COMPARATIVE STUDY BETWEEN MECHANOMYOGRAPHIC AND FORCE SIGNALS IN SPEED RUNNERS AND ENDURANCE ATHLETES

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RESUMO

O objetivo deste estudo foi comparar os sinais mecanomiográficos (MMG) e de força de atletas velocistas e de endurance, a fim de determinar diferenças no comportamento mecânico do músculo. Nas contrações voluntárias, o torque extensor de joelho e os valores RMS do sinal MMG aumentaram com o aumento do esforço para os dois grupos, e ambos os valores foram mais elevados para os velocistas. Não foram observadas diferenças nas flutuações de força obtidas nas contrações produzidas por estimulação elétrica; entretanto, o comportamento do sinal MMG foi diferente entre os dois grupos de atletas. Estes resultados sugerem que os sinais MMG são mais sensíveis do que os sinais de força na avaliação do comportamento mecânico de músculos de diferentes grupos de atletas.

PALAVRAS-CHAVE: mecanomiografia, força, atletas velocistas e atletas fundistas

ABSTRACT

The purpose of this study was to compare mechanomyographic (MMG) and force signals of speed runners and endurance athletes in order to assess differences in the muscle's mechanical behavior. For the voluntary contractions, the knee extensor torque and the RMS values of the MMG signal increased with increasing voluntary effort in both groups, and both values were higher in the speed runners. No differences were observed in the force fluctuations obtained during the electrically elicited contractions, whereas the behavior of the MMG signal was different between the two groups of athletes. These results suggest that the MMG signals are more sensitive than the force signals in assessing mechanical behavior of muscles from different groups of athletes.

KEYWORDS: mechanomyography, force, speed runners, endurance athletes

INTRODUCTION

Mechanomyography (MMG) is a non-invasive technique which has been used to study the mechanical properties of skeletal muscles with different types of motor units (MUs) (e.g. 23, 31, 32, 33, 37) and to investigate muscle behavior on myopathies (40, 7, 3), distinct actions (1, 2, 9, 28, 30), fatigue (10, 12, 21, 39, 48), functional demands (19, 20), arm dominance (25). Differently from the electromyographic (EMG) signal, which represents the algebric summation of all active MUs action potentials in a contracting muscle (8), the MMG signal has been associated to the muscle's mechanical behavior (17, 28, 41, 43, 51). However, evidences in the literature have demonstrated that there is a strong relationship between MU action potentials and the sounds/vibrations produced by these action potentials (11, 16, 29, 34, 45, 50). Assuming that this is true, then the MMG signal might be

associated to both MU activation and the mechanical behavior of these activated MUs during contraction.

MUs have been classified into three different types: slow contracting units (S), fast contracting units resistant to fatigue (FR) and fast contracting units which are fast fatigable (FF). This classification has been proposed based on the determination of the mechanical and physiological characteristics of the muscle fibers by which a MU is made of (14). Upon activation, these different types of MUs show distinct mechanical behavior, and the predominance of one MU type gives the muscle its own characteristic mechanical behavior (13).

Athletes participating in different modalities of sports may have different proportions or percentages of these types of MUs, which are related to the functional demands upon their muscles for many years of training, as well as to genetic characteristics.

Therefore, the same muscle of different types of athletes may show different percentages of MUs, and, therefore, these muscles will most likely show a different mechanical behavior during contraction.

We were able to find only five studies which have used MMG to study muscles with different fiber type or MU compositions (31, 32, 33, 37, 49). However, none of the five studies above has used the MMG signal in a systematic way to compare the mechanical behavior of muscles with assumed different fiber type (or MU type) distribution during maximal and submaximal voluntary contractions, and during electrically elicited contractions. This would allow a better understanding of the relation between MMG signals and the mechanical and electrical behavior of a muscle. Therefore, the purpose of this study was to verify if the MMG signal was capable of detecting a difference in the mechanical behavior of the vastus lateralis muscle of speed runners and endurance athletes.

