



Interpretation of the mechanisms related to the muscular strength gradation through accelerometry

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ABSTRACT

The aim of this study was to characterize the temporal and spectral components of the muscle contractions in different contraction levels through the accelerometry. Fifteen male and twelve female right-handed individuals participated in this study. The trial was constituted by a maximal workload (MW) test that allowed to determine five different workloads (20%, 40%, 60%, 80% and 100% of MW) which, by its turn, allowed to determine five percentage workloads during the strength test (20%, 40%, 60%, 80%, and 100% of the MW) in isometry during eight seconds each of them. A biaxial accelerometer was put on the muscular abdomen of the right brachii biceps muscle. The mean square root (RMS value), a temporal parameter, and the mean frequency (MFE), a spectral parameter were extracted from the accelerometry signals (MMG signals). Such parameters were analyzed towards the X (perpendicular to the fibers) and Y (parallel to the fibers) directions. Both groups presented a descent behavior pattern of the loaded MFE (Y), and the most accentuated was the female group. The MFE variable (X) in the female group presented similar behavior before the MFE (Y), and it was observed a statistically significant difference only between 20% of the MW and every other workload ($p = 0.0022$ for 40% and $p < 0.0001$ for the remaining). The male group did not present any statistically significant difference between workloads. The RMS value (Y) presented an ascent behavior with the workload in both genders, presenting differences between the 20% and 40% workloads of the MW ($p = 0.000$), and 80% and 100% of the MW ($p = 0.01$) in the male group. But it was observed no statistically significant difference between workloads in the female group. It is argued that during the muscular contraction, there is non-uniform variations on the fiber's diameter, besides the low frequency lateral oscillations. Such information seems to have strong correlation between the type of the fibers, and this could contribute for a better clarification on the possible mechanisms involved in the gradation process of the muscular strength.

INTRODUCTION

Mechanisms involving muscular contractions still constitute an important subject for studies in the Physiology and Biomechanical areas. Different authors have been dedicated themselves to understand how the strength gradation occurs under different conditions, mainly in situations such as the muscular stress⁽¹⁾, aging⁽²⁾ and under the influence of training programs⁽³⁾. In such context, two processes are normally considered: the recruitment of motor units (MU), and the frequency variation of the potentials of action of the motor units recruited (PAUMs).

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Aiming to understand how these processes are modulated during the muscular contraction, some authors have been using the electromyography (EMG) as a tool to interpret the studied muscle through the myoelectrical activity (EMG signal) generated by it. So, upon submitting an individual to different contraction levels and types, it is possible to extract different parameters in the time and frequency domains through the EMG signal, in order to interpret the gradation mechanisms of the muscular strength⁽⁴⁾.

On the other hand, there are works suggesting that the knowledge on the mechanical features involved in the contractile process must be also considered, as to allow a better understanding on the strength gradation processes in the myoelectrical point of view⁽⁵⁾.

In such a sense, another technique to analyze the muscular contraction that becomes more popular every day is the mechanomyography (MMG), which is basically characterized by the use of microphones placed on the surface of the muscle to catch those noises that reflect the muscular contraction caused by the PAUMs into the muscular fibers^(6,7). Such contractions that may be concentrated mainly in a frequency band defined between 5 and 50 Hz, would represent small vibrations and/or pressure waves produced by dimensional changing of the active fibers mainly on their transversal axes⁽⁸⁾. According to Neering *et al.*⁽⁸⁾, such process occur due to the redistribution of aqueous material presents in the sarcoplasm, and they still point out that despite these variations are present in a non-uniform way, they could contribute even to identify some structural features of the muscular fibers. So, with the increase in the triggering rate of the PAUMs that is one of the strategies to increase the muscular strength, there will be a reduction in the intervals between contractions, which will be summed up, and they will lead to a state known as the tetany⁽⁹⁾ whenever it occurs a maximal contraction.

Besides of using microphones to study muscular contractions, another type of sensor is suggested as an alternative form to study: it is the accelerometer. It is supposed that since the muscular contractions produce vibrations, and such vibrations occur both towards parallel and perpendicular directions in relation to the muscular fibers, such sensors would be able to detect these movements⁽¹⁰⁾.

Therefore, this technique has been also identified as vibromyography (VMG) and/or Acceleromyography (AMG). However, there are little studies discussing the actual meaning of the vibrations generated in both directions and in function of the muscular strength.

