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Complex Method for Localized Muscle Fatigue Evaluation

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***Abstract*—**The research was designed to examine the relationship between the development of muscle fatigue and the effect it has on sport performance, specifically during maximal voluntary contraction. This kind of this investigation using simultaneous electrophysiological and mechanical recordings, based on advanced mathematical processing, allows us to get parameters, and indexes in a short time, and finally, the mapping to use for the thorough investigation of the muscle contraction force, respectively the phenomenon of local muscle fatigue, both for athletes and other subjects.

***Keywords*—**Electromyography, mechanomyography, muscle fatigue

I. Introduction

MUSCLE fatigue is usually defined as a decrease in force production or an inability to regenerate the original force in the presence of an increased perception of effort. The physiological causes of fatigue have been classified as either peripheral or central in origin. Peripheral skeletal muscle fatigue is defined as a decrease in the capacity of the skeletal muscle to generate force because of action potential failure, excitation-contraction coupling failure, or impairment of cross bridge cycling, in the presence of unchanged or increasing neural drive. In contrast, central fatigue has been defined as a reduction in neural drive to the muscle resulting in a decline in force production or tension development that is independent of changes in skeletal muscle contractility. The present study was designed to examine the relationship between the development of muscle fatigue and the effect it has on muscular performance, specifically during maximal voluntary contraction.

II. Material And Methods

The groups of subjects participating in the research were composed of healthy athletes, who received a medical – sportive confirmation to participate at trainings and sport competitions. The total group (n=40) was made of male subjects (age = 22 ± 2,7 years, height = 183.71 ± 6.5cm, weight = 82.65 ± 8. kg), right-handed, professional athletes belonging to two categories of sports: group A (n=25), predominantly aerobes, and group B (n=25), predominantly anaerobes. In the same time, for these athletes there have been registered a surface EMG and MMG during a maximal isometric contraction, hand grip type, undertaken till brake point. We have chosen the usage of SEMG correlated with the simultaneous recording of the developed muscle force, by MMG, with the purpose of finding a synthetically relation between the muscle force and the SEMG parameters.

In order to determine the muscle bipotential we used surface electrodes places on the skin of the forearm, above the flexors of the fingers (*flexor digitorum superficialis* and *flexor digitorum profundus)*. We recorded the myoelectrical signal using a four channels Medicor MG 42 electromyograph. The recording was made on two channels where the time constant (go-up filter) was 20 ms and the frequency constant (go-down filter) was over 20 kHz. A 0.1 mV/div amplification was used for each channel. The signal was received by a DAP 1200 board fixed into an IBM PC AR 486 (66 MHz). The in-boards were coupled with the exit of the two channels of the electromyograph. After amplifying and filtering done by the electromyograph, the signal was initially processed by the board, dividing each channel with a frequency of 5000 Hz (200 ms between each division) and analogical digital conversion at a resolution of 12 bites (4096 levels).

The signal was received by the computer in 410 ms episodes every 5 seconds during the entire period of maximum voluntary muscle contraction, using a dedicated software for receiving the elecromyographic signal from the board and for its advanced processing, the software being an MS-DOS based one (licensed to the University of Medicine and Pharmacy of Craiova Craiova).

The recording of the muscle force was done using a transducer that recorded the voluntary and maximal isometric contraction of the flexors taken to exhaustion. A BIOPAC force isometric transducer was used, which is a SS25L hand dynamometer recording values ranging between 0-100 kg, with a nominal exit of 20μV/kg. The force transducer was connected to one of the analogical exits of the receiving unit MP30 of the BIOPAC system which was connected with a board in an IBM PC Pentium III.

The EMG surface analysis was preceded by the recovery of the myoelectric signal, its reestablishment, followed by the analysis for time and frequency. Based on the primary data we obtained a series of parameters through automatic computerizes mathematical analysis and processing. Some are

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direct parameters (such as the amplitude), whereas others are calculation parameters which derive from the primary ones (index, reports, coefficients).

From all the results we selected 31 SEMG and MMG parameters which were used for the evaluation of the muscle fatigue [1-4].

