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sEMG wavelet-based indices predicts muscle power loss during dynamic contractions

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ABSTRACT

The purpose of this study was to investigate the sensitivity of new surface electromyography (sEMG) indices based on the discrete wavelet transform to estimate acute exercise-induced changes on muscle power output during a dynamic fatiguing protocol. Fifteen trained subjects performed five sets consisting of 10 leg press, with 2 min rest between sets. sEMG was recorded from vastus medialis (VM) muscle. Several surface electromyographic parameters were computed. These were: mean rectified voltage (MRV), median spectral frequency (F_{med}), Dimitrov spectral index of muscle fatigue (FI_{nsm5}), as well as five other parameters obtained from the stationary wavelet transform (SWT) as ratios between different scales. The new wavelet indices showed better accuracy to map changes in muscle power output during the fatiguing protocol. Moreover, the new wavelet indices as a single parameter predictor accounted for 46.6% of the performance variance of changes in muscle power and the log-FI_{nsm5} and MRV as a two-factor combination predictor accounted for 49.8%. On the other hand, the new wavelet indices proposed, showed the highest robustness in presence of additive white Gaussian noise for different signal to noise ratios (SNRs). The sEMG wavelet indices proposed may be a useful tool to map changes in muscle power output during dynamic high-loading fatiguing task.

1. Introduction

Surface electromyography (sEMG) time parameters (i.e. root mean square amplitude) as well as spectral parameters obtained from the Fourier transform (i.e. mean and median frequency) have been frequently applied to monitor changes in sEMG signal during maximal isometric voluntary contractions. During a sustained static contraction, the sEMG amplitude was reported to either increase (Arendt-Nielsen and Mills, 1988; Lloyd, 1971; Maton, 1981; Moritani et al., 1982), decrease (Stephens and Taylor, 1972) or remain almost unchanged (Merton, 1954). Moreover, during dynamic exercises, the sEMG amplitude has been observed to increase during submaximal dynamic exercise (Tesch et al., 1990), or decrease during exercises at maximal level of voluntary contraction (Komi and Tesch, 1979). These controversial results obtained for the amplitude data, may be explained by the effects of the lengthening of intracellular action potential (IAP) profile with fatigue in the EMG amplitude characteristics. Using simulations, it has been shows that the sEMG amplitude increases, remains unchanged or decreases at large, medium and small distances from the active fibers, respectively, even though the IAP amplitude decreases with fatigue. Therefore, it seems that this factor may be sometimes more influential on the sEMG amplitude than alterations in neural drive defined by the number of active motor units and their firing rates (Arabadzhiev et al., 2010; Dimitrova and Dimitrov, 2002). Moreover, it has been found that the mean power spectral frequency usually decreased (Arendt-Nielsen and Mills, 1988; Moritani et al., 1982; Naeije and Zorn, 1982; Tesch et al., 1990; Viitasalo and Komi, 1977). However, others authors observed no changes (Ament et al., 1996; Arendt-Nielsen and Sinkjær, 1991). These decreases may be partly related to an increase in the duration of the motor unit action potential waveform and a subsequent decrease in muscle fiber conduction velocities (Bigland-Ritchie et al., 1981).

Although its practical implications in daily function, the study of sEMG during fatiguing dynamic contractions has recently attracted great attention due to the new techniques which make possible its study. During dynamic tasks, several factors such as differences in the type of contraction (i.e. maximal vs. submaximal), changes in

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the number of active motor units, changes in joint angle and fiber lengths as well as changes in force/power through the range of motion, together with the change in muscle fiber conduction velocity due to muscle fatigue may increase the non-stationarity of the myoelectrical signal (Farina et al., 2004; Farina, 2006). Therefore, it is also likely that the pattern of neural activation is different during dynamic and static contractions so the extraction of information from the sEMG signal during a static contraction to infer fatigue-induced changes during dynamic contractions may be also questionable (Cheng and Rice, 2005). Vollestad (1997) questioned the validity of the amplitude and the spectral shifts of the EMG signal to assess fatigue observing no straightforward relationship between them. For all these reasons the traditional parameters used to assess change in neural drive during dynamic fatiguing tasks (mean or median frequency) may not reflect accurately changes in the power spectral density (Farina, 2006).

