Time-variant spectral analysis of surface EMG – Applications in sports practice

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The aim of this paper is the presentation of time-variant spectrograms of surface EMG signals to estimate fatigue processes in muscle and to consider recruitments of motor units. For this we used techniques on the base of ARMA and AR models. We illustrate our applications by three examples: influence of training to maximal and explosive isometric contraction, fatigue processes in an all-out cycling exercise and intramuscular coordination during a fast movement.

KEY WORDS: EMG, time-frequency analysis, muscle fatigue, intramuscular coordination

INTRODUCTION: Spectral analysis of surface EMG signals has been used to study muscle fatigue (De Luca, 1997, Moretti et al., 1997, Bonato et al., 2001, Felici et al., 2001, Beck et al., 2005) and to infer changes in motor unit (MU) recruitment (Moritani et al., 1987, Bernardi et al., 1996, Fattorini et al., 2005). As a certain finding can be accepted that during an isometric contraction the median frequency decreases as a result of fatigue (Merletti et al., 1997, Felici et al., 2001). But for low-level dynamic contractions fatigue assessment using spectral analyses is possible too (Hostens et al., 2004). On the foundation that the lactate level increases in fatigued muscle, the muscle fiber propagation velocity decreases and the EMG power spectrum shifts to lower frequencies. Another aspect of the application of surface EMG spectral analysis is the estimation of the motor unit recruitment. Moritani et al. (1987) concluded from their empirical studies that the surface EMG spectral analysis can be used as a sensitive measure for relative changes of MU activities. Bernardi et al. (1996) found a change of motor unit recruitment strategy with skill acquisition. That means that the training influences the level of motor unit recruitment. But, obvious evidences about the motor unit recruitment on the base of median frequency are not possible, because different strategies of recruitments can lead to the same median frequency (Farina et al., 2004). This explains the different empirical findings regarding correlations between force and spectral variables. For estimation of the spectral parameters (such as mean or median frequency) several methods are used: Fast Fourier Transform, Wavelet Analysis and Cohen´s class time-frequency distributions. Because the application of FFT requires a stationary signal this method is considered critically. But Beck et al. (2005) show Fourier based methods are acceptable for determining EMG center frequency during fatiguing dynamic muscle actions at moderate velocities. In general, experimental data obtained during dynamic contractions, especially during fast movements, should be regarded with caution because of the limited information available about the effect of the relative muscle-electrode movement (Merletti et al., 1997). Hostens et al. (2004) investigate the application of wavelet spectral estimation technique to EMG signals. Contrary to the Short Time Fourier Transform, a wavelet analysis varies the time-frequency aspect ratio, producing good frequency localization at low frequencies (long time windows), and good time localization at high frequencies (short time windows). This method is valid for static and dynamic contractions at low level. Farina et al. (2004) believe that the critical limitations in the spectral analysis of the surface EMG are intrinsic to the properties of the surface EMG signals and not the type of signal analysis. Particularly, the lower frequencies in the EMG power spectrum should be considered rather than higher frequencies because the higher frequencies result from many various factors and so an interpretation is difficult.

From this the purpose of this paper is the presentation of dynamical EMG spectrograms and their understanding for different problems in sport practice.

METHOD: Generally the time-variant spectral analysis is able to react on structure changes of a non-stationary signal. The following two methods are applied: ARMA model and AR model. For the first method adaptive estimated statistical parameters were used for the construction of an adaptive algorithm to fit ARMA models to nonstationary time series which allows the self-exciting adaptation of the model parameters in every time point (Schack et al., 1995).The second method bases on an AR model and is described in detail by Arnold et al. (1998). They present an adaptive on-line procedure for autoregressive (AR) modeling of nonstationary time series by means of Kalman filtering, where the Kalman filter was used to perform an adaptive fitting of the model. By tests on simulated data they emphasize the procedure to be sensitive enough to disclose even small and/or transient changes of the spectrum and to respond most quickly to parameter changes, compared with standard methods. The handicap of both methods is that they require about 100 data points because the models have to adapt to the signal structure. This is a problem for fast movements and for analyzing the beginning of the movement. To solve this problem the model parameters were adapted by means of the original or similar signal or by mirrored original signal.

