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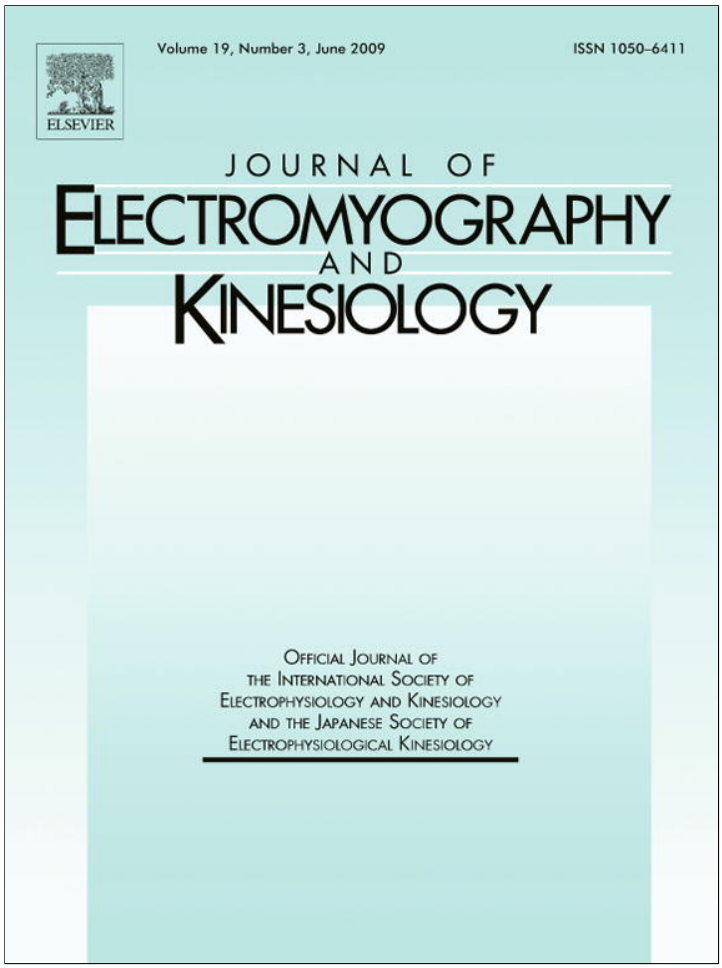

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Low-level activity of the trunk extensor muscles causes electromyographic manifestations of fatigue in absence of decreased oxygenation

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Abstract

This study was designed to determine whether trunk extensor fatigue occurs during low-level activity and whether this is associated with a drop in muscle tissue oxygenation. Electromyography (EMG) feedback was used to impose constant activity in a part of the trunk extensor muscles. We hypothesized that electromyographic manifestations of fatigue and decreased oxygenation would be observed at the feedback site and that EMG activity at other sites would be more variable without fatigue manifestations. Twelve volunteers performed 30-min contractions at 2% and 5% of the maximum EMG amplitude (EMGmax) at the feedback site. EMG was recorded from six sites over the lumbar extensor muscles and near-infrared spectroscopy was used to measure changes in oxygenation at the feedback site (left L3 level, 3 cm paravertebral). In both conditions, mean EMG activity was not significantly different between electrode sites, whereas the coefficient of variation was lower at the feedback site compared to other recording sites. The EMG mean power frequency (MPF) decreased consistently at the feedback site only. At 5% EMGmax, the decrease in MPF was significant at the group level at all sites ipsilateral to the feedback site. These results suggest that the limited variability of muscle activity at the EMG feedback site and at ipsilateral locations enhances fatigue development. No decreases in tissue oxygenation were detected. In conclusion, even at mean activity levels as low as 2% EMGmax, fatigue manifestations were found in the trunk extensors. These occured in absence of changes in oxygenation of the muscle tissue.
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Keywords: Muscle fatigue; Near-infrared spectroscopy; Electromyography; Erector spinae

1. Introduction

Studies using long-term electromyographic recordings (EMG) during every-day activities have shown that postural muscles such as the trunk extensors are mostly active at very low intensities with median EMG amplitudes not exceeding 10% of maximum (Dieën et al., 2001; Mork and Westgaard, 2005). While the activity levels are lower than in muscles of the upper and lower extremities, activity is of longer duration (Mork and Westgaard, 2005). Presumably, this low-level sustained activity is required to provide equilibrium against gravity and to provide stability of the spine. Because of the instability of the spine (Crisco and Panjabi, 1992), this requirement can be expected to be

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operative as long as an upright posture is maintained regardless of the activity performed. A laboratory study on 3 h of office work, performed seated with back support, found the trunk extensor muscles to be active for 93–98% of the time (Dieën et al., 2001).

