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Relationships Between Surface Electromyography and Strength During Isometric Ramp Contractions

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1. Introduction

From the many joints exposed to muscle-skeletal injuries, the knee joint is the one that more suffers consuming in the daily life, for both athletes and non-athletes [1], once for the maintenance of the corporal stability, it is necessary for the muscles of this joint to be the strongest as possible [2]. Such strengthening may be obtained through an isometric force training [3], which range from numbers of repetitions up to weekly frequencies [4,5].

The hamstrings muscle group is objeto de estudo devido seu papel como músculo bi-articular, bem como a sua função na insuficiência mecânica [6]. This group is composed of the *semitendinosus* (ST), *semimembranosus* (SM) and *biceps femoris caput longum* (BFCL) all of which are active during knee flexion. The activity of these muscles is often examined using surface electromyography (sEMG) [7,8,9].

The efficiency of muscle contraction depends on factors such as the fiber cross-section, the number of muscle fibers, the degree of fiber stretching, the traction angle and the type of contraction required [5,10].

Isometric exercise is one of several forms of exercise used to develop muscle force in humans. Isometric contraction occurs without any appreciable change in muscle length, such that although there is tension in the muscle there is little muscle movement for most of the time, hence the term static contraction [6,11].

A important fact that be associated with a force output is the neuromuscular fatigue. This can under certain conditions be reflected in a decreased performance and/or the failure point at wich the muscle is no longer able to sustain the requeried force or work output level [12,13,14].

Research by [15] Dimitrova & Dimitrov (2002) related that Muscle fatigue is recognized as a decline in force, or failure to maintain the required or expected force. It may occur at any point from the nervous centers and conducting pathways to the contractile mechanism of muscle fibers.

Study by [16] Moritani & Yoshitake (1998) Such changes have been shown to be related to hydrogen ion and metabolite accumulation and to sodium and potassium ion concentration shifts. These changes would in turn affect the muscle excitation traction coupling including the muscle membrane properties and muscle action potential propagation, leading to sEMG manifestations of muscle fatigue distinct from mechanical manifestations.

The increase in amplitude of the sEMG signal as an empirical measure of localized muscle fatigue or as an indicator of muscle fatigue [9,17]. The RMS-sEMG values tended increase with decreasing force as a function of the number of repetitions [6] phenomenon that determines the neuromuscular fatigue process.

The active motor units also discharge with increasing speed to compensate for the fall in the force of contraction of the fatigued fibers [13,18].

The surface electromyography behavior at different force levels is of particular importance. This can be either achieved by performing multiple isometric contractions at various force levels or using ramp contractions.

A ramp contraction is defined as a progressive linear increase in force over time and relationships sEMG-force is linear or quadratic [19], and then, sEMG parameters and physiological events used ramp contraction in investigation, as well, motor unit recruitments, force produce and gender influence [20].

Study by [19] Bilodeau et al (2003), [20] Pérot et al (1996) and [21] Stulen and DeLuca (1981) related the relationship of curve in ramp contraction were this behavior can be confirmed between of recruitment of large, type II muscles fibers, with a higher muscle action potential conduction velocity, is associated with an increase in the median frequency or mean power frequency values of the power spectrum of sEMG [22].

In the decade 80 researches showed that the ramp contraction procedure might be replaced by procedure comprising a number of distinct and constant force contraction. Ramp contractions involve the registration of sEMG while the strength performance gradually increases his or her level of effort up to maximal or submaximal levels. Although the latter procedure seems to be easier to use in some investigation, the ramp procedure has gained a wider acceptance since then. They have been extensively applied to examine muscle activation strategies as well as in new protocols of electromyography analysis. [19,23]

The purpose of the present study was to investigate the relationships of sEMG and time during isometric strength ramp contraction in the hamstrings muscle group. Hamstrings muscle group is composed of the *semitendinosus* (ST), *semimembranosus* (SM) and *biceps femoris caput longum* (BFCL) all of which are active during knee flexion.

2. Material and methods

2.1. Subject

Twenty female healthy adults (age 19.5 ± 0.8 yrs, body mass 63.4 ± 1.5 kg, height: 1.65 ± 0.05 m), without muscle skeletal disorders and similar anthropometric measurement, subject in this study. Subjects were all right leg dominant. All subjects signed a written informed consent. The study was approved by the AESA Ethics Committee protocol 344/10.