Four hypotheses or ideas were proposed and tested. Assuming that speed runners have a higher percentage of fast twitch fibers compared to endurance athletes (18, 27), and therefore stronger knee extensor muscles, it was expected that the absolute torque produced by speed runners should be higher compared to that of endurance athletes both during electrically elicited and voluntary contractions (hypothesis 1).

Considering that the MMG signal amplitude decreases with increasing frequencies of stimulation (4, 22, 31, 35, 42, 47), it was expected that the root mean square (RMS) values of the MMG signal of both types of athletes should decrease with increasing frequencies of stimulation.

However, this decrease should be different between groups as the RMS values of endurance athletes should be smaller when compared to those of speed runners, due to their higher percentage of slow twitch fibers in the vastus lateralis muscle (hypothesis 2).

Assuming the higher percentage of fast twitch fibers in the vastus lateralis muscle of speed runners, it was also expected that the RMS values of the MMG signal of speed runners should be higher compared to endurance athletes during the electrically elicited contractions, as speed runners should achieve a complete fused tetanic contraction later in the electrically elicited protocol when compared to endurance athletes (hypothesis 3).

Assuming that there is a relationship between MU recruitment strategies and the MMG signal obtained during different levels of voluntary effort (29), and assuming that MUs in large muscles are recruited up to 90%-100% of the maximal voluntary isometric contraction - MVIC (8), a linear increase in the RMS values of the MMG signal was expected with increasing voluntary effort in both groups. However, the magnitude of the vibrations (as measured by the RMS values) should be higher in the vastus lateralis muscle of the speed runners due to the assumed higher percentage of fast twitch fibers in this group compared to endurance athletes (hypothesis 4).

We found only four studies that used MMG for investigating human muscles with different percentage of MUs or muscle fibers.

It was suggested that the power spectra of muscle sounds (or vibrations) should be related to the predominance of one fiber type in a muscle (32). These authors compared the MMG frequency spectrum of two muscles with different percentages of fiber type distribution, the predominantly slow-twitch soleus muscle and the predominantly fast-twitch orbicularis oris muscle.

According to these authors, the power spectra of the muscle sounds appear to reflect the expected higher frequency in orbicularis oris (22 ± 5 Hz) as compared to that of soleus (10 ± 3.1Hz). They concluded that muscle sound power spectra may be related to fiber type composition and/or mean MU firing rates.

In another study, electrically elicited muscle contractions were used to compare the MMG signal of two muscles: the predominantly slow-twitch soleus muscle and the predominantly fast-twitch vastus lateralis muscle (31). According to these authors, the evoked phonomyogram rising time values obtained from soleus and vastus lateralis muscles were significantly different, and the difference was clearly due to their different mechanical properties. The power spectrum value was approximately 1.5 times greater in vastus lateralis ('fast' muscle) compared to that in soleus ('slow' muscle). The authors

concluded that evoked phonomyography can be considered as a useful technique for the assessment of mechanical properties of individual human muscles.

In yet other study MMG signals of the knee extensor muscles were compared between long distance and speed runners obtained during maximal voluntary isometric contractions (MVICs) until exhaustion (37). Clear differences were found between soundmyograms recorded from sprinters and those from long distance runners. The onset values and the time courses of time and frequency domain parameters seemed to be strongly affected by the muscle's fast and slow-twitch fibers proportion. The authors hypothesized that soundmyogram could be used together with electromyography for the non-invasive muscles fiber typing.

Power spectra of the predominantly slow-twitch soleus were compared with the mixed fibered biceps brachii, during a 50% MVIC.

It was concluded that the unimodal appearance of the power spectra of soleus MMG signal was related to its higher content of slow-twitch fibers, whereas the bimodal spectra of biceps brachii revealed a mixed fiber type distribution (33).

Finally, MMG amplitude and frequency were compared between fast medial gastrocnemius and slow soleus muscle during voluntary and electrically induced contractions (49). The RMS-MMG of the medial gastrocnemius increased as a function of force, while these values for soleus increased up to 60% MVIC, but decreased at 80% MVIC. During electrical stimulation at 5 Hz, the MMG power spectral peak frequency was matched with stimulation frequency in both muscles. At higher stimulation frequencies (e.g. >15 Hz), only in the medial gastrocnemius was MMG-power spectral peak frequency synchronized with stimulation frequency, while the soleus did not show any synchronization. These data suggest that the MMG frequency components might reflect active motor unit firing rates, and that the MMG amplitude depends upon mechanical properties of contraction, muscle fiber composition, and firing rate during voluntary and electrically induced contractions.

