

# LONGER CONCENTRIC ACTION INCREASES MUSCLE ACTIVATION AND NEUROMUSCULAR FATIGUE RESPONSES IN PROTOCOLS EQUALIZED BY REPETITION DURATION

LUCAS T. LACERDA,<sup>1,2</sup> CINARA G. COSTA,<sup>1</sup> FERNANDO V. LIMA,<sup>1</sup> HUGO C. MARTINS-COSTA,<sup>1,2</sup> RODRIGO C.R. DINIZ,<sup>1</sup> ANDRÉ G.P. ANDRADE,<sup>1</sup> GUSTAVO H.C. PEIXOTO,<sup>1</sup> MICHAEL G. BEMBEN,<sup>3</sup> AND MAURO H. CHAGAS<sup>1</sup>

<sup>1</sup>Weight Training Laboratory, School of Physical Education, Physiotherapy and Occupational Therapy, Federal University of Minas Gerais, Belo Horizonte, Minas Gerais; <sup>2</sup>Pontifical Catholic University of Minas Gerais, Belo Horizonte, Minas Gerais; and <sup>3</sup>Department of Health and Exercise Science University of Oklahoma, Norman, Oklahoma

## ABSTRACT

Lacerda, LT, Costa, CG, Lima, FV, Martins-Costa, HC, Diniz, RCR, Andrade, AGP, Peixoto, GHC, Bembem, MG, and Chagas, MH. Longer concentric action increases muscle activation and neuromuscular fatigue responses in protocols equalized by repetition duration. *J Strength Cond Res* 33(6): 1629–1639, 2019—The aim of this study was to investigate the impact of protocols equalized by the repetition duration but composed of different concentric (CON) and eccentric (ECC) durations on muscle activation and neuromuscular fatigue. Seventeen males with previous experience in resistance training performed 3 training protocols (A – 2 second CON: 4 second ECC; B – 3 second CON: 3 second ECC; and C – 4 second CON: 2 second ECC) with the Smith machine bench press exercise, all with 3 sets, 6 repetitions, 3 minutes' rest, and 60% of 1RM. The normalized root mean square of the electromyographic signal ( $EMG_{RMS}$ ) and mean frequency electromyography ( $EMG_{MF}$ ) for pectoralis major and triceps brachii muscles were calculated for second and fifth repetitions in each set. The results showed an  $EMG_{MF}$  decrease across the repetitions accompanied by a progressive increase of the  $EMG_{RMS}$  across the repetitions for all protocols and muscles. The  $EMG_{RMS}$  was higher in protocol C when compared with protocol A and B for pectoralis major. The  $EMG_{MF}$  was lower in protocols B and C than in protocol A for pectoralis major throughout the sets and repetitions. A higher  $EMG_{RMS}$  and a lower  $EMG_{MF}$  were observed in protocols B and C compared with protocol A for triceps brachii, solely in the fifth repetition. In conclusion, training protocols conducted with the same rep-

etition duration, but with different concentric and eccentric durations, produce distinct muscle activation and neuromuscular fatigue responses, in which performing longer concentric durations could be the more appropriate strategy to increase muscle activation and neuromuscular fatigue.

**KEY WORDS** electromyography, amplitude, frequency, resistance training, acute effect

## INTRODUCTION

Studies have investigated the impact of resistance training protocols performed with approximately 6-second repetition duration on acute blood lactate and electromyographic responses (20,30,38); on the rate of perceived exertion (7); and also on strength gains and muscle hypertrophy (40,41). There are studies that also investigated the effects of different types of muscle contraction times with the same repetition duration on neurophysiological responses to resistance training (16,19), but the training protocols were structured with distinct repetition numbers. Considering that concentric and eccentric actions have different characteristics in strength production and EMG responses (10,23), investigating the possible effects of manipulating different muscle action durations for the same repetition duration will provide additional information that would allow for a differentiated prescription of resistance training programs to match the specific needs of an individual. Moreover, there is still a gap in the literature regarding the understanding of the neuromuscular responses that occur from resistance training protocols performed with different muscle action durations, but equalized by repetition duration.

Eccentric and concentric muscle actions have different magnitudes of the EMG signal (EMG amplitude) (10,11,42), with lower EMG amplitudes for eccentric action when compared with the concentric action for the same external

Address correspondence to Mauro H. Chagas, mauroufmg@hotmail.com. 33(6)/1629–1639

*Journal of Strength and Conditioning Research*  
© 2017 National Strength and Conditioning Association

resistance (12). Thus, considering protocols with the same repetition duration, a longer concentric duration may result in a longer time with higher EMG amplitude. Therefore, it is possible that protocols performed with longer concentric durations coupled with the same repetition duration may provide a greater training stimulus, but this hypothesis has yet to be confirmed.

