Effect of Periodic Voluntary Interventions on Trapezius Activation and Fatigue During Light Upper Limb Activity

Effect of periodic voluntary interventions on Trapezius activation and fatigue during light upper-limb activity

Abbreviated title: How to reduce Trapezius muscle fatigue

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Number of pages: 35

Number of figures: 5

Number of tables: 1

Number of words for abstract: 250

Number of words for text: 4368

Conflict of interest statement: The authors report no competing interests.

Acknowledgments

All experiments were performed in the Sensory Motor System Laboratory of the Department of Health Sciences and Technology, Institute of Robotics and Intelligent Systems, ETH Zurich, Switzerland. The work was supported by a grant from the National Science Foundation (32003B_149645). Dongwon Kim received support from the University of Maryland Baltimore Institute for Clinical and Translational Research (ICTR) which is funded in part by Grant Number TL1 TR003100 from the National Center for Advancing Translational Sciences (NCATS) a component of the National Institutes of Health (NIH), and NIH Roadmap for Medical Research. The contents of this work are solely the responsibility of the authors and do not necessarily represent the official view of the University of Maryland Baltimore ICTR, NCATS or NIH.

Abstract

Objective: We investigate the effects of diverse periodic interventions on Trapezius muscle fatigue and activity during a full day of computer work.

Background: Musculoskeletal disorders, including Trapezius myalgia, may be associated with repeated exposure to prolonged low-level activity, even during light upper-extremity tasks such as computer work.

Methods: 30 healthy adults without chronic neck pain participate in a laboratory study that simulated two 6-hour workdays of typical computer work. One workday involves periodic interventions aimed at disrupting monotony (Intervention day), whereas the other workday does not (Control day). Alterations of Trapezius muscle activity are quantified by the 3-dimensional acceleration of the jolt movement of the acromion produced by electrically-induced muscle twitches. The spatio-temporal distribution of Trapezius activity is measured through high-density surface electromyography (HD-EMG).

Results: The twitch acceleration magnitude in one direction is significantly different across measurement periods (p = 0.0156) in Control day, whereas no significant differences in any direction are observed ($p > 0.05$) in Intervention day. The HD-EMG data from Intervention day show that only significant voluntary muscle contractions (swing arms, Jacobson maneuver) induce a decrease in the muscle activation time and an increase in the spatial support of muscle activation areas ($p < 0.01$).

Conclusion: The disruption of monotony via brief voluntary changes in Trapezius contraction effectively modifies the Trapezius contraction pattern (twitch acceleration, active epochs and spatial distribution). These changes support an associated reduction of fatigue.

Application: This study suggests that disruptive intervention activity is efficient in reducing the impact of Trapezius muscle fatigue.

Keywords: **M**uscle fatigue, Trapezius myalgia, work-related disorders, sustained working task, high-density EMG

Précis: The effects of diverse periodic interventions on Trapezius muscle fatigue and activity during a full day of computer work are evaluated. We found that the disruption of monotony via brief voluntary changes in Trapezius contraction effectively modifies Trapezius contraction pattern. Disruptive intervention activity is efficient in reducing Trapezius muscle fatigue.

INTRODUCTION

Neck and shoulder pain are common musculoskeletal disorders (MSDs) in seated and standing work(Kelson et al., 2018; Leclerc et al., 2004; Veiersted et al., 1993). The prevalence of neck pain is high among office workers(Fejer et al., 2006), and Trapezius myalgia is strongly associated with neck pain(Brandt et al., 2014; Goudy & McLean, 2006; Nordander et al., 2016). It has been proposed that Trapezius myalgia results from the prolonged activation of the muscle with limited periods of relaxation, such as static seated work. Although this activity may remain at a low level in computer/office work(Blangsted et al., 2004; Jensen et al., 1999), several studies have shown that prolonged muscle contractions of less than 5% maximal voluntary contraction (MVC) lead to a muscle fatigue of long duration(Blangsted et al., 2005; M. G. Garcia et al., 2015). This type of fatigue, not perceived(M. G. Garcia et al., 2015; Sejersted & Sjogaard, 2000) and due primarily to the failure of the excitation-contraction coupling resulting from a number of physiological mechanisms(Lamb, 2002; Macintosh et al., 2012; Sjøgaard, 1991), has been widely considered a precursor of MSDs(Hadrevi et al., 2019; Sejersted & Sjogaard, 2000; Vøllestad & Sejersted, 1988) and is associated with Trapezius myalgia(Vøllestad & Sejersted, 1988).

A neuromuscular origin of Trapezius myalgia may be linked to the Cinderella hypothesis proposed by Hägg(Hagg, 1991) and supported by posterior results(Abdelmagid et al., 2012; Sjøogaard et al., 2000). This hypothesis, based on the recruitment size principle(Henneman et al., 1965), proposes that the pool of motor units (MUs) that is recruited first is de-recruited last and is thus continuously activated (Cinderella MUs) in sustained muscle contractions. Furthermore, focalization of activity in sustained exertions could promote/exacerbate this mechanism as demonstrated in preliminary results concerning Trapezius myalgia in static work conditions(A. Botter, S.D.H. Soedirdjo, D.G. Kim, C. Nicolletti, P. Wild, T.Laubli, 2018). Hence, such prolonged monotonous activation of muscle fibers is expected to lead to muscle fatigue, muscle damage(Sjogaard & Sogaard, 1998; Visser & van Dieën, 2006) and in long-term MSDs, as mentioned above.