While activity at levels below 10% of maximum can be sustained for a long time, fatigue, i.e. a decrease in the force generating capacity of the muscle, (Blangsted et al., 2005; Fallentin et al., 1985; Krogh-Lund, 1993), does develop, accompanied by electromyographic manifestations of fatigue (Blangsted et al., 2005; Byström and Kilbom, 1990; Fallentin et al., 1985; Krogh-Lund, 1993), as well as subjective experiences of fatigue (Byström and Kilbom, 1990; Sjøgaard et al., 1986). Evidence on fatigue development in low-level activity was, however, obtained in muscles of the extremities, not habitually exposed to sustained activity. Recent studies on sustained low-level activity in another postural muscle, the descending part of the trapezius muscle, have revealed electromyographic and subjective manifestations of fatigue (Bosch et al., 2007; Rosendal et al., 2004), coinciding with indications of increased interstitial lactate and potassium concentrations (Rosendal et al., 2004). Studies on trunk extensor fatigue have, to our knowledge, not addressed low-level activity.

McGill et al. (2000) reported a decrease in oxygenation in the trunk extensor muscles at forces as low as 2% of maximum and suggested that this would lead to fatigue in sustained activity. However, because the contractions lasted only 30 s, it is unknown whether the drop in oxygenation would remain during a sustained contraction. One might expect that the trunk extensor muscles are adapted to the sustained activity associated with their postural role. Indeed a predominance of type I fibers has been found in the trunk extensor muscles (Mannion, 1999). Furthermore, these muscles have a well-developed capillary network and glycogen concentration and aerobic metabolic enzyme activity are pronounced compared to other muscles (Jorgensen et al., 1993). In addition, it has been suggested that the mechanical redundancy of this muscle group is exploited to prevent or delay fatigue development by alternating activity between muscle parts (Dieën et al., 1993; McLean et al., 2000).

The aim of present study was to determine whether electromyographic manifestations of trunk extensor fatigue occur during sustained low-level activity and whether these are associated with a drop in muscle oxygenation. We used EMG feedback to impose a fixed level of activity in one part of the trunk extensor muscles, while not constraining activity in other parts. We hypothesized that electromyographic manifestations of fatigue and decreased oxygenation would be observed at the site on which EMG feedback was provided. Furthermore, we hypothesized that other parts of the trunk extensors would show more variable activity than the feedback site and would show no consistent indications of fatigue in the EMG signal.

2. Methods

2.1. Subjects

Twelve healthy volunteers (three males, nine females) volunteered to participate in this experiment. Inclusion criteria were: age between 18 and 65; no current low-back pain; no history of low-back pain; no metabolic, cardiovascular, pulmonary, or orthopedic disorders; BMI below 28.6; skinfold thickness lateral of the L3 spinous process below 18 mm. The average physical characteristics were: age 27.6 (SD 12.5) yr; length 1.72 (SD 0.08) m; body mass 638 (SD 9.4) kg; BMI 21.4 (SD 1.4) kg/m^2; L3 skinfold thickness 12.1 (SD 2.5) mm. The experimental procedure had been approved by the local ethical committee and all subjects signed informed consent prior to participation.

2.2. Instrumentation

To exclude effects of gravitational loading, experiments were performed with the subject lying on the left side. The upper body was supported on a memory foam mattress on a board that could freely move in the horizontal plane on frictionless gliders (Fig. 1). Memory foam blocks were used to support the head and right leg. The lower body was also placed on a memory foam mattress with the pelvis strapped to a rigid fixation with hips flexed 45°, to allow full relaxation of lumbar musculature (Keegan, 1953). A chest

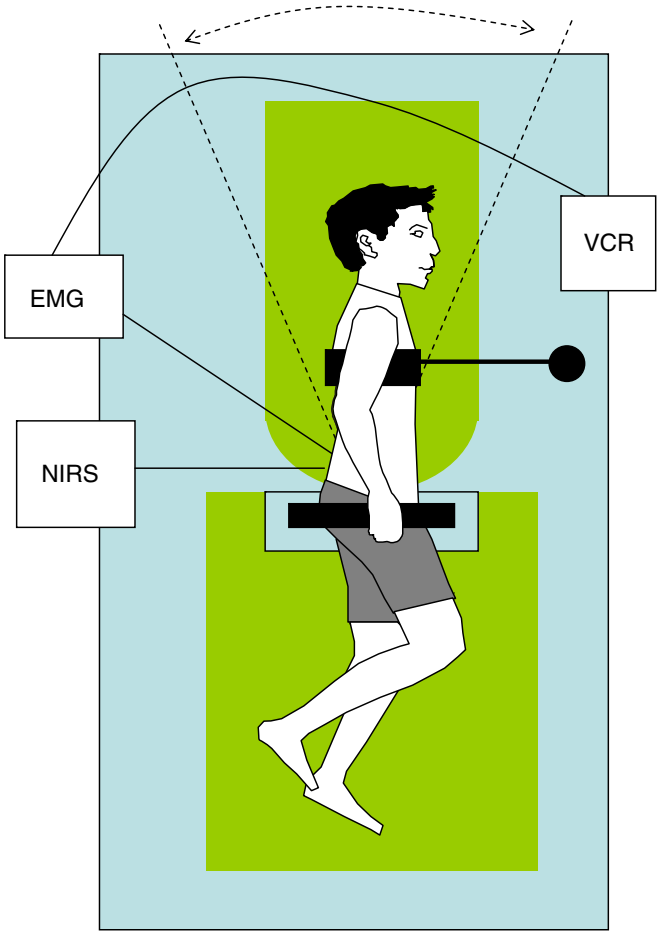

Fig. 1. Schematic of the experimental setup.

