tornqvist et al., 2009). Several reviews have examined the relationship between computer work and neck-shoulder pain (e.g., IJmker et al., 2007; Wahlström, 2005), and emphasized that non-neutral arm postures and continuously active neck-shoulder muscles may be key physical factors associated with pain in the neck and shoulder region.

The trapezius muscle in the upper back and neck region controls various movements of the neck and shoulder, and has been implicated as an important muscle lying in the affected region among those with neck and shoulder pain (Kuijpers et al., 2004; Pope et al., 2001). The pathophysiology of persistent neck-shoulder pain, including myalgia, has been reviewed in a number of papers, with the conclusion that there are multiple possible etiological mechanisms (Forde et al., 2002; Sjøgaard and Søgaard, 1998; Visser and Van Dieën, 2006). Among these, a review on the plausible connection between muscle activity and muscle damage (Visser and Van Dieën, 2006) concluded that both epidemiological and mechanistic studies support the Cinderella hypothesis of sustained low-intensity muscle activity causing continuous activation of type I motor units (Hägg, 1991), which may, in turn, lead to overload.

Accordingly, various studies have found that people whose movement patterns are associated with less ‘rest’ in the trapezius muscle, i.e. less periods at very low activity (referred to as “gaps” in electromyography (EMG) recordings) have a higher risk of developing trapezius myalgia (Hägg and Åström, 1997; Veiersted et al., 1990; Veiersted and Westgaard, 1993). A prospective study of newly hired manufacturing workers reported that those who showed a lower number of EMG gaps in the trapezius during their work were more likely to develop neck-shoulder pain in future (Veiersted et al., 1993). Some studies have reported excessive muscle activity in the upper trapezius among computer workers with chronic neck-shoulder pain (Johnston et al., 2008; Madeleine et al., 2016; Szeto et al., 2005; Xie and Szeto, 2015). These studies suggest a possible causal relationship between muscle activation and neck-shoulder pain, making it imperative to study trapezius muscle activation patterns to improve understanding of

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the development and prognosis of neck-shoulder pain. However, EMG gap analysis methods have been unable to differentiate between subjects with and without pain in computer work specifically, probably due to the inherently low levels of muscle activation during computer tasks (Blangsted et al., 2004; Vasseljen and Westgaard, 1995; Westgaard et al., 2001). Thus, a more detailed analysis of temporal activation patterns is of interest. In an occupational context, it may also be particularly relevant to investigate activation patterns in those subjects that have not yet developed severe, continuos pain conditions precluding work, but who still perform work at close-to-normal paces although they suffer from recurring pain at mild-moderate intensities.

Many studies have emphasized the importance of quantifying “variation” in trapezius muscle activation patterns, assuming that chronic pain may be associated with low levels of variation (Côté et al., 2009; Madeleine et al., 2008; Mathiassen, 2006; Srinivasan and Mathiassen, 2012). Some studies have expressed variation in terms of cycle-to-cycle variability in exposure, but in non-repetitive work such as computer work, this approach is not useful. Hence, there has been little consensus in the literature on a reliable and sensitive method of quantifying variation during computer work. As a consequence, a long-standing hypothesis that individuals with chronic pain would present longer durations of sustained muscle activation when performing computer work, and hence exhibit lower variation in muscle activation patterns, has not been confirmed.

In this context, exposure variation analysis (EVA) (Mathiassen and Winkel, 1991) is a tool that expresses continuous exposure-vs-time data in categories defined by exposure amplitude and accumulated time, thus giving way to an understanding of the differences in the temporal structure of exposures at different amplitude levels. EVA has been shown in studies of muscle activity, in particular in the upper trapezius, to be sensitive in various tasks outside computer work (Attebrant et al., 1997; Bao et al., 1996; Delisle et al., 2005; Fjellman-Wiklund et al., 2004; Januario et al., 2018; Mathiassen and Winkel, 1996; Reynolds et al., 2014). Specifically with regard to upper trapezius muscle activity during computer work, EVA has been shown to be sensitive to variation in task (Ciccarelli et al., 2013; Jensen et al., 1999; Mathiassen et al., 2003; Straker et al., 2009; Wærsted and Westgaard, 1997), demographic groups (pain, age and pregnant vs. non-pregnant) (Dumas et al., 2008; Hägg and Åström, 1997; Maslen and Straker, 2009), and configuration of work environment (Dumas et al., 2009; Samani et al., 2009a, 2009b). Of these studies, Hägg and Åström (1997) is the only study to have compared workers with and without pain using EVA. However, this study analyzed typing and paper handling tasks performed by medical secretaries (different from modern computer work), and while they illustrated EVA plots of average differences between groups, they performed statistical testing of group differences only in EMG gaps. Thus, to date, EVA has not been used to characterize differences in trapezius muscle activation patterns accompanying chronic neck-shoulder pain during computer work.

