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ORIGINAL ARTICLE

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Relationship between perceived exertion and mean power frequency of the EMG signal from the upper trapezius muscle during isometric shoulder elevation

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Abstract The aim of the study was to investigate the relationship between a fatigue-induced increase of perceived exertion in the neck with a decrease of mean power frequency (MPF) in the surface electromyography (sEMG) signal during repeated shoulder elevation endurance tasks. About Thirty-two healthy women (age range 20–62) performed two maximum 6-min shoulder elevation endurance tasks at 30% of their maximal voluntary contraction (MVC) level, separated by a rest of 6 min. During these exercises, perceived exertion was estimated using the Borg scale (range 0–10), whereas the MPF of the sEMG signal from the upper trapezius was simultaneously detected. Linear regression analysis was applied over time for each trial and subject for both MPF and Borg scale rating values. The MPF was normalized by the intercept of the linear regression analysis. The resulting slopes of normalized mean power frequency (nMPF) and Borg scale rating were correlated with each other by linear regression for both trials. In order to investigate the individual behavior of fatigue effects between trials, $\Delta_{\text{trial 2-trial 1}}$ slopes of nMPF and Borg scale ratings were calculated for each subject. These slopes of nMPF and Borg scale ratings were correlated with each other as well by linear regression. The increase of Borg scale ratings, as well as the decrease of nMPF, were significantly higher in trial 2 than trial 1 ($P<0.01$). The results show a linear correlation between slopes of nMPF and Borg scale ratings for both trials 1 and 2 ($r=0.76$, $P<0.01$). Trial-to-trial slopes ($\Delta_{\text{trial 2-trial 1}}$) of nMPF and Borg scale rating, were also significantly correlated ($r=0.68$, $P<0.05$). Thus, the individually sensed increase of perceived exertion in the neck during trial 2 was accompanied by a simultaneously higher detected decrease of nMPF. These findings indicate a close relationship between subjective perception of exertion in the neck and objectively assessed muscle fatigue of the upper trapezius.

Keywords EMG · Trapezius · MPF · Borg · Fatigue

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Introduction

Investigation of neck muscles has recently been of increasing interest, as neck pain is a common health problem, which can lead to the development of work-related musculoskeletal disorders (Hagberg and Hagberg 1989; Jensen et al. 1993). The complaints are frequently observed in female workers performing static and repetitive work at low load level (Hagberg and Wegman 1987; Åkesson et al. 1999). Besides physical demands, neck muscles seem to be very sensitive to subjective perception. For example, Rissen et al. (2000) found correlation between self-reported negative stress and electromyographic activity of the trapezius during work.

The upper trapezius muscle has often been investigated by surface electromyography (sEMG) during sustained fatiguing contractions in relation to neck pain (Öberg et al. 1992). The decrease of mean power frequency (MPF) of the sEMG signal has proven to be an indicator of neuromuscular fatigue for the upper trapezius, as well as for other muscles (Basmaijan and De Luca 1985; Moritani et al. 1986; Madeleine et al. 2002). Besides objectively measurable indicators, a subjective factor is also a conceptual part of fatigue (Simonson and

Weiser 1976). The perception of exertion has been used in many previous studies, quantified with the Borg scale, especially in the research fields of medicine and sports physiology.

The MPF, as an indicator of objective detectable fatigue, seems to be a sensitive measure for subjective sensation of fatigue. There are a few studies that compare changes in perceived exertion with changes in the sEMG signal during fatiguing muscle contractions. Recent findings about low back muscles showed a relationship between MPF and Borg scale ratings in high muscle loads (Dedering et al. 1999; Kankaanpää et al. 1997). It has been reported that MPF correlates with Borg scale scores at an absolute load level of 2 kg for isometric shoulder abduction endurance tasks in the trapezius muscle. In the same study, no such correlation was found at an absolute load level of 0 kg because there was no change of fatigue measures over time (Öberg et al. 1994). Such absence of fatigue effects of the MPF has also been reported in other studies (Farina et al. 2004; Arendt-Nielsen et al. 1989). In these studies fatiguing endurance tasks were investigated below a relative force level of 5% maximum voluntary contraction (MVC). Other findings investigating different type of muscles (Merletti et al. 2002; Rainoldi et al. 1999), as well as the trapezius (Madeleine et al. 2002), show significant fatigue effects in the sEMG signal at relative force levels of approximately 40% the MVC.

