VERIFICATION OF TIME-DEPENDENT ANALYSIS METHODS FOR QUANTIFICATION OF EMG SIGNALS

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Commercially-used stationary analysis techniques for quantification of surface EMG signals yield in general only small amounts of information about motor unit recruitments and their frequency behavior. Therefore, new methods for time-dependent analysis of EMG signals are of great interest. In this study two analysis techniques developed for non-stationary biological signals are verified. First, adaptive power estimation proved that the time characteristic of muscle activity is very variable under constant external conditions. Secondly, a bivariate ARMA model was used for a time-dependent frequency analysis of EMG signals showing specific similarities in the curves as well as the high variability of the time courses of median frequency. The application of the methods presented here to EMG signals gives a new understanding of the inner dynamics of the muscle functioning.

KEY WORDS: surface electromyography, non-stationary methods

INTRODUCTION: The surface electromyography is a well-known and commonly used method in the field of biomechanics (De Luca, 1994). Nevertheless, two problems exist:
(1) Averaging of a series of single cycles (Konrad & Tuula, 1997)
The averaging of several EMG signals under constant external conditions is only justifiable if general characteristics of the muscle activity are studied. For the quantification of the variability of the muscle activity it is necessary to analyze the individual EMG signals.
(2) The practicability of fast-fourier-transformation for frequency analysis
The fast-fourier-transformation requires stationary signals. Generally, we have to consider a time-dependence of muscle activity indicating the non-stationary nature of the EMG signals.
The application of non-stationary analysis methods is necessary in order to obtain more information about motor unit recruitment and their frequency behavior. The pupose of this paper is the presentation of the adaptive power estimation and the bivariate time-dependent ARMA model and the application on EMG signals.

METHODS: In this study two analysis techniques developed for non-stationary biological signals are verified.
At first, we applied adaptive power estimation (Grieszbach et al., 1994) to surface EMG signals. As an example we investigated the muscle activities of the lower extremities during walking. Three male sports students (22 to 27 years old) participated in this study. The walking velocities were for the subjects: EB 1.0, 1.4 and 1.8 m/s, HO 1.0, 2.0 and 2.4 m/s and SR 1.0, 2.0 and 2.2 m/s. Using a treadmill, the three velocity steps were realized for 4 minutes.
Secondly, a bivariate time-dependent ARMA model (Schack et al., 1995) was applied for a time-dependent frequency analysis of EMG signals during slow running at a velocity of v = 3.5 m/s. The study was carried out with two male subjects: a trained long-distance runner (21 years old) and a non-trained subject (27 years old).
Using the SIMI-Motion movement analysis system and EMG-Telemetry system by Noraxon-Neurodata, two dimensional video analysis (200 s^{-1}) of the left side was carried out and the EMG signals of five muscles (m. biceps femoris, m. vastus medialis, m. rectus femoris, m. gastrocnemius and m. tibialis anterior) were recorded synchronously. For the further analysis we used only the EMG signals of the support phase. For every velocity step 5 – 8 periods were analyzed. The used analysis methods were included in the software-package ”Adspec”.

RESULTS AND DISCUSSION: The computed adaptive power estimation (Grieszbach et al., 1994) of the EMG signals shows relative high differences between the single cycles in the time course. In order to describe essential characteristics of the muscle activity under constant conditions in the same movement phase we generated average-curves. In figure1 two examples are shown.

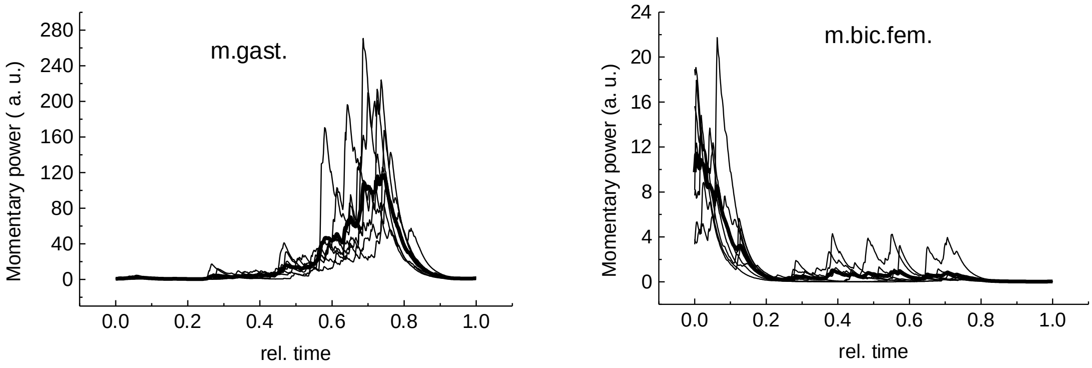

Figure 1 - Adaptive power estimation of the EMG signals of m.gast. and m.bic.fem. (subject HO, v = 2.0 m/s).

We can find remarkable differences between the single curves, but the form of the curve is typical for a specific muscle. In order to compare the muscle activities at different velocities we calculated the average-curves. Figure 2 shows the mean adaptive power estimations of all muscles in dependence on the walking velocity for subject HO. The comparison of the power estimations between the subject illustrates interindividual differences. In addition the average curves varied for different velocities.