Preventing muscle fatigue resulting from prolonged Trapezius activity may be an essential component in the reduction of MSDs, in particular, myalgia. It is generally accepted that a lack of rest time between successive contractions promotes fatigue and precludes recovery. The need for rest in muscle activity is necessary to prevent tissue damage(Physiology, 1991), especially damages and pain associated with the failure of the excitation-contraction coupling mechanism(Allard, 2018; Hadrevi et al., 2013, 2019). Other factors, including mental and psychosocial loads(Lundberg, 2002; Thorn et al., 2007) or anxiety, also contribute to prolonged Trapezius activity, as well as, reduction in Electromyography (EMG) gaps (short muscle rest periods). Accordingly, these factors lead to muscle fatigue and disorders(Schleifer et al., 2008). Furthermore, as opposed to other upper-limb muscles including the flexor pollicis brevis, biceps brachii and triceps brachii, the Trapezius muscle appears to uniquely lack adaptation (EMG reduction) to a repeated cognitive stressor(Willmann & Bolmont, 2012). Finally, brief cyclical increases in force exertion during a sustained contraction were shown to reduce fatigue(Falla & Farina, 2007). Hence, it is reasonable to assume that, regardless of all the possible contributions to Trapezius muscle tension, provoking periods of rest or disruption of monotonous activity beyond regular rest breaks may favor a reduction of muscle fatigue. In other words, disruption of monotony by introduction of variability in muscle activity may favor spatial redistribution(Falla & Farina, 2007) and heterogeneity in fiber activation(Samani et al., 2010) , and thus reduce muscle fatigue.

In this study, we investigate the effect of diverse brief interventions on Trapezius muscle fatigue during full days of simulated computer work in two situations which differ only by the insertion of regular interventions of different types in the test situation. This investigation determines which of these “disruptive intervention activities” might be the most efficient. Muscle fatigue was quantified by measuring the 3-dimensional (3D) acceleration of the acromion jolt movement produced by electrically-induced muscle twitches. Indicators of muscle recruitment were estimated by quantification of the spatio-temporal distribution of Trapezius muscle activity through high-density EMG (HD-EMG). The null hypothesis corresponds to an absence of difference in fatigue between the control and interventions situations.

METHODS

Participants

Thirty healthy young adults (15 males aged 28.4±6.7 years and 15 females aged 29.7±9.1 years) with experience in computer work participated in this study. Exclusion criteria included chronic pain (more than 30 days within the last 12 months according to the Nordic Questionnaire(Kuorinka et al., 1987)), other pathologies of the neck, prior and actual shoulder or neck pain caused by an accident, skin disease in the neck or shoulder areas, BMI > 30, sleep disorders (e.g. apnea, restless legs syndrome), use of medications such as psychotropic drugs, muscle relaxants or analgesics within the last 3 days prior to the experiment, or pregnancy.

Participants who reported any shoulder/neck pain on the day before the experiment were excluded. The study was approved by the ethical committee of ETH Zurich (EK 2015-N-23). Participants gave informed consent prior to the experiment. They were free to interrupt the experiment at any time without justification and without penalty.

Instrumentation

An inertial measurement unit (IMU; ReSense, ETH Zurich, Switzerland) including three orthogonal accelerometers was used to measure shoulder movements in response to the electrical muscle stimulation. This sensor was placed on the acromion of the right shoulder of the participants with the X, Y and Z axes corresponding to abduction, anterior-posterior and elevation directions, respectively (Figure 1A). Acceleration measurement was preferred over isometric force measurement(M. G. Garcia et al., 2015, 2016) insofar as the shoulder joint has multiple degrees of freedom and stimulation of the upper Trapezius induces a multi-directional movement extremely difficult to capture using a multi-axial strain gauge system. In this latter case, the major issue is to keep the initial condition of the shoulder constant in terms of posture and the complexity of adapting and adjusting the restraining system as a function of participant anthropometry. The acceleration signals were sampled at a rate of 50 Hz, stored into the IMU built in memory and downloaded to the computer after the end of the experiment.

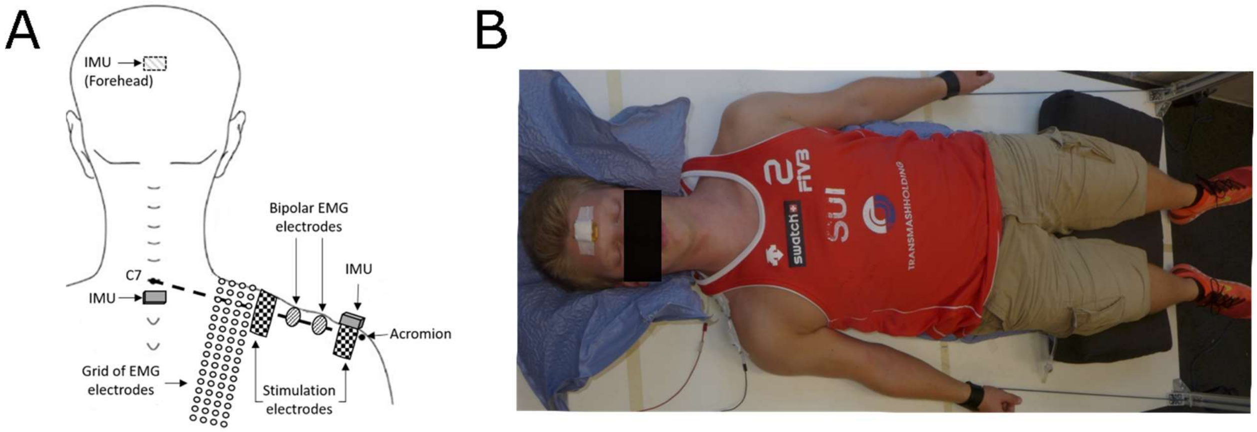

Figure 1. (A) The locations of the IMUs, EMG electrodes and electrical stimulation electrodes and (B) the instructed posture during MTA measurement.