2.2. Equipment and electrode placement

Surface electromyography activity was collected by an eight-channel unit (EMG System do Brazil Ltda®) consisting of a band pass filter of 20–500Hz, an amplifier gain of 1000, and a common rejection mode ratio >100dB. All data were acquired and processed using a 16-bit analog to digital converter (EMG System do Brazil Ltda®), with a sampling frequency 1024 Hz. A channel of the acquisition system was enabled for the utilization of the load cell (SF01 - EMG System do Brazil Ltda®) having an output between 0 and 20mV and a range up to 5kN.

The biosignals from the *semitendinosus* (ST), *semimembranosus* (SM) and *biceps femoris caput longum* (BFCL) muscles were recorded with pairs of bipolar silver–silver chloride surface electrodes (10 mm electrode diameter, fixed inter-electrode distance of 20 mm). Following skin abrasion with an alcohol soaked cotton pad, electrodes were placed with the recommendation of Marson [6].

2.3. Ramp contractions

This protocol was had increase of maximal voluntary contraction (MVC) (10, 20 30 e 40%). The knee was flexion to 90° and isometric contractions were done by pulling on a cable fixed to the ankle which was kept at 90° relative to the longitudinal axis of the leg. The cable length was adjusted to the size of the subject's leg.

The load cell traction was performed initial with 10% MVC during 20s, immediately increased to 20% MVC during 20s. This characteristic was used until 40% of MVC.

Initially the participant with the knee flexed 90°, is a traction against the cell load corresponding to 10% maintaining that drift for 20 seconds. Immediately the participant was asked to traction 20% and so on for 30 and 40% MVC (Figure 1).

Continuous samples were collected these traction. These collections take place without the participants to rest between them. The RMS-sEMG values there is a change in load has been discarded (Figure 2).

2.4. Signal processing

The sEMG signals were amplified with gain 1000. The analog channel band pass was set to 20-500 Hz and the sampling rate for analog-to-digital conversion was 1024 Hz.

For analyses time-domain the ramp contractions, sEMG-RMS value, were calculated from a 200 millisecond (ms) window at each the following force levels: 10%, 20%, 30% e 40% of MVC.

For signal processing of each isometric ramp contractions was used routine development by Matlab® and OriginLab©.

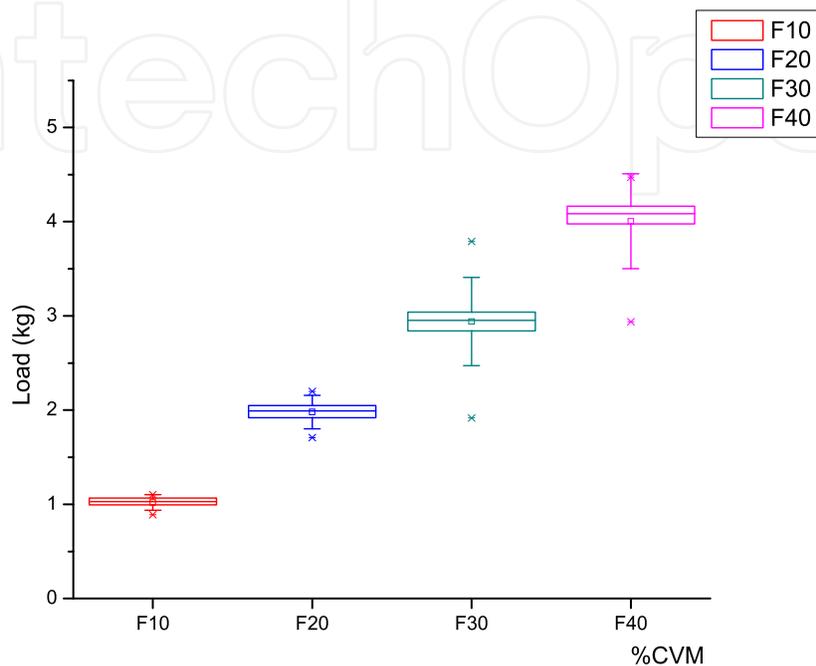


Figure 1. Box chart of mean, standard deviation and percentile (25,75) in 10% (F10), 20% (F20), 30%, (F30) and 40% (F40) of CVM