To overcome the non-stationarity condition and low sensitivity to muscle fatigue of the traditional parameters during dynamic tasks, new techniques and parameters are needed to monitor muscle fatigue more reliably. In this respect, MacIsaac et al. (2001) found that the short-time Fourier transform, and therefore, time–frequency and time-scale processing techniques are more suitable to deal with non-stationary sEMG signals during fatiguing dynamic contractions. However, some authors have demonstrated the validity of the traditional parameters as fatigue indicators during high-intensity dynamic exercises. Shankar et al. (1989) showed that the spectral sEMG analysis could be valid to assess muscle fatigue as it reveals changes in electrophysiological characteristics. Other authors validated the mean frequency as fatigue index during dynamic contractions until exhaustion (Gerdle et al., 2000; Potvin and Bent, 1997). However, during low and medium intensity dynamic exercises, some authors did not find decreases in median frequency. Van Dieen et al. (1996) found that during a dynamic protocol consisting of a series of 250 contractions at 25% and 50% of their MVC, the frequency content of the EMG signals showed weak relationships with fatigue. Similar results have been reported by Ament et al. (1996) during an uphill run at a speed of 5 km/h and a gradient of 20%. To overcome this problems, Bonato et al. (1996, 2001a,b) studied different Cohen class distributions concluding that the Choi–Williams distribution was the more suitable to analyze the sEMG recorded during dynamic contractions. In addition they proposed the instantaneous mean frequency (IMNF) (Bonato et al., 2001b) calculated over this distribution, as an index to monitor muscle fatigue during dynamic contractions. However, Karlsson et al. (2000) after comparing different time–frequency distributions as the short-time Fourier transform, the Wigner–Ville distribution, the Choi–Williams distribution and the continuous wavelet transform, concluded that the continuous wavelet transform had better accuracy and estimation capacity than the other time–frequency distributions on simulated data test and consequently better accuracy to map changes in sEMG during dynamic contractions. Using time–frequency and time-scale techniques (i.e. Choi–Williams distribution and wavelet distribution), a shift towards lower frequencies was found (Bonato et al., 1996, 2001b) and therefore, a decrease in the IMNF over the fatiguing dynamic contractions (Bonato et al., 2001b; Molinari et al., 2006). During dynamic trunk extensions, Sparto et al. (1999) used different scales from a Daubechies wavelet function of order 6 to report changes in the power spectrum. They reported positive relationships between maximal torque output and coefficients of the scale 4 (frequency range: 209–349 Hz) but negative relationships with the coefficients of the scales number 8 (105–175 Hz), 16 (52–87 Hz), 32 (26–44 Hz), 64 (13–22 Hz) and 128 (7–11 Hz). In this study, it was suggested that a decrease in high-frequency wavelet coefficients and an increase in low-frequency wavelet coefficients may be related with fatigue during dynamic tasks.

All the research of muscle fatigue based on the study of the sEMG power spectrum found a shift to lower frequencies which implies a decrement in the power at higher frequencies and a subsequent increment in the power at lower frequencies. Thus, it was suggested that ratios between different spectral moments calculated over the power spectral density obtained using the discrete Fourier transform achieved higher sensitivity under both isometric and dynamic contractions. Therefore, several authors (Basmajian and De Luca, 1985; Chaffin, 1973; Lindstrom et al., 1977; Moxham et al., 1982) adopted ratios between EMG power spectrum content in high and low-frequency ranges as indices of peripheral muscle fatigue to emphasizes both effects in the power spectrum content due to muscle fatigue. Based on these indices Dimitrov et al. (2006) proposed several indices calculated as ratios between EMG power spectral density content in high and low-frequency bands with promising results to muscle fatigue assessment. More precisely, they suggested the use of ratios of moment of order (-1) and moments of order 2 and higher. The reason of the selection of these moment orders was that the spectral moment of order (-1) emphasizes the increase in low and ultralow frequencies in EMG spectrum due to increased negative after potentials during fatigue. On the other hand, the spectral moments of order 2 and higher, emphasizes the effect of decreases in the high frequencies due to increments in the duration of the intracellular action potentials and decrements in the action potential propagation velocity. Recently, Gonzalez-Izal et al. (2010) also showed that the logarithm of the spectral index proposed by Dimitrov (FI_{nsm5}) (calculated as a ratio between spectral moment of order (-1) and spectral moment of order 5) could be useful for monitoring muscle power fatigue after multiple sets of dynamic fatiguing high-power contractions, accounting for 37% of the performance variance of changes in muscle power output. However, the percentage of performance explained by this parameter is not enough to map accurately changes in muscle power output during dynamic contractions. In addition, all these parameters used to assess changes in muscle power output were calculated over the entire power spectrum. Thus, they are normally affected by noise (i.e. noise from the main power supply, noise form the electronic devices, etc.).

The purpose of this study was to combine the use of wavelet transforms and the ratios between different spectral moments to obtained indices which can explain muscle power output during dynamic contractions. We hypothesized that the five new indices proposed, calculated as ratios of spectral moments and other features between two different wavelet scales, reflecting low and high-frequency components of the signals, would be able to predict more accurately changes in muscle power output during dynamic contractions than the other parameters studied. Moreover, the new indices proposed would also show a superior performance when the signal is affected by Gaussian noise of different levels spread across the entire spectrum, since their calculation implies the used of narrower bands than the other sEMG-based parameters which make used the entire power spectrum.

2. Methods

2.1. Experimental design

Fifteen physically active men (age, 34.2 ± 5.2 year; height, 177.3 ± 5.6 cm; body mass, 73.1 ± 6.4 kg) (mean ± SD) volunteered to participate in the study. The subjects had experience with recreational training, although no-one of them had been involved in any regular strength training program at the beginning of the study. Each subject gave his written informed consent to participate in the study after being informed about the experimental procedure, its risks and purpose. The experimental procedures were approved