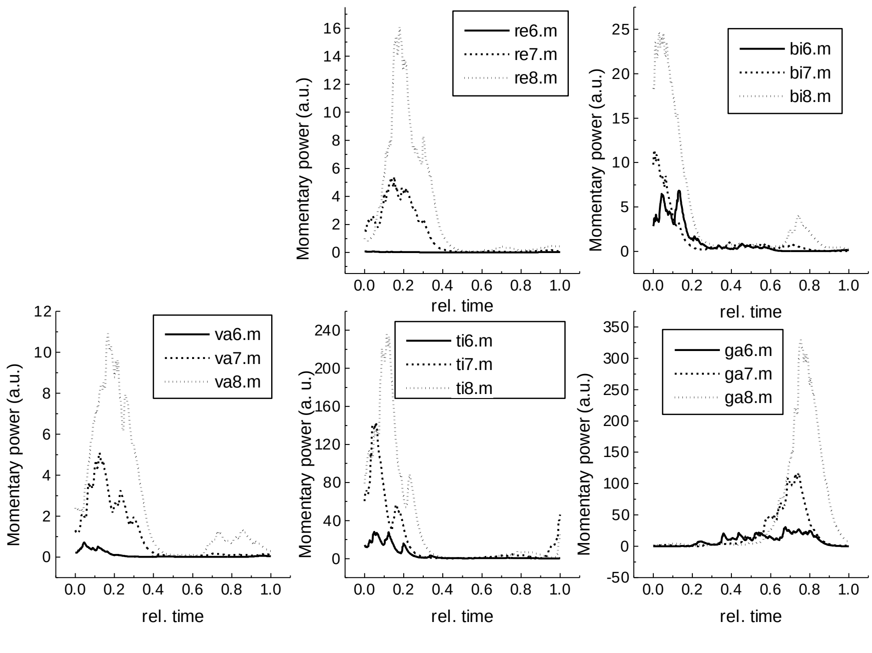

Figure 2 - Mean power estimations of EMG signals in dependence on the walking velocities for subject HO; 6 – 1.0 m/s, 7 – 2.2 m/s, 8 – 2.4 m/s; re – m.rec.fem., bi – m.bic.fem., va – m.vast.med., ti – m.tib.ant., ga – m.gast.

For the quantification of the mean power estimations the following two measurement parameters can be used:

- the relative time of the first main peak and
- the integral of the power-time-curve also called muscle activity.

For the determination of these quantities we used single power estimations. In addition to the calculation of the mean values of the relative time and of the integral of the power-time-curve, their ranges were computed and drawn as example for the m.bic.fem in figure 3.

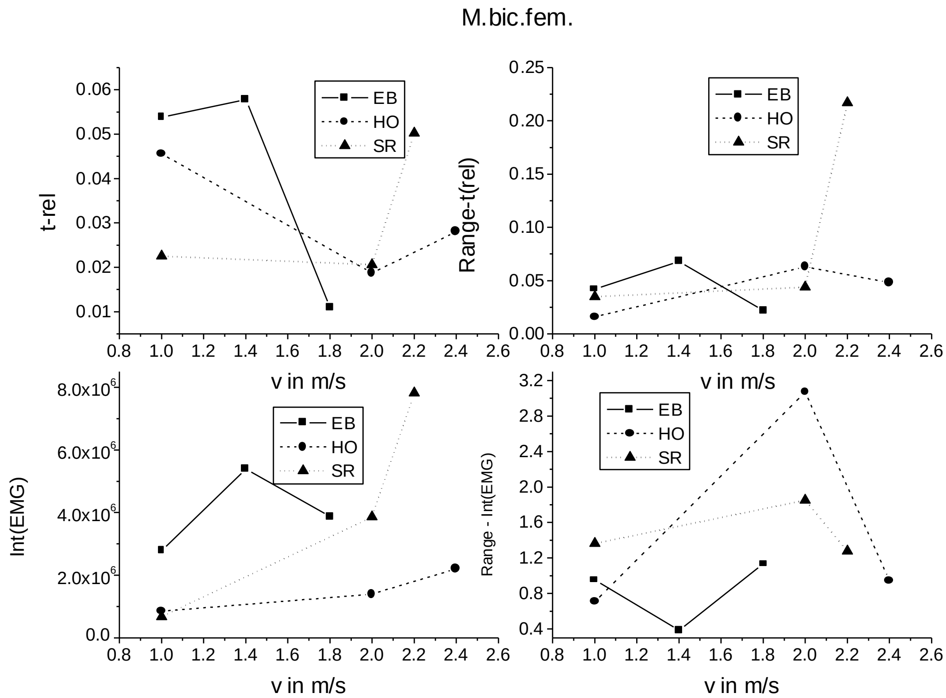

Figure 3 - Relative time of the first main peak t-rel and the integrals of the power estimations Int(EMG) of the m.bic.fem. for all three subjects.

We can see that changes of these quantities exist in dependence on the walking velocity. But these functions are not linear and individual. As the mean power estimations show (Figure 2) we have to assume different patterns of innervation of muscle.