On a related note, the day-to-day variability among individuals in muscle activation patterns expressed by EVA, i.e., the reliability of EVA, is also of interest. Studies by Delisle et al. (2005), Reynolds et al. (2014) and Fjellman-Wiklund et al. (2004) have investigated the consistency within workers of selected EVA variables. However, these studies addressed activities such as sign language interpretation and violin playing, and used a variety of statistical procedures to express reliability, including testing data only for systematic differences between days (Fjellman-Wiklund et al., 2004). Thus, no study has, to the best of our knowledge, explicitly estimated the day-to-day reliability in a wide selection of EVA variables describing trapezius muscle activation of computer users.

Hence, the aims of this study were to: (i) Determine the extent to which individuals with chronic neck-shoulder pain and non-symptomatic individuals differ in muscle activation patterns when performing computer work, as expressed by EVA; and (ii) Quantify the day-to-day variability of EVA metrics describing trapezius muscle activation among non-symptomatic individuals performing computer work. In order to be applicable to those individuals with chronic pain that still perform routine office work, our chronic-pain group was focused on identifying individuals with mild to moderate levels of pain, that still allowed them to perform regular computer work. Our hypothesis was that individuals with neck-shoulder pain would exhibit longer durations of sustained muscle contractions in the trapezius muscle than the non-symptomatic group.

2. Methodology

2.1. Participants

Thirteen right-handed, touch-typing computer users were recruited for this study, forming two groups – participants with pain (n = 5) and non-symptomatic controls (n = 8). Participants were included in the pain group if they reported typical pain intensity of at least three out of ten in a Borg-CR10 scale (corresponding to moderate intensity) in their neck or shoulder region; *and* having pain for 30 days or more in the preceding year; *and* currently experiencing pain at least 2–3 times per week. Pain frequency was reported on a 5-point Likert scale where numbers 1 to 5 correlated to verbal responses “never”, “seldom”, “once a week”, “2–3 times a week”, and “almost all the time” (Andersen et al., 2008). In order to be included in the study, participants in the pain group also needed to be able to perform 1–2 h of continuous computer work without substantial discomfort. They were excluded from the study if they rated moderate or higher pain intensity on the Borg CR-10 scale in at least three other body regions than the neck and shoulders, as this may be indicative of widespread or general pain. Additionally, all participants (in any group) had to be touch-typing adults that performed at least 4 h of computer work per day (on average), while they were excluded if they self-reported any current or recent cardiovascular, neurological or musculoskeletal conditions, or had undergone any surgery on their neck or shoulder regions. Participants in the pain-group were also required to not be experiencing intense pain (i.e. > 4 of 10 in Borg CR10 scale) on the morning of the experiment, so as to ensure that any observed changes in their motor behaviors stemmed from chronic adaptations to pain and were not short-term reactions to intense/acute pain (Madeleine et al., 2008). All data were collected in the mornings. Participant demographics are reported in Table 1. All participants signed an informed consent form, and the experimental protocol was approved by the Virginia Tech Institutional Review Board (IRB).

2.2. Workstation set-up

Prior to data collection, participants were seated at a computer workstation that was adjusted to their individual anthropometry. A computer chair was height-adjusted so that the participant's feet could rest flatly on the floor and their upper leg was parallel with the ground. The workstation was height-adjusted so that the participant's lower arms would be horizontal when they sat upright with arms resting on the desk. There were two computer monitors: one presenting task instructions to the participant, and one used by the participant for the

Table 1
Anthropometric data for each participant group; SD in parentheses.

Group Gender	Age (yrs)	BMI (kg/m2)	Pain Intensity (Borg CR-10)		Pain Frequency (5-point Likert scale)	
			Neck	Shoulder	Neck	Shoulder
Control	22.4	25.8	0.4	0.2	1.5	1.1
4M:4F	(4.9)	(9.2)	(1.9)	(1.9)	(1.5)	(1.9)
Pain	23.0	27.3	3.3	2.3	3.6	2.8
2M:3F	(4.0)	(4.9)	(0.4)	(0.3)	(0.5)	(0.4)

Table 2
Description and meaning of the summary derivatives of EVA, modified from (Delisle et al., 2006).