It is important to show a relationship between objective and subjective signs of fatigue at a relative load level in regard to the perception of exertion in the neck area and the development of neck pain at the workplace (Hünting et al. 1981). The evidence of a close relationship between objective and subjective fatigue at lower force levels would strengthen the concept that perceived exertion corresponds with physiological fatigue in the muscle. Eventually objective EMG measures could be substituted by questionnaire studies on perceived muscle exertion, which would facilitate the carrying out of large-scale field studies. The purpose of this study was to compare objective and subjective fatigue-induced effects during repeated shoulder elevation endurance tasks at 30% of MVC.

Materials and methods

Subjects

About 32 female subjects (age range 20–62 years, mean ± SD: 41.0 ± 14.8 years; height, mean ± SD: 164.5 ± 5.6 cm; weight, mean ± SD: 61.1 ± 6.9 kg) participated in the study. All subjects were healthy, sedentary, and free from neuromuscular diseases; they had no previous history of pain or injury to the shoulder, neck, or back and no known neuromuscular or cardiovascular disease. Subjects were informed of potential risks and benefits and signed an informed consent form prior to taking part in the study. Permission was obtained from the ethical committee of the Swiss Federal Institute of Technology Zurich.

Force measurement

Shoulder elevation force was measured using two independent force sensors (AFG 1000N, Mecmesin, West Sussex, Great Britain), incorporated in the metallic lever arms of the test chair (Fig. 1). Signals from the right force sensor were displayed with a visual biofeedback system (LabVIEW V6.0, National instruments, Austin, TX, USA), which provided the subject with information about the force exerted on that side.

Surface EMG acquisition

A portable EMG acquisition system (EMGlogger II, LISiN, Torino, Italy) (Pozzo et al. 2004) was used to detect multi-channel surface EMG signals from an adhesive electrode array, consisting of eight rectangular electrodes (1×2.5 mm) equally spaced at 5 mm inter-electrode distance (ELSCH008, Spes Medica srl, Battipaglia, Italy). For details of the technique see Masuda et al. 1985 and Merletti et al. 1999, 2003. Signals were detected in the single differential (SD) mode, amplified and filtered (−3 dB bandwidth 10–400 Hz), sampled at 2,048 samples/s, converted to 16-bit data and stored on a removable PCMCIA memory card. After data were transferred off-line on a desktop PC, signal quality was visually checked for artifacts, double differential EMG signals were computed and the MPF was calculated using a specific software (EmgAcq V2.1, LISiN, Torino, Italy).

Electrode placement procedure

The array was placed on the straight line between the spine of the seventh cervical vertebra (C7) and the lateral edge of acromion (Jensen et al. 1993). The electrode most medial was located 2 cm lateral from the midpoint of the acromion-C7 segment. Before electrode placement, the skin was cleaned and slightly abraded with paste (Meditec-Every, Parma, Italy). The cavities of each electrode were filled with 20 µl of conductive gel (Aquagel, Meditec-Every, Parma, Italy) using a gel dispenser (Multipette Plus, Eppendorf AG, Hamburg, Germany). Signal quality was checked with a few test contractions after placing the linear array. The amount of muscle covered by the surface electrodes was 35 mm.

Experimental protocol

The subjects sat comfortably on the test chair and were fixed in position by means of a belt. They were instructed to hang down their arms in a relaxed position during the experimental session. The subjects were asked to perform an isometric shoulder elevation against the metallic lever arms equipped with force sensors for the following MVC and endurance tasks at 30% MVC (Fig. 1).