RESULTS AND DISCUSSION: Following three examples for application of time-dependent EMG spectrograms are given.

Maximal and explosive voluntary isometric contraction
Thirteen male and six female students of sports science took part in a six week period of strength training doing bench throws. The subjects intensively trained three times a week. Four tests were done for each subject (pre, between 3rd and 4th week, post and two weeks after training was finished). In the tests the subjects were required to perform maximal and maximal explosive voluntary isometric contraction three times with 1 min rest in between. EMG signals of the m. triceps brachii caput laterale and the m. pectoralis major were acquired (bipolar surface electrodes) according to standard method (sampling rate 1kHz) and analysed using the time-variant spectral analysis using ARMA model. Several strategies in the time course of frequency bands for the subjects were observed. Strategy 1: During the training the frequency bandwidth decreases and the spectra have a greater structure (Fig. 1). Strategy 2: An increase of the highest frequency band was found. Our results indicate an influence of strength training on the one hand to changes in motor unit firing behaviour and on the other hand to a shift to higher frequencies of the spectra of surface electromyograms.

Changes in time variant spectra during a 30 second all-out cycling exercise
Ten sport students participated in an eight week cycling training. During this period actual performances were evaluated in a 30 second all-out exercise on a cycle ergometer, where subjects were asked to cycle maximally against varying resistance at a constant velocity (110 1/min). The appearance of fatigue was analysed by acquiring surface EMG of m. rectus femoris using standard methods (bipolar, 1kHz sampling rate). Signals were analysed using an AR model and time variant power spectra calculated. A high variability in the occurrence of frequency bands can be observed even in such an automated and restricted movement like cycling. Moreover, in the fatigued condition, the frequency bands tend to shift to lower values. This trend can also be observed in the time variant median frequencies of the power spectra. The mean time course of the latter five movement cycles is lower than for the first five cycles, resulting in a lower mean median frequency (Fig. 2 left). The decrease in the mean median frequencies of m. rect. fem. from beginning to the end of the test is significant for all tests of the ten subjects (Fig. 2 right).

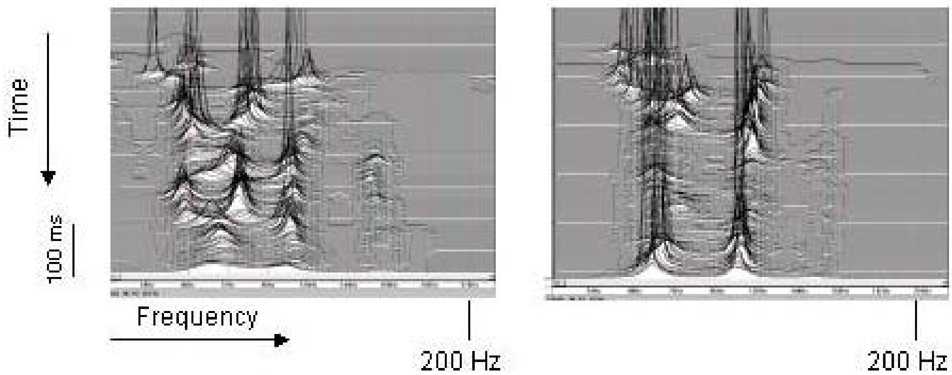

Fig. 1: Time-dependent spectra of EMG signals of m. triceps brachii caput laterale (strategy 1: higher structured spectra), left: pretest, right: two weeks after training

