Original Article

REPETITIONS TO FAILURE INCREASE PECTORALIS MAJOR ACTIVATION WITH SIMILAR NEUROMUSCULAR FATIGUE IN TRAINED MEN

REPETIÇÕES ATÉ A FALHA AUMENTAM A ATIVAÇÃO DO PEITORAL MAIOR COM SIMILAR FADIGA NEUROMUSCULAR EM HOMENS TREINADOS

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RESUMO

Protocolos de treinamento realizados até a falha muscular (FM) têm sido realizados na tentativa de maximizar a ativação e a fadiga neuromuscular. Portanto, o objetivo deste estudo foi comparar a amplitude do sinal eletromiografico (EMG_{RMS}) e a frequência (EMG_{FREQ}) do peitoral maior entre os protocolos realizados até a FM e sem falha muscular (SFM). Sete homens treinados realizaram três séries com 60% de uma repetição máxima, com um período de descanso de 3 min e uma duração da repetição de 6s. O protocolo FM foi realizado com o número máximo de repetições em todas as séries, enquanto no protocolo SFM os indivíduos realizaram 6 repetições em 3 séries. Para análise dos dados, foram utilizadas duas ANOVAs two-way com medidas repetidas (Protocolo x Repetição) e, quando necessário, foi realizado o post hoc de Bonferroni. Como resultado, a EMG_{RMS} foi maior no protocolo FM comparado ao SFM, mas não houve diferença na EMG_{FREQ} entre os protocolos. Embora não houvesse diferenças significativas no domínio da frequência entre os protocolos, a realização de repetições até a FM foi um fator determinante para gerar maior amplitude do sinal eletromiográfico. Assim, a realização de repetições até a FM pode ser considerada uma estratégia eficaz para aumentar a ativação muscular em indivíduos treinados, porém com fadiga neuromuscular semelhante.
Palavras-chave: Amplitude. Eletromiografia. Frequência. Falha muscular. Treinamento de força.

ABSTRACT

Resistance training protocols performed to muscle failure (MF) have been employed in an attempt to maximize activation and neuromuscular fatigue. Therefore, the aim of this study was to compare the surface electromyography amplitude (EMG_{RMS}) and frequency (EMG_{FREQ}) of the pectoralis major between protocols performed to MF and non muscle failure (NMF). Seven trained men performed three sets at 60% of a repetition maximum, with a 3 min rest period and a 6s repetition duration. MF protocol was performing with maximum number of repetitions in all sets, while in NMF protocol subjects performed 6 repetitions in 3 sets. For data analysis two two-way repeated measures ANOVAs (Protocol x Repetition) were used and when necessary, Bonferroni post hoc was performed. The EMG_{RMS} was higher in the protocol MF compare to NMF, but there was no difference in EMG_{FREQ} between protocols. Although there were no significant differences in the frequency domain between protocols, perform repetitions to MF was a determining factor to generate higher amplitude of the electromyography signal. Thus, perform repetitions to MF could be considered an effective strategy to increase muscle activation in trained individuals, however, with similar neuromuscular fatigue.
Keywords: Amplitude. Electromyography. Frequency. Muscle Failure. Strength training.

Introduction

Training protocols performed to muscle failure (MF) have been employed in an attempt to maximize activation and neuromuscular fatigue responses[1–3]. MF is defined as the inability to perform the full range of motion (ROM) of a repetition due to fatigue[4]. Given that among other factors strength performance can be influenced also by neuromuscular aspects[5], surface electromyography (EMG) is often used in studies that investigate muscular activation and fatigue changes occurring after complete training protocols[2,6].

Looney et al.[2] investigated EMG responses in training protocols performed with repetitions to MF or non muscle failure (NMF) with different intensities [50 and 70% 1 repetition maximum (RM)]. Regardless of the intensity used, higher EMG amplitude was observed for protocols performed to MF. However, the volume was not equated between protocols, allowing to execute a higher number of repetitions in the protocols performed to MF.

