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Alternating activation is related to fatigue in lumbar muscles during sustained sitting

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ABSTRACT

The aim of this study was to investigate the relation between variability in muscle activity and fatigue during a sustained low level contraction in the lumbar muscles. Twenty-five healthy participants (13 men 12 women) performed a 30 min sitting task with 5 degrees inclination of the trunk. Surface electromyographic (EMG) signals were recorded bilaterally from the lumbar muscles with 2 high density surface EMG grids of 9×14 electrodes. Median frequency (MDF) decrease, amplitude (RMS) increase and the rating of perceived exertion (RPE) were used as fatigue indices. Alternating activation and spatial and temporal variability were computed and relations with the fatigue indices were explored. During sitting, the mono- and bipolar RMS slightly increased while the MDF remained unchanged indicating no systematic muscle fatigue, although the average RPE increased from 6 to 13 on a scale ranging between 6 and 20. Higher frequency of alternating activation between the left and right side was associated with increased RPE ($p = 0.03$) and decreased MDF ($p = 0.05$). A tendency in the same direction was seen between increased spatial and temporal variation within the grids and increased RPE and decreased MDF. Present findings provide evidence for a relationship between variability in muscle activity and fatigue.

1. Introduction

The complex network of muscles in the lumbar spine consists of nearly 70 muscles of variable size. Each of the lumbar muscles is capable of several possible actions and exerts various forces and actions on the spinal motion segments (Bogduk, 2005). The numerous back muscles provide a pool of possible motor units that may be recruited to suit the needs of the vertebral column, and hence play a role in load distribution, load transfer and control of movement. How they are recruited into action and to what kind of action is poorly understood.

Muscular fatigue is the inevitable consequence of sustained contractions and is generally defined as an exercise induced reduction in the ability of a muscle to generate force or power (Gandevia, 2001). Spatial (Holtermann et al., 2010; Larivière et al., 2006) and temporal (van Dieën et al., 1993; van Dieen et al., 2009) variability in muscle activation are related to the rate of fatigue development. Moreover, females have been observed to be more fatigue resistant compared to men, and possible mechanisms for this gender difference include factors related to muscle mass, substrate utilization, muscle morphology, and neuromuscular activation patterns (Hicks et al., 2001; Larivière et al., 2006).

Muscle effort of trunk extensors during standing and sitting postures usually remains below 10% of maximum activation (Mork and Westgaard, 2005; van Dieën et al., 2001). Such low-level muscle activity can be sustained for a long time and is often accompanied by a subjective experience of fatigue (Sjogaard et al., 2004) as well as electromyographic manifestations of fatigue, like increased amplitude of the electromyogram (EMG) and a shift in the EMG power spectrum to lower frequencies (Blangsted et al., 2005; Jorgensen et al., 1988). In addition, fatigue prevention and pain intensity are shown to be inversely related to the frequency of differential activation between the heads of the biceps brachii muscle and parts of the trapezius muscle, respectively (Holtermann et al., 2010, 2011). Such a use of mechanical redundancy has been suggested to prevent or delay fatigue development also in lumbar muscles by alternating activity between muscle parts or synergistic muscles (Larivière et al., 2006; McLean et al., 2000; van Dieën et al., 1993), but has so far not been investigated in detail during low force contractions. Moreover, lumbar activation and fatigue during sustained low force contractions have rarely been studied, despite that muscle activation and fatigue have been linked to low back pain for decades (Bonato et al., 2003; De Luca, 1993; Roy et al., 1989). To our knowledge there are only two

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studies addressing this (Farina et al., 2003; van Dieen et al., 2009). Van Dieën et al. revealed electromyographic manifestations of fatigue during a very constrained lying task, while Farina et al. could not observe any fatigue related changes in the EMG signal from lumbar muscles during a less constrained standing task. In van Dieën at al's study, the development of fatigue was linked to the temporal variability in muscle activity, defined by the coefficient of variation (CV). However, the amount of variability in muscle activity during a less constrained task, e.g. sitting, and its relation to muscle fatigue remains unclear (van Dieen et al., 2009).

Furthermore, possible differences in fatigue development in deep and superficial lumbar muscle during low level muscle effort may be present due to differences in biomechanical load (Bogduk, 2005). Surface EMG with monopolar leadings (1 electrode above the muscle and the other not) represent activity from a larger area of muscle fibers than surface EMG from bipolar leadings (both electrodes above the muscle) that mostly represent signals from superficial motor units since the common signal present on both electrodes simultaneously is cancelled out and action potentials traveling over superficial muscle fibers are dominating (Hotta and Ito, 2011; Kleine et al., 2000; Roeleveld et al., 1997). In the trapezius muscle, monopolar and bipolar configurations showed different changes with fatigue (Kleine et al., 2000), while this has not been used to investigate low back muscles yet.