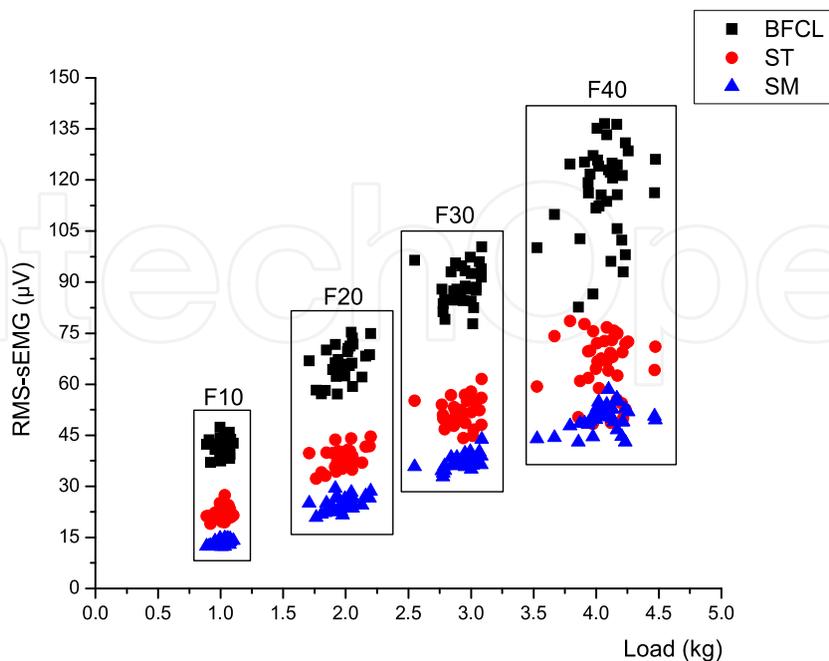


Figure 2. Relation of RMS-sEMG (μV) value versus CVM (kg). The rectangular box is the 10% (F10), 20% (F20), 30%, (F30) and 40% (F40) of CVM.

3. Results and discussion

Isometric exercises have shown a diversity of results regarding the strength gain and with it major changes have occurred regarding its inclusion within methods of strength training. This type of training is applied, mostly in clinics specializing in rehabilitation, physiotherapy and sports training centers aimed at improving muscle and joint injuries [8].

One of the most difficult physical qualities to be worked on is the strength, because a mistake in any application can lead to unpleasant consequences, such as stretching and muscle contractures. So the force is a physical quality that shows a vector quantity, it has magnitude and direction. The vectors are displayed graphically by a line of action, showing the direction and an attachment point of great importance for daily tasks as well as sports performance.

In the isometric there is a consensus response to an increase in sEMG as to alter some characteristic muscle joint as the increase in signal amplitude [13,24,25,26] changes the length and range of motion [27] and temperature [28,29,30].

Classic research shown that there is not always a tendency for this linearity. Research by [31] DeLuca & Lawrence (1983) studied the electromyographic behavior of the biceps brachii, deltoid and 1st dorsal interosseous fatigantes isometric contractions. They concluded that for the interosseous muscle was an almost linear relationship, but further analysis showed a characteristic polynomial 2nd order, the same is true for the biceps and deltoid muscles that showed a remarkable non-linearity of your data.

Studies [32] Clamann & Broecker (1979) who analyzed the triceps brachii, biceps, adductor pollicis and 1st interosseous, and [33] Woods & Bigland-Ritchie (1983) who analyzed the triceps brachii, biceps, adductor pollicis and soleus, showed that the electromyographic signal amplitude as a function of force applied to the interosseous muscle and adductor pollicis was always an almost linear relationship to the muscles and biceps, triceps and soleus this relationship was not linear, unless an exception of biceps brachii this relationship was almost linear [32].

Recent research report the nonlinear characteristic between amplitude of depolarization of motor units related to time and muscle strength [11,34]. This non-linear increase was also observed in this present study (Figure 3) in isometric ramp contraction test during time performance. The data presented in a slow onset, over time it has a rapid and finally back to grow slowly of sEMG amplitude.

According [35] Miyashita et al. (1981) and [11] Marson (2010) acting with incremental the amplitude of the electromyographic signal has an almost linear function of time to begin the individual fatigued. After the onset of muscular fatigue process the signal begins to have an increase predominantly curvilinear.