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harness connected via a horizontal cable to a force transducer was used to measure trunk extension force. Feedback of the linear envelope of the EMG signal (0.1 Hz low-pass filtered, full-wave rectified signal) measured 3 cm to the left of the L3 spinous process was provided on a computer monitor placed at eye level.

EMG electrodes (Blue Sensor; lead-off area 1.0 cm^2, inter-electrode distance 3 cm) were attached to the skin after abrading and cleaning with alcohol. Electrodes were placed bilaterally in a longitudinal orientation, 3 cm lateral of the L1 spinous process (lL1 and rL1), 3 cm lateral of L3 spinous process (lL3m and rL3m) and 5 cm left of the L3 spinous process (lL3l and rL3l). The reference electrode was placed on the right acromion. EMG signals were amplified 20 times (Porti-17^{TM}, TMSi, the Netherlands; input impedance $> 10^{12}\ \Omega$, CMRR > 90 dB), band-pass filtered (10–400 Hz) and A–D converted (22 bits at 1000 Hz). Force data were amplified and stored on the same system.

Near-infrared spectroscopy (NIRS) optodes were placed at 3-cm interoptode distance on the left 3 cm lateral to the L3 spinous process, such that one optode was placed between the lL3m EMG electrodes and the second just below the electrodes. The optodes were carefully covered with tape such that ambient light could not affect the measurements. To fix the optodes an elastic band around the waist was used. NIRS was measured at 10 Hz using the Oxymon system (Artinis Medical Systems b.v., the Netherlands, Lasertype: semiconductor, pulsed laser diodes, 20 W peak output, laser class IIb (1 mW average power output), 1 kHz repetition rate per laser with wave lengths of 850 nm and 780 nm). The estimated penetration depth was 18 mm.

2.3. Procedure

Each subject first performed a series of 3 maximum trunk extensor contractions by pulling on the cable. Each contraction lasted 3 s, and 2 min rest were given in between contractions. The test in which the maximum voluntary contraction force (MVC) was produced was used to obtain target values for the exertions during the actual experiment. After an additional rest period of 15 min, the subject performed a 30-s contraction at 50% MVC. Force, EMG and NIRS data were stored during this contraction. After this contraction, the subject rested for 10 min, before data collection was started again. In the subsequent 2 min, the subject was instructed to relax as much as possible, after which a 30-min contraction was performed in which the EMG signal that was fed back to the subject (lL3m) had to be maintained at either 2% or 5% of the corresponding highest 1-s averaged rectified EMG (EMGmax) obtained during the MVC contraction. A 30-s, 50% MVC contraction was again performed immediately after the 30-min contraction to verify stability of the NIRS recordings. Contractions at the two exertion levels were performed on separate days and the order was systematically varied over subjects.

2.4. Data analysis and statistics

To estimate muscle activation levels, EMG signals were high pass filtered at 30 Hz (to remove ECG interference), full-wave rectified and averaged over 1-s intervals. The first 10 s of each trial were discarded, because subjects usually needed some time to achieve a stable activation at the target level. EMG amplitudes were normalized to EMGmax and the overall average amplitude and the coefficient of variation of the amplitude (COV = 100 * SD/mean) were calculated. In addition, to determine fatigue related changes in the frequency content of the EMG signal, the mean power frequency (MPF) over each 1 s widow was calculated using Fast Fourier Transformation. Linear regression of the MPF versus time was performed and for each subject it was tested whether the slope of the regression line deviated significantly from zero. Repeated-measures ANOVA with muscle as a factor and mean and COV of the normalized EMG amplitude as well as the slopes of the MPF as dependent variables were performed, with a planned comparison (simple contrast) between the EMG at the feedback site and all other electrode sites. This analysis was performed separately for the 2% and 5% EMG max contractions. Additional analyses were performed with 2-way ANOVA with side (left/right) and muscle as factors. The group-averages of the MPF slopes for all muscles were tested against zero using the Student *t*-test and a 2-way repeated-measures ANOVA (contraction level * muscle) was used to compare MPF slopes between contraction levels.

From the changes in optical density measured with NIRS, contents of oxygenated hemoglobin (O_2Hb) and de-oxygenated hemoglobine (HHb) were calculated (Hamaoka et al., 1996). The sum of the O_2Hb and HHb content was used as an estimate of total hemoglobin content (tHb). The time-series of O_2Hb content during the two 30-s contractions were compared by calculating the cross-correlation. It has previously been shown that for each individual a reproducible pattern of change in O_2Hb content can be found at exertion levels similar to the 50% MVC used here (Kell et al., 2004). Hence, this comparison was used to verify that NIRS recordings were made of active muscle tissue and that the recordings were stable over the entire protocol. For the 30-min contractions, linear regression analysis was used to characterize changes in the hemoglobine contents over time. The slope of the regression line was tested against zero for each subject separately. The group-averaged values of the hemoglobine contents slopes were tested against zero using the Student t-test and repeated-measures MANOVA was used to compare slopes between contraction levels. In addition, average values were calculated over 120 s preceding the contraction and the first 30 s of the contraction, for comparison with previous literature. To test whether hemoglobine contents changed during the contraction relative to the period just before the contraction, repeated-measures MANOVA was performed on O_2Hb, HHb, and tHB, comparing these two episodes. This analysis was performed separately for the 2% and 5% EMG max contractions.