In each experimental session, the subjects produced 3–5 MVC, each MVC being separated by a rest period of 2 min. If the third MVC was at a minimum 5% higher than the previous MVCs, two additional MVCs were performed. The highest, right side value was chosen as the reference MVC value for the following endurance tasks. After MVC measurements and a subsequent 5-min rest, the subjects were asked to exert two isometric contractions at 30% MVC, to be held as long as possible (with a maximum of 360 s), separated by a rest period of 6 min. The subjects were given a real-time feedback of the exerted force on the right side, and asked to limit the force fluctuations in a range of ± 10 N centered on their nominal value. During both endurance tasks, perceived exertion in neck region was measured every min by rating the Borg category ratio scale (CR-10) (Borg 1982). Endurance tasks were interrupted when the subjects were no longer able to maintain the given force level. Endurance time was defined as the end of the task.

Data analysis and statistics

Linear regression analysis over time was applied to calculate the intercept (defined as initial value corresponding to the beginning of the contraction) and rate of change (defined as slope) of MPF and Borg scale values (Merletti et al. 1990; Merletti and Lo Conte 1997). Normalized MPF slopes were defined as the ratio between the slope of the regression line and the corresponding MPF initial value:

In order to measure fatigue effects within subjects between trials 1 and 2 ($\Delta_{\text{subj, trial 2-trial 1}}$), initial values and slopes of nMPF and Borg scale ratings were calculated for each subject and the following terms were defined:

$$\Delta_{\text{subj } i} \text{ initial value}_{\text{trial 2-trial 1}} \text{ nMPF} = \text{initial value}_{\text{subj } i, \text{ trial2}} \text{ nMPF} - \text{initial value}_{\text{subj } i, \text{ trial1}} \text{nMPF}$$
$$\Delta_{\text{subj } i} \text{ initial value}_{\text{trial 2-trial 1}} \text{ BSR} = \text{initial value}_{\text{subj } i, \text{ trial2}} \text{ BSR} - \text{initial value}_{\text{subj } i, \text{ trial1}} \text{BSR}$$
$$\Delta_{\text{subj } i} \text{ slope}_{\text{trial 2-trial 1}} \text{ nMPF} = \text{slope}_{\text{subj } i, \text{ trial2}} \text{ nMPF} - \text{slope}_{\text{subj } i, \text{ trial1}} \text{nMPF}$$
$$\Delta_{\text{subj } i} \text{ slope}_{\text{trial 2-trial 1}} \text{ BSR} = \text{slope}_{\text{subj } i, \text{ trial2}} \text{ BSR} - \text{slope}_{\text{subj } i, \text{ trial1}} \text{BSR}$$

subj i i subject, *nMPF* normalized mean power frequency, *BSR* Borg scale rating

Statistical analysis included analysis of variance for repeated measurements to check for differences between trials 1and 2, and calculation of Pearson's correlation coefficient between slopes of nMPF and Borg scale ratings. Statistical significance was set at $P < 0.05$. Data were reported as the mean and standard deviation.

Fig. 1 Experimental set up

Results

MVC and endurance time

The MVC value (mean ± SD) was 380.6 ± 112.2 N for the right side and 410.5 ± 117.1 N for the left side. From the total of 32 subjects, 24 reached the contraction time limit of 360 s in the trial one, and 19 in both trials. For the remaining eight subjects, the endurance time was less than 360 s in both trials.

Fatigue effects between trial-to-trial within subjects

The SEMG data of one subject were disregarded because of defective signal acquisition.

Fatigue effects during trials arose both in normalized MPF values (decrease of MPF) and Borg scale (increase of the Borg index) during endurance tasks in both trials. Fatigue effects occurred more quickly in trial 2 than trial 1 within subjects (Δ_{sub}trial). Initial values and slopes from normalized MPF and Borg scale ratings of both the trials 1 and 2 significantly correlated with each other (Pearsons $r = 0.7$–0.9) (Table 1).

Table 1 Initial values and slopes of normalized MPF (*nMPF*) and Borg scale ratings (*BSR*) for the trial 1

	Trial 1 mean (± SD)	Trial 2 mean (± SD)	$\Delta_{\text{subj, trial 2-trial 1}}$ mean (± SD)
NMPF			
Initial value (s^{-1})	71.99 (±7.29)	70.15 (±5.81)	−1.84 (±4.02)*
Norm. slope (s^{-1})×10^{-3}	−0.36 (±0.39)	−0.55 (±0.54)	−0.19 (±0.25)**
BSR			
Initial value	2.11 (±1.42)	1.99 (±1.42)	−0.12 (±1.12)
Slope (s^{-1})	0.99 (±0.52)	1.31 (±0.79)	0.32 (±0.53)**

The Δ_{sub} trial column reports average individual changes between trials 2 and 1
*$P < 0.05$
**$P < 0.01$; $n = 31$

Figure 2 presents the data of both trials together, with their corresponding regression lines (trial 1: $r = 0.76$, slope = −0.57, intercept = 0.21; trial 2: $r = 0.76$, slope = −0.50, intercept = 0.14).

