POSSIBILITIES OF A NON-INVASIVE DETECTION OF RECRUITMENT ORDER OF SKELETAL MUSCLE – NEW SUGGESTIONS IN EMG-PROCESSING

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The aim of the present study is the presentation of new suggestions in EMG-processing. Using the examples of explosive MVCs and the high speed phase of sprint running the concerning two models dealing with recruitment order, fiber type contribution and fiber type characteristics try to uncover some deficits of present knowledge. In particular, the so far not respected impulse-force-relation of different fiber types and their consequences for EMG-processing is discussed. Therefore two methods, a moving FFT and a digital band pass filtering, combined with a normalization of the resulting frequency bands are presented as a first attempt to solve the existing problems. Surface diagrams and graphs show interesting indications concerning the recruitment order and the use of frequency parameters.

KEY WORDS: EMG, methods, spectrum analysis, recruitment order, fiber type composition

INTRODUCTION: In many kinds of sport success is bounded up with the capability to realize explosive force development within a time limit. In biomechanical research, force-time-curves (FTC) of explosive-ballistic force developments serve as one possibility to record and to control the corresponding parameters of performance. As main effects of explosive-ballistic contractions (EBC) fiber type composition (FC) and cross-section of muscle as morphological-functional parameters as well as recruitment order (RO) and firing rate (FR) as neuronal parameters are to be considered. At present a determination of FC of a muscle is possible only by means of invasive methods. Therefore the question does arise whether there are alternative non-invasive methods to identify RO and FC of skeletal muscle. For this purpose Tidow and Wiemann (1993) developed a first model (fig. 1). By means of explosive FTC they could find some indications that in case of ballistic force developments against the principles of RO and FR fastest fibers are recruited at the beginning of activation and not gradual after slow and intermediate fibers. Because FTC only reflects the mechanical reaction upon the earlier neural impulses, the question does arise whether the principle of RO is violated at all. Under consideration that firstly innervations of α-motoneurons start in the spinal cord and that secondly different fiber types have different conduction velocities the mechanical response of different fiber types in muscle in spite of a gradual RO may happen e.g. at the same time.

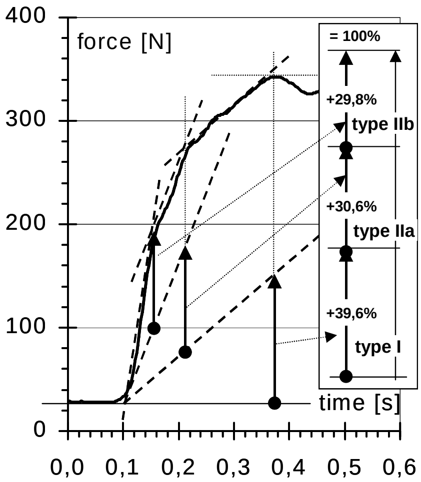

Figure 1 - Estimation of fiber type-force-relation modified by Tidow and Wiemann (1993)

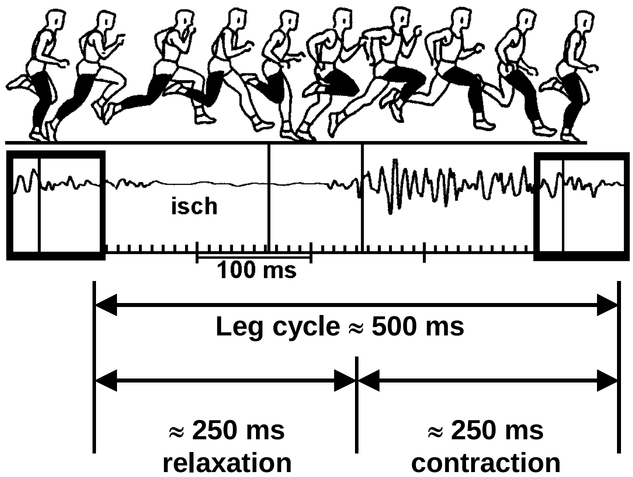

Figure 2 - Cinematographic study of the high speed phase in sprint running, EMG of *m. ischiocrurales*

