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Research Article

The Use of Acoustic MyoGraphy as a Measure of Training Effects in Athletes- A 10 Month Case Study of a BMX Rider

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Abstract

Objectives: Assessing effects of a training programme in a fast and non-invasive way is a must for most athletes to prevent over-training and injury, and to design the right programme for a particular athlete for optimum performance at the time of an event. The aim of this study was to test if Acoustic MyoGraphy (AMG) could be just such an assessment method.

Methods: As an example, a 15 year old BMX rider from a national team was followed over a 10 month period to see how his training programme affected his performance development and his final ability. One of the most important muscles in cycling, m. Quadriceps, was assessed at baseline, one, two, 5 and 10 months thereafter with an AMG-recording CURO device, recording spatial (S-score), temporal (T-score) and efficiency score (E-score).Muscle health was assessed with multi-frequency bio impedance at baseline and at the finish, 10 months later.

Results: A clear development of efficiency in use of muscle fibres was seen following training over the 10 month period, witha very rapid improvement in the T-score, and a slower improvement in the S-score and E-scores.

Conclusion: Our results show AMG to be a fast non-invasive method capable of following the effects of training on muscle performance, as well as being able to quantify improvements in actual physical performance in a specific sports setting, giving the opportunity to follow the particular athlete and his potential for further training without causing injury. The method can be applied in most sports disciplines.

INTRODUCTION

Objective physiological assessment of effects of training is an important issue in all sports and all age groups, and at all levels. A good measure of an athlete's condition and his development following a training scheme at any given time could allow an adjustment of this programme, should it appear not to have the intended effect.

There are several aspects of training which must be considered:

1) Do the muscles in question stay healthy and without over-training during the programme?

2) Does the recruitment of fibres during the training programme improve in terms of using less fibres at any given time and/or a lower frequency of recruitment?

3) Does the training programme lead to a better switching on/off of involved muscle fibres, resulting in better efficiency through improved coordination?

4) Does the overall training programme lead to a symmetrical and balanced use of the muscles of interest?

To assess points 1 to 4 at a regular interval and with minimal interference to the training programme, non-invasive and easily applicable methods must be used. With multi-frequency bioimpedance (mf-BIA) it is possible to give a snapshot of the condition/health of a particular muscle [1,2] – a so called "static" assessment, but during activity other methods must be applied – ones that can assess "dynamic" activity. Recently, a new method, Acoustic MyoGraphy (AMG), has shown great potential [3], proving itself capable of measuring muscle fibre use under most conditions, i.e. during the actual performance (real-time), where ever it may take place.

The bio-impedance parameters, Xc, Ri and Mc all relate to the health of muscle tissue. They relate to the ability of fibres to store energy (Xc), to a fibres VO2 at rest (Ri) and finally, to the membrane viability as a result of trans-membrane trafficking (Mc) [2].

The AMG technique directly measures muscle contractions, unlike sEMG which detects electrical activity in the neuromuscular junction as well as in active fibres [4]. The AMG system (CURO) used in this study is designed to perform a signal analysis. Three parameters are analysed, the degree of efficiency/coordination with which the muscle is used (E-score), the number of active fibres recruited (spatial summation; S-score), and the frequency with which these active fibres are contracted (temporal summation; T-score), all three of which are utilised by the CNS when developing force in an active muscle. The E parameter represents the period of time a muscle is active relative to periods of inactivity for a set recording interval. The S-score is determined as the signal amplitude in relation to a full 6dB signal. Finally, the T-score is determined as the frequency in relation to a Max T value [4].

Early acoustic myography recordings have been obtained using piezoelectric microphones with an air cavity between the skin and the sensor, a configuration that was subsequently shown with the aid of accelerometers to be incapable of detecting the lower frequency range of muscle contractions [5]. This frequency issue has been solved with the CURO device. With the aim of finding an optimal method to follow the effects of a designed training programme for an athlete, we were permitted to follow a junior BMX rider from the national Danish team, using the new technique of AMG over a training period of 10 months.