The electromyographic signal has quite often been used as a mean of assessment of muscle fatigue [17]. The increase in amplitude (Figure 3) of the EMG signal as an empirical measure of localized muscle fatigue or as an indicator of muscle fatigue [15].

Research by [15] Dimitrova & Dimitrov (2002) related that muscle fatigue is recognized as a decline in force, or failure to maintain the required or expected force. It may occur at any point from the nervous centers and conducting pathways to the contractile mechanism of muscle fibers.

Study by [16] Moritani & Yoshitake (1998) such changes have been shown to be related to hydrogen ion and metabolite accumulation and to sodium and potassium ion concentration shifts. These changes would in turn affect the muscle excitation traction coupling including the muscle membrane properties and muscle action potential propagation, leading to sEMG manifestations of muscle fatigue distinct from mechanical manifestations.

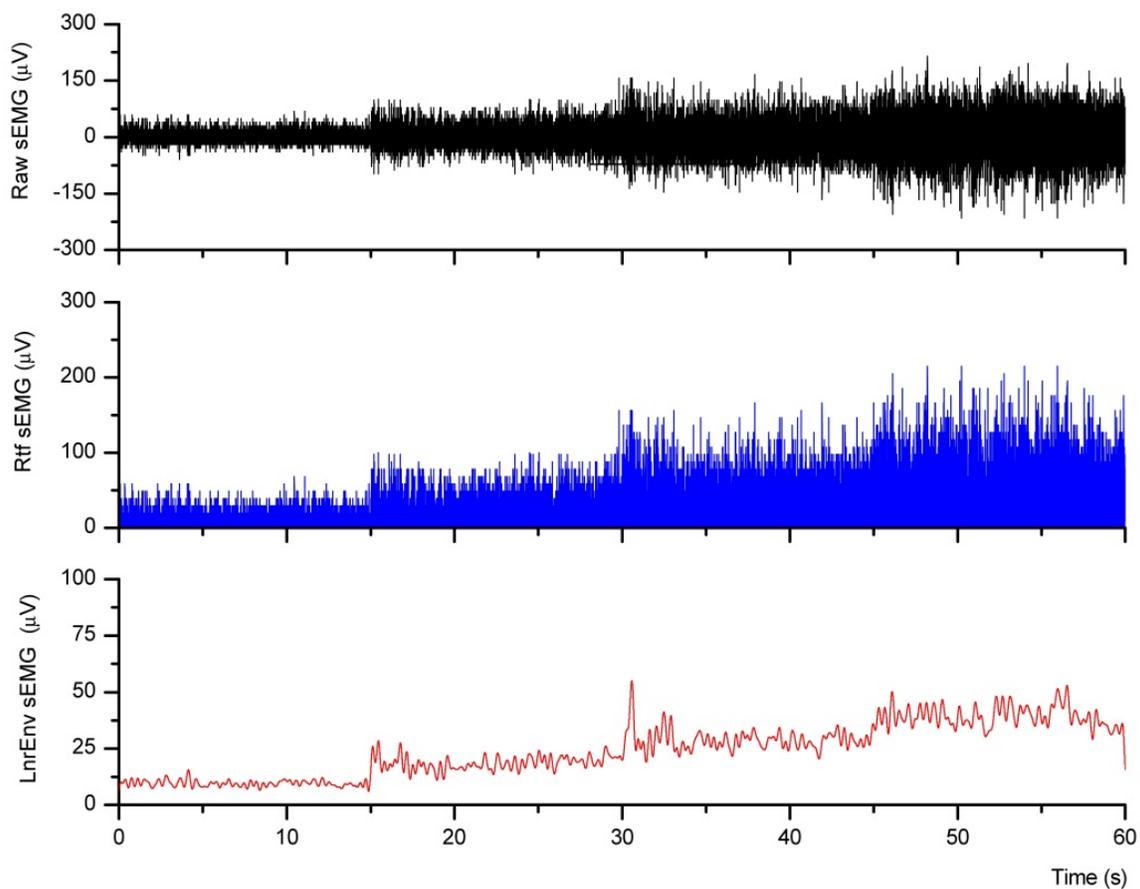


Figure 3. The raw sEMG (Raw sEMG), retificated (Rtf sEMG) and Linear envelope (LnrEnv sEMG) during ramp isometric contraction. Example figure.

The EMG amplitude increased progressively with increasing force in all muscles. The similar behavior was expressed as a percent of the RMS-sEMG value obtained during the brief pre-fatigue MVCs.