3. Results

Subjects were able to maintain the amplitude at the feedback site quite constant (see Fig. 2 for an example). At the other electrode sites, EMG amplitudes were more variable over time, while the mean was sometimes higher and sometimes lower than the target value. At the group level, no significant differences in mean EMG amplitudes were found between muscles, but the COV was significantly different between muscles (Fig. 3; Table 1). In line with our hypothesis, the COV was significantly smaller at the feedback site (lL3m) than at most other electrode sites.

For all muscles on the left side, the side from which the feedback signal was derived, the COV of the EMG amplitudes was lower than at the right side (Fig. 3). This side

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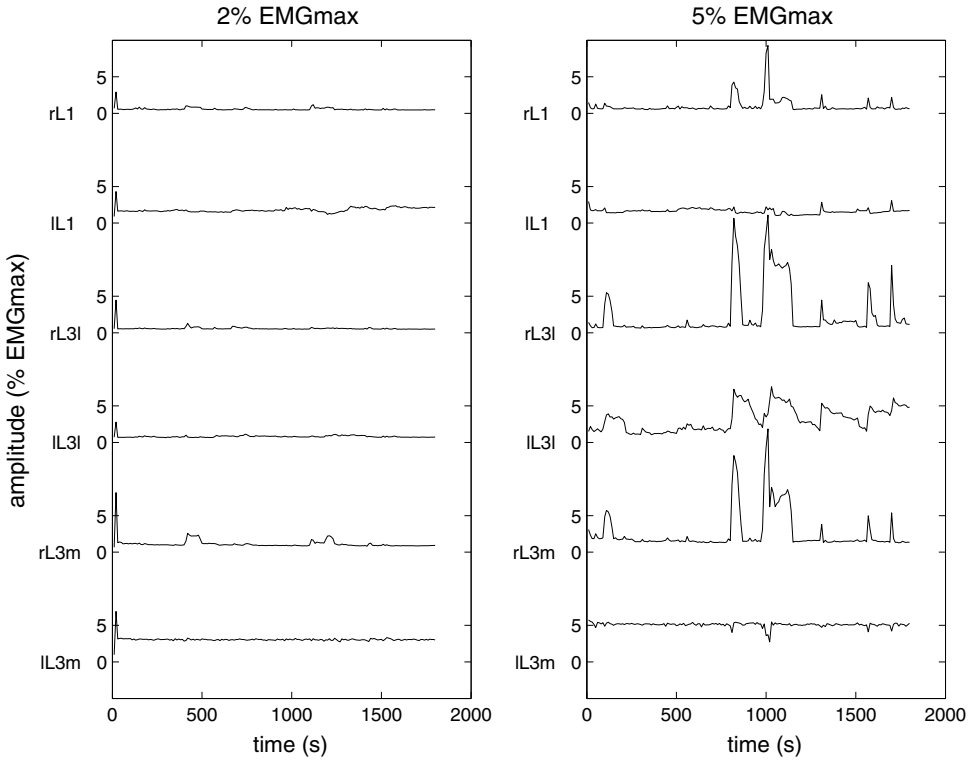

Fig. 2. Example of the EMG-amplitudes at all electrode sites in both contractions. lL3m = electrode site to left of L3 medial (3 cm) feedback site, rL3m = right of L3 medial, lL3l = left of L3 lateral (5 cm), rL3l = right of L3 lateral; lL1 = left of L1 (3 cm), rL1 = right of L1.