Among those works present in the literature, the majority develops discussions from the vibrations laterally generated by the muscular fibers, implying that only this direction has a physiological meaning. Despite Ouamer *et al.*⁽¹¹⁾ indicate that the mechanical signals that come from muscular vibrations are promising to be used in clinic applications, they also point out the lack of further

information on the real mechanisms involved in such phenomenon, mainly related to those longitudinally generated vibrations related to the fibers. Those authors, using microphones distributed on the muscular abdomen of the brachii biceps suggest that the recruitment pattern of the MU, and the frequency of the PAUMs could be a better foundation when it is considered both the directions of the muscular vibration (perpendicular and longitudinal to the fibers), and even contradicting a great number of authors as to the actual meaning of the lateral oscillations⁽¹¹⁾.

Thus, as it was found no works in the literature discussing the muscular contraction in both directions (perpendicular and longitudinally to the fibers) through the use of the accelerometry, this study had as purpose to fulfill such lack of knowledge on the proposed technique, thus characterizing the temporal and spectral components of the MMG signals in both directions, related to the muscular strength generated by the brachii biceps muscle, but also upon different contraction levels, and thus, comparing it in both genders.

MATERIALS AND METHODS

The sampling was composed by two groups of both genders, being 15 male (with ages 24.0 ± 5.25 years), and 12 female (ages 21.7 ± 1.5 years), right-handed students of a graduation course in Physical Education at EEFD/UFRJ, regular practitioner of regular physical activities, and with no history of lesions in the musculoskeletal system in the upper limbs. Every volunteer received orientation on the procedures adopted, and signed a consent term to participate in the study, which was duly submitted to the HUCFF/UFRJ's Ethics Committee, and received the number 125/03.

The acquisition system was composed by a Personal Computer (Pentium – 200 MHz), a 12 bits analogical-digital converter (Daq-Pad 1200 – National Instruments, USA), with dynamic band of ± 5 V. To capture the MMG signals, it was used a biaxial accelerometry system (ADXL202E model, Analog Devices, USA), with transmission band of 200 Hz and sensitivity of 315 mV/g (g = gravity acceleration), with total mass of 1.5 g (figure 1). Such system was developed at the Biomechanical Lab of the EEFD/UFRJ, and it allowed to measure accelerations up to 2 g. The sampling frequency was of 2 kHz. The acquisition programs and signal processing, as well as the one developed to perform the tests were elaborated on a LabVIEW 5.0 (National Instruments, USA).

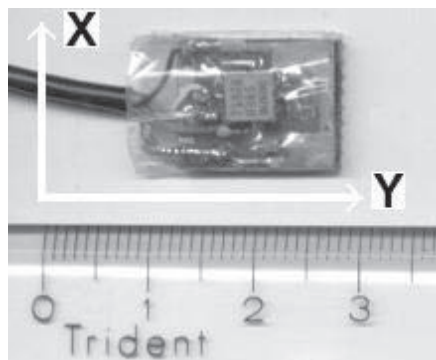


Fig. 1 – Accelerometer and axes defined as to the directions of the measured accelerations (X – lateral vibrations of the muscular fibers; Y – longitudinal vibrations of the muscular fibers). A ruler is placed aside the accelerometer to allow a better visualization of its dimensions.

To perform the tests, it was developed a mechanical device to support the right upper limb, and it was used a dynamometry system with capacity to perform individual adjustment of the height and distance related to the right shoulder articulation, when keeping it in 70° abduction (figure 2). A dynamometer (Kratos Dinamometros Ltda.) fixed to the ground was used to the acquisition of the strength signals.

While the tests were accomplished, each volunteer remained seat having his (her) knees and hip articulations flexed at approximately 90° and having the right upper limb abducted, according to what is shown in the figure 2.

