ISSN 1413-3555
Rev Bras Fisioter, São Carlos

Use of electromyography to assess pain in the upper trapezius and lower back muscles within a fatigue protocol

Uso da eletromiografia na análise de dor dos músculos trapézio superior e lombares durante protocolo de fadiga

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Abstract

Objective: The aim of this study was to investigate whether muscle fatigue indices obtained using surface electromyography and calculated in the time and frequency domains would be capable of objectively diagnosing pain and discriminating between subjects with and without pain in the upper trapezius muscle and the lower back muscles. **Methods:** Forty-seven individuals underwent a muscle fatigue test for thirty-five seconds at 80% of the maximal voluntary contraction (MVC), while EMG and muscle force data were recorded. The RMS value and the median frequency (MF) were calculated within consecutive one-second windows. Linear regression analysis was used to obtain the slope coefficients and the respective y-axis intercept values, which were considered to be localized muscle fatigue indices. **Results:** In the frequency domain, the slope coefficients were negative for both muscles, while in the time domain, the coefficient for the upper trapezius was positive and the coefficient for the lower back muscles was negative ($p<0.01$). Significant differences were also found in the frequency domain between subjects with and without pain in the upper trapezius ($p<0.01$). The subjects with pain had significantly lower force values than the subjects without pain ($p<0.05$), in both the upper trapezius and the lower back muscles. **Conclusion:** The force values associated with the fatigue indices (MF slope and y-axis intercept) were able to predict the presence of pain in the upper trapezius ($p<0.05$), but not in the lower back muscles.

Key words: electromyography; fatigue; pain; upper trapezius muscle; lower back muscles.

Resumo

Objetivo: A proposta do estudo foi investigar se índices de fadiga, obtidos a partir de eletromiografia de superfície, calculados no domínio do tempo e da frequência, são capazes de diagnosticar a dor objetivamente, discriminando entre sujeitos com e sem dor no trapézio superior e nos músculos lombares. **Métodos:** Quarenta e sete indivíduos foram submetidos a um teste de fadiga muscular por 35s a 80% da contração voluntária máxima (CVM), enquanto EMG e força muscular foram registradas. O valor RMS e a mediana da frequência (MF) foram calculados em janelas consecutivas de 1s. Análise de regressão linear foi utilizada para obter os coeficientes de inclinação e seus respectivos valores de interseção no eixo y, os quais foram considerados índices de fadiga muscular localizada. **Resultados:** Os coeficientes de inclinação analisados no domínio da frequência apresentaram comportamento similar, sendo negativos para ambos os músculos, enquanto que, no domínio tempo, o trapézio superior apresentou coeficientes positivos, e músculos lombares, coeficientes negativos ($p<0,01$). Diferenças significativas também foram identificadas no domínio da frequência entre os sujeitos com e sem dor no trapézio superior ($p<0,01$). Os indivíduos com dor apresentaram valores de força significativamente menores que os sujeitos sem dor ($p<0,05$), tanto nos músculos lombares quanto no trapézio superior. **Conclusão:** Os valores de força associados aos índices de fadiga (inclinação da MF e intersecção do eixo y) foram hábeis para predizer a presença de dor no trapézio superior ($p<0,05$), mas não nos músculos lombares.

Palavras-chave: eletromiografia; fadiga; dor; trapézio superior; músculos lombares.

Received: 01/05/2008 – **Revised:** 16/09/2008 – **Accepted:** 02/12/2008

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Introduction

Localized muscle fatigue has been extensively studied over recent years and has been indicated as a factor in chronic pain-related muscle conditions[1-4] as subjects with muscle pain show reduced muscle endurance and force, probably due to lack of use because of the pain[3,5]. Despite the large number of studies on associations between pain and fatigue, questions regarding the cause and effect relationship remain. Traditionally, clinical diagnoses of muscle pain have been made by physicians or physical therapists using subjective evaluation methods such as palpation, anamnesis and the Borg scale. Moreover, the evolution of pain within physical therapy treatment is followed up subjectively, i.e. it depends on patients' reports and physical therapists' interpretations.

