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Effect of step and ramp static contractions on the median frequency of electromyograms of back muscles in humans

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Abstract The purpose of this study was to compare the electromyogram median frequency (MF) values from two contraction modes (ramp vs step) at different force levels of eight back muscles. A group of 20 healthy male subjects stood in a dynamometer with the trunk in a vertical position and performed trunk extension contractions using the displayed L5/S1 extension moment as visual feedback. The electromyogram (EMG) signals from four pairs of back muscles were collected at 4096 Hz using active surface electrodes during two 7 s static ramp contractions ranging from 0% to 100% of the maximal voluntary contraction (MVC) and two 5 s static step contractions performed at five forces (10%, 20%, 40%, 60% and 80% MVC). The root mean square (RMS) and MF of the EMG signals corresponding to 250 ms windows were computed at each force level for both contraction modes. The RMS from the ramp contractions were significantly higher than from the step contractions in six muscles. The corresponding MF showed a significant (z = 0.05) contraction mode/force interaction in four muscles. A significant contraction mode main effect was obtained in four muscles having higher MF during step than during ramp contractions. These differences were more obvious (10–15 Hz) and more frequent at the lower (10%, 20% and 40% MVC) forces. It was suggested that mechanisms not related to motor unit recruitment might influence MF in contraction modes. These unknown mechanisms contaminate any possible relationship between the MF measurements and muscle composition.

Keywords Electromyography · Power spectrum analysis · Back muscles · Median frequency · Ramp and step contractions

Introduction

Electromyography (EMG) is a common investigative tool for determining specific muscle function and signs of muscle fatigue (Basmajian and DeLuca 1985). It has also been suggested that parameters from the EMG power spectrum can predict the fibre type content of a given muscle (Kupa et al. 1995). A strong relationship is observed between fibre type composition and spectrum statistics for some human muscles including the vastus lateralis (Gerdle et al. 1988, 1991) and the masseter (Westbury and Shaughnessy 1987) and many animal muscles (Kupa et al. 1995). It is to be expected that such a relationship would be useful in evaluating the back muscles of patients experiencing chronic low-back pain (CLBP) who show atrophy of the muscle fibres (Ng et al. 1998) and changes in fibre type distribution (Mannion et al. 1997a).

Previous findings have suggested that the initial median frequency (MF) of back muscles can be used to discriminate CLBP from other disabilities (Roy et al. 1989, 1995). A valid use of this estimate requires the recording of the maximal voluntary contraction (MVC) so that individuals can be compared at similar relative
forces. However, the measurement of MVC is a major problem when assessments are performed on CLBP patients. One way to overcome this problem would be to compute the slope of the relationship between the MF and force. This supposes a linear relationship:

1. Between the increase in force and mean power frequency (MPF) and
2. Between the slope of this relationship and fibre type composition.

Previous studies have observed a linear relationship between the force and the MPF (Gerdle et al. 1991; Westbury and Shaughnessy 1987). Gerdle et al. (1991) obtained a positive correlation \( r = 0.65 \) between the slope of this relationship and the proportion of type I fibres of the vastus lateralis. Westbury and Shaughnessy (1987) explained 94% of the variance of the MPF-force relationship (slope) with three predictor variables based on the distribution and diameters of the masseter muscle fibres. Moreover, Gerdle et al. (1991) observed that the intercept of the relationship between force (expressed as a percentage) and MPF of the vastus lateralis was negatively correlated \( r = -0.71 \) with the proportion of the type I fibre.