MATERIALS AND METHODS

Participant

A 15 year old male BMX cyclist from the Danish national BMX team volunteered to participate in this study. The subject weighed 67 kg and had a height of 181 cm at the start of this study. Upon completion of the measurements, some 10 months later, the subject weighed 74 kg and was 182 cm tall. The growth spurt for this subject had taken place prior to the start of this study. The subject and his parents gave informed written consent to his participation. There were no ethical issues since the apparatus and measurements were CE approved for use amongst a healthy population and could be bought freely by sports clubs or private people.

Training Programme

Training for this subject included weekly strength-training sessions for the upper body, core and lower body muscles, track training, sprint training and road biking. At the start of the study the subject was in winter training, which comprised of strength training two times a week, track training three times a week, road biking one day a week, and a single day with no organised training out of every seven. In the spring months the training comprised of strength training two times a week, track training three times a week, road biking one day a week, and a single day of sprint training. During the spring months the subject trained every day of the week. Over the summer the training comprised of strength training two times a week, track training three times a week, sprint training two times a week, and a day of road biking set to 1.5 hours of high-speed cycling. Finally, at the start of the autumn, and the end of this study, the subject undertook a training programme comprising of strength training three times a week, track training two times a week , road biking one day a week (1.5 hours at high speed), and a single day free of training out of every seven.

The results of the AMG-measurements were shared with the subject's trainer, who used them to follow the progress of the adopted training programme, as well as to assess the level of performance of the subject's thigh muscles with regard to the explosive power needed to leave the start gate on a BMX track successfully.

Measurements

At the first and last visit, mf-BIA measurements were taken prior to exercising for m. Quadriceps to ensure that this muscle group was healthy, balanced left versus right-side, and had no signs of inflammation or swelling. mf-BIA measurements were taken using an Impedimed human device (Impedimed, Brisbane, Australia). In each case, four silver-silver chloride electrodes (ImpediMed, Brisbane, Australia) were placed at each end of the muscle body, according to the manufacturer's recommendations. The outer two electrodes provided the electrical field, and the inner pair was the sensing electrodes. Care was taken to ensure that there was one cm between the voltage and the sensing electrode. A frequency range of 4-1000 kHz was applied in each case, and 6 consecutive measurements were carried out. The following parameters were measured or calculated applying Impedimed software: Impedance (Z), Reactance (Xc), Centre Frequency (fc), Resistance (R), Extracellular and Intracellular Resistance (Re and Ri), Membrane Capacitance (M_c).

Acoustic MyoGraphy measurements were obtained at baseline, and then subsequently at 1, 2, 5 and 10 months. The participant performed cycling on an exercise bike at the same speed (70 rpm), but with increasing load (1 to 22 on an arbitrary scale: equating to 33 to 345 Watts). During the cycling, AMG measurements were made using a CURO (MyoDynamik ApS, Frederiksberg, Denmark) with CURO sensors placed at the centre of the muscle body with a thin layer of acoustic gel applied to the sensor and adjacent skin, and the sensor strapped to the muscle with a soft bandage. ESTi™ - scores, expressing Efficiency (E), Temporal (T) and Spatial (S) summation when using a muscle, were calculated with the use of the CURO software (www.myodynamik.com).

Data handling

mf-BIA data gives a static snapshot of the condition of the muscle in question. The various parameters were measured at the start and end of this study, looking at right-left symmetry in m. Quadriceps, muscle damage, dehydration, overtraining, and build-up of muscle over time. Impedimed software was used to obtain all the parameters used [6].

AMG data, which presents dynamic muscle contractions, was analysed using CURO software (MyoDynamikApS) calculating the E, S and T parameters mentioned earlier. These three parameters determine the training effects: efficiency of muscle use and the strategy of recruitment, and take account of possible changes in this with increasing load.