Intra-individual variability was large for both differences ($\Delta_{\text{subj i}}$ slope$_{\text{trial 2-trial 1}}$ nMPF, $\Delta_{\text{subj i}}$ slope $_{\text{trial 2-trial 1}}$ BSR) and it is of interest to investigate if a swifter fatigue process within subject can be simultaneously measured by subjective (Borg scale rating) and objective (nMPF) evaluation. If a stronger increase in Borg is seen between trials 2 and 1, simultaneously a stronger decrease is expected in MPF between these trials. Then these differences should significantly correlate with each other. For this purpose, the differences of the slopes of the Borg scale rating and nMPF were correlated and illustrated in Fig. 3 ($r = 0.68$, slope = 1.49, intercept = 0.05).

Discussion

In the present study, neuromuscular fatigue-induced effects in the upper trapezius muscle were analyzed and compared with changes of perceived exertion in the neck during shoulder elevation endurance tasks at 30% MVC.

Our results show that a decrease of normalized MPF detected in the upper trapezius highly correlates with an increase of Borg scale ratings in the neck for isometric shoulder elevation endurance tasks at 30% MVC. Faster fatigue-induced effects in the Borg scale rating were simultaneously detectable in the sEMG signal. The question arises whether a swifter neuromuscular fatigue is related with a swifter perceived exertion; this could be answered on the basis of the increased effects between trials 1 and 2; the differences of both normalized MPF and Borg scale ratings indeed correlated significantly (Fig. 3). The individual estimated difference in the perception of fatigue could also be simultaneously detected in the upper trapezius. The more strenuous the fatiguing contractions were perceived by the subjects in the second trial, the larger the detection of the objective fatigue-induced effects in the upper trapezius. The relationship describes approximately 50% of the variance. The correlation coefficient between trials 1 and 2 was $r^2 = 0.57$ and was 0.46 for the simultaneously increased effects of the Borg scale and MPF. This 50% of the variance is an underestimation, since the calculation of normalized MPF in the upper trapezius can vary in reliability from 100 down to 60% according to electrode position (Farina et al. 2002).

In order to compare these findings with our results, two different methodological aspects must be considered. First, the extent of fatigue effects in the sEMG signal can vary using absolute load levels, due to the individual variability of performing muscle force, especially for shoulder elevation (see SD for MVC). To avoid this variation, we used relative instead of absolute load levels as reference values for endurance. Farina et al. (2004) estimated that the shoulder abduction task at 0 kg force load in Öberg's study corresponds to approximately 15–20% MVC. Second, the function of the trapezius is different in shoulder abduction tasks; it must compensate torque due to the lifted arm. Furthermore, other muscles are activated in addition to the trapezius muscle (Matthiassen and Winkel 1990). Investigating the biceps muscle, Merletti et al. (2002) also found no fatigue effect in nMPF at 20%, whereas at