A second approach is based on theoretical reflections on sprint running. In the high-speed phase only about 500 ms are available for a complete leg cycle (fig. 2). In this period on the one hand muscles have to realize a maximum acceleration in preparing the support phase. On the other hand after relaxation of this muscles there must be enough time for the antagonists to lead them back in the starting position for the next acceleration. The condition of a fastest possible movement of the agonists is only to be realized if the respective antagonists are completely relaxed. Therefore agonists and antagonists have only 250 ms each (fig. 2) for a complete contraction-relaxation-cycle (CRC). Under consideration of the contraction times (CT) and the twice as long relaxation times (RT) of the different fiber types (Tidow, & Wiemann, 1993) only the fastest fibers (type IIb, CT ≈ 60 ms, RT ≈ 120 ms ⇒ CRC ≈ 180 ms) seem to be able to realize this condition. For the intermediate fiber type (type IIa, CT ≈ 100 ms, RT ≈ 200 ms ⇒ CRC ≈ 300 ms) this condition seems hardly and for the slow fiber type (type I, CT ≈ 140 ms, RT ≈ 280 ms ⇒ CRC ≈ 420 ms) not realizable. Therefore it is to be derived that some courses of movement as e.g. sprint running are only to be realized in an optimum i.e. fastest way if type IIb-fibers either at the beginning of a contraction are already mechanically active or - under consideration of an innervation time of 200 ms - are exclusively active (fig. 3). The latter requires that the athlete possesses a corresponding part of fastest fibers. It should be possible to establish this considerations by means of the frequency spectrum of the EMG-signal of the concerning muscles. But missing suitable methods up to now there was no success in this area. Therefore it was the aim of the present study to give new suggestions for a solution of this problem based on two methods: a moving fast-fourier-transformation technique (MFT) and a digital band pass filtering technique (DBF).

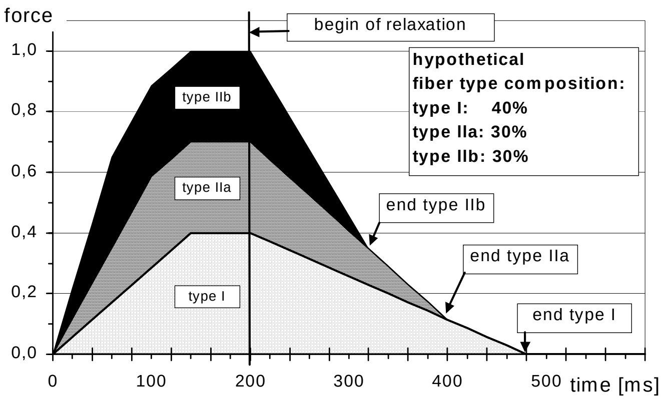

Figure 3 - Contraction-relaxation-course, when mechanical activity of all fiber types begins at the same time, innervation period 200 ms.

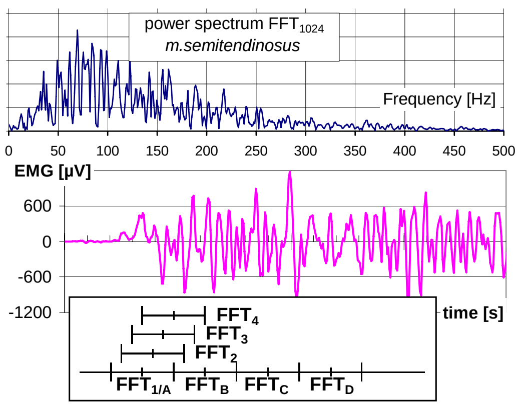

Figure 4 -Top: exemplary power spectrum of an EMG by FFT (1024 steps); bottom: description of moving ($FFT_{1..4}$) vs. conventional ($FFT_{A..D}$) FFT-technique.