Thus, in searching for objective diagnoses, electromyography (EMG) has been proposed as an alternative method for assessing the muscle pain associated with localized muscle fatigue. Fatigue testing using more than 30% of the maximal voluntary contraction (MVC) and monitored using surface EMG in the frequency and time domains is believed to accurately detect the fatigue process by measuring the median frequency (MF) and root mean square (RMS), respectively[6]. Typically, as the fatigue process progresses, the MF tends to decrease[7] and RMS to increase[8,9], thus reflecting a decrease in the firing rate of the potential action of the motor unit (MU) that is recruited during muscle contraction and changes to the discharge properties, such as in relation to the synchronization and recruitment of motor units[10-13]. Based on spectral and temporal variables, indices for muscle fatigue during isometric contractions have been proposed[3,7].

There is considerable evidence in the literature to show that the behavior of the MF and RMS during fatigue protocols changes in individuals with low back pain[1,3,7,14-16]. However, there is no conclusive evidence to demonstrate that fatigue testing is able to evaluate back pain in these studies.

Furthermore, there is evidence to suggest that upper trapezius pain is as much as 84% more frequent than pain in other body muscles[17]. Unfortunately, however, few studies have been carried out on the behavior of the upper trapezius muscle while conducting protocols to investigate local muscle fatigue.

Hence, it seems to be of considerable value to investigate whether early manifestations of muscle fatigue identified in subjects with lumbar pain[3,4] can also be observed in subjects with trapezius pain when undergoing examination using fatigue protocols. Therefore, the present study attempts to contribute towards developing a means of objectively monitoring muscle pain in lower back and shoulder-neck muscles. Thus, the aim of this study was to investigate whether muscle fatigue indices obtained using surface EMG and calculated in the time and frequency domains would be capable of objectively diagnosing pain and discriminating between subjects with and without pain in the upper trapezius muscle and the lower back muscles.

Methods

Subjects

Fifty-seven university students who performed physical activity regularly were analyzed. The subjects were included in one of the following four groups: (1) with upper trapezius pain (n=15), (2) without upper trapezius pain (n=14), (3) with lumbar pain (n=18) and (4) without lumbar pain (n=10). The inclusion criterion was multiple episodes of pain in the lower back or upper trapezius muscles within the preceding three months, characterized as chronic pain (daily or almost daily). The subjects were assessed and recruited by a physical therapist. The exclusion criteria were as follows: previous surgery; symptoms of nerve root engagement (i.e. pain distal to the knee); spondylolisthesis; spinal stenosis; inflammatory disease; or cancer. This study was approved by the ethics committee of Universidade do Vale do Rio dos Sinos (03/052) and the subjects signed a written consent form. Table 1 presents the subjects' mean age, body mass and height.

Protocol

The right and left upper trapezius muscles were simultaneously subjected to isometric contraction with the subject's shoulders secured by leather straps fixed to the ground. Thus, seated on a chair, the subjects raised both shoulders against

Table 1. Mean values and standard errors of subjects' age, body mass and height. Groups: (1) with upper trapezius pain; (2) without upper trapezius pain; (3) with lumbar pain; (4) without lumbar pain.

	Group 1		Group 2		Group 3		Group 4	
	Men (n=4)	Women (n=11)	Men (n=10)	Women (n=4)	Men (n=8)	Women (n=10)	Men (n=7)	Women (n=3)
Age (years)	25.2±1.9	27.9±2.7	23.1±1.2	30.5±4.7	26.1±1.9	26.9±2.8	25.3±1.4	28.5±5.3
Mass (kg)	73.2±4.5	57.8±2.7	71.6±3.0	58.0±4.6	75.9±4.1	63.9±3.4	69.6±3.7	66.2±2.7
Height (cm)	176.7±3.7	164.5±2.2	173.3±1.5	161.5±2.8	178.2±2.4	163.2±2.9	171.0±2.7	160.2±2.6

the resistance described above, although a load cell was only attached to the right strap. To evaluate the lower back muscles, trunk isometric extension was performed in a prone horizontal position on the exercise bench, with the lower back, hip and knees securely fixed by straps. All the subjects were secured at the level of the scapula by a leather strap, which was attached to the load cell. A steel wire was then attached to the load and fixed to the ground. All the subjects performed the evaluation protocol once.