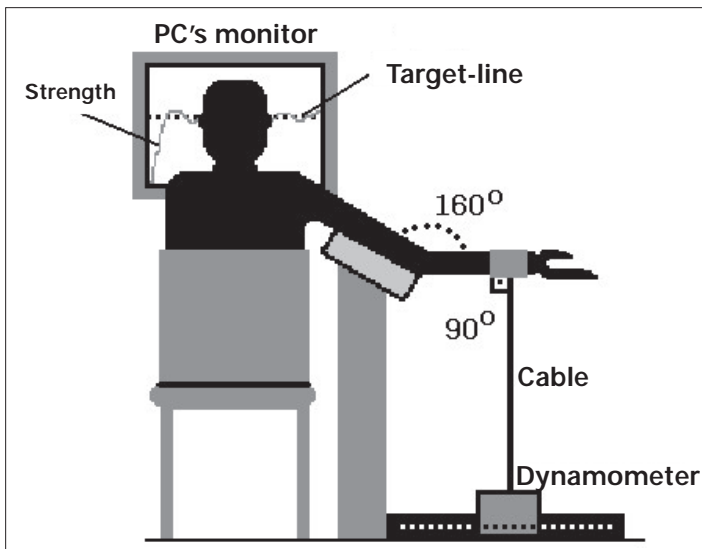


Fig. 2 – Scheme of the mechanical device and positioning of the volunteer related to the strength acquisition system and the PC's monitor

The trial protocol was composed by a maximal workload test (MW) for 6 s. From such data, it was calculated the percentage workloads ministered in the strength tests: 20%, 40%, 60%, 80%, and 100% of the MW. All tests were performed in a sole day, and each isometric contraction was kept for eight seconds, with a two minutes minimum interval between each test. In order to reach the target-workload, each volunteer received visual feedback supported by a Personal Computer's monitor (figure 2) for each of the random workload which was chosen in random order through a ballot before each acquisition.

Besides, the researcher stimulated verbally every volunteer.

Since there is no clear protocol in the literature to place the accelerometer, it was placed on the ventral portion of the right brachii biceps muscle using a double-face tape, following the protocol suggested by Hermens *et al.*⁽¹²⁾ to place surface electrodes when acquiring EMG signals. This protocol is based on the distance measured from the acromion and the cubital fossa close to the articular line of the elbow.

When such measurement was taken having the individual seat to acquire the MMG signals at 1/3 of the cubital fossa, the accelerometer was put in place (figure 3).

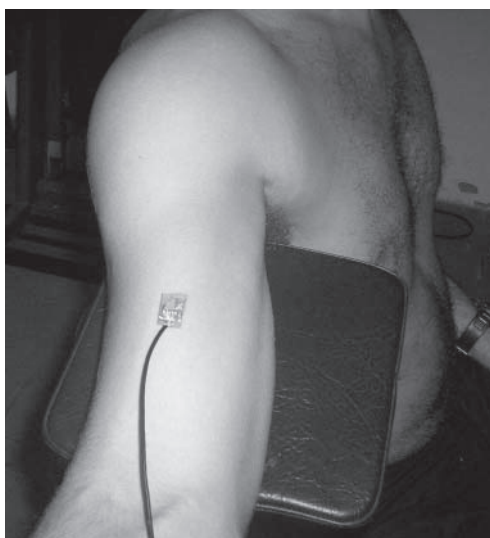


Fig. 3 – Position of the accelerometer on the muscular abdomen of the right brachii biceps following the protocol to put the EMG's surface electrodes

The acquisition of the strength and the MMG signals were defined from the reach of the target-workload for 8 seconds. Nevertheless, in order to analyze the data, it was studied only the 6 intermediary seconds of each signal acquired, and thus excluding the first and the last ones. Such procedure was adopted in order to attain the minimal steady MMG signals from the behavior of the strength signal (figure 4).

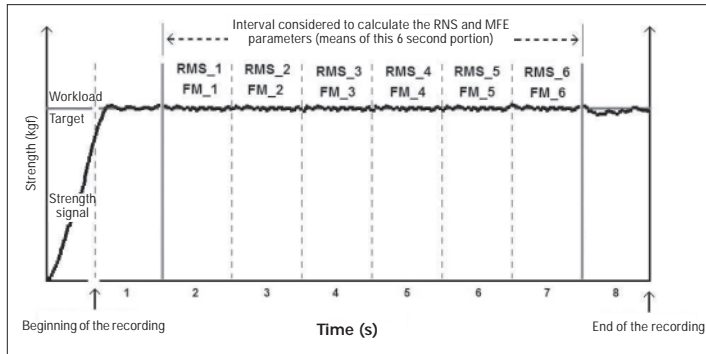


Fig. 4 – Example of the procedure adopted to record the MMG signals from the strength signals that acted as reference to calculate the different analysis parameters in the time and frequency domains

From the MMG signals, it was calculated the following parameters towards the X (perpendicular to the muscular fibers) and Y (parallel to the muscular fibers) signals: mean frequency (MFE), a parameter to discriminate the behavior of the components of the signal's frequency from the potency spectrum and the mean square root (RMS value), a temporal parameter that reflects the variation of the amplitude. On the other hand, each of these parameters was extracted from the 1 second-window from the intermediary portions selected. Next, it was calculated the arithmetical average of the parameters for 6 seconds of the collected signals, as it was suggested in the figure 4.