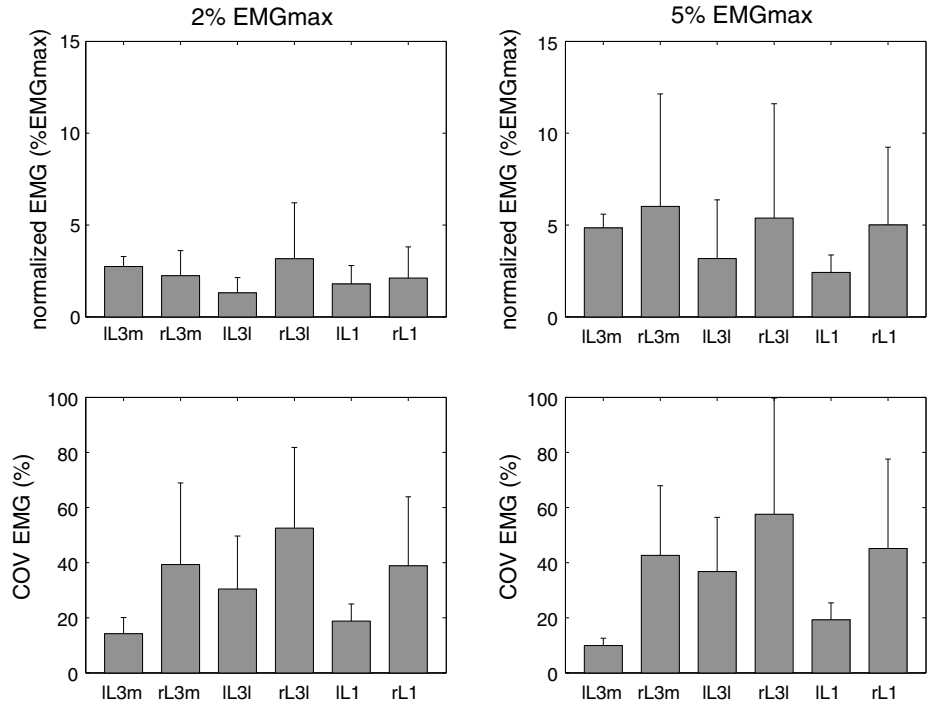

Fig. 3. Group-averages of the means and coefficients of variation of the EMG amplitudes at all electrode sites at both contraction levels. Error bars indicate the standard deviation. lL3m = electrode site to left of L3 medial (3 cm) feedback site, rL3m = right of L3 medial, lL3l = left of L3 lateral (5 cm), rL3l = right of L3 lateral; lL1 = left of L1 (3 cm), rL1 = right of L1.

difference was significant in both the 2% and 5% EMGmax conditions ($p = 0.002$ and $p = 0.003$ respectively). The mean amplitudes did not differ between sides ($p > 0.180$).

In line with our hypothesis, the MPF of the EMG signal at the feedback site (lL3m) generally declined in a linear fashion over time. At other electrode sites, variability over

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Table 1
ANOVA results for the differences between muscles for all EMG parameters

	F	d.f. (Hynh-Feldt)	*p*-Value	*p*-Values contrast with feedback site lL3m
Mean EMG 2%	2.004	2.0/13.8	0.173	–
Mean EMG 5%	1.431	1.8/14.0	0.269	–
COV EMG 2%	9.718	2.6/28.2	<0.001	rL3m 0.006 lL3l 0.016 rL3l <0.001 lL1 0.072 rL1 0.002
COV EMG 5%	8.440	2.4/26.1	0.001	rL3m 0.001 lL3l <0.001 rL3l 0.003 lL1 0.001 rL1 0.003
Slope MPF 2%	0.687	5/55	0.635	–
Slope MPF 5%	3.845	5/55	0.005	rL3m 0.040 lL3l 0.708 rL3l 0.060 lL1 0.225 rL1 0.021

lL3m = electrode site to left of L3 medial (3 cm) feedback site, rL3m = right of L3 medial, lL3l = left of L3 lateral (5 cm), rL3l = right of L3 lateral; lL1 = left of L1 (3 cm), rL1 = right of L1.

time was larger, and inclines as well as declines of the MPF were found (Fig. 4). At 2% EMGmax, the group-averaged slope was significantly lower than zero for the feedback site (lL3m) only, with individual results significant for 10 out of 12 subjects (Table 2). Differences between muscles were however not significant at 2%EMGmax (Table 1). At 5% EMGmax, the group-averaged slopes were significantly lower than zero for all left side electrode sites, with individual results significant in 8 up to 11 subjects at the feedback site (Table 2). Differences between muscles were significant at this contraction level and contrasts with the feedback site (lL3m) were significant for two right side electrode sites and almost so for the third right site. Testing for the effect of side revealed no significant effect on the slope of the MPF at 2% EMG max ($p = 0.450$), while at 5% EMGmax a highly significant difference between left and right slopes was observed ($p = 0.006$).

Due to technical problems in data storage, NIRS measurements could not be used in 2 subjects for the 2% EMGmax condition and 1 of the same 2 subjects for the 5% EMGmax condition. The NIRS measurements during the 30-s contractions at 50% MVC showed patterns of change that were comparable to previous measurements (Kell et al., 2004; Kell and Bhambhani, 2006), i.e. a transient increase or decrease of O_2Hb in the first 10 s, followed by a gradual decline. The patterns were generally well correlated between measurements before and after the 30-min contractions (Fig. 5), with mean coefficients of correlation of 0.79 SD 0.15 and 0.88 SD 0.12 for the contractions at the day of the 2% and 5% MVC conditions, respectively.

No evidence of a decrease in O_2Hb during the 30-min contractions was found (see Fig. 6 for a typical example).