The data was fitting non linear by equation (1)

$$f(x) = \frac{A_1 - A_2}{1 + e^{(x_n - x_0)/d_x}} + A_2 \quad (1)$$

The $f(x)$ represents the data set in the RMS x -axis (time), A_1 is the initial value of the RMS collected, the final value of A_2 RMS, x_0 is the point of inflection of the sigmoidal fit curve, i.e., the instant that there is a change from convex to concave curve which is found by the coordinate (x_0, y_0) , where y_0 and found by equation (2). Since the coordinate y_0 is found the value of x_0 on the time axis.

$$y_0 = \frac{A_1 + A_2}{2} \tag{2}$$

The dn parameter is found using equation (3)

$$d_n = \frac{x_n - x_0}{\log(A_1 - A_2) - 1/y_n - A_2} \tag{3}$$

The dn parameter is the value obtained for each of the coordinate values x and y . After obtaining all the values of dn is done an average, and this is adopted with the value of the constant parameter dx .

Several studies report that the increase in the electrical function of time, fatiguing contractions, is characterized by the linearity between these data. Methods to assess muscle fatigue by surface electromyography are elaborated upon this predominance [11,34,36].

This nonlinear increase was also observed in this present study in ramp isometric contractions test. The data presented in the early slow growth over the same time is a rapid increase and eventually grow back slowly. With these data in hand a mathematical model was developed, based on the characteristic sigmoidal or logistic curve (Figure 4-6).

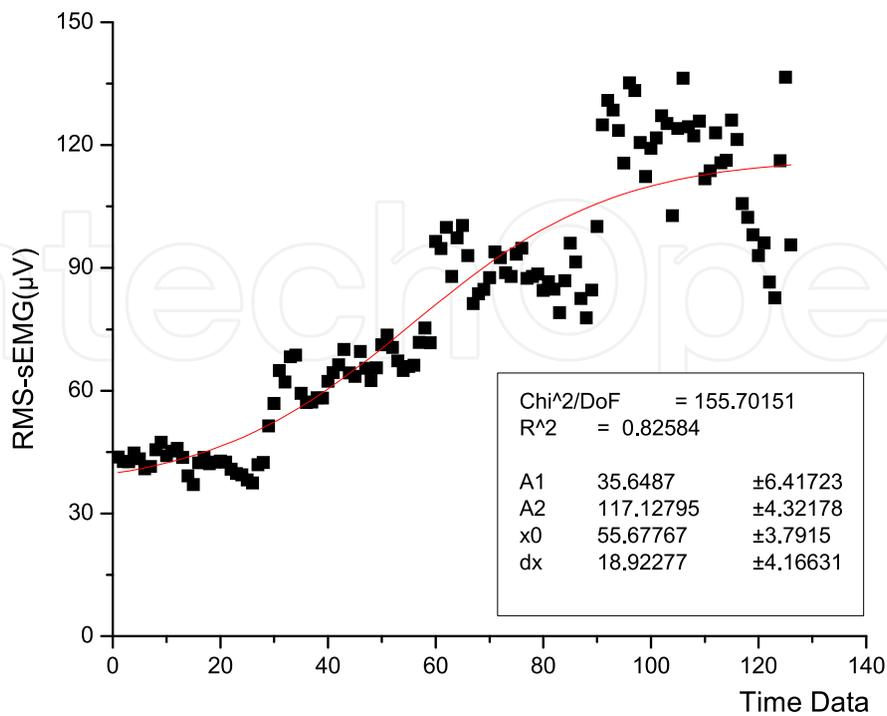


Figure 4. Relationship, adjust and parameter nonlinear of RMS-sEMG value. BFCL example.