Because non-linear relationships between force and MF have been observed in other studies (Hagberg and Ericson 1982; Mannion and Dolan 1996), the results of Gerdle et al. (1991) might be difficult to use to make inferences about fibre type composition. One factor that would create non-linearity in the relationship between force and power spectrum parameters is the use of step rather than ramp contractions. A step contraction protocol involves several different steady forces, each maintained for a few seconds, while a ramp contraction protocol involves a single contraction varying linearly from 0% to 100% MVC, generally made within 7 to 10 s. The relationship between MF and muscle force has generally been assessed using step contractions (DeLuca et al. 1986; Hagberg and Ericson 1982; Mannion and Dolan 1996; Roy et al. 1989, 1995). However, Bilodeau et al. (1991) have shown that the step contractions cause an initial sharp increase of the MF and MPF at low forces, followed by a levelling off or a decrease at higher forces, while the ramp contractions generally produce a linear increase of the MF across all forces. Bilodeau et al. (1991) proposed that changes in the recruitment versus firing rate interaction may explain the differences between ramp and step contractions. It is obvious that the clinical use of power spectrum parameters to predict fibre type composition requires a mode of contraction (ramp vs step) that could provide the best physiological link with the recruitment pattern of muscle fibres.

The aim of this study was to compare the MF between two modes of contraction (ramp vs step) at different relative force levels in eight back muscles. It was hypothesised that the MF would change differently between modes of contraction (ramp vs step) across the force levels.

### Methods

#### Subjects
A group of 20 men [mean (SD)] age 25 (4) years, height 1.77 (0.06) m, mass 72 (9) kg] with no back problems or physical disabilities participated in the study. Potential subjects were excluded if they had experienced back pain in the preceding 6 months or if they were obese. The subjects selected were informed of the experiment protocol and of its potential risks and gave written consent prior to their participation. The experiments performed in this study complied with the current laws of Canada.

#### Protocol
To familiarise the subject with the apparatus, two to four sub-maximal static trunk extension contractions were performed. Two MVC were performed and averaged to obtain a reference target value for the ramp and step contractions. The experiment protocol consisted of two initial 7 s static ramp contractions ranging from 0% to 100% MVC, followed by two static step contractions (2 s to reach the predetermined force and 6 s to maintain it) performed at three levels (10%, 20%, 40%, 60% and 80% MVC) and two final 7 s static ramp contractions ranging from 0% to 100% MVC. During the step contractions, to avoid too many high level contractions being presented successively, the 10% contraction followed the 80% and the 20% contraction followed the 60% leaving the 40% contraction. The 80%-10% and 60%-20% pairs and the 40% contraction were then presented to the subject following a latin-square design. The two final ramp contractions evaluated the possibility of muscle fatigue developing during the protocol. Verbal encouragement was given, especially during the efforts to produce MVC. A 2 min rest was given between each ramp and step contraction.

#### Dynamometry
The dynamometer is described elsewhere (Larivièere et al. 2001) and consists of a triaxial force platform (Advanced Mechanical Technology Inc., model MC6-6-1000) mounted on a steel frame that allowed the stabilisation of the feet, knees and pelvis. The subject stood in the apparatus with the trunk erect and the knees straight. He had to generate trunk extension against a padded bar adjusted at the T4 level using the displayed L5/S1 moment as visual feedback. The visual feedback consists of a vertically moving target with lower and upper bounds corresponding to a tolerance limit of ± 10% of the extension moment. When the target bounds were not respected, the trial was rejected and repeated immediately after a 2 min rest.

#### Electromyography
Eight active surface electrodes (model DE-2.3, DelSys Inc., Wellesley, Mass.) composed of two silver bars (10 mm long, 1 mm wide) spaced 10 mm apart were used to collect EMG. The EMG from the recording sites were bandpass filtered between 20 and 450 Hz, preamplified with a gain of 1,000, analogue to digital converted at a sampling rate of 4,096 Hz and stored on a hard disk for later analysis.

After the skin at the electrode sites had been shaved, and degreased with alcohol, the electrodes were positioned bilaterally on the multifidus at the L5 level (MU-L5-Left and MU-L5-Right), iliocostalis lumborum at L3 (IL-L3-L and IL-L3-R) and longissimus at L1 (LO-L1-L and LO-L1-R) following the recommendations of DeFoa et al. (1989) with regard to muscle fibre direction. Two additional electrodes were positioned over the belly of the longissimus (approximately 5 cm from the midline of the back) at the T10 level (LO-T10-L and LO-T10-R). A reference silver-silver