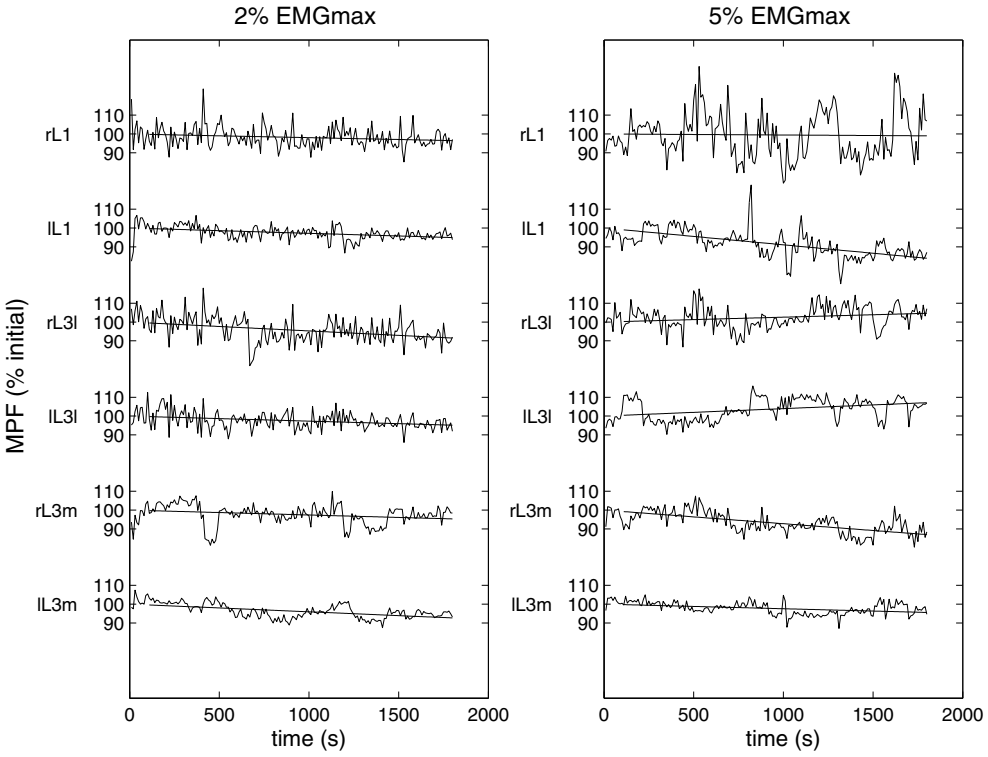

Fig. 4. Example of the changes in MPF at all electrode sites at both contraction levels. lL3m = electrode site to left of L3 medial (3 cm) feedback site, rL3m = right of L3 medial, lL3l = left of L3 lateral (5 cm), rL3l = right of L3 lateral; lL1 = left of L1 (3 cm), rL1 = right of L1.

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Table 2
Group-averages and standard deviations of MPF slopes over time (%/min). With Student *t*-values (*T*) and corresponding *p*-values for a difference between average and zero as well as the number of subjects in which the slope was significantly smaller than zero ($n < 0$) out of the total number of subjects (n). lL3m is the electrode site from which EMG feedback was provided

	2% EMGmax					5% EMGmax				
	Mean	SD	*T*	*P*	$n < 0/n$	Mean	SD	*T*	*P*	$n < 0/n$
lL3m	−0.136	0.218	−2.16	0.027	10/12	−0.165	0.114	−5.00	<0.001	11/12
rL3m	−0.045	0.220	−0.72	0.244	7/12	0.038	0.277	0.48	0.320	3/12
lL3l	−0.072	0.363	−0.69	0.253	6/12	−0.193	0.244	−2.74	0.010	8/12
rL3l	−0.005	0.196	−0.08	0.467	6/12	−0.045	0.189	−0.82	0.215	7/12
lL1	−0.121	0.416	−1.00	0.169	6/12	−0.278	0.300	−3.21	0.004	9/12
rL1	−0.099	0.250	−1.37	0.100	7/12	0.052	0.256	0.70	0.249	6/12

lL3m = electrode site to left of L3 medial (3 cm) feedback site, rL3m = right of L3 medial, lL3l = left of L3 lateral (5 cm), rL3l = right of L3 lateral; lL1 = left of L1 (3 cm), rL1 = right of L1.

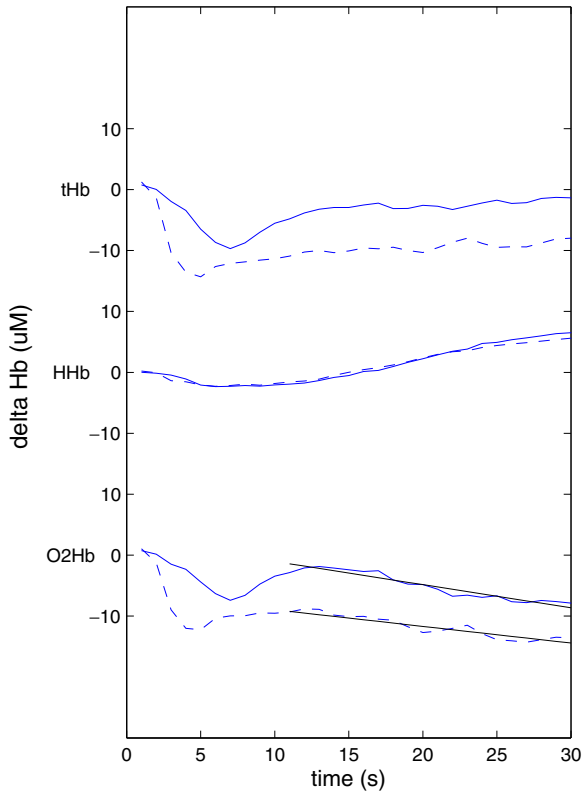

Fig. 5. Example of the changes in hemoglobine contents over time at 50% MVC in the contractions before and after a 30-min 2% MVC contraction. In this subject, the cross-correlation of the O_2Hb time-series was 0.80. The regression lines based on the last 20 s of the trial illustrate the gradual decline in O_2Hb.