Therefore, the findings of this study might have occurred not only as a result to executed repetitions to MF (or not), but also due to greater number of repetitions performed in the protocols to MF. In another study, Marshall et al.[6] compared protocols with multiple sets at 80% 1RM. One of the protocols consisted of 5 sets, 4 repetitions each, 20 s rest interval between the sets, and was performed NMF. In the other protocol, denominated rest pause protocol, subjects should perform the same total number of repetitions (20), but they did not have a predetermined number of sets. Therefore, subjects were instructed to perform repetitions to MF with a rest interval of 20 s until completing 20 repetitions. Similarly to the findings of Looney et al.[2], the protocol MF presented higher EMG amplitude than the NMF protocol. These results could be explained by an attempt to maintain the force production by not interrupting the exercise when performing the repetitions to MF which would impact in higher EMG amplitude. A higher EMG amplitude can be at least partially explained by an additional recruitment of motor units (MUs), especially fast MUs[2,8,9]. However, only Marshall et al.[6] attempted to equate the repetition duration and, consequently, the time under tension in different training protocols. Nevertheless, the repetition duration or the time under tension were not presented in the results of this study to confirm this assumption.

It has been previously demonstrated that protocols with different repetition duration can result in different muscle activation[10,11]. Comparing protocols equalized by volume, Burd et al.[11] have found greater EMG amplitude in the protocol performed with longer repetition duration (12 s vs 2 s). Given that in the study of Burd et al.[11] there is a marked difference in the repetition duration between protocols and that the duration of 12 s is poorly recommended in strength training prescriptions[12,13], Martins-Costa et al.[13]compared two protocols of equal volume. Both protocols were performed with different repetitions duration (4 s and 6 s) and a higher EMG amplitude of the pectoralis major was found when the duration was 6 s in agreement with the results of Burd et al.[11].

Furthermore, frequency analysis of the EMG signal has been used to investigate neuromuscular fatigue in training protocols[7,14]. It is expected that during resistance training EMG frequency spectrum moves to lower frequencies[7,15] due to a decrease in the action potential conduction velocity[8] and to blood pH decreases[16], which may be more pronounced in the protocols performed to MF[7,17]. Additionally, Sundstrup et al.[17] found that during shoulder abduction exercise to MF there was an increase in EMG amplitude and decrease in frequency across the set in all analyzed muscles. Jenkins et al.[7] also observed a decrease in EMG frequency in both intensities (30% and 80% 1RM) when subjects performed protocols to MF, and this decrease was more pronounced in the low intensity protocol.

Therefore, the aim of the present study was to compare muscle activation (EMG_{RMS}) and average frequency (EMG_{FREQ}) of matched training protocols performed to MF and NMF. The hypothesis is that the protocol performed to MF would result in a greater EMG_{RMS} and a lower EMG_{FREQ} compared to NMF protocol. Considering various possibilities of protocol configurations in these conditions, it is expected that the present study would increase the analysis spectrum of MF training prescription.

Methods

Sample

Seven health trained males (age 21.7 ± 1.5 years; height = 173.2 ± 7.9 cm; body mass = 71.5 ± 7.3 kg; Smith machine bench press 1RM = 81.7 ± 8 kg) who trained for at least 6 months and have no previous record of musculotendinous lesions at shoulder, elbow or wrist joints, and are capable of lifting in bench press 1RM test a weight corresponding to own body mass[18] participated in this study. The sample size was determined in Gpower software (version 3.1.9.2) using the data from the study of Lacerda et al.[9] and setting the effect size

(*partial eta-squared*) to 0.25, power to 0.8, sphericity correction to 1, and level of significance to 5%, thus reaching the sample size of 7 subjects. Subjects were informed about the purpose, procedures and possible risks of the study and assigned the Informed Consent form. The study was approved by the local Ethics committee and was conducted in accordance of the *Declaration of Helsinki*.

Procedures

Each subject presented to testing in the Laboratory in 4 different days with a minimum interval of 48 hours between the sessions. Considering the possible influence of circadian rhythm on strength output[19], for each subject the experimental sessions were performed always at the same time of the day. The experimental sessions were performed on a Smith machine bench press with a 20 kg barbell and an adjustable bench. Head and hands position were standardized for each participant and replicated in each session. A complete extension of the elbows without no other movement determined the upper limit of ROM of the barbell and the lower limit was marked when the barbell touched the rubber protective bulk placed on the sternum. 1RM test was performed during the first and the second data collection session to familiarize the subjects with the procedure and to determine the weight (60% 1RM) that would be used in the 3d and 4th sessions. 1RM test was performed according to the procedure used by Lacerda et al.[20], with a maximum of 6 attempts and 5 minutes of the rest interval. The load was gradually increased until the participant failed to perform the concentric action at full ROM, and the weight lifted previous to this failure was considered 1RM. Lastly, the subjects were familiarized with the 6 s repetition duration, adjusted by a metronome, and randomly performed the training protocols planned for the execution during the third and fourth experimental sessions.