The protocol consisted of measuring the maximal voluntary contraction (MVC) prior to the fatigue test, three times for approximately five seconds, with a two-minute interval between tests. The highest value obtained was used to calculate the submaximal level at 80% of the MVC. The fatigue test was performed two minutes after the last MVC test. This test consisted of maintaining the calculated submaximal level at 80% of the MVC for thirty-five seconds. An oscilloscope (Minipa MO, model 1225, Minipa Electronics Co. Ltd., Shanghai, China) was used to provide visual feedback, and the subjects received strong verbal encouragement during the MVC and the fatigue test.

Although no subjective assessment of fatigue was made, the subjects showed exhaustion at the end of the protocol. Moreover, although the force levels for the upper trapezius and lower back muscles used in this protocol were far greater than those normally used in daily and occupational activities[18], evaluation of the functional condition of these muscles (pain and fatigability) requires higher force levels. Thus, the force level corresponding to 80% of the MVC was chosen because the protocol aimed to trigger muscle fatigue. This figure has been used in similar studies[1,3,7,15,19].

Data acquisition

The force and EMG signals were acquired simultaneously while conducting the protocol, by using a Pentium 200MHz PC-compatible microcomputer, through a converting 12-bit AD board (Lynx Tecnologia Eletrônica Ltda., São Paulo, Brazil), with a sampling frequency of 1000Hz per channel. The force signals were obtained using a load cell instrumented with strain gauges (model S-200, Alfa Instrumentos Eletrônicos Ltda., São Paulo, Brazil) connected to the same A/D board converter, so that the force and EMG signals would be automatically synchronized. The EMG activity was recorded bilaterally from the longissimus and iliocostalis lumbar muscles (at the levels of the first and the fifth lumbar vertebrae respectively), and from the right upper trapezius (at a point two-thirds of the distance from the spinous process of the seventh cervical vertebrae towards the lateral edge of the acromion), in accordance with the "Standards for reporting EMG data"[20]. Disposable passive surface electrodes (Ag/AgCl; 1.0 cm in diameter) were placed in a single differential configuration on the bellies of the muscles, observing the supposed alignment of the muscle fibers. The reference electrode was placed on the left wrist, over the ulnar styloid process. The preparation for surface EMG detection included shaving the skin and applying alcohol to cleanse the skin. The impedance between the electrodes was checked and was accepted when maintained at less than 5 kohms. Recordings were made with the aid of a sixteen-channel EMG system (Model EMG-800C, EMG System do Brasil Ltda, São José dos Campos, Brazil) with preamplifiers (fixed gain of 20) located approximately 10 cm from the electrodes. The input impedance of the system was 10 Gohms; the common mode rejection rate (CMRR) was greater then 100 dB (at 60Hz); and the signal-to-noise ratio (SNR) was 3.0 μvolts RMS.

Data processing and analysis

Force and EMG data were analyzed using self-developed data acquisition software (SAD32; version 2.61.07mp, 2002). The raw EMGs were initially subjected to bandpass filtering (Butterworth, third order, 20-500Hz), and then the EMG signal (including the MVC test) was smoothed by means of a moving window RMS averaging process using one-second Hamming windows. The filtered EMG signal was also analyzed in the frequency domain: the median frequency (MF) was calculated from the power density spectrum obtained after one-second Hamming windowing, using the Fast Fourier Transform (FFT) technique. The EMG signal from each muscle was normalized using the highest RMS value obtained during its respective MVC test (maximum value from smoothed signal) in the time domain, and using the maximum frequency obtained during its respective MVC test[21]. The initial two seconds and the final three seconds of the test recording were rejected. Consequently, thirty windows remained, which were represented by their corresponding RMS and MF values attributed to the center of each window.