METHODS: Data for this study come from two subjects, which performed four isometric EBC of the knee flexors respectively the knee extensors in an optimum muscle length. EMG-time-curves (ETC) of *m.biceps femoris* and *m.semitendinosus* respectively of *m.vastus medialis*, *m.vastus lateralis* and *m.rectus femoris* and the concerning FTC were digitally recorded by a sampling rate of at least 1 kHz. MFT was performed by a stepwise overlapping (≤ 1 ms) FFT-analysis using a window of 64 ms width (fig. 4 bottom), resulting in a resolution of the frequency bands of 15,6 Hz. For purposes of DBF EMG-signal was subdivided by a series of band pass filters in frequency bands of 16,1 Hz. However both have to consider the main methodological deficit of previous methods. Lower parts of higher frequencies in the frequency spectrum are explained with higher absorption. This conclusion is doubtful. Single motor units are innervated by short impulses of about 1 kHz independent of fiber type. But spectrum analysis usually looks at a frequency area up to 300-500 Hz (Fig. 4, top). This represents the discharge frequencies i.e. only the time sequence – which should not be absorbed - of single short impulses.

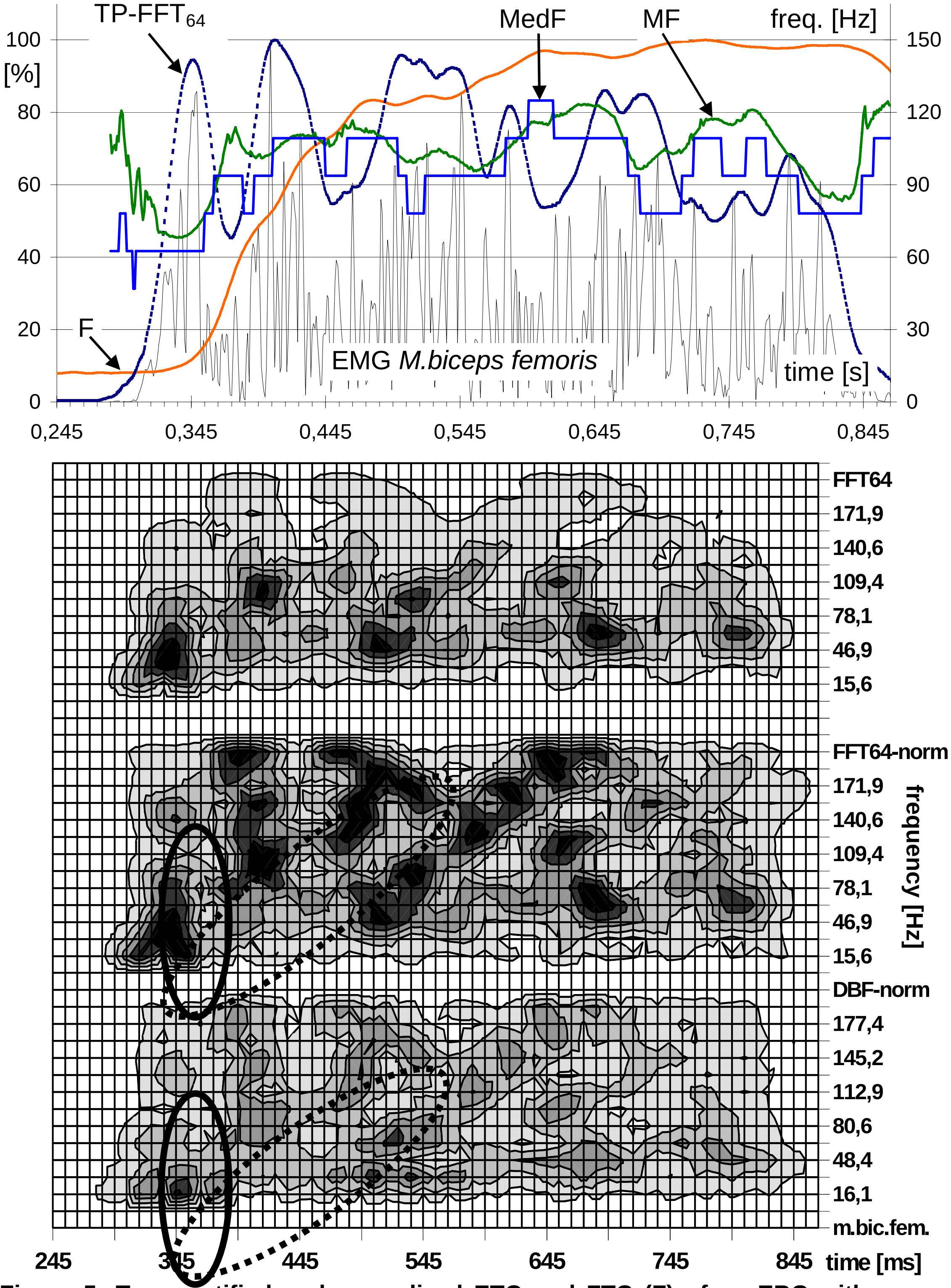

Figure 5: Top: rectified and normalized ETC and FTC (F) of an EBC with concerning MFT-parameters total power (TP-FFT$_{64}$), median frequency (MedF) and mean frequency (MF); bottom: Surface diagrams (time / frequency / amplitude) of spectrum analysis by means of MFT (64 ms) and DBF; normal (FFT64) and normalized (FFT64-norm / DBF-norm).

A possible explanation for the low part of higher frequencies in spectrum is found in the so far not respected impulse-effect-relation of different fiber types. Type IIb fibers are up to 5 times stronger than type I fibers (Tidow, & Wiemann, 1993). So each impulse of type IIb fibers produces a force, which is 5 times higher than each impulse of type I fibers. Therefore to produce the same force as 1 impulse of a fast fiber 5 impulses of slow fibers are required. This should lead also to a 5 times higher part of lower frequencies in the frequency spectrum. Therefore it is to be concluded that spectrum analysis in the previous form does not represent the mechanical effectiveness of EMG or parameters as RO in a correct way. As a first attempt for a solution of this problem each frequency band of MFT and DBF was normalized. Analysis was realized by help of a specially designed computer program.