An electrical stimulator (DS7A, Digitimer Ltd stimulator, USA) was used to induce muscle twitches. The stimulator was driven by a pulse generator (DG2A, Digitimer Ltd stimulator, USA) to deliver square pulses of 1-ms duration at a frequency of 1 Hz with a constant current in the range of 20-40 mA. The stimulation frequency was selected to avoid the overlap of successive twitch acceleration signals due to the duration of the shoulder motion. The intensity of stimulation was adjusted for each participant up to a maximal tolerable level of discomfort while obtaining a significant displacement of the shoulder, as validated by previous experiments (Bellew et al., 2018; M. G. Garcia et al., 2015).

HD-EMG signals were recoded with 64 electrodes arranged in array of 4×16 (column × row) with 10-mm inter-electrode distance (LISiN, Politecnico di Torino, Italy). The third column of electrodes was aligned by line-linking the acromion with C7 (Figure 1A). Such positioning allowed to cover the whole upper trapezius and part of the middle Trapezius. A two sided-adhesive foam pad with 64 cavities matching the electrode locations was used to fix the electrode array to the skin. Prior to electrode application, the skin was shaved and treated with conductive abrasive paste (Every, Spes Medica, Italy) to reduce electrode-skin impedance. The 64 signals were collected in monopolar derivations referred to a remote reference on the left acromion, amplified, band-pass filtered (3-dB bandwidth, 6–1200 Hz), sampled at 2441 Hz, and A/D converted with 24-bit resolution (WEMG, Politecnico di Torino, Italy) (Barone & Merletti, 2013).

Procedure

The experiments were conducted over a period of 2.5 days. A half-day training session preceded the two experimental sessions. The schedule was arranged so that training and first experimental session were consecutive or separated only by one day. The experimental sessions were separated by 2 or 3 days to avoid fatigue accumulation. Before all the experimental sessions, participants were required to refrain from heavy shoulder exercise such as weight lifting, push-ups, etc.

Training session. The training session included measurement of the maximal right shoulder elevation force (MVC), a test of the neuromuscular electrical stimulation for definition of optimal electrode placement, familiarization with the stimulation procedure, and introduction to the color-word matching "Stroop test".

A submaximal reference contraction was obtained by a 90° arm abduction (arm horizontal in frontal plane) sustained for 20 seconds prior to each session for normalization purposes(Mathiassen et al., 1995). This task was repeated three times separated by a 40 second break.

A rest test was conducted in the training session. The two purposes of the rest test were: (i) to verify the ability of participants to completely relax the upper Trapezius, and (ii) to measure the background noise for defining the periods of rest and activity in HD-EMG recordings. Hence, a required upper Trapezius rest period preceded each work period. Participants were required to find a comfortable posture with the arm resting on the lap and remaining relaxed in this posture for 1 minute.

During the training session, the optimal electrode location for muscle electrical stimulation was determined using the procedures described in a previous study(Botter et al., 2009). Briefly, a large anode electrode (5×5cm) was positioned over the acromion and the electrical stimuli were delivered through a stimulation pen electrode (cathode: 2-mm diameter). The stimulation was manually triggered, the pen electrode moved slightly by steps over the skin, and the stimulation current was progressively increased (1-mA steps) until a clear muscle twitch was observed. The location that corresponded to the maximal mechanical response induced by the lowest current was defined as the motor point. Then, a 5×5cm cathode electrode (TENS, Axion™) was placed over the motor point. The positions of both electrodes were marked to ensure a consistent placement on the following test sessions. Sustainability of the stimulation in experimental conditions was tested at the selected frequency (1 Hz) during a 10 second period, unless it stopped on request by the participant. If participants felt that the stimulation was too uncomfortable, the stimulation intensity was slightly decreased for another similar test until it was judged acceptable under the assumption of a 4-minute train duration with a sufficient shoulder twitch.