A. EMGS Time Parameters

rAmax (mV) (Maximum amplitude – redressed, *rAmed* (mV) (Median amplitude redressed), *rAav* (mV) (Average amplitude – redressed), *rA-CV* (Coefficient of variation of average amplitude – redressed), *Amax pp* (mV) (Maximum amplitude – peak to peak), *Amed* (mV) (Median amplitude), *Aavd* (mV) (Differential average amplitude), *A-CV* (Coefficient of variation of average amplitude), *Aav pp* (mV) (Average amplitude peak-to-peak), *rAmed-lp* (mV) (Median amplitude redressed of local peaks — turns), *rAav-lp* (mV) (Average amplitude redressed of local peaks — turns), *rA-lp-CV* (Coefficient of variation of local peaks average amplitude – redressed), *Rms* (mV) (Root Mean Square Signal), *Isr* (mV.ms) (Redressed Signal Integral), *Raa* (ms) (Area Amplitude Ratio).

B. EMGS Frequency Parameters

Fmed (Hz) (Median Frequency), *Fav* (Hz) (Average Frequency), *Fsmax* (Hz) (Maximum spectrum frequency), *Smax* (mV^2/ms) (Maximum Spectral Energy), *IF-CV* (Coefficient of Variation of mean interval frequency), *Nlp* (no/s) (Local Peaks Number; Turns Number), *Nzc* (no/s) (Zero Crossings Number), *Nlp/Nzc* (Nlp/Nzc Ratio);

C. EMGS Time-Frequency Parameters

Stav (mV/ms) (Mean Steepness), *AstI* (mV^2/ms) (Amplitude Steepness Index), *AFR-FFT* (mV/Hz) (Amplitude/Frequency-FFT Ratio), *AIFR* (mV/Hz) (Amplitude/Interval Frequency Ratio), *Syn*(%) (Synchronization);

D. MMG Parameters

MF (Kgf) (Muscular Force), *IF*(Kgf·s) (Force Integral), *ECCEI* (Kgf/Hz) (Index of excitation-contraction coupling efficiency).

The program, which has been elaborated by of group of researchers from Medical University of Craiova [1-4], allows the analyses of all the 31 parameters, either continuously or partially, for 410 ms with gaps of 4590 ms. This way every 5 seconds, we obtain values of all the EMGS and MMG parameters, with which the program forms a curve of time evolution for each parameter during the entire contraction period.

Based on this curves we have drawn lines of regression. The regression lines have supplied more information: intercept (ordinate value of a point where the regression line intersects the ordinate) and slope (shows the brutal change of the parameter because of the fatigue).

Starting with the primary EMGS and MMG parameters described above, we have made a secondary processing, getting more synthetic values which can be used to define the behaviour of the two researched groups (the aerobes group and the anaerobe one) during the contraction process and that of muscle fatigue.

Finally, we have used three values which allowed us to make a more specific comparative analysis of the behaviour the two groups of athletes had during the contraction effort.

E. The statistical analysis

In processing the data we used the software pack EPI 2000, distributed by World Health Organization (WHO), SPSS, developed by SPSS company, and Statistica, a software for statistical and graphic process program, developed by StatSoft. The recording of the data base for this study was done using EXCEL. The actual processing used the following commands: Cross Tab, Basic Tables, General Tables, Correlate, Regression in SPSS. The ANALYSIS module in EPi was also used for tables, graphs and statistical tests, as well as the Basic Statistics, Linear Regression and Factor Analysis modules in Statistica.

III. Results

A. Evolution of Intercept

For the Intercept of time SEMG parameters we found at group B values higher than the values of group A parameters. The biggest values were for Aavd = +265.56%. Medium differences for, rAmedIp= +56.27%, rAav-Ip= +50.86%, rAav= +47.00, Aavpp= +46,10%, Isr= +46.84%, Rms= +45.03%). $Amax_{pp}$ (+34.41%) and rAmax (+31.51%) had smaller differences (Figure 1).