Variable	Description	Meaning
Amplitude Mean	Average position of the EVA distribution along the amplitude axis max. = 5; min. = 1	A high value indicates that a large percentage of working time is spent in the high amplitude class.
Duration Mean	Average position of the EVA distribution along the duration axis max. = 5; min. = 1	A high value indicates that a large percentage of working time is spent in the long duration class.
Total Mean	Average position of the EVA distribution; resultant of Amplitude and Duration Mean max. = 7.07; min. = 1.41	A high value indicates that a large percentage of working time is spent in combinations of high amplitude *and* long duration classes.
Amplitude SD	Standard deviation over the five sums of time spent in each amplitude class max. = 44.72% (one cell = 100%); min. = 0 (all five cells = 20%)	A high value indicates that the amplitude is unevenly distributed between classes
Duration SD	Standard deviation over the five sums of time spent in each duration class max. = 44.72% (one cell = 100%); min. = 0 (all five cells = 20%)	A high value indicates that the time spent in the duration classes are unevenly distributed.
Total SD	Standard deviation over the 25 cells max. = 20% (one cell = 100%); min. = 0 (all 25 cells = 4%)	A high value indicates uneven distribution across EVA cells. Smaller standard deviations reflect a more equal distribution over all the cells.

experimental work task. The latter was centered in front of the participant with the top of the monitor at eye level and the screen one arm's length away. The first monitor was placed slightly to the right of the latter. All participants confirmed that the workstation setup was visually comfortable before proceeding with the experiment. Workstation set-up was documented for consistency across sessions, while participants were instructed to work in their natural and preferred seated postures.

2.3. Computer tasks

The experimental session consisted of three tasks: a typing task (TYPE), a point-and-click task (CLICK), and a task in which a digital form was filled in by typing and pointing/clicking (FORM). For the TYPE task, participants typed a passage of text into a word processing program. For the CLICK task, participants would use the mouse to select boxes in an image that corresponded to a symbol in an image editing software. For the FORM task, participants would read a series of instructions and complete the instructions by typing or clicking, as instructed. Each task lasted 10 min and participants were allowed to complete the task at their own preferred pace. The number of completed words and number of errors were found as a performance measure for the TYPE task, while number of completed boxes and number of errors were found as performance measures for the CLICK task. These measures were compared across groups to confirm that pain and non-symptomatic control groups were completing similar amounts of work of similar quality.

2.4. Experimental design and procedures

While participants in the pain group completed one session, participants in the non-symptomatic control group completed two sessions, which were at least 48-h but no more than one week apart. At the start of the session, participants were asked to complete reference voluntary exertions (RVE), performing three bilateral arm abductions with 1 min of rest in between, at 90° in the frontal plane for 10 s while holding at 0.5 kg weight in each hand. This procedure is based on (Mathiassen et al., 1995), but slightly modified to ensure that the RVE was about 15% of the maximum voluntary exertion (MVE) according to pilot work on healthy subjects. All participants then completed a training session, replicating the experiment, but comprising only 2–3 min of each task in order for the participants to ask questions and be given feedback prior to data collection. After a brief period of rest following the training session, experimental data collection began. The order of computer tasks (TYPE, CLICK and FORM) was randomized for each participant. Between each task, participants were allowed to rest for 2 min. At the end of each task, participants rated perceived discomfort (RPD) on the Borg CR-10 scale (Borg, 1990).

2.5. Instrumentation and data processing

During the experimental sessions, muscle activity was monitored on the dominant side using surface electromyography (EMG) with pairs of bipolar Ag/AgCl surface electrodes (AccuSensor, Lynn Medical, MI, USA) with a 2.5-cm inter-electrode distance. After skin preparation (abrasion of skin using sandpaper and cleaning using alcohol), these were applied to the upper trapezius muscle, 2 cm lateral to the midpoint between the C7 vertebrae and acromion. Raw EMG data was recorded using a telemetered system (TeleMyo Desktop DTS, Noraxon, Scottsdale, AZ, USA) at a sampling frequency of 1500 Hz. All EMG signals were band-passed filtered using a sixth-order Butterworth filter of zero lag in the 20–450 Hz band and corrected for DC offset. A median filter was then applied to remove spikes in the data from motion artifacts in the signal cables, and then the raw signals were RMS converted using consecutive 100 ms windows. The RMS signal was adjusted using EMG values collected during instructed rest (Jackson et al., 2009), according to the following equation:

$$RMS_{adjusted} = \sqrt{RMS_{unadjusted}{}^2 - RMS_{rest}{}^2}$$

The $\mathrm{RMS}_{\mathrm{adjusted}}$ EMG was normalized to the average across the three reference contractions of the middle 3 s of the RVE signal in each contraction.

2.6. Data analysis

Trapezius muscle activity was expressed in terms of 5x5 EVA matrices, as described below. Logarithmic scales were used, as recommended for low-level repetitive work (Mathiassen and Winkel, 1991). The five amplitude classes were 0–6.67, 6.67–20, 20–46.67, 46.67–100, > 100% RVE. The five duration classes were 0–1, 1–3, 3–7, 7–15, > 15 s. Marginal sums along the duration and amplitude axes as well as summary derivatives of the EVA matrix (Table 2) modified from Delisle et al. (2006) were computed.