The ROM in the elbow joint and the duration of muscle actions were determined using an electrogoniometer (Noraxon, Scottsdale, AZ, USA) placed on the left elbow of the subjects. Surface electrodes were placed on the pectoralis major muscle, on the right-hand side. When the electrodes and the electrogoniometer were fixed in place, the subjects were positioned on the Smith machine bench press and performed 10 repetitions without any additional weight added to the bar. After 3 minutes they started the training protocols; EMG activity was registered in each exercise set. The training protocols consisted of 3 sets, 60% RM, 3 minutes of rest interval between the sets and 6 s of repetition duration (4 s concentric and 2 s eccentric action), one of which was performed to MF and the other protocol to NMF with 6 repetitions per set. The number of repetitions for the protocol NMF was selected after a pilot study, in which the subjects were able to perform 6 repetitions in 3 sets, whilst keeping the other training variables and not perform repetitions to MF. Besides, this number of repetitions was selected to ensure that each subject performs a similar total maximal number of repetitions in both protocols and consequently maintaining a similar volume and time under tension, thus allowing interpretation of the results of the study as a function of perform or not MF. In the protocol MF the number of repetitions was determined as the number of repetitions completed at the full ROM.

The EMG procedure was performed in accordance with the recommendations found in Hermens et al.[21] and Lagally et al.[22]. Bipolar surface electrodes (Ag/AgCl - 3M-2223, Brazil) were placed parallel to the muscle fibers on the right pectoralis major muscle (sternal part) of the subjects. Before placing the electrodes, the skin was shaved and cleaned with alcohol. The electrodes were placed in pairs, at 2 cm center-to-center distance, at the point of the largest muscle venter and the ground electrode was placed on the olecranon. Signal was amplified 1000 times and 2nd order band-pass Butterworth filter (20-500 Hz) was used. Normalization of the EMG signal was similar to the one presented in the study of Martins-Costa et al.[13]. An average of root mean square (RMS) of the first two repetitions of the first set was used as a

normalization criterion. The RMS of the first, median and last repetitions in the three sets were divided by the average RMS of the two initial repetitions, thus generating a normalized RMS (EMG_{RMS}) for each of these repetitions. These EMG_{RMS} values of the first, median and last repetitions in three sets were used for data analysis. The same normalization procedure was adopted for the analysis of frequency domain; an average normalized frequency value (EMG_{FREQ} normalized) was calculated for the first, median and last repetition of each set. EMG_{FREQ} was calculated using a short-time Discrete Fourier Transform (STFT), which was obtained applying the Fourier transform with the fixed size window (Hamming window- 50 ms) in all EMG signal. The frequency resolution was 20 Hz. EMG_{FREQ} was used to represent the power spectrum of EMG signal in accordance with Kwatny et al. [23]

Statistical analysis

For the statistical analysis the software *Statistical Package for the Social Sciences* for windows version 22.0 (SPSS, Inc., Chicago, IL, USA) was used. In both protocols, the first, median and last repetitions of each of the three sets of bench press were used for the analysis of normalized EMG_{RMS} and EMG_{FREQ} of pectoralis major. The results are presented as mean and standard deviation. The distribution normality and homogeneity of variances were verified using the Shapiro-Wilk and Levene's tests, respectively. These tests have demonstrated distribution normality and homogeneous variances of the normalized EMG_{RMS} and EMG_{FREQ}. Therefore, two *two-way* ANOVAs with repeated measures (Protocol x Repetition) were used to compare the values obtained in the protocols MF and NMF. When necessary, Bonferroni post hoc test was used to identify the differences. The interclass correlation coefficient of EMG_{RMS} and EMG_{FREQ} values, which were obtained in the normalization tests of each training protocol, was 0.96 for the time domain and 0.82 for the frequency domain. To represent the effect size between the protocols, the *eta-squared* (η^2) values were used: small = 0.01, medium = 0.06 and high = 0.14[24]. The significance level was set to $p < 0.05$ in all the tests.