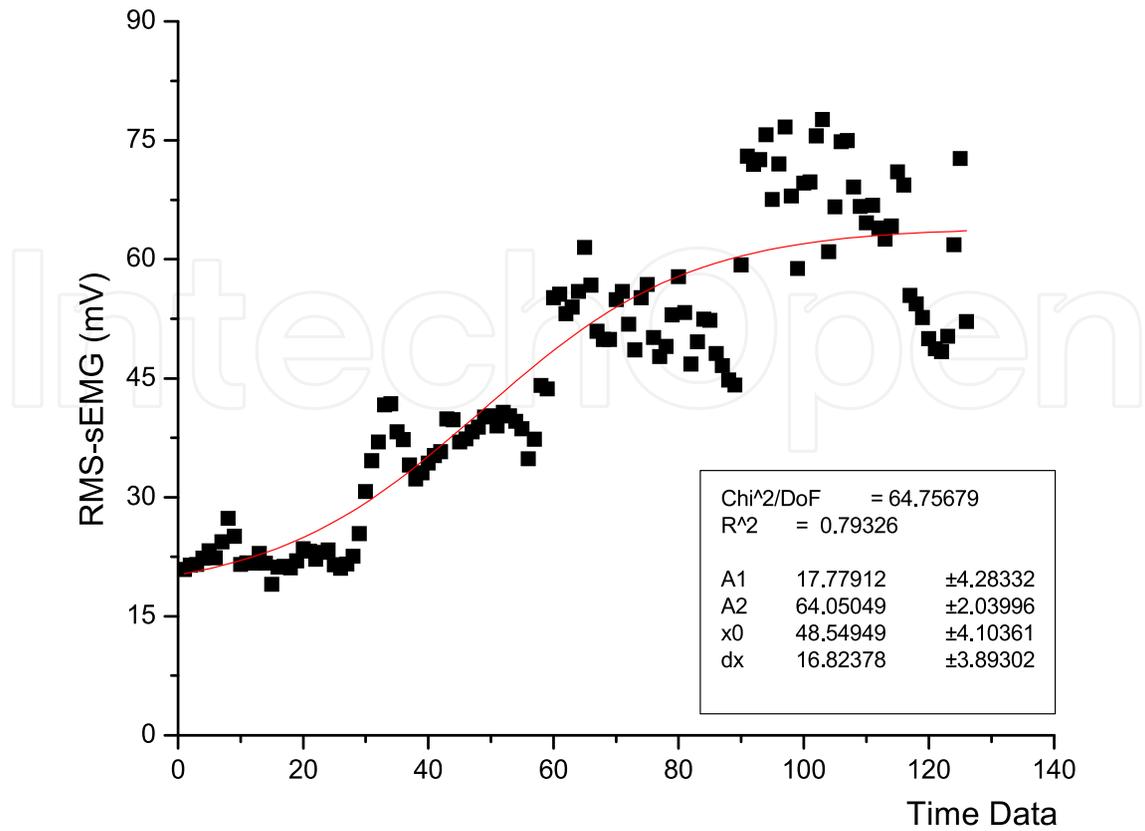


Figure 5. Relationship, adjust and parameter nonlinear of RMS-sEMG value. ST example.