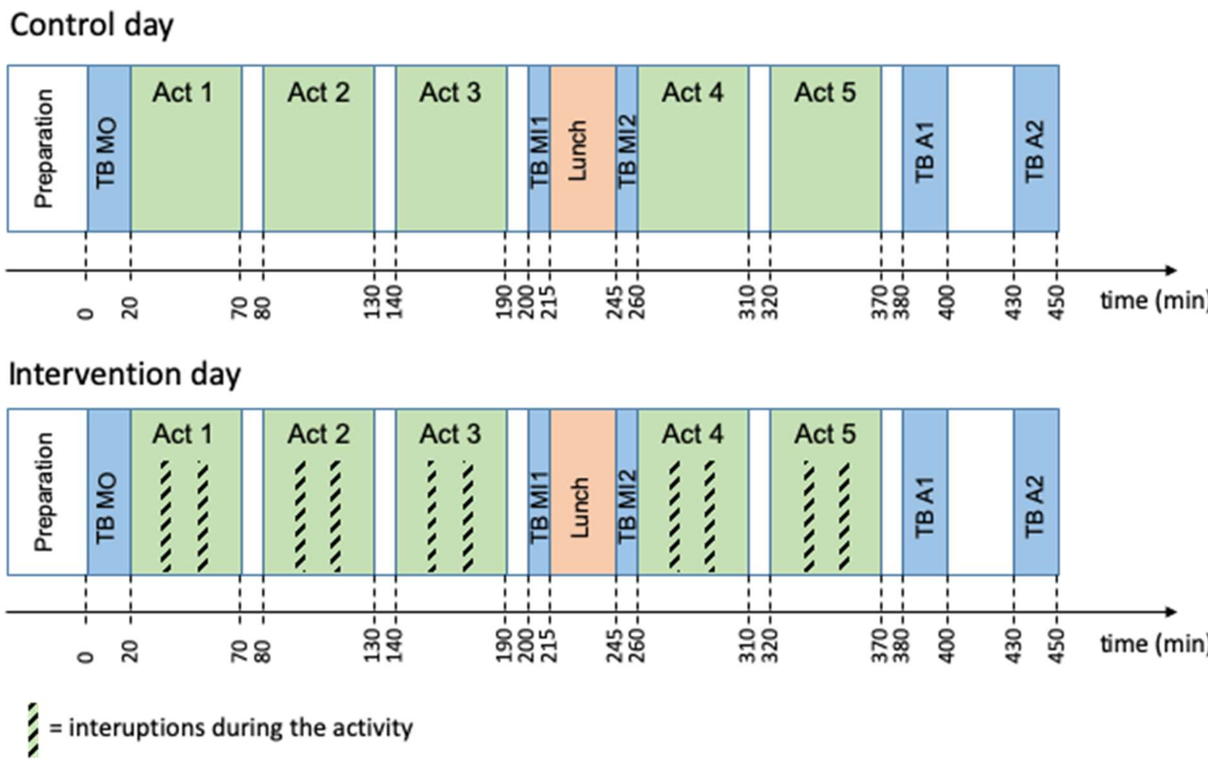

Figure 2. Time sequence of work periods and measures carried out during Control day and Intervention day. Five 50-minute work activities (colored bands) separated by 10-minute breaks (white bands) are performed on each day. Interruptions during work periods on Intervention day are indicated by dashed areas. The work activities are performed in the same order for Control day and Intervention day, while their sequence is randomized across participants. The interruptions are randomized and called by the experimenter.

Experimental sessions. Two experimental sessions were designed to simulate two 6-hour workdays of computer work: Control day and Intervention day. Within each workday, participants performed five 50-minute computer work activities separated by 10-minute breaks (Figure 2). The computer work tasks included typing text with a keyboard that was adjusted to elbow height(Zennaro et al., 2004), typing text with a keyboard that was set 10 cm above the recommended height, playing the spider solitaire game, Stroop test, and puzzle assembly. Work was never disrupted in Control day, whereas in Intervention day, two short interruptions of 5 minutes were introduced at 1/3 and 2/3 of each working period (Figure 2, lower panel). During these interruptions, participants were asked to perform "muscle disrupting/relaxing" activities as follows: a) active interruptions while standing [move shoulders and torso, swing arms in anterior-posterior shoulder plane, Jacobson test - repeated slow but forceful elevation of shoulders as high as possible, stretch torso-shoulder-neck, and rotate head in all directions] and b) passive interruptions [tell a joke and engage conversation, walk to get a drink, focus on trapezius relaxation, qualitative comments on posture and actual comfort/discomfort, and lay on the couch]. For each day, a 30-minute lunch break took place after the third work period. The specific sequence of the type of work activity and disrupting/relaxing interruptions was randomized across participants but for each participant the work activities remained the same for the two workdays (Control day and Intervention day). The order of Control day and Intervention day was also randomized across participants.

To quantify the mechanical effects of muscle fatigue in the experimental session, measures of muscle twitch acceleration (MTA) were performed in terms of direction and duration with participants laying on the back on a horizontal platform (Figure 1B). This method is a variant of the muscle twitch force method(M. G. Garcia et al., 2015, 2016; Kim & Johnson, 2014) as it measures motion acceleration instead of isometric twitch forces. Two vacuum cushions were placed to respectively support the lower back-hip and the neck-head for posture stability and reproducibility during each measurement period. The posture was further stabilized by two suspended weights pulling on each wrist by a rope-pulley system maintaining a constant load (Figure 1B). The maximal stimulation intensity defined during the training session was verified in the testing posture and the stability of twitch acceleration signals was verified through a series of five to ten test stimuli. The electrical stimulation was applied for a period of about 3-4 minutes to reach potentiation before measurement over the stable period(M. G. Garcia et al., 2015, 2016; Kim & Johnson, 2014). Twitch characteristics were defined by time averages over two series of 25 stimulations after potentiation. Participants moved and were repositioned after the first series to verify and validate the stability of the responses by comparison of respective average values (<5%). MTA was quantified before, at the end and 50 minutes after the end of the workdays (Figure 2). This last period corresponded to a post work rest period.

The HD-EMG of the Trapezius muscle was recorded by the 2D electrode array. This technique was used to sample the entire muscle surface with multiple electrodes in order to increase the detection sensitivity to the localized activation of single motor units (or small groups of motor units). The signals were recorded for one minute every five minutes throughout all work tasks for each day.