2.7. Statistical analysis

The marginal distributions of the EVA matrices along each axis and the calculated EVA summary derivatives exhibited significantly skewed distributions across participants. They were tested for normality and presence of outliers using the Shapiro-Wilk's test. Since the normality assumptions were violated, all measures were subsequently log-transformed for further analysis.

Muscle activation data from all three computer tasks (TYPE, CLICK and FORM) were concatenated and used for composing EVAs for reliability testing. For all EVA variables from the non-symptomatic control group, the following random-effects model was resolved using ANOVA in MATLAB to give estimates of the between-subjects and within-subjects (i.e., between-days) variance components ($\sigma_b{}^2$ and $\sigma_w{}^2$, respectively), along with their 95% confidence intervals:

$$P_{sub,day} = \mu + \alpha_{sub} + \varepsilon_{day(sub)}$$

where $P_{sub,day}$ is the recorded EVA measure for a particular subject on a certain day, μ is the grand mean, α_{sub} is the subject effect (σ_b^2 refers to the variance in α_{sub}), and $\varepsilon_{day(sub)}$) is the residual effect of repeated recordings over days within subjects (σ_w^2 refers to the variance in $\varepsilon_{day(sub)}$). $\varepsilon_{day(sub)}$ also includes any other sources of error such as measurement error.

Intra-class correlation coefficients (ICCS) (Denegar and Ball, 1993) were computed using the following equation:

$$ICC = \frac{\sigma_b^2}{\sigma_b^2 + \sigma_w^2}$$

Absolute measures of reliability – coefficients of variation (CVs) and standard errors of measurement (SEMs) (American Educational Research Association et al., 1999; Denegar and Ball, 1993) – were found using the following equations.

$$CV = \frac{\sqrt{(\sigma_b^2 + \sigma_w^2)}}{\mu}$$

$$\text{SEM} = \sqrt{\sigma_W^2}$$

Forty-one percent of all the data in the 3rd, 4th, and 5th EVA amplitude categories were zero values that could not be log-transformed. Hence, before being log-transformed, data in the third, fourth and fifth categories of the amplitude marginal sum were merged into one measure (i.e., > 20% RVE). A three-way mixed model ANOVA was then performed on the amplitude and duration marginal distributions, with task and order of tasks as within-subjects factors and group as a between-subjects factor. Statistical significance was accepted at $p < 0.05$. All statistical testing was done using JMP Pro 13. When task effects were significant, Tukey's HSD was used to perform post-hoc comparisons.

3. Results

3.1. *Differences between groups*

The EVA analyses showed that participants in the pain group spent, on average, more time in “long” periods at “high” loads than the non-symptomatic control group (Fig. 1). The amplitude and duration marginal sums are shown in Fig. 2. On average, the non-symptomatic control group spent 80% more working time in the 2nd amplitude marginal class compared to the pain group ($p = 0.0001$). The pain group, on the other hand, spent more time in the 5th amplitude marginal class, but this was not specifically tested statistically as this class was combined with the 3rd and 4th amplitude class. There were no statistical differences in the concatenated classes across groups. Participants in the pain group spent 3% less time in each of the first four duration marginal classes compared to the control group ($p = 0.01$, $p = 0.002$, $p = 0.001$, $p = 0.03$).

The EVA summary measures include the means and SDs along each EVA axis and the overall mean and SD across all EVA cells. The results of EVA means along each EVA axis are plotted as 2-D plots in Fig. 3, for the combined three tasks of each participant group. On average, the pain group showed larger amplitude means and longer duration means. The results of the EVA SD along the marginal amplitude and duration EVA axes, as well as the overall SD of all cells are shown in Fig. 4. In general, the SDs were higher in the pain group than in the control group for both amplitude and duration classes, showing that muscle activity was more unevenly distributed across classes in the pain group (cf. Table 2). The pain group had a significantly larger duration mean ($p = 0.05$) and total mean ($p = 0.002$) compared to the control group, and a significantly larger amplitude SD ($p = 0.02$), duration SD ($p = 0.04$) and total SD (0.01) compared to the control group.

The FORM task showed a larger percentage of working time in the 3rd through 5th amplitude marginal classes ($p = 0.01$) compared to the CLICK task. Additionally, the FORM task had higher percentages of working time in the 1st duration marginal class compared to the TYPE task ($p = 0.05$) and to the CLICK task ($p = 0.05$). Participants showed higher duration means in the CLICK task compared to the FORM task ($p = 0.05$). In general, both groups had a low number of errors for the TYPE and CLICK task, and there were no group differences across any of the performance measures. This suggests that the FORM task had higher exposure levels and shorter durations of continuous exposure, and consequently more variable loading, compared to the CLICK and TYPE tasks.