The MFE was obtained through the signal potency's spectrum ($S_m(f)$) calculated through the Fourier's Fast Transformed (FFT). Such method allows to determine every component of the frequency that composes the signal that can be mathematically expressed as follows:

$$MMG_{FME} = \frac{\int_0^f f S_m(f) df}{\int_0^f S_m(f) df} \quad (1)$$

where, $S_m(f)$ is the spectral density function of the MMG signal related to 1 second.

By its turn, the RMS value determining the variation of the amplitude was attained through the following equation:

$$MMG_{RMS} = \sqrt{\frac{1}{T} \int_0^T x^2(t) dt} \quad (2)$$

where, $X(t)$ is the portion of the signal on the T endurance segment, also equals to 1 second.

In order to compare the parameters between the five studied workloads, it was used the ANOVA two-way ($\alpha = 0.05$), and the Tukey's post-hoc HSD analysis. The data analysis was performed on the *Statistica* software® 6.0 (StarSoft, USA).

RESULTS

The amplitude of the signal between groups that was analyzed through the RMS value on X (perpendicular axle to the fibers' di-

rection) did not present any statistical difference related to the gender factor ($F_{(1,25)} = 4.08$; $p = 0.054$). However, there was differences between "workloads" ($F_{(4,100)} = 47.03$; $p = 0.0000$). Furthermore, there was no interaction between both factors ($F_{(4,100)} = 0.62$; $p = 0.64$). The RMS value on X presented higher mean results with progressive increase of the workload compared to those calculated on Y. However, such difference was not statistically tested. Another difference observed in the comparison between the RMS values attained in both directions, which was not statistically tested as well, was the higher variability of data between individuals of the X sampling. The Tukey's post-hoc analysis has shown statistically significant difference only between 20 and 40% of the MW ($p = 0.003$) to the male group (figure 5).

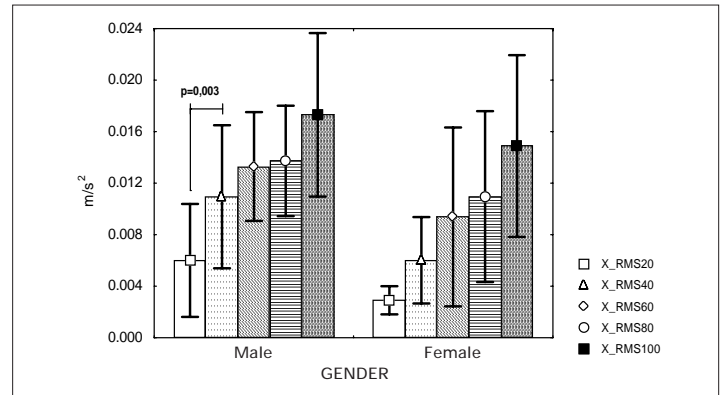


Fig. 5 – Mean behavior (\pm standard deviation) of the accelerations attained (RMS value) in the X direction (perpendicular to the muscular fibers) for every workload and both genders

As to the RMS value's behavior on Y (parallel axle towards the direction of the fibers), it presented statistically significant differences to the following factors: "gender" ($F_{(1,25)} = 8.39$; $p = 0.0077$), and "workloads" ($F_{(4,100)} = 45.89$; $p = 0.0000$). Even so, there was no interaction between both factors ($F_{(4,100)} = 2.00$; $p = 0.09$). The Tukey's post-hoc analysis has identified that the RMS value (Y) presented an ascent behavior, and presenting the highest differences between the 20% and 40% MW ($p = 0.0004$), and 80% and 100% of the MW ($p = 0.01$) for the male group. The female group presented similar behavior to that observed in the male group, but it was detected no statistically significant difference between workloads ($p > 0.05$). Upon the comparison of both groups, the male group presented mean results higher to those found in the female group only between workloads of 40% ($p = 0.001$), 60% ($p = 0.002$), and 100% ($p = 0.01$) of the MW (figure 6).