As the above evidences in the literature show, the MMG and soundmyogram signals are useful non-invasive tools used to evaluate muscle function in muscles with different mechanical properties. Assuming that muscles undergoing different training regimens show different mechanical properties, the purpose of this study was first to compare the behavior of the knee extensor MMG signals of the vastus lateralis muscle of speed runners and endurance athletes. We also compared the force behavior between these two athletes groups in order to determine if

MMG signals shown additional information than that of force signals when evaluating a muscle's mechanical property.

Electrically elicited and voluntary contractions were used to determine the behavior of these two signals (MMG and force).

METHODS

Twenty male subjects (18 to 30 years of age), without history of neuromuscular disease, gave their written consent to participate in this study, that was approved by the Ethics Committee of the Federal University of Rio Grande do Sul (protocol number 99007). Subjects were assigned into two groups: speed runners (n=10) and endurance athletes (n=10, with 2 long distance runners, 3 cyclists and 5 tri-athletes). All the athletes have approximately the same hours of training per week, in both groups. In the endurance athletes, we have marathoners, cyclists and triathletes.

Force Signals

Subjects were seated in an isokinetic dynamometer (Cybex, NORM; Lumex & Co., Ronkonkoma, New York, USA) and strapped by the dynamometer belts in order to maintain body stability. The thigh and knee angles were maintained at an angle of approximately 90° of flexion (0° = full thigh and knee extension).

In addition to the knee extensor moments, knee extensor force was also registered by means of a custom aluminum arm instrumented with calibrated strain gages (7), connected to a signal amplifier (sampling frequency: 1000 Hz).

MMG Signals

A miniature unidirectional accelerometer (Entran EGA-125 D, USA; frequency response = 0 to 200 Hz) was fixed to the skin of the distal third of the vastus lateralis muscle with double-sided adhesive tape. MMG signals passed through a main amplifier (Entran MSC6, Fairfield, NJ, USA) before being stored on a personal computer. The dynamometer belts did not constrain the motion of the accelerometer.

Force and MMG signals were collected simultaneously with the software SAD32 (version 2.59b), and stored on a Pentium (200 MHz) personal computer for signal analysis.

Artificial Electrical Stimulation

Artificial electrical stimulation of the femoral nerve (square pulses of 0.8 ms of duration) was delivered percutaneously for 2 seconds using a GRASS stimulator (S88, Quincy, Mass., USA) and an isolation unit (SIU8T) approved for human studies. Two electrodes (4.5 x 10 cm) were positioned in the anterior-medial surface of the thigh, over the estimated anatomical point of the femoral nerve (which was determined by applying single pulses in that region previous to the tests), and over the distal

portion of the quadriceps muscle (45). The skin was prepared prior to the placement of the stimulation electrodes and of the accelerometer using standard procedures (e.g. 8).

Protocol

All subjects warmed up prior to the tests by performing 20 submaximal isokinetic dynamic contractions, at an angular velocity of 120°/s. After the warming up session, the accelerometer and stimulation electrodes were positioned as described previously.

Singular pulses were applied at different voltages in order to determine the highest voltage for the electrically elicited protocol. This was determined as the maximal voltage that the

(electrically elicited and voluntary contractions) to avoid fatigue.

Data Analysis

All signals were processed using the software SAD 32 (version 2.59b). A band-pass filter (3 Hz and 200 Hz) was applied to all MMG signals in order to eliminate potential noise. In addition, Fast Fourier Transformation was applied to the signals to detect 60Hz noise. Whenever necessary further filtering was applied to the signal.