At 2% EMGmax, HHb and tHb contents decreased significantly, without a change in O_2Hb, while at 5% EMGmax, HHb decreased and O_2Hb even increased (Table 3). No significant differences were found between the slopes at 2% and 5% EMGmax.

For comparison to previous literature, we calculated average values of O_2Hb, HHb and tHb over the first 30 s of the contraction and compared results to the average over the 2 min preceding the contractions. No significant differences were found between these periods.

4. Discussion

The present study was designed to study fatigue development in the trunk extensor musculature during sustained low-level (2% and 5% of maximum) contractions such as typically seen in every-day activity. We hypothesized that fatigue development would be discernible only when activity was held relatively constant. EMG feedback was used to impose constant activity in one part of the extensor muscles and indications of fatigue were indeed consistently found at this location. Based on earlier findings in the trapezius muscle (Rosendal et al., 2004), it was anticipated that such constrained muscle activity would require anaerobic metabolism due to limitations in blood flow. The resulting accumulation in interstitial lactate (Rosendal et al., 2004) was then expected to result in changes in the frequency content of the EMG signals. However, changes in the EMG frequency content were observed in absence of any change in oxygenation. Instead, decreasing HHb and increasing O_2Hb (at 5% EMGmax) appeared to indicate that adaptations in blood supply exceeded the increased demand. These results may suggest that increasing interstitial potassium concentrations (Rosendal et al., 2004) underlie the change in EMG frequency content in these conditions rather than changes in pH. A similar dissociation of changes in O_2Hb and EMG frequency content was found in trunk extensor contractions at 60% MVC (Kramer et al., 2005) and in biceps brachii contractions at 10% MVC (Blangsted et al., 2005). Although a moderate correlation ($r = 0.3$) between change in oxygenation and EMG frequency content has also been reported for trunk extensors active at approximately 50% MVC (Albert et al., 2004). Two studies on trunk extensor activity in approximately 50–60% MVC contractions reported substantial between-subject variations in the pattern of change in O_2Hb, with a decrease in most but not all subjects (Kell et al., 2004; Kramer et al., 2005), while a third study reported a consistent decrease at 60% MVC (Yoshitake et al., 2001). These results suggest that blood flow starts to be a limiting factor in these muscles only around these levels of contraction. Results on oxygenation in short (30 s) low-level activity have been inconsistent. McGill et al. (2000) found a decrease in oxygenation during

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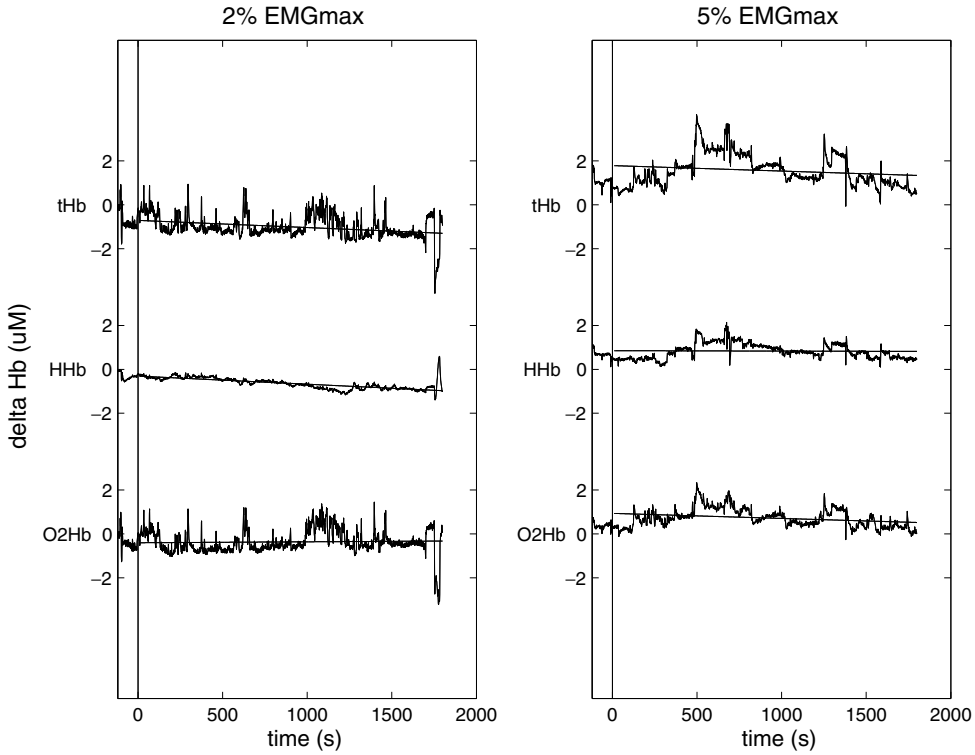

Fig. 6. Example of the changes in hemoglobine contents over time at both contraction levels. The vertical line marks the start of the contraction.