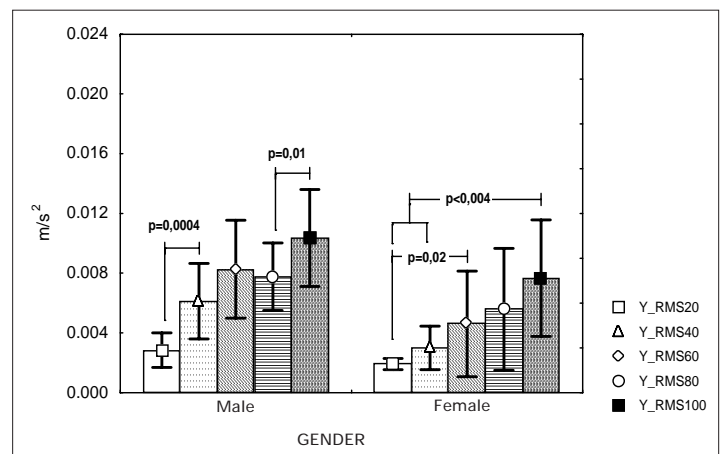


Fig. 6 – Mean behavior (\pm standard deviation) of the accelerations attained (RMS value) in the Y direction (longitudinal to the muscular fibers) for every workload and both genders

The FME on X (perpendicular axle to the direction of the fibers) between both genders did not present statistically significant difference ($F_{(1,25)} = 2.72$; $p = 0.1115$) but it was found differences between "workloads" ($F_{(4,100)} = 19.14$; $p = 0.00000$) and interaction between factors ($F_{(4,100)} = 12.02$; $p = 0.00000$). The variable MFE (X) in the female group presented similar behavior to the MFE (Y), and it was observed a statistical significant difference only between the 20% MW and every other workloads ($p = 0.0022$ to 40%, and $p < 0.0001$ to the others). As to the male group, it was observed no statistically significant difference between workloads (figure 7).

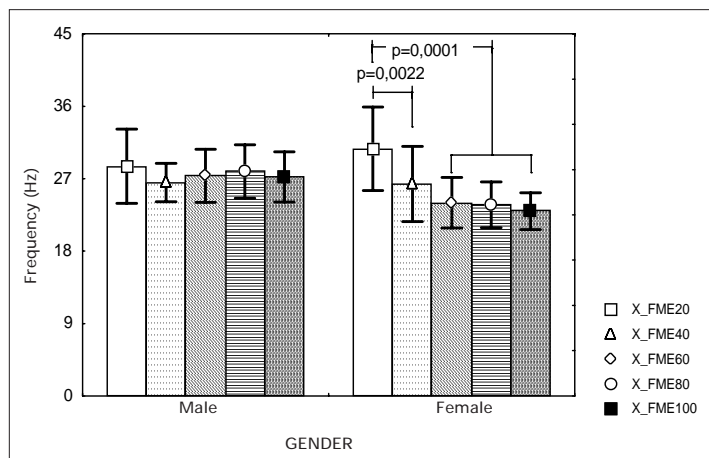


Fig. 7 – Mean behavior (\pm standard deviation) of the frequencies attained (MFE value) in the X direction (perpendicular to the muscular fibers) for every workload and both genders

The MFE on Y (parallel axle towards the direction of the fibers) presented similar behavior to that presented by MFE on X, that is, absence of statistical difference between the "gender" factor ($F_{(1,25)} = 0.35$; $p = 0.85$), and differences between "workloads" ($F_{(4,100)} = 61.25$; $p = 0.0000$), besides of interaction between both factors ($F_{(4,100)} = 8.87$; $p = 0.00000$). The male group presented a higher MFE (Y) at 20% of the MW to those presented in other levels. Between other contraction levels (40%, 60%, 80%, and 100% of the MW) it was observed no statistically significant difference ($p > 0.05$). On the other hand, the female group presented a more accentuated fall bias of the MFE (Y) upon the ascent workload (figure 8).

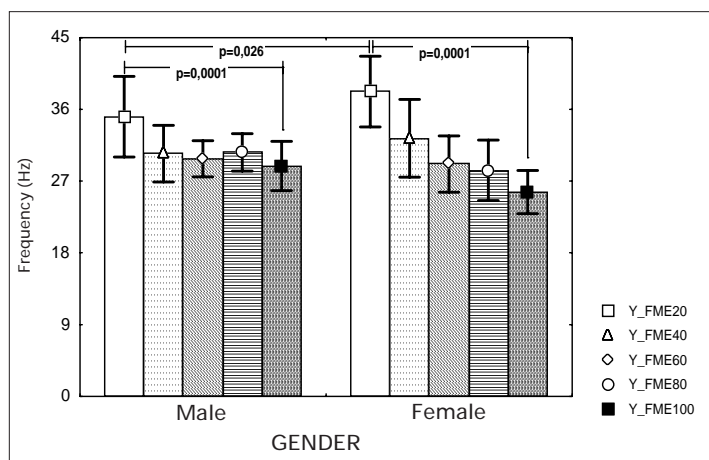


Fig. 8 – Mean behavior (\pm standard deviation) of the frequencies attained (MFE value) in the Y direction (longitudinal to the muscular fibers) for every workload and both genders