Root mean square (RMS) values were calculated from selected segments of the MMG signals. For the MVICs and for the electrically
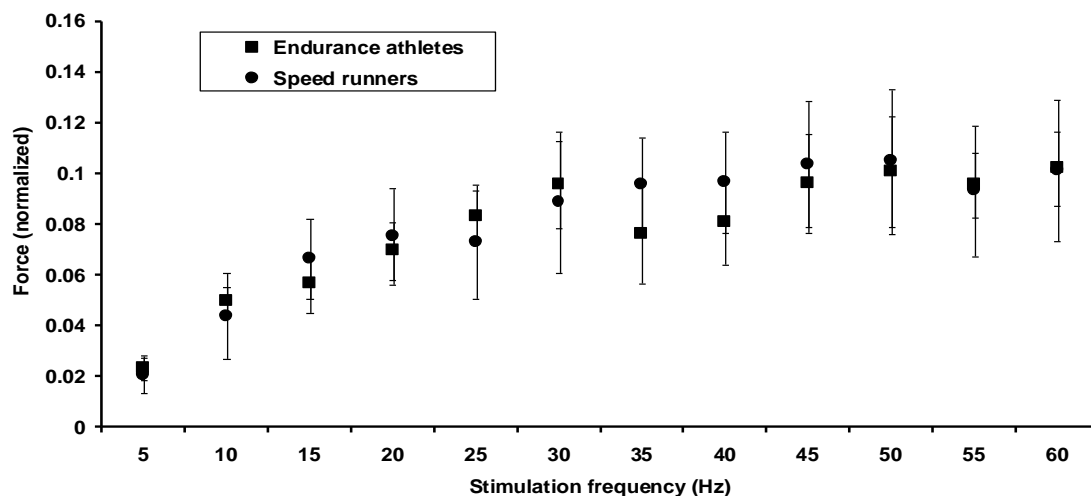
subject could stand with little discomfort or pain. After the voltage was determined, it remained constant throughout the entire protocol of electrically elicited contractions. The protocol consisted of two-second contractions at a constant submaximal voltage set prior to the experiment and with stimulation frequencies ranging from 0 to 60 Hz (increments of 5 Hz). The order of stimulation frequencies was randomly chosen for each subject.

The voluntary effort protocol began at least five minutes after the electrically elicited protocol was over. Three maximal voluntary isometric contractions (MVICs), lasting two seconds each, were performed and the contraction with the highest force value was used to calculate the different levels of voluntary effort (from 0 to 100% MVIC, with increments of 10%). Then the subjects performed voluntary contractions (0-100% of MVIC), each with 7 seconds duration. Visual feedback was given to the subjects with an oscilloscope, in order that they could reach and maintain the desired level of voluntary effort. The order of the submaximal voluntary contractions was randomized.

The electrically elicited protocol always preceded the voluntary effort protocol. Two-minute intervals were observed between consecutive contractions in both protocols

elicited contractions, one-second segments were extracted from the force plateau; for the submaximal voluntary contractions, five-seconds segments were extracted from the middle of the plateau of the force signals. This was done to avoid MMG signal transients which are related to the beginning and end of the contractions when the muscle undergoes large mechanical changes until a force plateau is reached (17).

RMS values were also calculated from the force signals obtained at the same times as the MMG RMS values. The force values obtained during the electrically elicited contractions were normalized with respect to the torque values obtained during the MVIC for each subject.

Statistics Analysis

A two-way Analysis of Variance was used to compare RMS values of the MMG and force signals obtained from the two groups of athletes during the different frequencies of stimulation and during the different levels of voluntary effort. When interaction was observed, a one-way Analysis of Variance was used to determine statistical differences within each group for the different stimulation frequencies and for the different levels of voluntary effort. The Bonferroni post-hoc test was used to determine the

differences. A level of significance $\alpha=0.05$ was adopted for all tests.