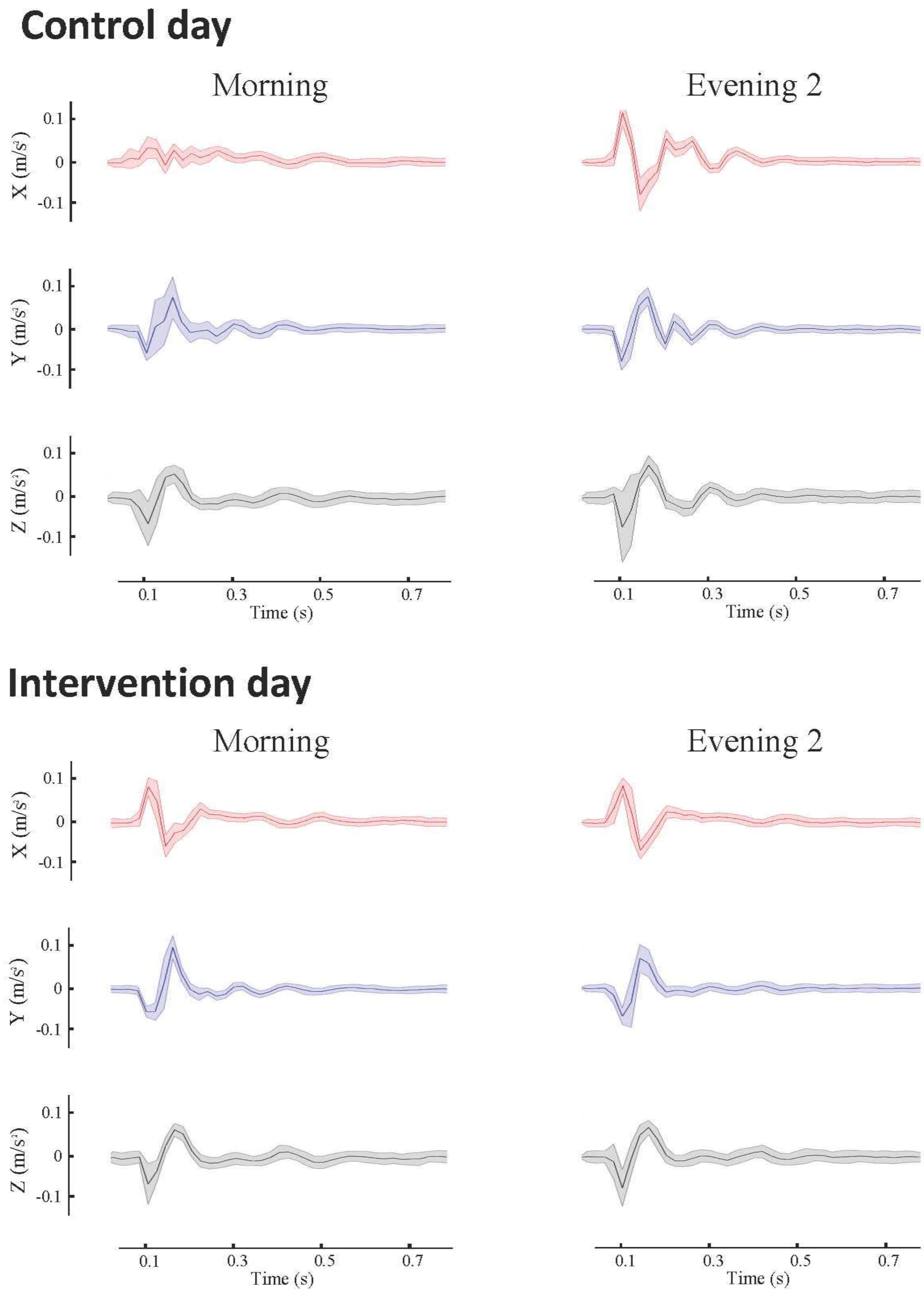

Figure 3. MTA of a representative participant for Control day and Intervention day. Means (bold) and ± 1 standard deviations (shaded) of the traces of accelerations X, Y and Z.

Data Processing and Analysis

MTA. The peak-to-peak amplitude of the time averaged (2×25 twitches) X, Y and Z acceleration components (see Figure 3) and the length of the acceleration vector were computed for each measurement period [morning (M), immediately after the end of work (E1) and 50-min post work (E2)]. These outcome variables were analyzed using a mixed-effects model with subject as the random effect and day (Control, Intervention) and measurement period (M, E1 and E2) as the fixed effect.

HD-EMG. Monopolar signals were band-pass filtered with a second-order Butterworth filter (zero lag, 10-400 Hz). Residual electromagnetic noise from power line was removed using the filtered virtual reference technique(Botter & Vieira, 2015). Then the RMS value of each monopolar EMG signal was computed for 30-ms epochs to obtain the time course of the RMS distributions during each working activity. For each epoch, the active regions were defined as the group of adjacent EMG channels whose RMS value was larger than the noise threshold. Noise threshold was defined as 3 standard deviations of the RMS noise distribution computed from the rest signal recorded immediately before each working activity. The degree and timing of muscle activity was described with: a) the 90^{th} percentile of the RMS EMG amplitude in the active regions, b) the area of the active region (total number of contiguous active channels = Cluster) and c) the activation duration (percentage of active epochs relative to number of epochs) (Botter & Vieira, 2017; Gallina & Botter, 2013). EMG data corresponding to time periods post intervention (on intervention day) and to entire work periods (on Control day) are used for comparison to the reference rest period and to no intervention periods.

The data were summarized for each subject and each day over the 1-minute periods and were analyzed using a three-level mixed-effects model with the one-hour task periods within subject as the random effect. The independent variables fitted as fixed effect were: day (Control, Intervention), measurement period (M, E1 and E2), task, order of tasks (from 1 to 5 in order to explore fatigue over the day), and the type of intervention preceding the current time period (the time periods in the first part of each work period -prior intervention- would be assigned to "no intervention" as well as all work time periods in the control day).