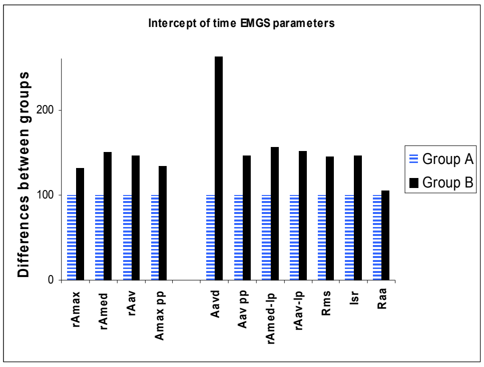

Fig. 1 Intercept differences (%) of time EMGS parameters between group B and group A

For the Intercept of frequency parameters SEMG found values very slightly lower, not larger than in group B versus group A for Fmed (+0.69%), Nip (+0.75%), Nzc (-2.06%), Nlp/Nzc (+2.30%), Fav (+0.29%), FSmax (+2.4%). Except Smax, which at group B had much higher values (+116.89%) comparative with group B (Figure 2).The Intercept of mixed SEMG parameters was very expressive for AStl who presented a difference of +119.84% in group B, while AFR-IF(+62.65%), AFR-FFT(+52.75%). Stav (+40.88%), had a relatively lower value. For Syn wasn't difference (+0.27%) (Figure 3)

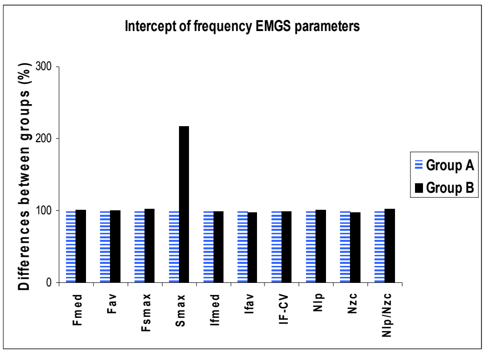

Fig. 2 Intercept differences (%) of frequency EMGS parameters between group B and group A

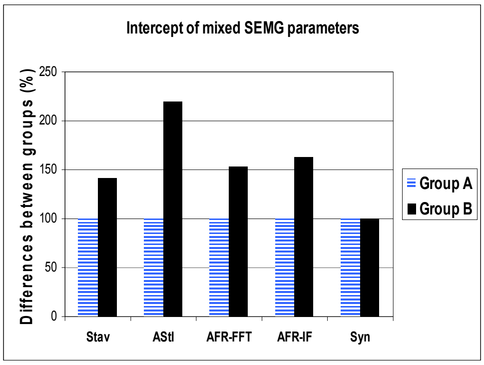

Fig. 3 Intercept differences (%) of mixed SEMGS parameters between group B and group A

The Intercept of MMG parameters, which proved high in athletes of group B, was very expressive (ECCE=+163.17%), Force=154%, Force Int=123.86%) (Figure 4).

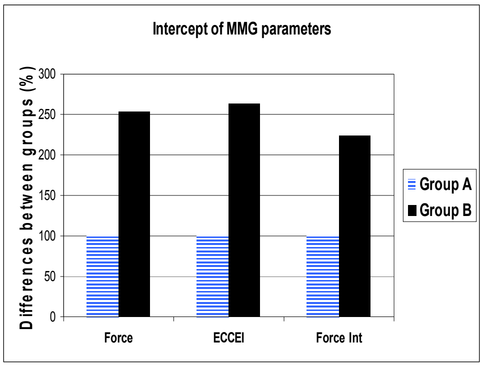

Fig. 4 Intercept differences (%) of mixed SEMGS parameters between group B and group A

B. Evolution of Slope

The Slopes time SEMG parameters were higher for group B, with great differences for rAmed-Ip (+124.89%), rAmed (+107.88%), rAav-Ip (+106.80%), Aavd, rAav, rAav pp and Isr (+98%), Rms (+92.45%), rAmax (+88.04%), Amax pp (+86.42%). The smallest difference, as at Intercept, was recorded for Raa (+49.53%). In conclusion, the amplitude SEMG parameters, which show a superior performance to Intercept, will present brutal time evolution. This evolution was defining for the group B. (Figure 5).

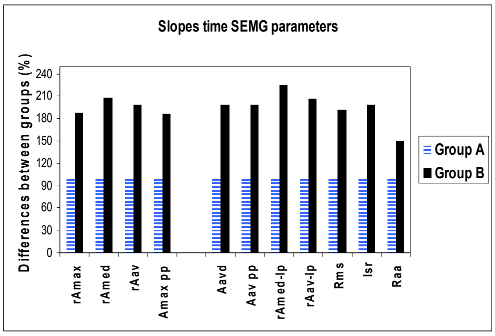

Fig. 5 Slope differences (%) of time SEMGS parameters between group B and group A

The Slopes of frequency SEMG parameters at group B don't meet the uniformity of the time parameters. Thus, while difference for Smax (+151.82%) and FSmax (+84.65%) were significantly higher in group B compared with group A, moderate differences were recorded at other parameters (Fmed=+44.75%, Nzc=+40.77%, Fav=+35.41%). The Slope of Nlp is less, for Nlp/Nzc isn't difference. The biggest difference was recorded for Smax, which is the parameters most expressive (Figure 6).