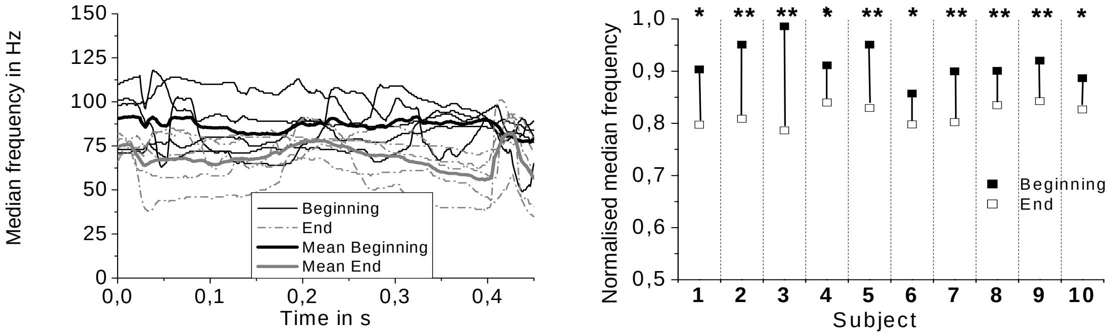

Fig. 2: Left: The time variant (mean) median frequencies of the EMG of m. rectus femoris for the first 5 (Beginning) and the latter 5 (End) movement cycles of one 30 second all-out cycling exercise of subject 2. Right: Decrease of the mean median frequency of m. rect. fem. (normalized to the intraindividual maximum) from the beginning to the end of the test for ten subjects (1-10; each performed 15 to 20 exercise tests). The difference of the means is significant (* $p<0.05$; ** $p<0.01$).

Intramuscular coordination during a karate technique

To achieve very fast movements an improvement of the intramuscular coordination is important. For instance the Gyaku-Zuki as a reverse arm push movement was studied (Witte et al., 2005). Four competitive karateka participated in this study. For each athlete nine performances of the Gyaku-Zuki were analysed. Spectral analysis by means of an AR model was done for the EMG signals of m. triceps brachii due to its importance for the extension of the pushing arm. Fig. 3 shows the raw EMGs and the spectra of several exercises of an karateka with black belt and 3rd Dan.

The frequency spectra (fig. 3) seem to demonstrate that with the beginning of the muscle activity several wave bands are emerged within shortest time. These persist during the pushing, although the fist is positively and negatively accelerated. The optimal intramuscular coordination which is necessary for karate techniques can be recognised by using an adaptive frequency analysis in small and parallel frequency bands. But we have to attend the effect of the relative muscle-electrode motion during fast movements to the EMG signal.

CONCLUSION: By means of three practical sports problems the using of time-variant spectral analysis of surface EMG was demonstrated. Special focus was set on the spectrograms to avoid errors in the interpretation of median frequency solely. So we could present examples which show potentialities of dynamic spectral analysis regarding muscle fatigue and recruitment of motor units.

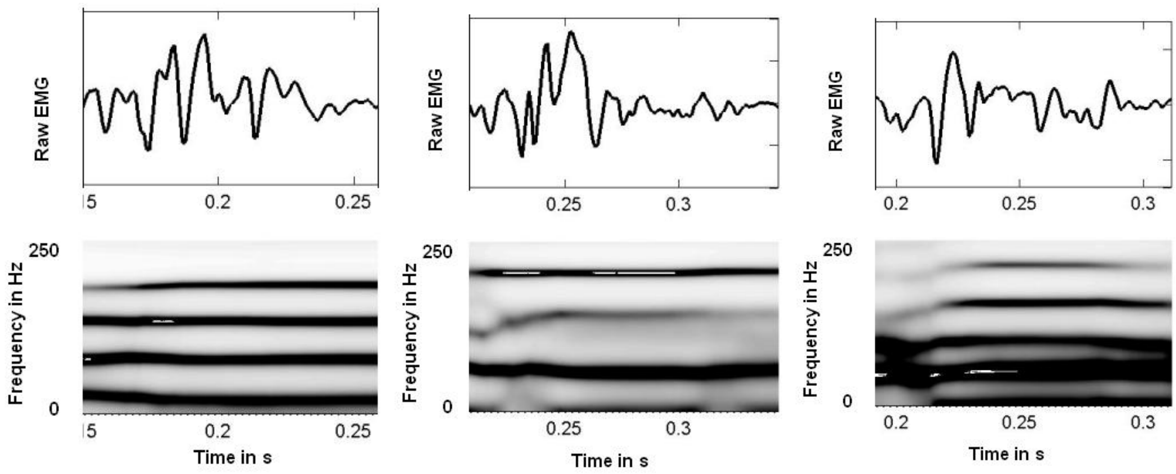

Fig. 3: Three exercises of Gyaku-Zuki. Raw EMG and time-dependent spectra of m. tric.brachii lat.

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