The comparison of the average repetitions durations was done using the t-test for paired samples. Both time under tension and the total number of repetitions in each protocol were compared using Wilcoxon t-test, and the data presented as a median and interquartile deviation.

Results

The repetition duration (MF: 6.07 ± 0.07; NMF: 6.04 ± 0.14) ($t_{(20)} = 0.94$, $p = 0.35$) and the total number of repetitions (MF: 19 ± 4; NMF: 18 ± 0) ($U = 1.57$, $p = 0.11$) were not significantly different between the protocols. Therefore, the time under tension also did not differ between the protocols (MF: 36.63 ± 18.24; NMF: 36.19 ± 0.48) ($U = -1.21$, $p = 0.224$).

EMG_{RMS} the *two-way* ANOVA did not identify interaction effect (Protocol x Repetition) ($F_{(2.40)} = 2.32$, $p = 0.11$, power = 0.44, effect size < 0.01). However, there was found a main effect of protocol ($F_{(1.20)} = 5.53$, $p = 0.02$, power = 0.61, effect size = 0.08) so that the all repetitions in the protocol MF showed higher normalized EMG_{RMS} than NMF (Fig. 1). In both protocols was observed a main effect of repetition ($F_{(1.20)} = 223.34$, $p = 0.0001$, power > 0.99, effect size = 0.50), with EMG_{RMS} been greater in the last repetition than in the middle repetition, and in the middle repetition greater than in the first (Figure 1).
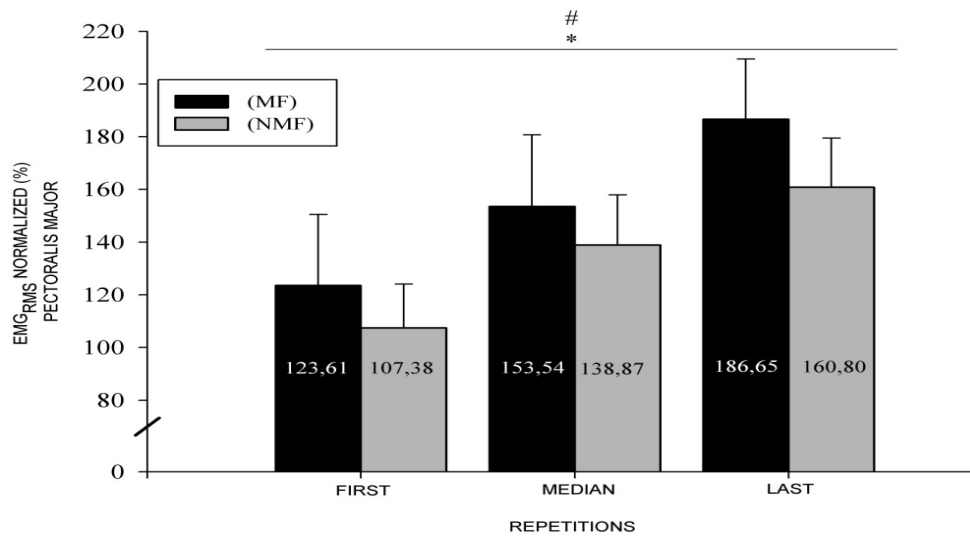
Figure 1. Normalized pectoralis major EMG$_{RMS}$ for each training protocol
Note: *$p < 0,05$. Protocol comparison (NMF < protocol MF); #$p < 0,05$. Repetitions comparison (last > median > first). MF: muscle failure; NMF: non muscle failure
Source: Authors