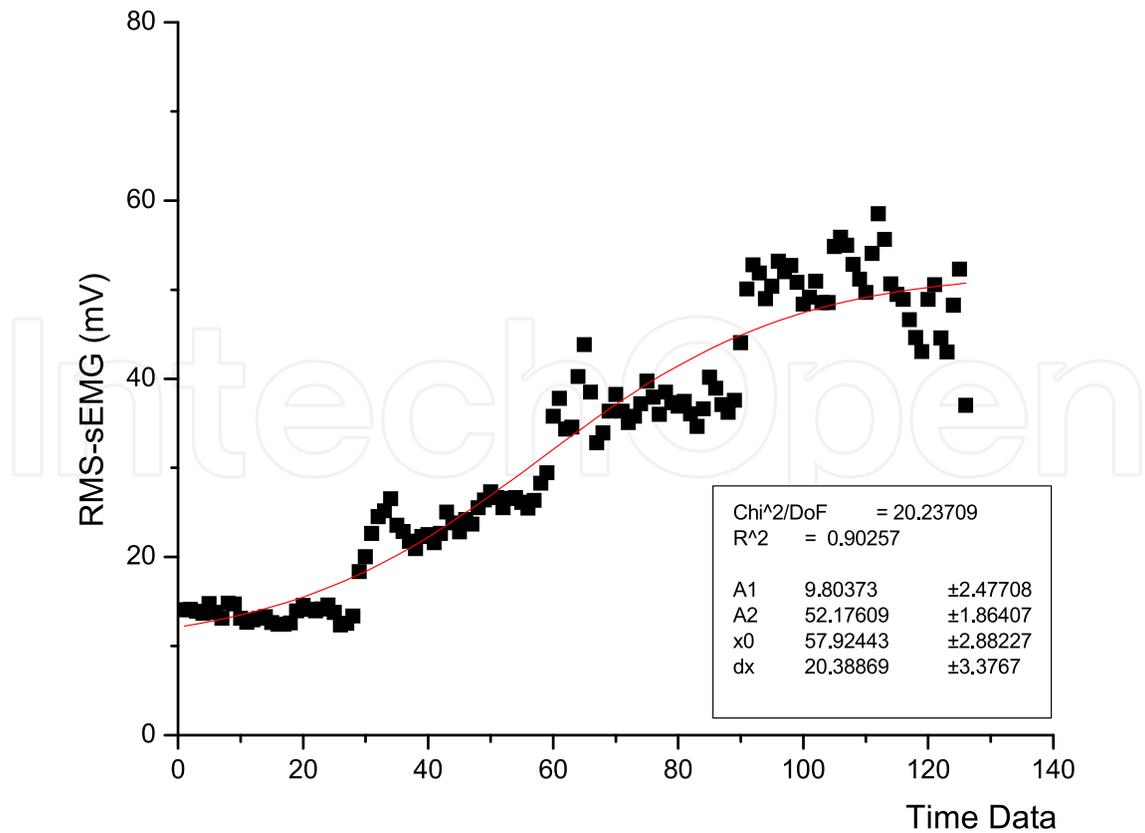


Figure 6. Relationship, adjust and parameter nonlinear of RMS-sEMG value. SM example.

The adjustment was made by equation 1. To verify that this setting was close to actual data (data collected) was analyzed the coefficient of determination (r^2) between the actual data and the adjusted data, where the r^2 values greater than 0.80.

According to [37] Enoka and Stuart (1992), [35] Miyashita et al. (1981) in incremental overhead fatiguing exercise with the amplitude of the electromyographic signal has an almost linear function of time until the individual begins to fatigue. After the onset of muscle fatigue process the signal begins to increase a predominantly curvilinear [38].

This characteristic presented in this mathematical adjustment points that are side left of the parameter x_0 which is the turning point of the concavity of the sigmoidal curve. This behavior provides a characterization of possible fatigue neuromuscular isometric ramp contractions.

4. Conclusion

Investigations have been concerned in the restricted use of the isometric contraction ramp during a single, non-fatiguing, and linearly increasing contraction force variation at short intervals, it is suggested that where the isometric ramp contractions can provide higher resolution in the entire spectrum force, less time required for data acquisition electromyography, and less susceptible to fatigue than contractions step. It is possible, however, that whereas the ramp and contraction power spectrum characteristic of the control strategies can incorporate various engine and comparing the dynamic and isometric contractions isokinetic step.

This present study revealed that the relationship between electromyography, force and time has characteristic sigmoidal. This demonstrates that the initial changes in a relationship are slowly increasing, but at intermediate loads this increase is more rapid and exponential. However, this behavior the load end presents a decrease in the rate of increase and maintenance of a depolarization of motor units at the end of execution of the isometric ramp contraction.

This sigmoidal relationship data is well described in the equation proposed for modeling (curve fitting) of hamstring muscle electromyographic signal analyzed, which is presented the start point ($A1$), the constant in equation (dx), the turning point the concavity of the curve (x_0) and peak ($A2$) to be kept in mathematical adjustment of the curve in relation to actual curve acquired.

In summary, the results of this study indicate that RMS values of the hamstrings muscles tend to increase nonlinear whereas force with the number of isometric ramp contractions performed.

5. Future directions

Since these responses are characteristic of neuromuscular fatigue, the test described here may be useful for identifying muscle fatigue in ramp isometric contraction test. With this

feature researches, in future studies, propose mathematical models to identify the turning point of the concavity of the sigmoid adjustment for the analysis and identification of the electromyographic fatigue. Therefore, in order to develop a new protocol for the identification of fatigue could be observed electromyographic initial characteristics of the sigmoid curve which is a slow increase over time data, which has an exponential characteristic. With these parameters can ascertain exponential models as the inflection point of the curve for possible identification of neuromuscular fatigue.

Understanding the importance of digital signal processing, in this case the surface electromyographic signal, the mathematical adjustment (mathematical modeling), presents itself as a tool to direct future research related to bioengineering, which may direct future investigations from the area of instrumentation to the development of new systems of man-machine synchronization.

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