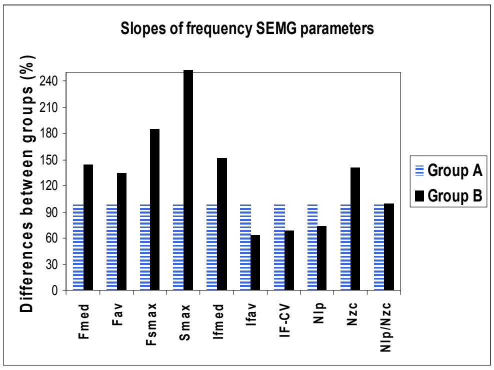

Fig. 6 Slope differences (%) of frequency SEMG parameters between group B and group A

The Slopes of mixed SEMG parameters recorded significant differences for Astl (+163.13%) and Stav (+90.35%). A special mention must be made for the synchronization of motor unit activity which shows divergent evolution compared with other mixed parameters evolution, -63% in group B, compared with group A (100%) (Figure 7). We can observe, in that circumstance, that although the Intercept values are approximately equal with the synchronization at the two groups, Slopes of same parameter indicates a higher synchronization at the point of exhaustion, as an expression of a greater muscle fatigue process in group B.

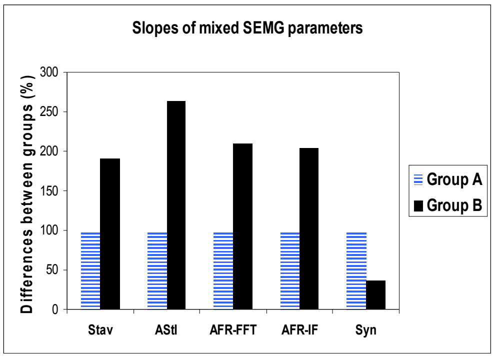

Fig. 7 Slope differences (%) of mixed SEMG parameters between group B and group A

The Slope of MMG parameters in group B show great differences in all three parameters*,* ECCEI (+167.93%), Force (+136.15%) and IF (+123.86%), compared with group A (the contractile performance, although starting from lower values, has a slower growth over time) (Figure 8).

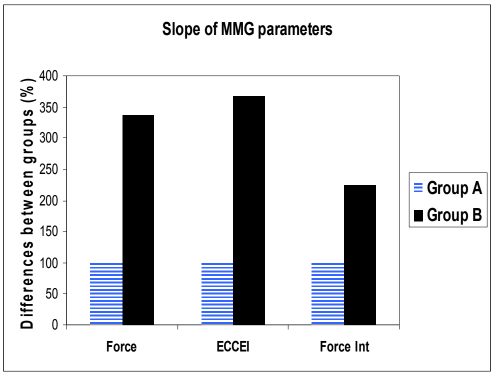

Fig. 8 Slope differences (%) of MMG parameters between group B and group A

IV. CONCLUSION

The results of this study shows that, based on simultaneous electrophysiological and mechanical recordings, using advanced mathematical processing, and getting dozens of parameters, indexes, reports, graphs, mappings, we can objectively follow the maximum effort capacity and the evolution in the appearance of the local muscle fatigue. Perhaps in the future we will eventually give up registering the mecanograma, as this has a similar behavior as the *Isr*, or even use a ratio between Isr and frequency (in Hz), obtaining similar results as the ratio between the contraction force and the frequency (Hz), thus simplifying the working conditions and the related mathematical processing.This kind of this investigation using simultaneous electrophysiological and mechanical recordings, based on advanced mathematical processing, allows us to get parameters, and indexes in a short time, and finally, the mapping to use for the thorough investigation of the muscle contraction force, respectively the phenomenon of local muscle fatigue, both for athletes and other subjects.

On the other hand, this methodology can be also used for selecting different kinds of athletes who will be oriented, using objective criteria, towards mainly aerobe or anaerobe activities, enhancing the odds of reaching superior sport performance.

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