3.2. *Day-to-day reliability of muscle activation patterns using EVA*

The between-subjects variance, within-subject (between-days) variance and the ICC – with 95% confidence intervals – as well as the CV and SEM are presented in Table 3. In general, following the standard criteria for defining low, moderate and high levels of reliability corresponding to ranges 0–0.4, 0.4–0.75 and > 0.75 respectively (Fleiss, 2011), the ICCs were high, while CVs and SEMs – absolute measures of variability – were moderate to good, with some exceptions.

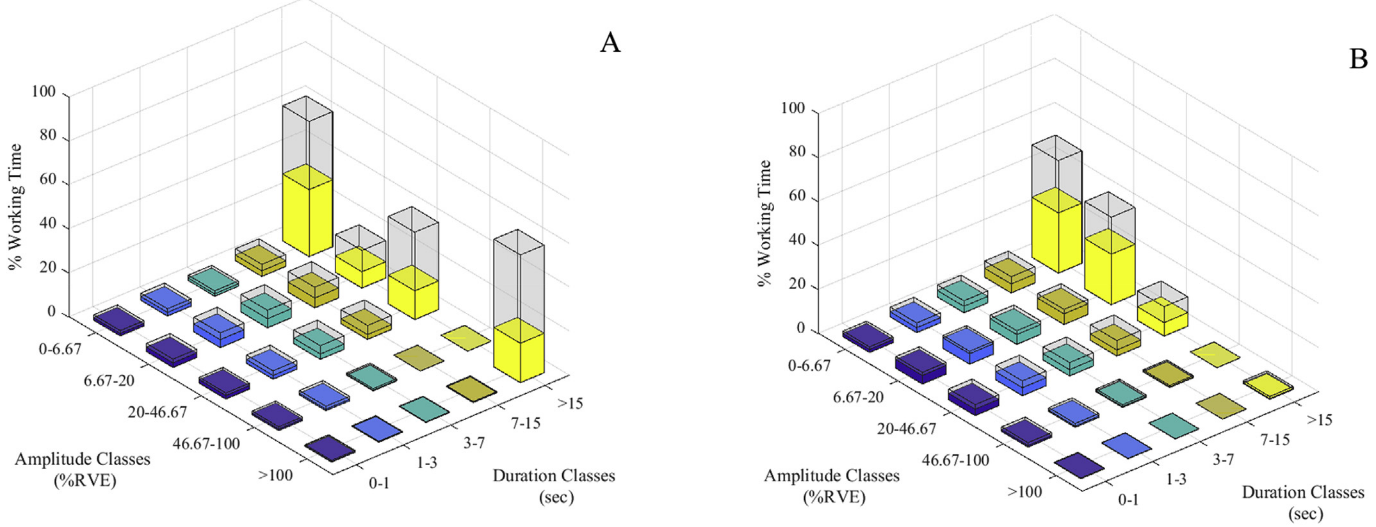

Fig. 1. Average EVA tables for pain group (A) and non-symptomatic control group (B); grey bars illustrate SD.

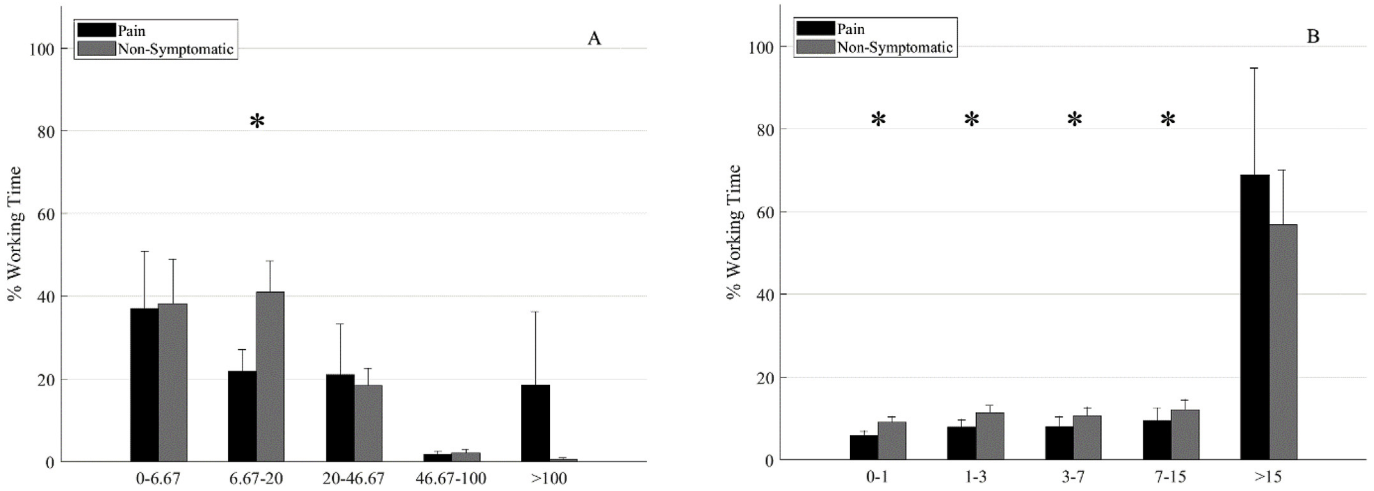

Fig. 2. Distribution of EVA amplitude marginal sums (A) and duration marginal sums (B) for all tasks; $p < 0.05$ denoted with asterisk.