RESULTS: The analyzed ETC and FTC show similar results. Exemplary surface diagrams (fig. 5) show a distinct correspondence between MFT and DBF with same peaks but higher level on the part of MFT. It seems that the lower selectivity of MFT results in overlapping i.e. amplifying of adjacent frequency bands. While parts of higher frequencies are of no importance in the non-normalized graph they become evident in the normalized graphs. With the beginning force onset a marked activity with mainly parts of lower and middle frequencies is to be seen, but also a distinct peak at higher frequencies. In the further course example shows high activities particularly of parts of higher and middle frequencies up to the maximum of force. Considering the times of ballistic contractions this could be an indication for a predominant recruiting of fast fibers for an explosive force development. Looking upon the surface diagrams the answer to the question whether RO follows the size principle or not that’s a matter of opinion because for both arguments are to be found (fig. 5: dotted vs. solid ellipse). Another important result is that frequency parameters i.e. median and mean frequency distinctly show an overrepresentation of lower frequency parts. Every high activity in lower frequency parts leads to decreasing frequency parameters independent of activities in middle and higher frequency parts. Therefore the use of median and mean frequency is to be considered as problematic at least if time critical parameters as RO are looked at. Statements concerning fatigue may be less effected.

CONCLUSIONS: Nevertheless it remains open if there will be statistically significant conclusions from these descriptive indications in future. Further investigations and improved frequency analysis techniques is needed. One possibility we are working on now is a better adapting of the results of the spectrum analysis to the impulse-effect-relation. As a promising alternative method the adaptive spectrum analysis by Schack et al. (1995) developed for purposes of EEG and presented by Jöllenbeck and Witte (1999) for one muscular example has to be regarded. However one important conclusion is to be drawn. We have to take care not to fit EMG-signals to the existing methods as often down in past. Rather we have to use the high potential of the modern computational equipments to develop methods that analyze the real content of the EMG-signals e.g. considering the impulse-effect-relation of different fibers types or effects of interference. Just to do so may help to avoid misinterpretations in future works. The present study intends to encourage the discussion to create a new quality in EMG-analysis and to get a better understanding of the “language of muscle”.

REFERENCES:

Jöllenbeck, T. & Witte, K. (1999). EMG-Analyse zur nicht-invasiven Identifizierung der Innervationsfolge der Skelettmuskulatur. In K. Roth, T. Pauer, & K. Reischle (Eds.), *Dimensionen und Visionen des Sports* (p 203). Hamburg: Czwalina.

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.*

Tidow, G. & Wiemann, K. (1993). Zur Interpretation und Veränderbarkeit von Kraft-Zeit-Kurven bei explosiv-ballistischen Krafteinsätzen. *Deutsche Zeitschrift für Sportmedizin* **44**, 3, 92-103.