RESULTS
Electrically Elicited Contractions
The electrically elicited absolute (results not shown) and normalized force values showed a slight increase from 0 to 30 Hz of stimulation frequency, and remained approximately constant from 30 Hz to 60 Hz for both groups of athletes. No differences in the normalized force values were observed between groups during the electrically elicited protocol (Figure 1).
The MMG signals decreased with increasing stimulation frequencies in both groups (Figure 2). However, the RMS values of the speed
**Figure 1**: Normalized force values by MVC (mean ± SE) of speed runners and endurance athetes,

runners were higher (between the frequencies of 5 and 15 Hz) compared to those of the endurance athletes.
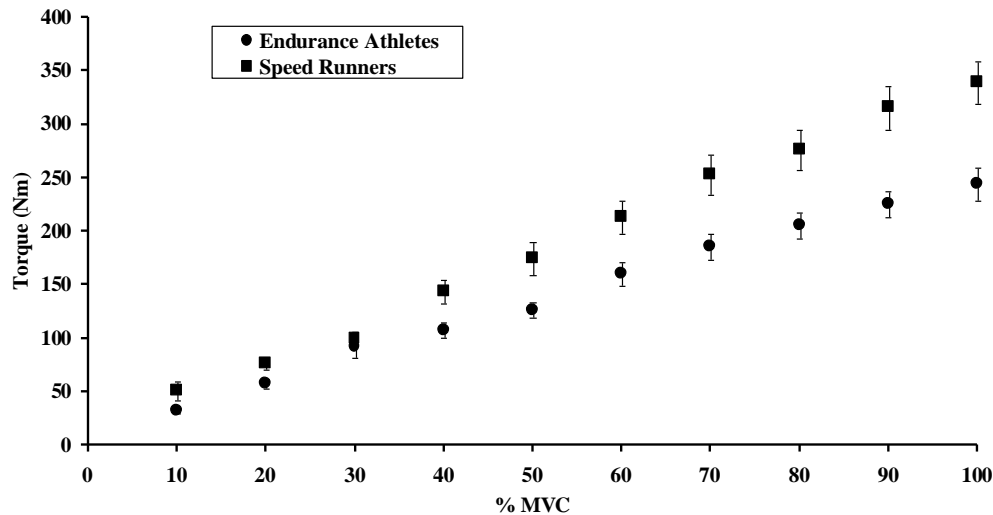*Voluntary Contractions*
The absolute torque values increased linearly with increasing voluntary effort in both groups. This linear increase was higher for the speed runners when compared to that of the endurance athletes (Figure 3).