Both acute (19) and chronic (16) responses to protocols with different concentric and eccentric durations have been investigated. Goto et al. (19) compared several protocols that manipulated concentric and eccentric contraction timed with similar 6-second repetition durations (3 second CON: 3 second ECC; or 1 second CON: 5 second ECC; or 5 second CON: 1 second ECC) and found greater blood lactate concentrations and serum cortisol responses after the completion of the protocol 5:1 compared with protocol 1:5. However, these differences observed in the physiological responses may not be attributed to the manipulation of the muscle action durations because the repetition numbers performed for both protocols were different. Gillies et al. (16) reported that at a 6–8 one repetition maximum (1RM), intensity with longer concentric durations (6 second CON: 2 second ECC) resulted in greater increases in the area of type IIA fibers than training with shorter concentric durations (2 second CON: 6 second ECC) when both protocols were equalized by repetition duration. However, there is still a lack of data on the EMG responses (i.e., RMS and mean frequency) during the execution of equivalent multiple-set resistance training protocols (volume, intensity, and rests) with different muscle action durations but similar repetition duration. In previous studies that analyzed the EMG responses in multiple-set training protocols (14,43), the protocols were not equalized based on repetition durations and the muscle action duration was not considered as an independent variable.

Neuromuscular activity during resistance training protocols is often evaluated by recording EMG activity (30,32,43). Collecting EMG activity (amplitude and frequency) during an actual training session could contribute to a better understanding of the muscle activation and neuromuscular fatigue accumulated throughout the exercise session and provide insights about the chronic effects of resistance training (13,30,43). No studies were found that analyzed the EMG frequency responses when manipulating the muscle action durations at the same repetition duration. With the same repetition duration, a longer concentric duration provided higher concentration of blood lactate compared to a protocol with a shorter duration of this muscle action (19). A greater metabolic product accumulation has been related to increases in EMG amplitude and decreases in EMG frequency because of greater fatigue resulting in increased muscle activation to meet force demand and reduced action potential conduction velocity, respectively (3,25). Therefore, the purpose of this study was to compare the effects of equalized multiple-set resistance training protocols with different concentric and eccentric durations (2 second con: 4 second ecc;

3 second CON: 3 second ECC; and 4 second CON: 2 second ECC), on muscle activation (RMS and mean frequency –MF). Based on the previous literature, it may be expected that the EMG amplitude will be significantly higher in the protocols with the longer concentric muscle action durations. It is also likely, based on the literature, that using a single-set training protocol that the EMG amplitude will increase during the repetitions and sets and will be accompanied by a reduction in the EMG frequency.

The results from this study may lead to a better understanding of the neuromuscular responses to training and provide different possibilities for prescribing a resistance training program for coaches under different training circumstances (1).

## METHODS

### Experimental Approach to the Problem

This study used a crossover design (26) to examine the electromyographic responses of resistance training protocols differentiated by concentric and eccentric duration times (2:4; 3:3 and 4:2 seconds). Each volunteer attended the laboratory on 5 different days (experimental sessions 1 through 5) separated by at least 48 hours.

### Subjects

Seventeen males with weight training experience and aged between 18 and 30 years (mean  $\pm$  SD: age = 23.8  $\pm$  2.9 years; height = 1.76  $\pm$  0.08 m; mass = 75.1  $\pm$  8.6 kg; and 1RM Smith machine bench press = 89.6  $\pm$  14.9 kg) participated in this study. The inclusion criteria for participation were (a) currently weight training continuously for at least 6 months before the start of the study; (b) no functional limitations regarding performing the 1RM test or the training protocols; and (c) the ability to lift a weight corresponding to their own body mass on the 1RM Smith machine bench press (27). Subjects were informed about the study objectives, procedures, and risks and freely signed an informed consent form. The local ethics committee of the Federal University of Minas Gerais approved this study, which complied with international standards. The subjects' training routines were modified during the data collection period to avoid performing exercises that require the pectoralis major and triceps brachii muscles 48 hours before each testing session. Additionally, each subject was instructed not to do any physical activity immediately before the testing sessions and to maintain the same dietary practices before each session.

### Procedures

*Experimental Sessions 1 and 2.* The anthropometric measurements (height and body mass) were performed first. Immediately afterward, subjects were positioned on the Smith machine bench press and hand and head positions were standardized, as well as the range of motion. The body positions used on the Smith machine bench press took into account the position normally used during the subjects own training program. Subjects then performed 10 repetitions

without any weight added to the bar. Subsequently, subjects performed the 1RM test for the Smith machine bench press exercise. The 1RM test was executed during the first and second sessions to familiarize the subjects with its procedures and to determine the weight to be used during the after 3 testing sessions. The 1RM test began with an eccentric muscle action by lowering the bar to the sternum, followed by a concentric muscle action, determined by the extension of the elbows and pressing the bar away from the chest. The 1RM was determined within a maximum of 6 attempts, with 5-minute rest periods between each attempt (7,30). The final procedures of experimental sessions 1 and 2 familiarized the subjects with the durations of the different testing conditions by using a metronome ( $60 \text{ b} \cdot \text{min}^{-1}$ ) and allowing the subjects to practice the timing of the different contraction periods for the 3 protocols.