For EMG$_{FREQ}$ there was no significant interaction effect (Protocol x Repetition) ($F_{(2.40)} = 0.72$, $p = 0.48$, power = 0.16, effect size < 0.01). In addition, the main effect of protocol was not observed ($F_{(1.20)} = 0.01$, $p = 0.91$, power = 0.05, effect size < 0.01), therefore, there were no differences between protocols. However, a main effect of repetition was demonstrated ($F_{(1.20)} = 22.44$, $p = 0.0001$, power > 0.99, effect size = 0.32), with EMG$_{FREQ}$ showing greater values in the first repetition than in the middle and last repetitions, and no difference between the middle and the last repetition in both protocols (Fig. 2).
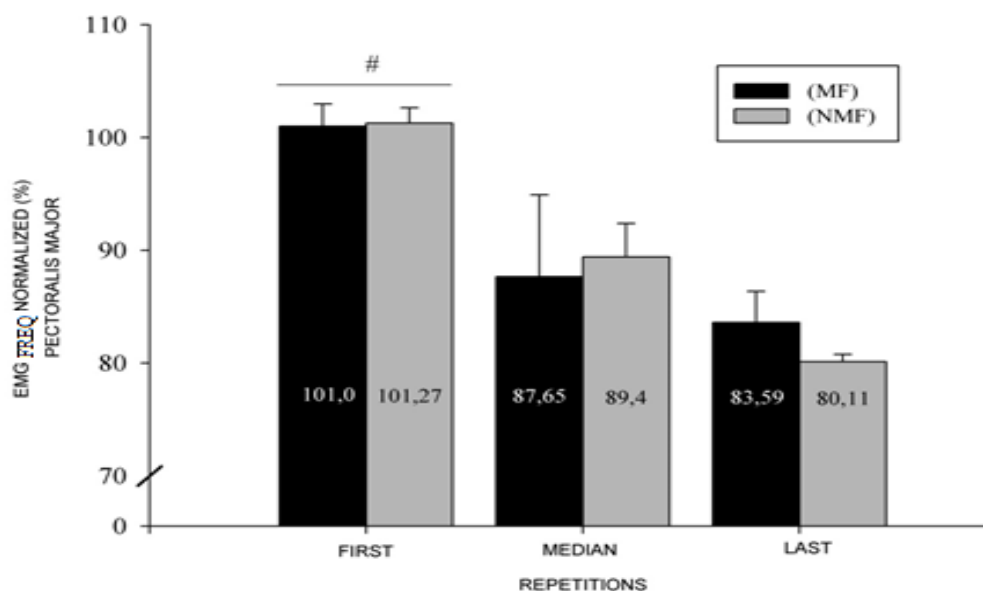

Figure 2. Normalized pectoralis major EMG$_{FREQ}$ for each training protocol
Note: #$p < 0,05$. Repetitions comparison (first > median and last). MF: muscle failure; NMF: non muscle failure
Source: Authors

Discussion

This study investigated if matched training protocols performed to MF or NMF would result in different responses of EMG amplitude (EMG_{RMS}) and average frequency (EMG_{FREQ}) from pectoralis major during Smith machine bench press exercise. It was found that the normalized EMG_{RMS} response was greater in the protocol to MF than NMF in all analyzed repetitions (first, median and last). It was also found that both protocols presented higher normalized EMG_{RMS} values in the last than in the middle repetition, and also in the middle these values were greater than in the first repetition. No significant differences between the protocols were found in the normalized frequency response EMG_{FREQ}, however, in both protocols normalized EMG_{FREQ} was higher in the first than in the middle and last repetitions.

A higher normalized EMG_{RMS} value found in this study for the protocol MF is in agreement with the results of Looney et al.[2] and Marshall et al.[6] This result may be explained by the attempt to maintain the force production when performed repetitions to MF. In this sense, it is expected that the nervous system adopts a strategy of increasing the recruitment of MU to compensate the decrease in the firing rate of the activated MU and the decrease in the action potential conduction velocity[6], which might result in an increased EMG amplitude[2]. Besides, it is also possible, that larger EMG amplitude is related to an increased activation synchronization of the MUs[25] that allows simultaneous MU activation to maintain force production [3]. However, as already explained, in the study of Looney et al.[2] the number of repetitions was not equal between the protocols, and only Marshall et al.[6] made an attempt to equate the repetition duration, yet, the repetition duration and the time under tension were not shown in the results. Considering that the protocols with different repetitions durations may present different muscle activations[10], it is necessary to match the durations of the repetitions in the investigated protocols to MF and NMF and minimize the influence of other variables on the EMG amplitude. These considerations were taken into account in the present study for a reliable comparison of the protocol effect on the EMG amplitude is to be achieved.