Statistical analysis

Differences between means were tested for statistical significance using GraphPad InStat 3 for Mac (Version 3.0b, 2003; Graph- Pad Inc., La Jolla, CA). Data were initially tested for normal distribution and equal variance, and then subsequently analysed using a Tukey-Kramer multiple comparisons test. Differences between means with a P value > 0.05 were considered non-significant. Values are presented as the mean.

RESULTS

mf-BIA data

The baseline and final bio impedance data are presented in Table (1). It can be seen that this subject was very slightly weaker at the start of the study, having a lower Z, R and X_c– especially for the left leg. Training resulted in not only a more even bio impedance measurement for this muscle group, but also improved the muscle mass (Z) and the cellular health (X_c) parameters. However, the right side remained the most dominant and powerful of these two muscles.

There were no signs of tension imbalance between the left and right legs (f_c), and the Mc values, which express membrane integrity (cellular transport) are quite healthy for well-trained and routinely exercised muscles, likewise the Re and Ri values [2]. The slightly lower Mc and elevated Re and Ri values are most likely the result of training earlier in the same day of the final measurement at 10 months.

AMG data

Our AMG measurements caused the trainer to make a change in the existing training programme towards one that more intensively focused on the thigh muscles so as to improve their strength for the gates. The data in this study were also used by the trainer to reflect on the level of overtraining achieved during the spring months and to subsequently time the training programme so that the subject was perfectly ready for the start of the race season. Finally, the subject's trainer used the AMG data to learn more about the training programmes he routinely uses, and to gain a more detailed and individual knowledge of his athlete's physical performance.

The AMG data covering the period from baseline to 10 months of training can be seen in Figures (1a to c). The individual component parameters of E-score for efficiency (Figure 1a), S-score for spatial summation (Figure 1b) and T-score for temporal summation (Figure 1c) are presented.

There was a significant overall response to training for the E-score (P< 0.0001), S-score (P< 0.0001) and T-score (P< 0.0001). Significant changes in the E-score between months 1 and 2 (P< 0.001), and 5 and 10 (P< 0.01), as well as 1 and 5 (P< 0.001), 1 and 10 (P< 0.001) and 2 and 10 (P< 0.001) months, were noted. Likewise, significant changes in the S-score between months 1 and 2 (P< 0.001), and 1 and 5 (P< 0.001), as well as 1 and 10 (P< 0.001) months, were noted. Finally, significant changes in the T-score between months 1 and 2 (P< 0.001), and 1 and 10 (P< 0.001), as well as 2 and 5 (P< 0.001), and 5 and 10 months (P< 0.001), were found (Figure 1).

Overall, training was found to result in a clear improvement in the E- S- and T-scores, with the frequency response being the first to change (lower frequency – higher T-score). This means that for any given load (Watts) a lower firing frequency was used to achieve the power needed, in response to the training programme. The S-score also improved greatly, albeit not at the same rate as the T-score. However, it improved from a level of 3 to something close to 8 over a period of 10 months of training. This means that for any given load (Watts), fewer fibres were recruited to achieve the power needed, in response to the training programme. The final parameter, the E-score, which defines the efficiency of muscle contraction, that is to say the period of activation expressed as a unit of total exercise time, also improved with training. It is important to note though that any improvement in the E-score will also be reflected in the T- and S-scores.

The combined training effects represented by Figures (1a to c) illustrate how training over a period of time results in not only a more efficient and coordinated form of contraction at any given load (Watts), but also serves to show how a more efficient form of contraction results in fewer active fibres and a lower firing frequency.

DISCUSSION

Training programmes must be individually designed if the most optimum results are to be reached. Decisions concerning training programmes are typically made based on experience from earlier athletes from the same field, scientifically derived knowledge, as well as collaboration between the trainer and the trainee. With a professional BMX rider as an example, we have hereby illustrated that the non-invasive and easily applicable method of acoustic myography can be used to assess and follow a specific training programme for an individual

Table 1: mf-BIA values for the left and right leg m. Quadriceps at baseline and after 10 months of training.