Data were processed using Matlab (R2015a, MathWorks, USA). Statistical analysis was performed using Stata (V15, StataCorp LP, USA). The significance level was set at 0.05.

Workday	Measurement period	X Mean (S.D.)	Y Mean (S.D.)	Z Mean (S.D.)	Vector length Mean (S.D.)
Control day	M	0.035 (0.047)	-0.087 (0.059)	-0.052 (0.052)	0.128 (0.058)
	E1	0.041 (0.046)	-0.074 (0.080)	-0.053 (0.061)	0.135 (0.060)
	E2	0.060 (0.047)	-0.079 (0.059)	-0.051 (0.049)	0.131 (0.061)
Intervention day	Morning	0.041 (0.047)	-0.082 (0.069)	-0.045 (0.038)	0.125 (0.062)
	E1	0.036 (0.053)	-0.072 (0.073)	-0.047 (0.048)	0.129 (0.056)
	E2	0.054 (0.048)	-0.079 (0.062)	-0.041 (0.044)	0.125 (0.060)
Test for Workday (*p*-value)		0.58	0.51	0.17	0.14
Test for Period (*p*-value)		**0.02**	0.28	0.81	0.72
Test for Interaction (*p*-value)		0.75	0.92	0.90	0.98

Table 1. Means and standard deviations (S.D.) by workday and measurement period of the peak-to-peak amplitudes of the time-averaged values of the accelerations for each direction and the length of the acceleration vector (morning (M), immediately after the end of work (E1) and 50-min post work (E2)). The *p*-values of the main effects of workday, measurement period and interaction are presented. The bold expression indicates statistical significance ($p < 0.05$).

RESULTS

MTA. None of the differences between the two series of stimulations (before and after moving) obtained for each measurement in each measurement period were statistically significant ($p >$ 0.1). Hence, the averages of the two series were used to assess changes in acceleration between measurement periods (M, E1, E2) in Control and Intervention days. A summary of the analysis results is presented in Table 1. In Control day, differences between the three measures of acceleration were statistically significant for the X direction ($p = 0.0156$), as illustrated in Figure 4, left panel. However, no significant difference was observed for any acceleration direction as a function of period in Intervention day ($p > 0.05$, see Figure 4). For all acceleration directions, the interactions of measurement period × direction were not significant ($p > 0.1$). Finally, the length of the acceleration vector did not vary with period in either experiment day ($p > 0.5$).

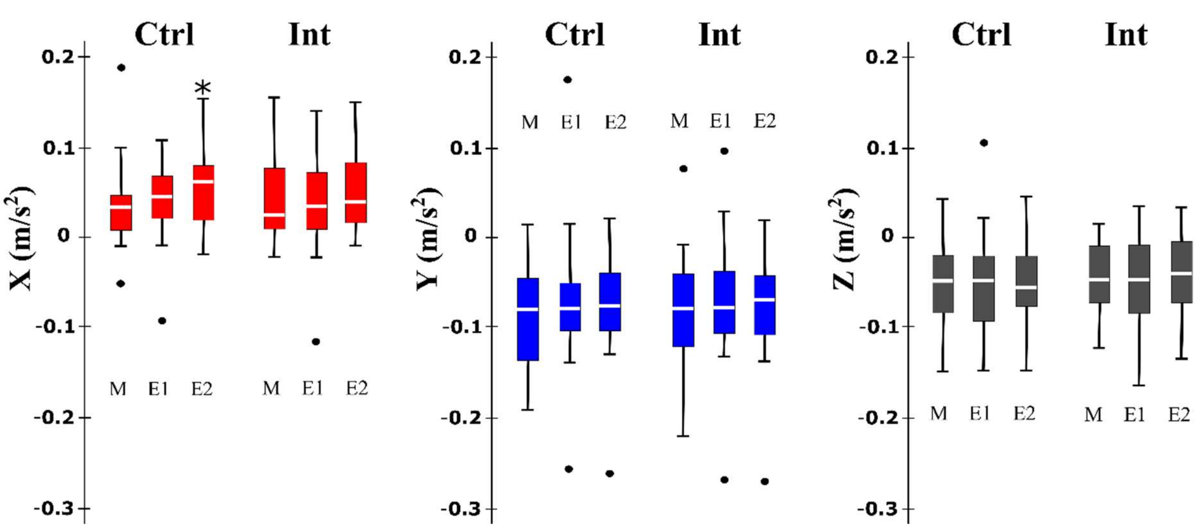

Figure 4. Box plots of the averaged peak-to-peak amplitudes of the time-averaged values of the accelerations across all participants for each direction (X, Y and Z) and each measurement period (morning (M), immediately after the end of work (E1) and 50-min post work (E2)) during Control day (Ctrl) and Intervention day (Int). The error bars represent the maximum and minimum values. The upper and lower quartiles form the box bounds with

the median value splitting the box. The dots represent outliers according to the standard 1.5 interquartile range rule. The asterisk indicates statistical significance ($p < 0.05$).