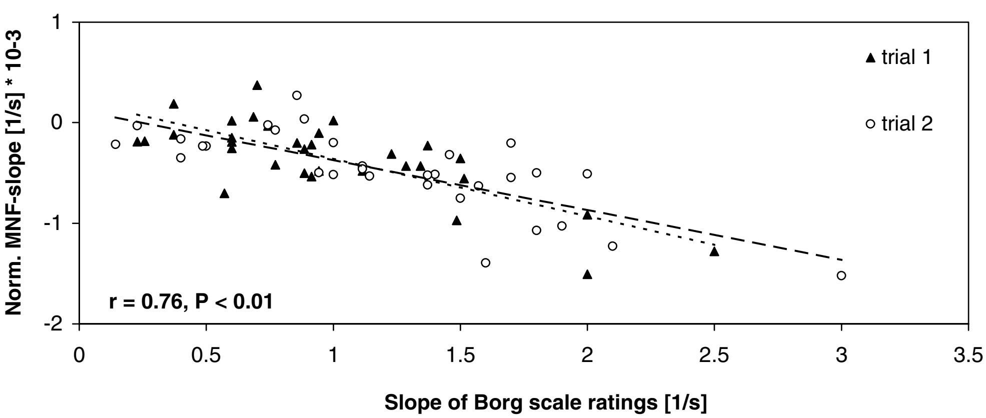

Fig. 2 Significant correlation ($P < 0.01$) between normalized slope of MPF and slope of Borg scale ratings for shoulder elevation endurance tasks at 30% MVC. $n = 31$, linear regression lines: trial 1 (*dashed*) $y = -0.5707\ x + 0.2118$; trial 2 (*dotted*) $y = -0.504\ x + 0.1386$

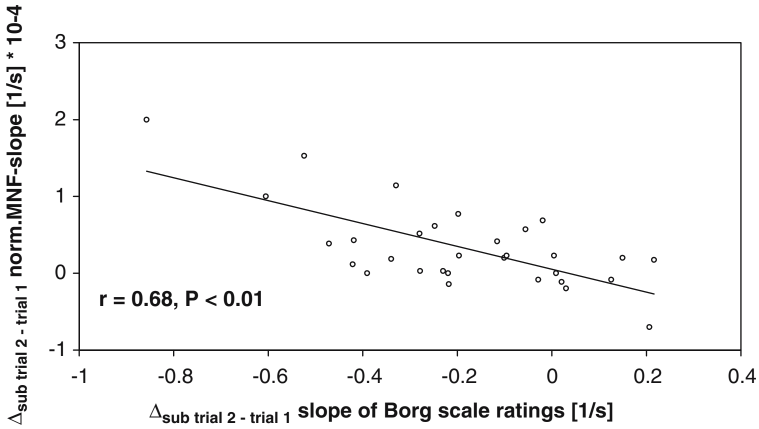

Fig. 3 Individually differentiated slopes of normalized MPF and Borg scale ratings were significantly correlated ($P < 0.01$) for repeated shoulder elevation endurance tasks at 30% MVC. $n = 31$, $y = -1.489\,x + 0.051$

40% MVC fatigue effects occurred. Rainoldi et al. (1999) were able to demonstrate a slight fatigue effect in nMPF, even at 10% MVC.

In relation to daily work (e.g. computer work) it is questionable if the relationship between a decrease of normalized MPF and an increase of Borg scale ratings could also be valid for lower relative load levels. This can possibly be deduced from the endurance time during 30% MVC contractions. For isometric endurance tasks, a mean endurance time of 200–240 s has been reported (Rohmert 1966; Grandjean 1991). Most of the subjects fully completed the trial one (360 s) in our study and more than half completed the trial 2. This could indicate that some subjects were not fully motivated during MVC measurements, and consequently only reached sub-maximal voluntary contraction levels instead of MVC. These subjects would have performed endurance trials at a load level below 30% MVC, and consequently show a smaller decrease of normalized MPF and a milder increase of Borg scale ratings, which can be deduced by approximately half of all the dots in Fig. 2.

Observing fatigue over two trials, our results show significantly lower normalized MPF initial values in the second shoulder elevation endurance task at 30% MVC. Incomplete recovery after a rest of 6 min was also observed at similar load levels in other muscles by Petrofsky (1981) and Roy et al. (1989). Subjects started the second trial in a pre-fatigued state. The slopes were significantly different between the trials 1 and 2, which was not expected, as the value of slope is predominantly dependent on relative MVC value and not on the point of time of the measurement in the course of the experiment.

In summary, our results provide evidence of a linear correlation between decrease of normalized MPF and increase of Borg scale ratings during repeated shoulder elevation endurance tasks at 30% MVC. It can be concluded that subjective perception of exertion in the neck accompanies the objectively detected, fatigue-induced changes in the sEMG signal of the upper trapezius. Consequently and if supported by further studies, subjective perception of exertion could be a measure for objective measurable fatigue.

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