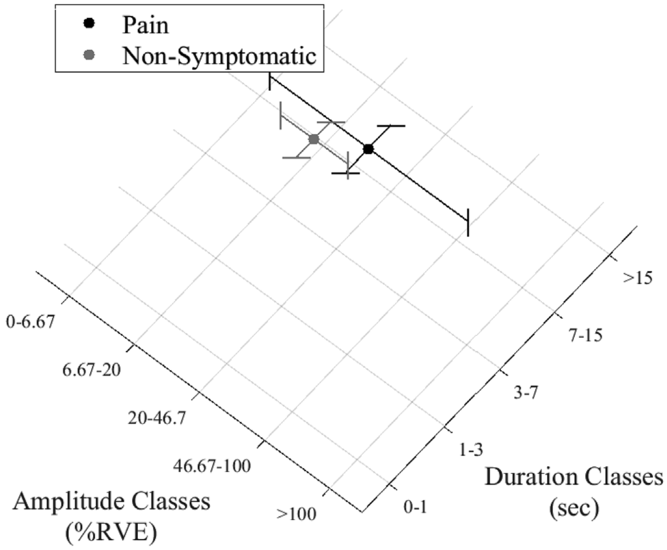

Fig. 3. Amplitude and duration marginal means plots; significant group difference observed in the duration mean.

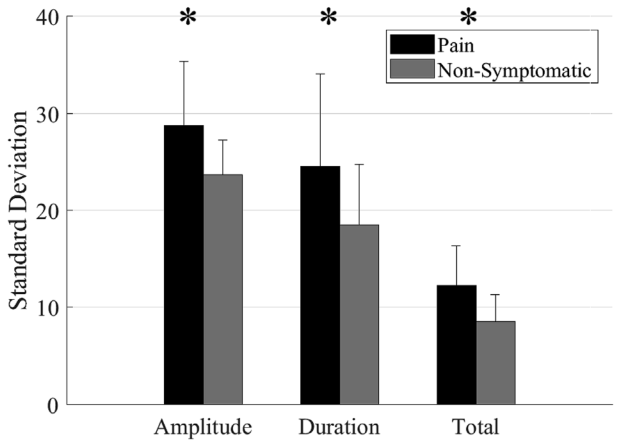

Fig. 4. Amplitude, duration and total marginal standard deviations; error bars show standard deviation between participants within group; $p < 0.05$ denoted with asterisk.

3.3. Discomfort

Participants within the pain group rated, on average, their shoulder pain at 1.6 (SD 0.7), 2.3 (SD 0.6), and 1.6 (SD 1.0) on the Borg CR-10 scale during the TYPE, CLICK, and FORM tasks, respectively. Corresponding ratings for the non-symptomatic control group were 0.4 (0.7), 0.5 (0.9), and 0.3 (0.7), respectively. The TYPE task-related difference in pain rating between the groups was statistically significant ($p = 0.0087$).

4. Discussion

The main goal of this study was to explore variation of upper trapezius muscle activity using variables derived from Exposure Variation Analysis (Mathiassen and Winkel, 1991) in a comparison of non-symptomatic control individuals and those suffering from regular neck-shoulder pain when performing computer work. Also, we aimed at estimating the reliability of EVA variables presented in the literature.

Overall the completion rate for the three investigated computer tasks was similar across groups, and the number of errors were very small (less than 2%) in both groups. This indicated that the sample consisted of experienced computer workers and that pain did not affect performance in these short-term controlled computer tasks. While all participants were relatively pain-free at the beginning of the experiment (by design), the pain group reported increased perceived shoulder discomfort after completing the tasks compared to the control group.