The aim of the present study was to investigate if electromyographic manifestations of fatigue occur in deep and superficial lumbar muscles during sustained sitting, whether such fatigue is associated with lumbar muscle variability between- (i.e. the alternating activation) or within sides (i.e. reduced temporal or spatial variation of the signal) and whether there are gender differences. We hypothesized a beneficial effect of spatio-temporal variability; increased temporal and spatial variability and low frequency alternating activation was expected to be associated with reduced fatigue development indicated by less decreased EMG frequency content, less increased EMG amplitude and less increased perceived effort. Moreover, we expected that deep and superficial lumbar muscles would have different fatigue development due to differences in biomechanical loading, and that this would result in differences between bipolar and monopolar EMG. In addition we hypothesized that female subjects, as a consequence of an expected lower trunk mass, would show less pronounced electromyographic manifestations of fatigue and report less perceived exertion.

2. Methods

2.1. Design

A cross-sectional laboratory experiment was carried out. Participants performed a 30 min sitting task with maximal voluntary back extension prior to and after this task while low back muscle activation was evaluated with high density surface electromyography (HDsEMG) and position with two inclinometers.

2.2. Participants

32 healthy adults (16 males and 16 females) without back pain in the age range 29–53 years were included in the study. The two genders were matched on age. The exclusion criteria were back pain in the previous year or back pain lasting longer than one week in the previous 3 years, surgery on the musculoskeletal system of the trunk, known congenital malformation of the spine or scoliosis, body mass index >27 kg/m^2, systemic-neurological-degenerative disease, history of stroke, pregnancy and abnormal blood pressure. After inspection of the EMG signal, 7 subjects with subcutaneous soft tissue and fascia >15 mm were excluded due to poor signal quality. Therefore, 25 subjects were included in final analyses (13 males and 12 females) of which the characteristics are summarized in Table 1. The project was approved by the Regional Committee for Medical Research Ethics (REK) in the South-Eastern Norwegian Regional Health Authority and all subjects signed an informed consent prior to participation.

2.3. Experimental setup and procedure

A custom-made questionnaire was utilized to collect the participants' characteristics. Ultrasound measurements were taken of the distance between the skin and the paraspinal muscles (subcutaneous soft tissue and fascia) 3 cm lateral of the spinous process at the L3–L4 level.

Two inclinometers were placed on the back to control the sitting position; one located on the proc spinous in the lower part of the thoracic spine (Th 12), and one on the sacrum at the S1-level. Target position (horizontal line with marked area of ±1 degree on a total figure display of 10 degrees) and real time feedback (rising bar) of the inclinometer at Th 12 was provided on an 19″ computer screen placed at a distance of ~90 cm at eye level. Data from the inclinometers was collected with a sample rate of 1500 Hz and saved in a separate file during acquisition in MyoResearch XP Master Edition (Noraxon).

Two HDsEMG grids consisting of 126 (9 × 14) Ag–AgCl electrodes with 4 mm inter electrode distance (IED) were attached to the skin. The skin was prepared with an abrasive paste before double-sided tape was attached to the skin. Electrode gel was applied before the electrode grids were attached to the tape. The orientation of the grid was with 9 mediolateral columns and 14 caudal–cranial rows (Fig. 1). The surface EMG data was recorded using two 128-channel ActiveTwo amplifier systems (BioSemi, Amsterdam, The Netherlands) in a "daisy-chain" configuration, with a sample rate of 2048 Hz per channel. The acquisition software (MyoDaq) was developed at the Department of Clinical Neurophysiology of the Radboud University Nijmegen Medical Center.

To determine maximum voluntary contraction (MVC) the subjects performed 3 maximal contractions of back extension against resistance of a strap around the upper part of the trunk while sitting, each lasting 5 s with 3 min rest between the contractions. After another break of 10 min, the participants were asked to maintain the target inclination of the trunk for 30 min or until "task failure", defined as a deviation from the target inclination of ±1 degree for more than 3 s. Every five minutes, subjects rated their perceived exertion (RPE) experienced during the sustained sitting on a scale ranging from 6 to 20 (Borg, 1982).

2.4. Data analyses

Prior to further analysis, HDsEMG channels with poor quality were removed. Thereafter, the signals were band pass filtered at 30–300 Hz and bipolar spatial filtered in the cranial–caudal direction (12 mm IED) leaving 99 bipolar EMG signals in 9 columns

Table 1
Subjects characteristics. Mean and standard deviation (SD) of the subjects characteristics for the 13 male (Men) and 12 female (Women) participants. Results of independent *T*-test (t) or Mann–Whitney U (U) test evaluating gender differences with the level of significance (*p*) are also included.

	Men Mean (SD)	Women Mean (SD)	t or U	*P*
Age (year)	39.5 (6.6)	40.2 (6.8)	0.25^t	0.81
Height (cm)	182.1 (4.7)	165.5 (4.5)	−9.03^t	<0.01*
Weight (kg)	79.5 (8.6)	59.8 (4.5)	155.5^u	<0.01*
BMI (kg/m^2)	24.0 (2.5)	21.8 (1.0)	−2.83^t	0.01*
Muscle depth (mm)	9.1 (2.3)	10.1 (2.6)	1.04^t	0.31

* Statistically significant effect ($p < 0.05$).