Linear regression analysis was used on these thirty points, and a straight-line equation was obtained for each muscle. This equation supplied the linear slope coefficient and the y-axis intercept value, which were both considered to be fatigue indices[14,16,22]. For inclusion in the study, the determination coefficient (r^2) obtained by linear regression had to be greater than or equal to 0.6. Thus, the EMG response from the fatigue protocol was expressed using four muscle fatigue indices:

1. The slope coefficient (α_F) of the straight line that best fitted all thirty MF values[2];
2. The slope coefficient (α_T) of the straight line that best fitted all thirty RMS values;
3. The y-axis intercept (y_F) of the straight line that best fitted all thirty MF values[2];

4. The y-axis intercept (y_T) of the straight line that best fitted all thirty RMS values.

Statistical analysis

The data obtained were analyzed using the SPSS 10.0 software. The Shapiro-Wilk test was used to investigate and confirm that the data presented normal distribution, and Levine's test to show that the variances were homogenous. One-way variance (ANOVA) was applied in order to check for possible differences in the fatigue indices of the four lower back muscles. As there were no significant differences in the fatigue rates between the four lower back muscles (right and left longissimus and right and left iliocostalis lumbar), a simple arithmetic mean was calculated, in which these four muscles were considered as a single lower back muscle group. To determine the presence or otherwise of differences in the behavior of the force and fatigue indices between the lower back muscle group and the right upper trapezius muscle, the *t* test was performed on independent samples. To assess the ability of the force and fatigue indices to differentiate between subjects with and without pain in the lower back muscles and the right upper trapezius muscle, discriminant analysis was performed: (1) Wilk's Lambda test to evaluate the homogeneity of the variances; (2) canonical correlation to investigate the linear combination of the variables; (3) stepwise Wilk's Lambda discriminant analysis to classify the individuals of each group; and (4) the predicted score for each group[23]. The significance level adopted was 0.05.

Results

Table 2 shows the force values obtained during the MVC test, according to gender. Significant differences between the subjects with and without pain were found for the upper trapezius ($p=0.011$) and lower back muscles ($p=0.044$). Low force values were found for subjects with pain, when men were compared with men, women with women and also without gender discrimination. Comparison of the force values for the upper trapezius muscle and the lower back muscle group showed that there was no significant difference, but a tendency for the lower back muscle group to show higher force values was noted.

Figure 1 shows the typical behavior of the MF for the right upper trapezius muscle of two subjects, one with and the other without pain. Note that in both cases, the MF tended to diminish over the course of the fatigue test.

Figure 2 shows that the right upper trapezius and the lower back muscles displayed similar EMG signal behavior in the frequency domain, i.e. α_F indicated a trend towards a lower MF during the test. Comparison between the groups with and without pain showed that there was only a significance difference in α_F in the upper trapezius (Figure 2). However, the behavior of the EMG signal in the time domain was significantly different between the right upper trapezius and lower back muscles for α_T ($p<0.001$). The upper trapezius muscle presented a positive slope coefficient while the lower back muscle group presented a negative slope coefficient, thus indicating higher and lower RMS values, respectively (Figure 3). Comparison between the groups with and without pain showed that there was no significant difference in either of the muscles analyzed (Figure 3). Discriminant analysis was used in order to classify the subjects into two groups: with pain and without pain, using the fatigue rates and the force values obtained from the MVC. The data were found to present homogeneity of variance. The results from the discriminant analysis in the frequency and/or time domain showed that for the lower back muscle group, none of the fatigue indices and force values were able to discriminate between subjects with and without low back pain. The results of this discriminant analysis in the time domain showed that, for the trapezius muscle, the independent variables were not able to correctly classify the subjects. Analysis in the frequency domain indicated that for the upper trapezius muscle, two fatigue indices (y_F and α_F) and the force value were able to correctly classify 69% of the subjects [$WL=0.723$; $\chi^2=8.256$; $df=3$; $p=0.041$] (Table 3). When analysis in the time and frequency domains were used together in the discriminant analysis, neither the fatigue indices nor the force value were able to discriminate between groups with and without pain in the upper trapezius muscle. When the force variable was removed from the

Table 2. Mean values and standard errors of the force (N) from the upper trapezius and lower back muscle group for subjects with and without pain.