4.1. Differences between groups

A recent review on scapular muscle activity in patients with idiopathic pain found that there was moderate evidence of no systematic differences in average upper trapezius muscle activity between those with neck pain and pain-free controls, during rest as well as activities below the shoulder (Castelein et al., 2015). However, in specific investigations of computer work, some previous studies have shown pain group participants to exhibit higher muscle activity in the upper trapezius compared to a control group, during typing tasks (e.g., Szeto et al., 2005), while others have reported no differences in average upper trapezius muscle activity between workers with no pain, mild pain and moderate pain (Johnston et al., 2008). The study that did find differences in muscle activity further reported that this pain-related difference in muscle activity was associated with small but significant increases in neck flexion and shoulder abduction angles, suggesting a difference in postural control strategies between the two groups (Szeto et al., 2005). Our study contributes to this body of literature by not only

Table 3

Means (μ), between-subjects (σ_b^2) and within-subjects variances (σ_w^2), intra-class correlation coefficients (ICC), coefficients of variance (CV) and standard errors of measurement (SEM) of amplitude marginal sums (AMS) and duration marginal sums (DMS) and EVA summary derivatives for Control group; 95% confidence intervals (CI) are presented.

Measure	μ (% total task time)	σ_b^2 [95% CI]	σ_w^2 [95% CI]	ICC	CV	SEM
AMS 1 0–6.67%RVE	38	762 [129–3387]	126 [58–463]	0.9	0.8	11.2
AMS 2 6.67–20%RVE	41	362 [57–1613]	63 [29–230]	0.9	0.5	7.9
AMS 3 20–46.67%RVE	18	271 [0–1406]	153 [70–562]	0.6	1.1	12.4
AMS 4 46.67–100%RVE	2	11 [0–55]	5 [2–19]	0.7	2.0	2.3
AMS 5 > 100%RVE	0.5	NaN	3 [1–10]	NaN	3.5	1.7
AMS 3-5 > 20%RVE	21	416 [0–2026]	164 [75–602]	0.7	1.2	12.8
DMS 1 0–1 s	10	10 [0–51]	5 [2–20]	0.7	0.4	2.3
DMS 2 1–3 s	12	13 [0–62]	6 [3–20]	0.7	0.4	2.4
DMS 3 3–7 s	11	8 [0–52]	10 [4–36]	0.5	0.4	3.1
DMS 4 7–15 s	12	9 [0–74]	20 [9–73]	0.3	0.4	4.5
DMS 5 > 15 s	55	175 [0–867]	77 [35–281]	0.7	0.3	8.8
Amplitude Mean	1.9	0.2 [0.01–1]	0.1 [0.03–0.2]	0.8	0.3	0.2
Duration Mean	3.9	0.1 [0–0.5]	0.0 [0.02–0.2]	0.7	0.1	0.2
Total Mean	4.4	0.1 [0.01–0.2]	0.0 [0–0.04]	0.8	0.1	0.1
Amplitude SD	27.0	1 [0–55]	27 [12–98]	0.05	0.2	5.2
Duration SD	19.8	54 [0–265]	23 [11–84]	0.7	0.4	4.8
Total SD	8.6	7 [0–33]	3.1 [1–12]	0.7	0.4	1.8

*Note: The NaN values for the between-subjects variance component and ICC refer to a case in which only one subject registered muscle activity in that category, and hence there were not sufficient data to compute a between-subjects variance component or other metrics derived from it.

looking at average muscle activity in occupationally relevant groups, i.e. pain-free subjects and subjects with pain to an extent still allowing work, but also quantifying the patterns of muscle activity (in terms of timing and amplitude), using Exposure Variation Analysis (EVA). In our study, participants in the pain group spent more working time in larger amplitude classes compared to their control counterparts. This is inferred by the pain group showing significantly lower times in the 2nd amplitude class compared to the control group, high time in the 5th amplitude class (although this effect could not be statistically tested directly), and a significantly higher EVA mean on the amplitude axis.

The pain group in our study also spent less time in the first four duration classes and had a larger duration mean compared to the healthy group. While previous studies have shown that workers with pain had more difficulty returning to rest in the trapezius muscle after completing a computer task (Hägg and Åström, 1997; Johnston et al., 2008), our study demonstrates that the pain group exhibits longer continuous durations of contractions than the control group even during task performance. This pattern of longer continuous activation may be indicative of a motor control strategy involving prolonged contraction of type I motor units (Cinderella fibers), however, whether this is a cause or consequence of pain cannot be explained by the current cross-sectional study design.

The pain group exhibited higher SD along both marginal axes and for the total EVA. A higher SD reflects that individuals in the pain group showed both low and high intensity and both short and long duration muscle contractions. According to Jensen et al. (1999), more variable muscle activation patterns combined with equal distributions across both intensity and duration classes is preferred, and this has been a foundation of understanding for studies utilizing SDs along marginal axes and for the total EVA for many studies (Ciccarelli et al., 2013; Delisle et al., 2006, 2005). However, this may be true if the higher EVA SD is achieved by having a distribution with longer times spent in short duration categories and less time spent in long-duration categories. In the case of our pain group, it seems that higher SDs are achieved by shorter times in short duration categories and longer time in long-duration categories. Hence relying on the EVA SD summary measure may not be sufficient to conclude whether the muscle activation pattern may be physiologically beneficial or not.