EMG. The results for the 90th percentile of the RMS EMG, the number of active regions (area of activity) and the duration of muscle activity for each intervention period (by type) are illustrated in Figure 5. The 90th percentile of the RMS EMG was significantly different between Control and Intervention days ($p < 0.001$) and between tasks ($p < 0.001$), but no difference was found for the order of tasks and the type of intervention (Figure 5A). For the number of active regions, the only significant independent factors were the task ($p = 0.0022$) and the type of intervention ($p = 0.0070$). Post-hoc multiple comparisons showed the number of active channels was significantly greater for the swing arm ($p = 0.048$) and Jacobson ($p = 0.003$) interventions (i.e. work periods corresponding to these interventions) in comparison to no intervention (Figure 5B). For the duration of activity, the task was the only significant independent factor ($p < 0.0001$), while the type of intervention was not significant ($p > 0.05$). Post-hoc comparisons of the differences between interventions showed that the number of active epochs (duration of activity) was shorter for the Jacobson intervention when compared to control without intervention ($p = 0.002$, Figure 5C). Differences between interventions were not significant ($p > 0.05$) and of lesser interest as the primary concern is about their efficacy when compared to the control condition.

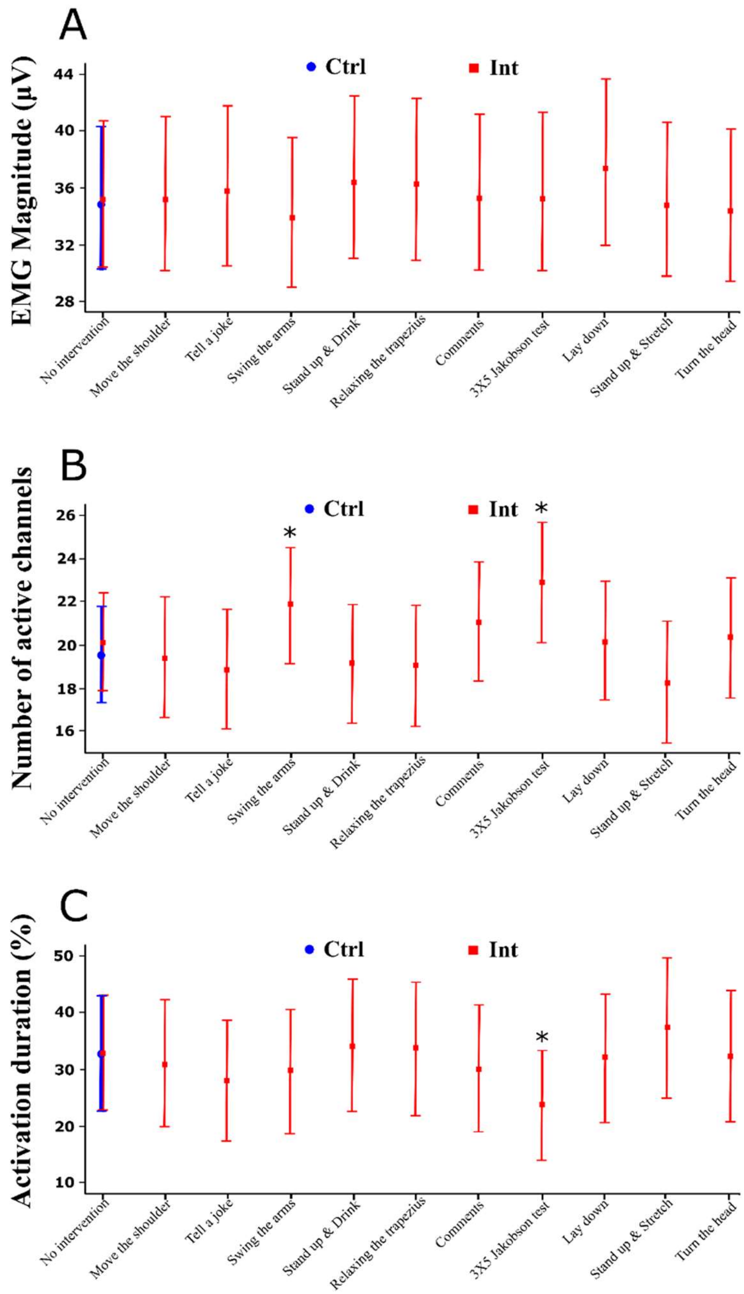

Figure 5. Intervention type effects: (A) the 90th percentile of the RMS value of EMG, (B) the number of active EMG regions and (C) the total duration of EMG activity. Ctrl = Control day and Int = Intervention day. Means± SD are represented. The asterisks indicate statistical significant post-hoc comparisons with control (p < 0.05).

DISCUSSION

MTA clearly indicates a change in the pattern of Trapezius contraction between the beginning and the end of the workday only in the absence of intervention, or in other words when the work-associated monotony of Trapezius activity is not disrupted by active solicitations. It turns out that the concurrent reduction in the number of active epochs and increase in the area of EMG activity following the Jacobson exertion suggest that the Jacobson exertion is the most effective intervention as it promotes mechanisms contributing the reduction of muscle fatigue.

Trapezius activity is related to its multi-functionality including head rotation and shoulder elevation as well as its sensitivity to mental load and/or stress. A study reported that the number of periods of sustained low-level muscle activity longer than 10 minutes predicted musculoskeletal discomfort in the Trapezius(Østensvik et al., 2009). Similar studies that tested light manual work demonstrated that the low-level monotonous contraction of the Trapezius muscle leads to muscle fatigue(Bosch et al., 2007; Goudy & McLean, 2006; Scandinavian et al., 1992). This fatigue is associated with the long-lasting activity of low-threshold motor units(Hägg, 1991; Sjøogaard et al., 2000; Westgaard, 1996). The absence of complete relaxation that keeps low-threshold MUs active is considered as a critical factor for the development of MSD(Lundberg, 2002; Thorn et al., 2007; Veiersted et al., 1993). Hence, regardless of the origin of prolonged Trapezius activity, the role of proposed interventions was to promote relaxation and de-focalization of muscle activity, which in turn would alleviate or prevent muscle fatigue. A detailed attention to the Trapezius heightened activity under stress and high cognitive load(Holte & Westgaard, 2002; Lundberg, 2002; Thorn et al., 2007) was beyond the scope of the present work.