DISCUSSION

According to Neering *et al.*⁽⁶⁾, a portion of the aqueous material present into the sarcoplasm is redistributed to other parts of the muscular fiber during the muscular contraction, and this would lead to a change in the volume of the different portions along its structure, thus generating laterally distributed pressure waves. These authors point out that the variations are presented in a non-uniform way, but they could contribute even to the identification of some structural features of the muscular fibers, as it was already pointed out. As major part of the studies on the MMG is based on the use of especially adapted microphones to capture the signal generated by the changing in the volume of fibers, the behavior on the frequency domain is defined as an increase in the MFE to the increase of the muscular contraction level⁽¹³⁾. Through the accelerometry, the method used in this work, it was possible to observe a descent behavior in both directions (X and Y) of the MFE, with an increase in the percentage level of the MW, mainly in the female group. These results corroborate the theory of the mechanical fusion process of the motor units, which is consequence of the ascent in the PAUM's triggering rate whenever there is an increase in the contraction level⁽¹⁴⁾. The justification for these possible differences is in the fact that the skin and the layer of the adipose tissue can act as a low-pass filter that attenuates those components with higher signal frequency when captured through an accelerometer⁽¹⁵⁾. Besides, it is discussed that the components of the frequency of the MMG signal is strongly dependent on the type of the muscular fiber⁽⁷⁾. So, in order to determine the reason for such MFE's behavior mainly on Y, it would be necessary to obtain further information as to the type of the fiber of the individuals analyzed. Even though, it is believed that in low contraction levels, the activity of a reduced number of motor units would let to a "shaking" picture of the muscle, and such signal of small amplitude is observed through the RMS value, but rather with high frequency components.

When the contraction level is raised with more recruited MUs and upon the contraction of the phase, it is possible to cause an increase in the amplitude and a reduction of the frequency components both on X⁽¹⁴⁾.

The RMS value (X) presented an ascent behavior in the workload. Yoshitake *et al.*⁽⁶⁾ discuss that an increase in the RMS value in this direction is defined by an increase in the sum of the potentials in the action of the motor units. Upon the comparison of the results found, it is supposed that the male group with mean values higher than those presented by the female group presents a higher Type II-fiber rate. On the contrary of the female individuals who would present a lower proportion of such fiber, the MMG signal on X would result in presenting such initially expected behavior. As to the amplitude of the MMG signal on Y, it was found no work in the literature presenting an ascent behavior related to the level of the contraction, except through the use of microphones. So, it was not possible to set a relationship between the mechanisms discussed by Neering *et al.*⁽⁶⁾ and the RMS value on Y. Even though, it is supposed that the elastic components in series of the muscle commonly represented by tendons in mechanical models have some kind of interference on such behavior.

CONCLUSION

As to the technique presented, it is undoubted that there is several gaps that must be fulfilled, not only related to the methodological limitations, but also as to the interpretation of the muscular strength gradation mechanisms. Due to the little knowledge on the MMG signal features, its acquisition was determined through isometric contractions, i.e., with no significant variances of the muscular length, whose variable is determinant to the promotion of muscular strength, and this variable is determinant to the production of "noise" into the signal.

Besides, as it is being discussed the use of a biaxial accelerometer, not to use a dynamic way of contraction was chosen for the movement devices would not be introduced into the signal, as this work had as purpose to characterize some of its basic properties. Thus, upon the application of a sole biaxial accelerometer on the muscular abdomen and setting the acquisitions in non-dynamic conditions, it can be attained more safety in the results found in this study.

Despite the little knowledge on this technique, the application of the accelerometry has proved to be easy to be used and at a low cost. However, despite the potential contribution involved in the muscular strength gradation process in different conditions, including in an associated way to the EMG, and as it is not yet a

commercially available technique, this makes difficult to reproduce its results to attain a better evaluation on the consistency of each of the time and frequency parameters extracted from the MMG signal.

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