Table 3
Group-averages and standard deviations of slope of hemoglobin content changes over time (μM/min). With Student *t*-values (*T*) and corresponding *p*-values for a difference between average and zero as well as the number of subjects in which the slope was significantly smaller than zero ($n < 0$) out of the total number of subjects (*n*)

	2% EMGmax					5% EMGmax				
	Mean	SD	*T*	*p*	$n < 0/n$	Mean	SD	*T*	*p*	$n < 0/n$
O2Hb	−0.0013	0.0625	−0.066	0.4744	6/10	0.0406	0.0463	2.773	0.0098	1/11
HHb	−0.0487	0.0261	−5.901	0.0001	10/10	−0.0402	0.0357	−3.560	0.0026	9/11
tHb	−0.0500	0.0608	−2.602	0.0143	7/10	0.0004	0.0588	0.024	0.4908	6/11

30-s contractions at 2% and 5% of maximum force, whereas Jensen et al. (1999) found no change at 5% of maximum force. We observed initial changes in oxygenation in most subjects that could however be either positive or negative, both in the low-intensity contractions and in the 50% MVC contractions. We therefore submit that NIRS may not yield a reliable results in short-lasting contractions, possibly due to changes in posture, muscle shape or movements of the optodes at the initiation of the contraction (Masuda et al., 2005). This may be especially problematic in low-level contractions where changes will be limited anyway.

We furthermore hypothesized that the redundancy of the extensor musculature at these low contraction levels, would allow substantial variability of activity in other parts of the extensor musculature such that fatigue development would be avoided. In contrast, significant fatigue-related changes in the EMG frequency content were found at locations other than the feedback site in all subjects. The location of these changes varied between subjects, although effects were found mainly ipsilateral to the feedback site. We conclude that the experimental task used entailed some degree of co-activation between the different parts of the extensor musculature, in particular between ipsilateral parts, such that fatigue did occur at other locations as well.

To some extent the results support the assumption that the trunk extensor muscles are adapted to sustained low-level activity, i.e. we found no decrease in oxygenation at the feedback site and found considerable variability in activity at other sites that appeared to prevent fatigue locally. On the other hand, the results also show that sustained activity as lows as 2% EMGmax can cause consistent fatigue-related changes in the EMG frequency content. Obviously, the latter conclusion depends on the assumption that such changes are valid indications of muscle fatigue. We have previously shown that the rate of change of the MPF of trunk extensor EMG is a predictor of the rate of fatigue development in these muscles (Dieën et al., 1993; Dieën et al., 1998). The main determinant of the MPF decline with fatigue appears to be a reduction of the action potential conduction velocity (CV), although other factors such as changes in motor unit

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firing behavior may contribute (Hägg, 1992; Linssen et al., 1993). Farina et al. (2006) showed a reduction in CV in individual motor units active throughout contractions of the trapezius muscles under force feedback at 2 and 5% of maximum. This effect was however masked in the frequency content of the surface EMG due to recruitment of additional motor units. The changes in CV occurred six times faster than the changes in MPF found in the present study (approximately 5% in 5 min instead of 30 min). Since EMG feedback should largely prevent additional recruitment, this might indicate a difference in fatigability between the trapezius and trunk extensor muscles.

The rate of fatigue development as evidenced by the decreases in MPF was not significantly different between the 2% and 5% EMGmax conditions. At 5% EMGmax, the significant increase in O_2Hb content and concomitant decrease in HHb content suggest that blood flow is increased during these contractions with the increased inflow of oxygen rich blood exceeding the O_2 consumption related to the contraction. At 2% EMGmax, no significant increase in O_2Hb content was observed, suggesting that such a response in blood flow would be lacking or be less pronounced than at 5% EMGmax. Such a difference in blood flow responses might explain a difference in fatigue development between the conditions. Increased blood flow might in particular limit the accumulation of interstitial potassium that was assumed to cause the changes in EMG frequency content. Nevertheless, compared to 2% EMGmax, 5% EMGmax contractions elicited fatigue manifestations, i.e. significant negative slopes of the MPF, more consistently at the feedback site and more frequently at other sites as well.

The results of the present study suggest that motor tasks requiring low-level activity of trunk extensor muscles could lead to fatigue development, resulting in impaired function and discomfort or pain. It should be noted that in terms of force level the contraction intensities may have deviated slightly from 2% and 5% of maximum. Previous studies have indicated non-linear relationships between trunk extensor EMG and the extensor moment generated (Potvin et al., 1996; Vink et al., 1988). It is however unclear to what extent this is due to load sharing between trunk extensor muscles, or due to non-linearity of the EMG force relationship of each of the extensor muscles (Staudenmann et al., 2007). It would also suggest that even slight increases in trunk extensor activity, such as associated with small postural changes (Andersson et al., 1974) or disorders like low-back pain (Dieën et al., 2003), could have negative effects. However, the difference in fatigue development between muscles and between the left and right side found coincided with a similar pattern of differences in the COV of muscle activation. This implies that in addition to the mean activity, variation of activity is a co-determinant of the rate of fatigue development. Since, to our knowledge, no data are available on the variability of trunk extensor activity during realistic tasks, generalizability of the present findings is unknown.

In conclusion, the present study showed that even at mean activity levels as low as 2% EMGmax indications of muscle fatigue could be found in the trunk extensors already after 30 min. These effects occurred in absence of changes in oxygenation of the muscle tissue and appeared affected by the variability of the activity level.

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