	With pain		Without pain	
	Men	Women	Men	Women
Upper Trapezius	535±96	299±24	630±71	311±34
Lower Back Muscles	592±97	321±29	633±67	404±40

Table 3. Discriminant analysis: correct classification of the subjects with and without pain in the upper trapezius muscle. Variables in descending order of discriminating power.

Variables used for correct classification	Percentile of correct classification[a]: Upper Trapezius Muscle		Canonical correlation
	Group with pain	Group without pain	
Force - y_F - α_F	73.3%	64.3%	0.526

[a] 69% of originally grouped cases were correctly classified.

discriminant analysis, no significant result was obtained, i.e. the fatigue indices were unable to discriminate between the groups with and without pain.

Discussion

The motive behind this study was not merely to discriminate between subjects with and without pain, but to contribute towards developing a means for objectively monitoring muscle pain in the lumbar, shoulder and neck regions. The results will be analyzed as four topics: (1) force values in the MVC; (2) EMG behavior in the frequency domain; (3) EMG behavior in the time domain; and (4) discrimination between subjects with and without pain.

Force values in the MVC

The group with lower back pain presented force values 24.7% lower than in the group without lower back pain. The percentage of this difference was greater in the trapezius muscle, for which the group with pain exerted 36% less force than did the group without pain. It has been found that subjects with pain exert submaximal force and not the "true" maximal force during MVC testing, because of the pain itself[15]. This behavior may be reflected in the results from fatigue testing, i.e. subjects' abilities or lack of ability to activate muscle fibers sufficiently to achieve fatigue could be a serious problem when protocols are based on MVC. Because significant differences between the groups with and without pain were found, it is suggested that the results from the present study (Table 2) are in agreement with those mentioned above, considering that the subjects with pain did not exert maximal force during the MVC test in either muscle that was evaluated. Nevertheless, it is speculated that the subjects in the present study may have reached localized muscle fatigue while performing the evaluation protocol.

Despite the controversy relating to lower back pain, which focuses on the interpretation of changes to muscle activity in subjects with pain, the basic theory of one of the models proposed is that the pain reduces muscle activation when the muscle acts as an agonist and increases muscle activation when it acts as an antagonist. This *pain adaptation model* postulates that the changes in motor recruitment may be due to some type of strategic control that the nervous system exerts through specific neural pathways. In this, the feedback of afferents can, via both inhibitory and excitatory interneurons, excite or inhibit the alpha motor neurons, depending on the motor command. The effects of this neural mechanism suggest that there is a reduction in agonist activation and

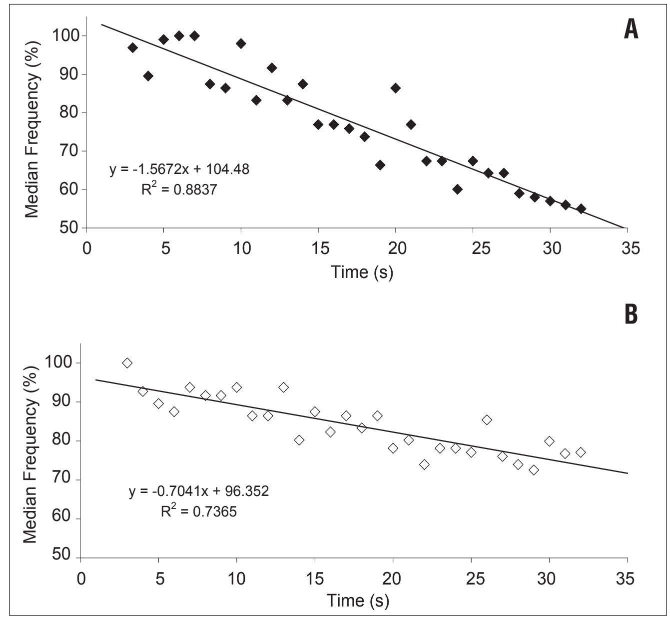

Figure 1. Typical behavior of the MF in upper trapezius muscle for two subjects: (A) with pain and (B) without pain.