	BASELINE		10 MONTHS	
m. Quadriceps	Left	Right	Left	Right
Impedance (Z) Ω	70.3	80.0	89.4	97.1
Resistance (R) Ω	68.3	78.1	87.4	95.2
Reactance (Xc) Ω	16.6	17.4	18.8	19.3
fc (kHz)	41.3	39.7	40.7	38.9
Re Ω	94.3	106.2	117.7	127.8
Mc nF	20.1	17.4	15.2	14.3
Ri Ω	97.4	123.1	139.3	158.6

The values were taken at rest, prior to cycling. Values are the mean of 6 repeats taken using an Impedimed Bioimpedance unit.

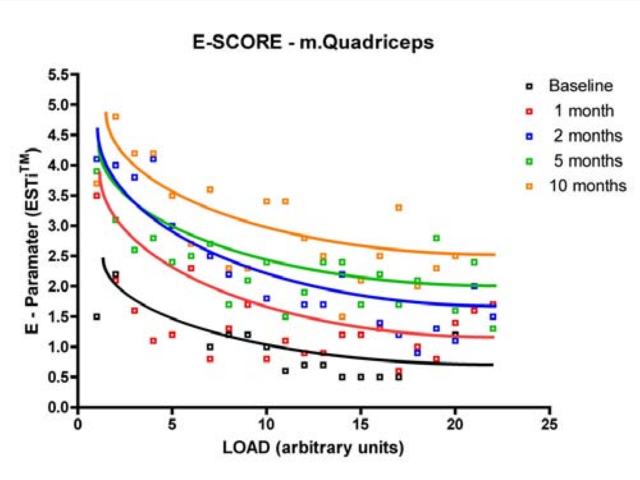

Figure 1a Acoustic MyoGraphy recording showing changes for m. Quadriceps of a BMX rider during a 10 month period of training, measured using an exercise bike at a rate of 70 rpm covering a load range of 1 -22 (arbitrary units) equating to 33 to 345 Watts. A) The AMG efficiency score (E-score) representing the ratio of active to inactive periods of muscle contraction.

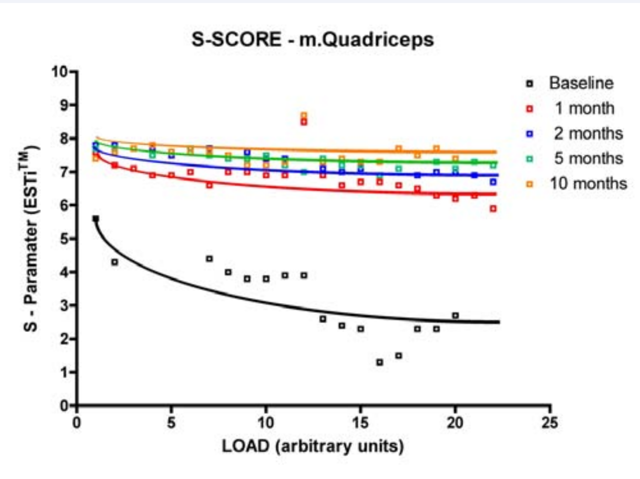

Figure 1b The AMG spatial summation (S-score) representing the number of recruited fibers (signal amplitude).

athlete. This approach and methodology also enables the trainer to alter and adjust the programme to fit the athlete's level and needs, thereby making the training programme personalized to a degree that has hitherto been impossible. Assessing muscle groups with mfBIA, in this case m. Quadriceps, prior to the start of a training programme gives the trainer an idea of the static muscle mass and health of an individual athlete, but it does not provide any details as to the dynamic capabilities of the muscle in question. This can only be achieved through the use of an accurate and precise dynamic assessment of a muscle whilst it is physically active and performing in the sports field relevant for the athlete. Our study demonstrated that it is easy and non-traumatic to objectively assess an athlete's muscles in a given training and competition situation using a CURO system. AMG measurements