The results of the comparison of the normalized EMG_{RMS} between the repetitions (last > middle > first) are in agreement with data available in the literature[7,15]. Comparing EMG_{RMS} from pectoralis major muscle during bench press exercise to MF, Sakamoto and Sinclair[15] obtained results similar to the results of the present study. These authors found that EMG_{RMS} values from the pectoralis major muscle at the end of the set were higher than at the beginning of the set.

Besides a larger EMG_{RMS} response, it was also assumed that because of a possible increased local acidity[7,16] and, consequently, a greater nerve impulse conduction velocity decrease[8], the protocol to MF would result in a greater EMG_{FREQ} reduction than the protocol NMF. However, the present study did not reveal a significant difference in EMG_{FREQ} between protocols. Larger EMG_{RMS} values in the protocol to MF and absence of the EMG_{FREQ} difference between the protocols can be explained by a possible nervous system strategy when fast MU recruitment threshold is decreased[26] in an attempt to maintain the force output, as the exercise is not interrupted in the state of fatigue (MF protocol). In this way, recruitment of additional MU due to reduction of the recruitment threshold would explain larger EMG_{RMS} value in the protocol to MF without differences in the EMG frequency spectrum of the investigated protocols. In addition, according to Santos et al.[27], fatigue response in the single-set protocols to MF or NMF could be higher than in multiple-set protocols. According to these authors, this response is due to a greater number of repetitions that can be performed in single-set protocols to MF. In multiple-set protocols (like in the case of the present study), a difference in the number of performed repetitions tends to decrease with the sets, which causes an attenuation of the differences in the volume[3].

It is worth highlight that in the present study there were no significant differences between the total number of repetitions performed in the protocols (MF: 19 ± 4; NMF: 18 ± 0; $p = 0.11$), and this might have contributed to the obtained similar results in EMG_{FREQ}. Comparing the protocols to MF with different intensities (30% and 80% 1RM), Jenkins et al.[7] found that a decrease in the EMG frequency along the repetitions was more pronounced in the low-intensity protocol. Since the number of repetitions in the protocol at 30% 1RM was higher than in the protocol at 80%, the authors suggested that the EMG frequency is more influenced by the change in the number of repetitions. Besides, though the EMG frequency is commonly used to compare neuromuscular fatigue response caused by different training protocols[7,9,15], in dynamic actions the use of the EMG frequency analysis might have its limitations[28]. According to these authors, in isometric actions the EMG frequency decrease can be more pronounced than in dynamic actions. This is explained by ischemia generated by vascular occlusion, that leads to blood pH drop and, consequently, to nerve impulse conduction velocity decrease in muscle fibers; in case of dynamic contractions, this might not occur at the same magnitude. Lastly, the observed decrease in the normalized EMG_{FREQ} between the repetitions (first > middle and last) in the present study is in agreement with an assumption that during the force production task the EMG spectrum moves to lower frequency zone[15,17]. Sundstrup et al.[17] found that in the shoulder abduction exercise to MF all muscles showed lower EMG frequency in the last repetition of the set than in the first repetition.

Though significant differences in normalized EMG_{FREQ} were not observed between protocols, performing repetitions to MF induced higher normalized EMG_{RMS} values. This indicates that the neuromuscular demands of the investigated protocols are different. There are numerous possibilities of configuring training protocols to perform MF, and caution should be exercised when upholding the superiority of the protocols to MF in producing training response. Several studies that reinforce the expectation of this superiority did not equalized such important training variables as intensity[29], repetition duration[2], and volume[2,30], which might cause bias in the interpretation of their results. It is important to emphasize that in the present study the number of repetitions was similar between the protocols, and this could be an important factor for the obtained result of EMG_{FREQ}. Nevertheless, further studies are necessary to determine the impact of MF and NMF protocols on EMG responses from the subjects with different characteristics (untrained males; women; elderly subjects), as well as chronic adaptations induced by matched protocols.

Conclusion

The results of the present study demonstrate that, considering the exercise and training variables used in the protocols, matched training protocols normalized EMG_{RMS} is higher when performing training to MF than NMF, but no differences were found in the normalized EMG_{FREQ}. In this case, performing repetitions to MF provided greater activation with similar neuromuscular fatigue.

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