For all muscles investigated we found large values of the ranges defined by the differences between maximum and minimum of the integrals of power estimations and of the relative time of the first main peak, respectively. These two ranges of the parameters give a quantity of the variability of the muscle functioning. The results described indicate that an increasing walking velocity does not influence the stability or variability of the functioning of muscles essentially. This is in contrast to our assumptions of an influence deduced from some theories of movements.

The time-dependent spectra are computed by means of the bivariate time-dependent ARMA model (Schack et al., 1995). At first, we discover great differences between the spectra of successive walking cycles. This result agrees well with the results of Tax et al., 1989,1990, who found a high variability of the firing rates of the single motor units. When comparing the spectra of the two subjects we establish for the sportsman higher frequencies and a clearer structuring of the spectrum. To quantify the spectra, we used the momentary median frequency. Figure 4 shows the time courses of this quantity. Besides the evident variability of the single curves a specific behavior of a muscle can be recognized. Therefore we used the mean average curve to characterize the time course of the median frequency (Figure 4). In order to compare the variability of the momentary median frequency of the single cycles between the two subjects we calculated the mean standard deviation related to the mean value (Table 1).

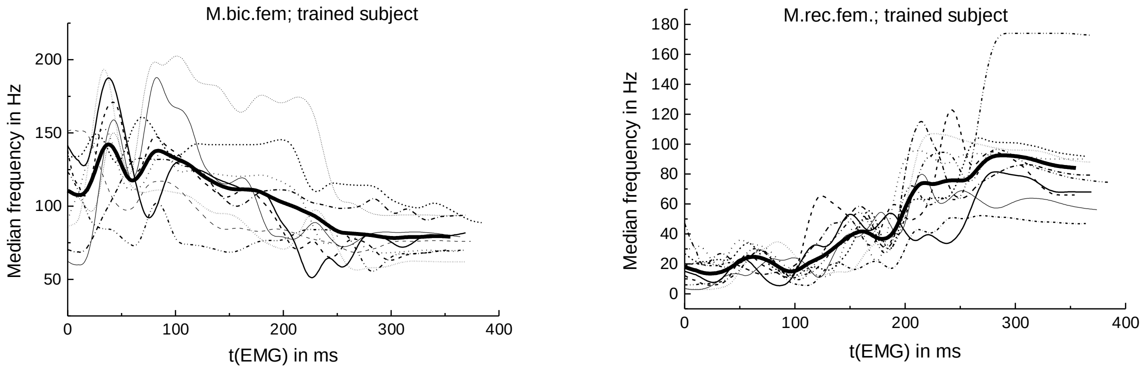

Figure 4 - Momentary median frequency of EMG signals of the m.bic.fem and the m.rec.fem. (trained subject).

Table 1 Mean Variability Coefficient of the Momentary Median Frequency

	m.rec.fem.	m.bic.fem.	m.vast.med.
Trained subject	39.5	24.1	23.7
Untrained subject	40.1	45.9	30.1

On the basis of these results we conclude that sport coaching leads to a more stable time-dependent frequency behavior in the muscles. Further investigations are necessary to gain a better understanding of the muscle dynamics.

CONCLUSION: By means of the presented non-stationary analysis methods it is possible to obtain detailed knowledge about the temporal behavior of the muscle activity. The muscle dynamics are characterized by high variability under constant external conditions but also by a non-linear dependence on a external quantity (for example moving velocity). The analysis of the time-dependent spectra of an EMG signal shows a high variability in the muscle dynamics.

REFERENCES:

Adspec-Software (1997). of the Institute of Medical Statistitics and Computer Science (director: Prof.Dr.H.Witte) of the University of Jena, Germany

De Luca, C.J. (1997). The use of surface electromyography in biomechanics. *J. of Appl. Biomechanics*, **13**, 135-163.

Grießbach, G., Schack, B., Putsche, P., Bareshova, E., & Bolten, J. (1994). Dynamic description of stochastic signal by adaptive momentary power and momentary power frequency estimation and its application in analysis of biological signals. *Medical & Biological Engineering & Computing*, **32**, 632-637.

Konrad, P., & Tuula, T. (1997). EMG-based gait analysis. *Myo Research,* **97,** Handbook of Software (by Neurodata).

Schack, B., Grießbach, G., Bareshova, E., Anders, Ch., Schumann, N.P., & Florian, G. (1995). Parametric methods of dynamic spectral analysis of non-stationary biological signals. *Medical & Biological Engineering & Computing*, **33**, 605-610.

Tax, A.A.M., Van der Gon, J.J.D., Gielen, C.C.A.M., & Kleyne, M. (1990). Differences in central control of m. biceps brachii in movement tasks and force tasks. *Experimental Brain Research*, **79**, 138-142.

Tax, A.A.M., Van der Gon, J.J.D., Gielen, C.C.A.M., Van den Tempel, & C.M.M. (1989). Differences in the activation of m.biceps brachii in the control of slow isotonic movements and isometric contractions. *Experimental Brain Research*, **76**, 55-63.

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