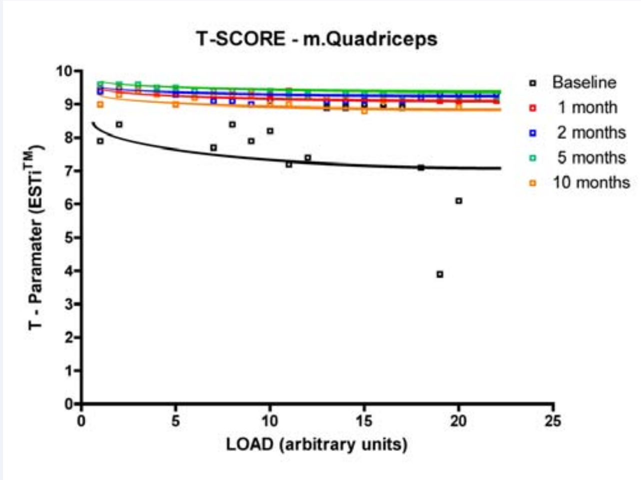

Figure 1c The AMG temporal summation (T-score) representing the firing frequency of active fibers (signal frequency). All scores range from 0 to 10, where an improvement is seen as a change from a lower to a higher score. For significant differences between the individual training periods see the results section.

made during this study have shown that the training programme adopted successfully achieved what it was initially designed to do. That is to say, muscle contractions capable of producing a given power (Watts) with the minimum number of active fibres and at the lowest possible firing rate, all achieved through a higher degree of muscle fibre coordination/efficiency. The mf-BIA data reveals an approx. 24% increase in muscle mass (Z) over the training period. It is well-known that an increase in muscle fibre cross-sectional area is correlated with an increase in muscle force, although the percentage of the isoform type II myosin heavy chain in the muscle in question also has great importance [7]. However, in this case there was a very rapid improvement in the T-score, and a slower improvement in the S-score, such that any increase in muscle mass with training most likely had a major impact on the S-score rather than the T-score.

Of course, one cannot ignore the importance of coordination and training and in this respect the increase in muscle mass. When the latter is combined with an improved efficiency or coordination, this will also have impacted on the improvements seen in the S- and T-scores. The initial increase in the S-and T-scores (fewer active fibres and a lower firing frequency) is believed to be due to improved coordination of muscle function created by a structured training program. It is well accepted that subsequent training over a longer period of time, results in both hyperplasia and hypertrophy of the muscle, which will not be represented by the T-score. However, the slight continued improvement in the S-score is most likely in part due to fibre hypertrophy requiring fewer fibres per unit load.

PERSPECTIVES

Current training programmes are often based on acquired knowledge and expertise, although new advances in training are beginning to be adopted. Taking cyclists as an example, it is now possible with accurate pulse measuring devices and accelerometers to monitor their cardiovascular performance, as well as gain some information about their level of physical activity. The power use (Watt) is further applied as a measure of effect of training at the highest levels of cycling with a great deal of success [8]. However, up until now it has not been possible to measure muscle performance in a muscle-specific way. With AMG as a tool, the evaluation of performance and the attainment of training goals for cycling and many other sports like running [9] or football [10] is now possible. This will help to adjust training programmes to the optimum for the particular athlete, and thereby avoid overtraining and possible injury.

CONCLUSION

It is concluded that acoustic myography represents a promising tool that offers an insight into improvements in actual physical performance in a specific sports setting, since it gives a direct picture of muscle activation and coordination. Furthermore, AMG offers a fast, non-invasive, reliable way of measuring muscle improvements following training, as well as enabling the monitoring of early signs of muscle fatigue – important if muscle injury as a result of over-training is to be avoided.

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CONFLICTS OF INTEREST

The CURO system was provided by MyoDynamikApS and APH, AH and KSH were all in the employment of MyoDynamikApS. The study protocol was designed by EMB who had no financial association with the company. JP and ITA were also independent of MyoDynamikApS. All authors have complied with the Vancouver declaration.

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