The RMS values of the MMG signals remained about constant from 10% MVC to 40% MVC in both groups of athletes, and increased with increasing voluntary effort from 50% MVC to 100% MVC (Figure 4).
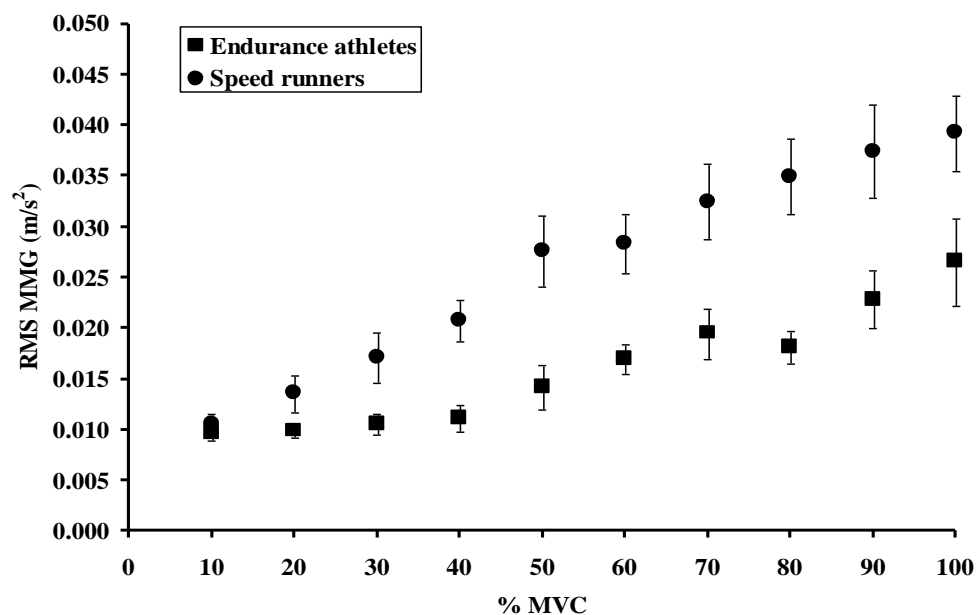
during elicited evocked contractions protocol (5 to 60 Hz).
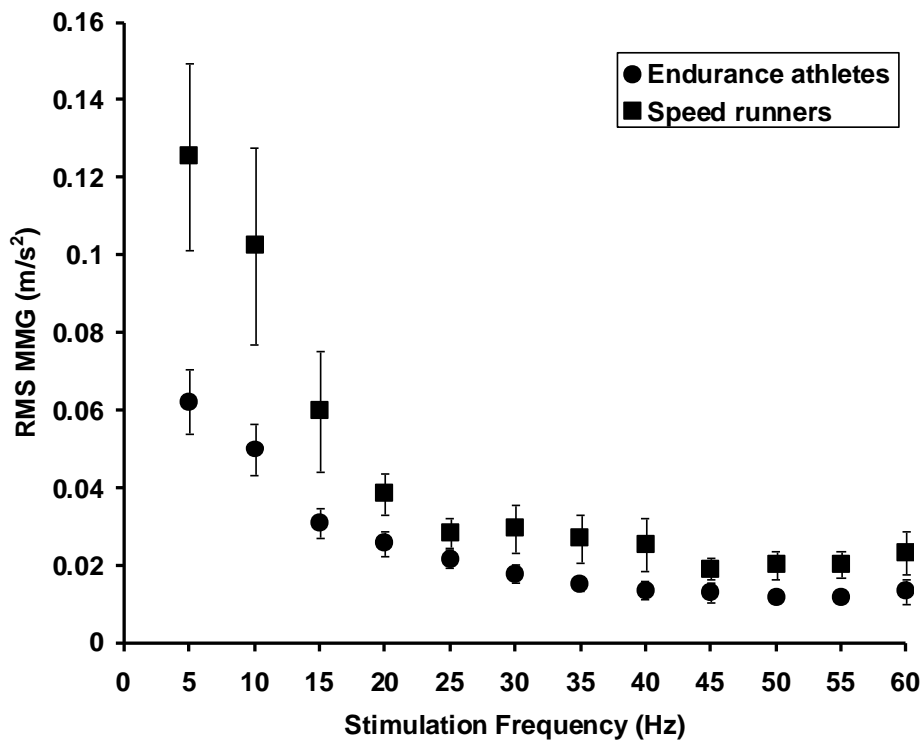
Figure 2: MMG RMS values (mean ± SE) of speed runners and endurance athletes, during elicited evocked contractions protocol (5 to 60 Hz).

Figure 3: Torque values (mean ± SE) of speed runners and endurance athetes, during voluntary contractions protocol (10% to 100% MVC).

Figure 4: MMG RMS values (mean ± SE) of speed runners and endurance athetes, during voluntary contractions protocol (10% to 100% MVC).

DISCUSSION

In this study we investigated the MMG and force signals in speed runners and endurance athletes. Four hypotheses or ideas were proposed based on the evidences found in the literature, and tested in this study. Each of these hypotheses will be discussed based on the results found.

The first hypothesis was based on the fact that speed runners have a higher percentage of fast-twitch fibers when compared to endurance athletes (18, 27). As these fast-twitch fibers are known to produce higher force levels when compared to slow-twitch fibers, it was expected that the absolute force produced by the speed runners should be higher both in the electrically elicited and voluntary protocols.

The results of Figure 1 do not support this hypothesis, as there was no difference in the normalized force values of the electrically elicited contractions between the two groups. This similarity in the electrically elicited force might have occurred due to the voltage used in

the artificial electrical stimulation, which was determined purely by the comfort level of each subject. This elicited force was very low (around 10% MVIC for both groups), and did not allow for determining differences in knee extensor force production between the two groups with artificial electrical stimulation. However, this first hypothesis was partially supported by the results of Figure 3, in which the maximal absolute torque produced by the speed runners was higher than that of endurance athletes.