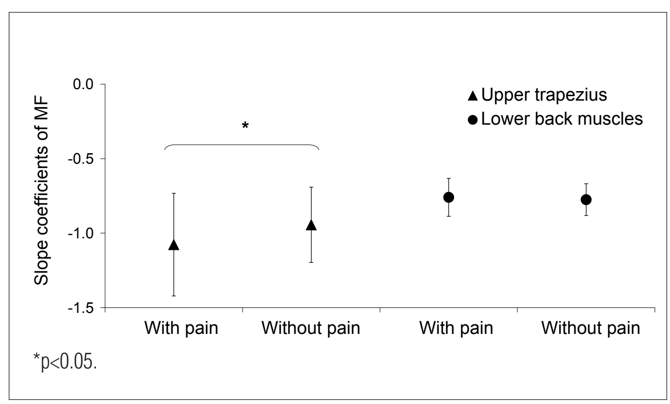

Figure 2. Means and standard errors of MF slope coefficients (α_F) for both groups (with and without pain) for upper trapezius and lower back muscles.

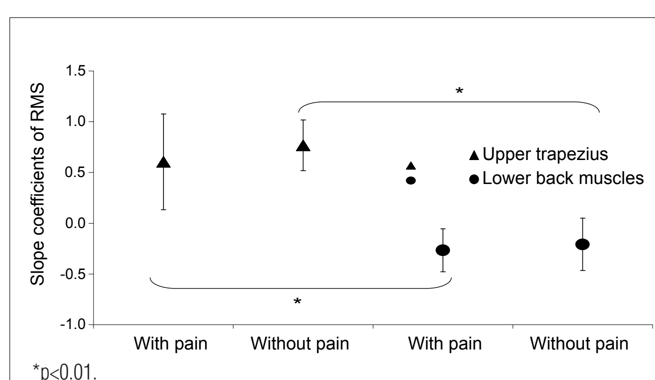

Figure 3. Means and standard errors of RMS slope coefficients (α_T) for both groups (with and without pain) for upper trapezius and lower back muscles.

an increase in antagonist activation[24]. Thus, it is suggested that pain can affect voluntary activity in painful muscles (the upper trapezius as the agonist for scapula elevation and the lower back muscles as agonists for trunk extension), in order to prevent injury through inappropriate muscle contraction.

Based on the above theory, it can be supposed that the fact that the subjects with pain did not exert maximal force during MVC testing might be associated with a kind of protection mechanism. Although there is no widely accepted explanation for this, it is interesting to speculate that the existence of a relationship between force and motor unit recruitment[25] might be the cause for such a discrepancy in the MVC between the groups, thus suggesting that selective adaptation occurs at fatigue levels. Hence, the fact that the group with pain did not exert maximal force capacity may have influenced the outcome, thereby changing the muscle fatigue quantification and, consequently, resulting in less accurate classification of the subjects.

The upper trapezius muscle and lower back muscle group have been associated with chronic muscle pain[26], and it has been supposed that dynamic reorganization of EMG activity takes place in the presence of pain. Thus, a new form of synergy is developed, resulting in minimization of the use of the painful muscles[27]. Further studies are needed to investigate pain in other muscles, such as the upper trapezius muscle, using a method other than MVC in order to determine the level of sustained contraction and to minimize any possible effect from a supposed pain protection mechanism.

EMG behavior in the frequency domain

Traditionally, the Fast Fourier Transform technique (FFT) has been used to analyze the behavior of the EMG signal during fatigue tests involving sustained isometric contraction, although parametric methods of power spectrum estimation may also be used (AR, MA and ARMA). The behavior of the MF throughout the duration of muscle contraction while conducting the fatigue protocols was confirmed from linear regression analyses, which supplied the linear slope coefficient of the MF curve (Figures 1 and 2). A negative slope coefficient indicated that while performing the fatigue protocol there was a decrease in the MF (Figure 2). It has been documented that establishing a fatigue process in the lower back muscles causes compression of the EMG spectrum towards low frequencies, while MF decreases. However, this behavior seems to differ between subjects with lower back pain and subjects without pain, such that subjects with pain tend to show a higher slope coefficient, i.e. greater decreases in the MF curve. Consequently, compared with individuals without lower back pain, subjects who suffer from lower back pain show muscle dysfunction and early myoelectrical manifestations of muscle fatigue[28]. In the present study, a negative MF slope coefficient was found in all cases, although a significant difference between subjects with and without pain was only obtained for the upper trapezius muscle (Figure 2).