On this basis, changes in MTA during Control day must be indicative of muscle fatigue and its effects on the Trapezius contraction pattern as they do not occur when interventions (specifically swing arm and the Jacobson exertion) induce a decrease in the number of active epochs and/or an increase in the area of EMG activity (i.e. number of channels detecting EMG amplitude larger than the noise level). This assumption is supported by convergent phenomena. First, a change in acceleration pattern in the absence of intervention strongly suggests a fatigue-induced change in the organization of muscle contraction and thus some redistribution of the contracting areas. Three major phenomena can be invoked to support this claim: a) the altered and/or absence of response of fatigued muscle fibers obviously changes the force distribution within the muscle as evidenced by changes in strain profiles exposed by ultrasound imaging(Witte et al., 2006), which in turn induces a change in the displacement of the shoulder rather than a simple reduction of acceleration due to the multiple degrees of freedom of that joint; b) this mechanical outcome is likely exacerbated by the possible fatigue induced rotation/substitution of motor units(Bawa & Murnaghan, 2009; Pascoe et al., 2014) which also modifies the locus and spatial distribution of muscle contraction in the Trapezius muscle(Falla & Farina, 2007; Farina et al., 2008) and may be also associated with c) the activation of MU driving muscle fibers of different orientation. Second, the expansion of the locus of muscle contraction (larger area of activity) associated with the Jacobson intervention (Figure 5B), in comparison to the control workday, supports indirectly the development of fatigue in the Trapezius muscle in the absence of intervention. Indeed, a narrower area of activity suggests that a narrower distribution of active motor units that over the whole day, despite some possible rotation, may contribute to fatiguing the pool of motor units engaged systematically in low level muscle contractions. This expansion effect was not observed in the absence of intervention in

Control day. It is worth noting that simple rest periods (no manual activity) are not sufficient to prevent the development of fatigue and thus not promoting relaxation or disruption of monotonous activation that would change the driving of MUs. Third, as observed in the previous studies of muscle fatigue induced by low level muscle contractions, the long-lasting component of fatigue continues to develop/progress after rest and thus may appear to be significant immediately post work and/or after ≥ 30-60 min. of rest post work(M. G. Garcia et al., 2015, 2016; Kim & Johnson, 2014). This phenomenon is reflected by the gradual change in MTA along the X direction post work (Figure 4 left panel).

The occurrence of significant changes in EMG activity is primarily associated with the Jacobson maneuver (and to a lesser extent the swing arm maneuver). The changes expressed by the concurrent reduction in number and an increase in area of active epochs are coherent with a disruption of the sustained monotonous muscle activity by a large voluntary recruitment. Indeed, as indicated above, displacement of the locus ("centroid") and/or redistribution of muscle activity in response to periodic small increase in muscle contractions during a sustained contraction were observed in the Trapezius muscle via indwelling EMG(Westad et al., 2003) and HD-EMG(Farina et al., 2008). Note that in the latter cases mild superimposed contractions were repeated frequently while here the disruptive interventions occur only briefly and only two times during the work periods. Hence, this as opposed to the otherwise mild interventions here or frequent changes in muscle contraction in other studies, the influence of the drastic increase in MU recruitment by the voluntary drive of the Jacobson maneuver, and to a lesser extent by arm swinging, appears necessary to modify the central drive of the MUs. This "reset" can be viewed as a significant change in a motor program that the central nervous system (CNS) may be reluctant to modify without intervention. Indeed, the CNS attempts to optimize the cost of the motor programming effort(Kibbe & Kowler, 2011; Wolpert & Landy, 2012) and optimize behaviors based on the expected value of the motor outcome(Trommershäuser et al., 2003). As fatigue resulting from the failure of the "excitation-contraction coupling"(Chin et al., 1997; Sejersted & Sjogaard, 2000) associated with low level exertion is not signaled to the CNS(M. G. Garcia et al., 2015, 2016; Sejersted & Sjogaard, 2000), then there is less incentive for the CNS to significantly modify the contraction pattern. A similar line of argument in support of the present proposition has been used to explain the reduction of muscle fatigue resulting from prolonged standing (which also corresponds to low level muscle activity) by walking periods(M.-G. Garcia et al., 2020). The CNS behavior perspective (reluctance to change monotony) is also in agreement with a proposition by De Rugy(de Rugy et al., 2012) postulating that motor coordination is habitual rather than optimal. Hence, to be effective, it appears that breaking monotony requires voluntary muscle activations either large and infrequent or mild and frequent rather than rest. Regardless of the light work activities performed in this investigation, two short Jacobson exertion periods within the "work hour" were sufficient to produce a significant effect during the task period. Hence this type of maneuver may be recommended to reduce the risk of developing Trapezius muscle myalgia in the long term, as very frequent exertions may not be practical.

KEY POINTS:

- Alterations of Trapezius muscle activity are quantified by the 3-dimensional acceleration of the jolt movement of the acromion.
- The spatio-temporal distribution of Trapezius activity is measured through HD-EMG.

- The twitch acceleration magnitude in one direction is significantly different across measurement periods in Control day, whereas no significant differences in any direction are observed in Intervention day.
- The HD-EMG results in Intervention day show that only significant voluntary muscle contractions induce a decrease in the muscle activation time and an increase in the spatial support of muscle activation areas.

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