As the amplitude of the MMG signal is reduced with increasing frequencies of stimulation during electrically elicited contractions (4, 22, 31, 35, 42, 46, 47), it was expected that a reduction in the RMS values of the MMG signal should occur in both groups; however, a different behavior was expected between groups, with the RMS values of the endurance athletes decreasing at an earlier stage when compared to those of speed runners.

It was assumed that the presumed higher percentage of slow-twitch fibers in the vastus lateralis muscle of the endurance athletes (18, 27) should produce fused tetanic contractions with lower stimulation frequencies when compared to the presumed fast-twitch fibered vastus lateralis of the speed runners, which would need higher frequencies of stimulation to achieve fused tetanus (hypothesis 2).

The results of Figure 2 do not fully support this idea. Although the MMG signal behavior was different between the two groups, a steeper decrease was observed in the RMS values of the speed runners than that of endurance athletes, exactly the opposite of what we expected. It is not clear the reason for this behavior, but it might be related to the fact that the vibrations of the speed runners showed higher amplitude than those of endurance athletes for low frequencies of stimulation. Therefore, increases in stimulation frequencies produced a relative higher change in amplitude in the speed runners than in endurance athletes.

As the mechanical behavior of the vastus lateralis muscle was not influenced in any way by the central nervous system during the electrically elicited contractions, it should be emphasized that the different behavior in the RMS values of the MMG signal might be attributed solely to the intrinsic properties of this muscle in the two groups of athletes. Assuming that these differences reveal the predominant mechanical behavior of the MUs of a muscle as suggested by the literature, then MMG might be a good tool to study muscle function, as it might be possible to use this non-invasive technique to indirectly determine the predominance of one type of MU and/or muscle fiber.

Assuming that there is a relation between MU recruitment and the MMG signal obtained at different levels of voluntary effort (29, 49), and that MUs are recruited up to 90%-100% MVIC in large muscles of the limbs (4), it was expected that the RMS of the MMG signal should increase linearly with increasing voluntary effort. However, this increase should be higher in the speed runners than in endurance athletes due to their higher percentage of fast MUs, which should produce larger force fluctuations with increasing voluntary effort (hypothesis 3).

The approximately linear behavior of the RMS values of both groups of athletes with increasing voluntary effort (Figure 4) do not support this idea as there was no linear increase in the MMG RMS values with increasing voluntary effort. The low-level voluntary contractions (10%MVC to 40%MVC) apparently did not produce vibrations of high magnitude to differentiate between contraction levels. An approximately linear increase occurs only at high levels of voluntary effort, as the MMG RMS values of both groups of athletes increased with increasing voluntary effort from 50% MVC to 100% MVC. The fact that there was no interaction between the MMG RMS values of both groups goes against our hypothesis that the MMG signals would be able to differentiate the mechanical behavior of different types of athletes.

A linear behavior of the MMG RMS values with increasing voluntary effort has been shown in several studies reported in the literature (e.g. 5, 17, 23, 37, 38). The results of the present study, however, showed a quasi-linear behavior only at high levels of voluntary effort (50% to 100% MVC). Therefore, these results go against these previous studies, but are probably similar to other studies that did not find a linear behavior between these two variables (26, 29, 36, 44). The reason for these differences in the results of the studies might be related to the muscles used in each study (as they might have different MU recruitment strategies), as well as to different types of equipment used to measure muscle sounds (microphones) and vibrations (accelerometers). Another possibility is that the inter-subjects variability is too high and does not allow for a clear difference between athletes with different skeletal muscle mechanical properties during voluntary contractions.

In conclusion, we have shown that the MMG signal might be an important tool in accessing the mechanical behavior of muscles of athletes with assumed different percentages of fiber types and/or different types of MUs. Further studies should try to establish direct measurements of fiber type distribution of muscles through biopsies and determine a possible relationship between the RMS values of the MMG signal of these muscles in order to establish if the MMG signal could be used as a possible tool to evaluate fiber type distribution non-invasively.

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C. De La R. Freitas, M. A. Brentano, M. A. Vaz

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