4.2. Reliability of EVA

For most EVA variables, the within-subjects (i.e., between days) variance component point estimates and lower confidence interval limits were non-zero, which indicate that participants used different strategies for activating the upper trapezius on different days.

The ICCs were generally moderate to high in this study except for the 5th amplitude marginal sum and for the overall amplitude SD. However, since only one participant in the control group registered any muscle activity in the 5th amplitude category, the between-subjects variance component for this category or ICC could not be calculated. While ICCs were, thus, in general moderate to high, it is important to note that the confidence intervals for the variance components were wide, possibly owing to the limited sample size. Table 3 shows that control individuals were similar in most EVA measures, indicated by the lower 95th percentile of the confidence interval for the between-subject variance being zero.

While ICCs are measures of relative reliability, CV and SEM represent measures of absolute reliability (Searle et al., 1992). CV measures the gross variability between subjects relative to the grand means, and good and excellent CVs indicate a high precision in the measure (Searle et al., 1992). The CVs were moderate to high for all of the marginal sums, but low for the EVA summary derivatives. The lower amplitude classes showed lower CVs compared to higher classes, with the 3rd-5th amplitude marginal sum having a CV of 1.15. This difference is driven mainly by the difference in the mean values of the classes and not the variance. However, this does not seem to be the case for the duration marginal sums.

The SEM is another measure of absolute reliability, providing a measure of reproducibility (American Educational Research Association et al., 1999; Hallman et al., 2015). High SEMs represent high variation across repeated measures from each participant. Higher SEMs for the amplitude marginal sums imply that participants used different strategies in using the upper trapezius across different days even though they performed the same simulated computer tasks. The duration marginal sums showed lower SEM values, with exception of the 5th duration marginal sum, indicating that control participants spent similar durations of time on different days at various exposure levels across task conditions. The EVA summary means showed very low SEM values compared to the marginal distributions, suggesting that control participants did not vary by much in their average amplitude level and duration period across days. However, healthy individuals did vary in the dispersion of amplitudes and durations across days, as shown by moderate SEMs values for the EVA SD measures.

4.3. Limitations and future work

This study had a small sample size (n = 13), which could be attributed to the strict inclusion and exclusion criteria for the pain group, affecting statistical power across the study. Hence, our results may be considered as preliminary, and the findings need to be verified in a larger scale study. The data were non-normally distributed and therefore, needed to be log-transformed with zeros corrected in the data by combining larger amplitudes, which may have increased the reliability with a consequent loss in sensitivity.

EVA, as a tool, has some limitations as well. EVA categorizes continuous data into discrete categories, and as such, there is a loss of temporal sequence of data (Mathiassen, 2006). This could hinder the analysis of EVA SD measures. For low-intensity work, logarithmic scales are recommended (Mathiassen and Winkel, 1991). However, recent studies have adopted slightly different scales with increased resolution at the low end of amplitudes to facilitate EMG gap detection (Ciccarelli et al., 2013; Delisle et al., 2006). Because all cells within EVA add up to 100%, there is an innate dependence across the cells and marginal distributions, which may, in future studies, necessitate analysis approaches adapted to so-called compositional data (Pawlowsky-Glahn et al., 2015).

Since we did not objectively measure postures in this study, although the experimenter's observations did not indicate any major differences in posture between the two groups, to what extent postural differences between groups contribute to the observed differences in muscle activity needs to be understood in future studies. Future studies should also focus on obtaining normative EVA data from healthy workers in order to allow detection of any possible change in muscle activation patterns that could be of significance to distinguish tasks and workers in need of intervention. In extension, there is a need for longitudinal studies in order to identify adaptive or maladaptive muscle activation patterns, as a basis for determining biologically relevant changes. Finally, further studies of activity in separate muscle compartments within the upper trapezius may be meaningful to further discriminate between groups and understand patterns of spatial and temporal variation of relevance to health and disease. The goal is to utilize muscle-acitivty-pattern based measures (e.g., EVA) to better characterize chronic motor control changes occurring in adaptation to pain, thereby having improving the understanding of the etiology of neck and upper-limb musculoskeletal disorders.

4.4. Conclusion

Individuals with chronic neck-shoulder pain exhibit larger duration marginal means in an EVA of upper trapezius EMG, representing a tendency towards longer continuous durations of muscle activation. Thus, non-symptomatic computer workers switched between amplitude categories more often than those with pain did. A more variable muscle pattern may be indicative of increased likelihood of type I motor unit de-recruitment and substitution. The pain group EVA is suggestive of chronic motor control changes occurring in the adaptation of pain, and while this has been suggested before, this is the first empirical evidence for this in computer work.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apergo.2019.102908.

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