It has been suggested that muscle fatigue may be a factor related to the muscle disorders that are associated with chronic pain[1]. However, in order to make such an association, fatigue needs to be understood as a continuous process that starts with the initiation of neuromuscular activity and is capable of causing changes to electrical activity, electrical propagation, excitation-contraction coupling and various elements of the contraction process. Some authors[29-31] have suggested that during sustained isometric contraction with 50% of maximal force or greater, the accumulation of lactic acid leads to decreased pH in contracting muscles. This accumulation also inhibits the excitability of the muscle membrane, thereby causing a decrease in the firing rate and, consequently, a decrease in MF.

EMG behavior in the time domain

The occlusion of blood flow due to intramuscular pressure during static contraction[31] leads to a reduction in the oxygen supply to the active muscle. Consequently, glycolytic metabolism increases, and there is an accumulation of lactate. In order to compensate for this situation and maintain force levels, recruitment of new motor units (MUs) can be expected. This motor unit recruitment is reflected in the EMG signal amplitude and, therefore, can be identified by calculating the root mean square (RMS)[8]. The increase in RMS is related to the recruitment of additional motor units and also an increased firing rate, and these are necessary to compensate for the loss of force[19]. The spectral compression produced by the slower conduction of action potential also increases the RMS[32]. In the present study, this behavior was noted in the upper trapezius muscle.

In contrast, some studies have indicated that the RMS value behaves differently. For example, Gerdle et al.[6] reported that the RMS value showed various patterns within the same group (increased, unchanged or decreased) during the fatigue phase. Such divergences may arise from differences in characteristics between individual subjects, such as the subject's resistance to fatigue, the contraction properties of the skeletal muscle, muscle fiber composition, enzyme activity levels, differences in metabolic systems and differences in signal processing. Despite the characteristics of individual subjects, divergent RMS behavior was consistent with the muscle group in the present study. The RMS increased in the right upper trapezius, but decreased in the lower back muscle, for groups with and without pain (Figure 3). The reason for this divergence remains unclear because the fiber composition was similar[18], the signal processing was the same and there was no information regarding enzyme activity or differences in metabolic systems within this protocol.

Discrimination between subjects with and without pain

Both the MF slope coefficient and the y-axis intercept value from the straight line have been used as localized muscle fatigue indices that have the ability to distinguish between subjects with and without pain[14,15,22,33]. In the present study, correct classification of 73.3% of the subjects with upper trapezius pain was only achieved when the force value was associated with the fatigue indices obtained from analysis in the frequency domain (Table 3). When a new discriminant analysis was performed and the force variable was extracted, no significant result was obtained. It seems that the force values had a fundamental role in achieving the results described above. These findings are in agreement with Elfving, Dedering & Németh[15].

In contrast to other reports in the literature[1,15,22,33,34], the present study was unable to discriminate subjects with low back pain. Assuming that EMG amplitude is a source of information on localized muscle fatigue, it was hypothesized that an increase in the RMS value during isometric testing could be an indication of muscle fatigue. The results from this study did not confirm this hypothesis because the fatigue indices obtained from analysis in the time domain were not capable of discriminating between subjects with and without pain in the upper trapezius and lower back muscles. The divergent RMS behavioral patterns (Figure 3) may explain the failure to discriminate between subjects using fatigue indices in the time domain. It is notable that there is still much debate concerning the use of the RMS value as an indicator of muscle fatigue.

In summary, regarding the analyzed sample, the behavior of the upper trapezius muscle and lower back muscle group was seen to be similar when assessment was based on the MF slope coefficient (negative slope coefficient for both muscles) and divergent when the assessment was based on the RMS value (positive slope coefficient for the upper trapezius and negative slope coefficient for the lower back muscles). Concerning the capacity of the fatigue indices to discriminate between subjects with and without pain, the results showed that force values associated with fatigue indices (MF slope and y-axis intercept) were able to predict the presence of pain in the upper trapezius, but not in the lower back muscle group.

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