*Experimental Sessions 3, 4, and 5.* An initial pilot study was conducted to test the feasibility of the proposed 3 different training protocols that manipulated concentric and eccentric duration times. Additionally, training protocols with similar concentric and eccentric durations were investigated previously in our laboratory (7,30,34). The overall experimental protocol consisted of 3 sets of 6 repetitions (each repetition 6 second in duration) of bench press at 60% 1RM with 3-minute rests between sets. In protocol A, subjects completed each repetition with 2 second con and 4 second ecc (2:4). In protocol B, the subjects performed each repetition 3 second con and 3 second ecc (3:3), and in protocol C subjects performed each repetition with 4 second con and 2 second ecc (4:2). Because we aimed to maintain the protocol integrity for each condition, the protocols complied with recommendations for resistance training and muscle hypertrophy (1,45), and none of the protocols took subjects to momentary muscle failure during any of the sets.

According to procedures described in Lacerda et al. (30), an electrogoniometer was positioned on the subjects left elbow, and electrodes were fixed to the pectoralis major and triceps brachii muscles as part of the first procedures during experimental sessions 3, 4, and 5. The skin was marked using a semipermanent pen to allow for exact repositioning of the electrogoniometer and electrodes during each successive testing session by the same researcher. After the electrodes and the electrogoniometer were fixed, the subjects rested in a seated position for 10 minutes before completing the training protocol. Electromyographic activity was recorded while performing each set of the training protocol.

In more detail, a calibrated electrogoniometer (Noraxon, Scottsdale, AZ, USA) was fixed on the left elbow of participants using double-sided adhesive tape and elastic bands. The electrogoniometer raw data were converted into angular displacement data and filtered through a fourth-order Butterworth low-pass filter with a cutoff frequency of 10 Hz. The electrogoniometer was also used to determine

the range of motion for the elbow. The duration of each muscle action was comprised of the time spent between the maximum (elbow flexion) and minimum (elbow extension) angular positions; thus, the eccentric duration corresponded to the period between the minimum and maximum angular positions, whereas the concentric duration corresponded to the maximum and minimum angular positions. Additionally, concentric/eccentric and repetition durations were determined throughout the angular displacement time.

The surface electromyography procedure (Biovision, Wehrheim, Germany) followed the recommendations of Hermens et al. (21) and Lagally et al. (31). Bipolar surface electrodes (Ag/AgCl - 3M-2223, Brazil) were placed parallel to the muscle fibers on the subjects' right pectoralis major (sternal portion) and triceps brachii (long head portion) muscles. The skin areas were shaved and cleaned with alcohol and a cotton pad before placing the electrodes. The electrodes were placed in pairs, 2 cm apart from their centers at the point of the greatest muscle area. The ground electrode was fixed at the olecranon.

The electromyographic and electrogoniometer signals were synchronized and converted using an A/D board (Biovision) and sampled at a frequency of 1,000 Hz. Appropriate software (DasyLab 11.0; Measurement Computing Corporation, Norton, MA, USA) was used to record and treat the data. The electromyographic data acquisition was amplified 1,000 times and filtered (second-order Butterworth band-pass filter of 20–500 Hz) to calculate the EMG amplitude as the root mean square ( $\text{EMG}_{\text{RMS}}$ ). Before commencing each experimental session, subjects were asked to perform 3 maximum voluntary isometric contractions (MVIC) on the Smith machine bench press exercise  $90^\circ$  elbow flexion (controlled by the electrogoniometer). The bar was fixed by 2 chains, and the highest value found during the 3 MVIC was used as reference for the normalization of the subsequent measurements (normalization test). Each MVIC was 5 second in duration with 2-minute rest periods between trials (31). Finally, the second and fifth repetitions during each set in the 3 different protocols was used to collect  $\text{EMG}_{\text{RMS}}$  and these values were divided by the respective reference values previously described, generating the normalized  $\text{EMG}_{\text{RMS}}$  per repetition.

The same normalization procedure was adopted for the frequency domain analysis and the mean frequency electromyography ( $\text{EMG}_{\text{MF}}$ ) values obtained for each repetition. These values were normalized by the highest mean frequency value detected during the 3 MVIC attempts during each data collection session. The  $\text{EMG}_{\text{MF}}$  was calculated using the short-time discrete Fourier transform (STFT), which was obtained by applying the Fourier transform in a fixed window size (Hamming window–50ms) on the entire electromyographic signal. The frequency resolution was 20 Hz. The  $\text{EMG}_{\text{MF}}$  was selected because it adequately represented the power spectrum of the signal according to Kwatny et al. (29).

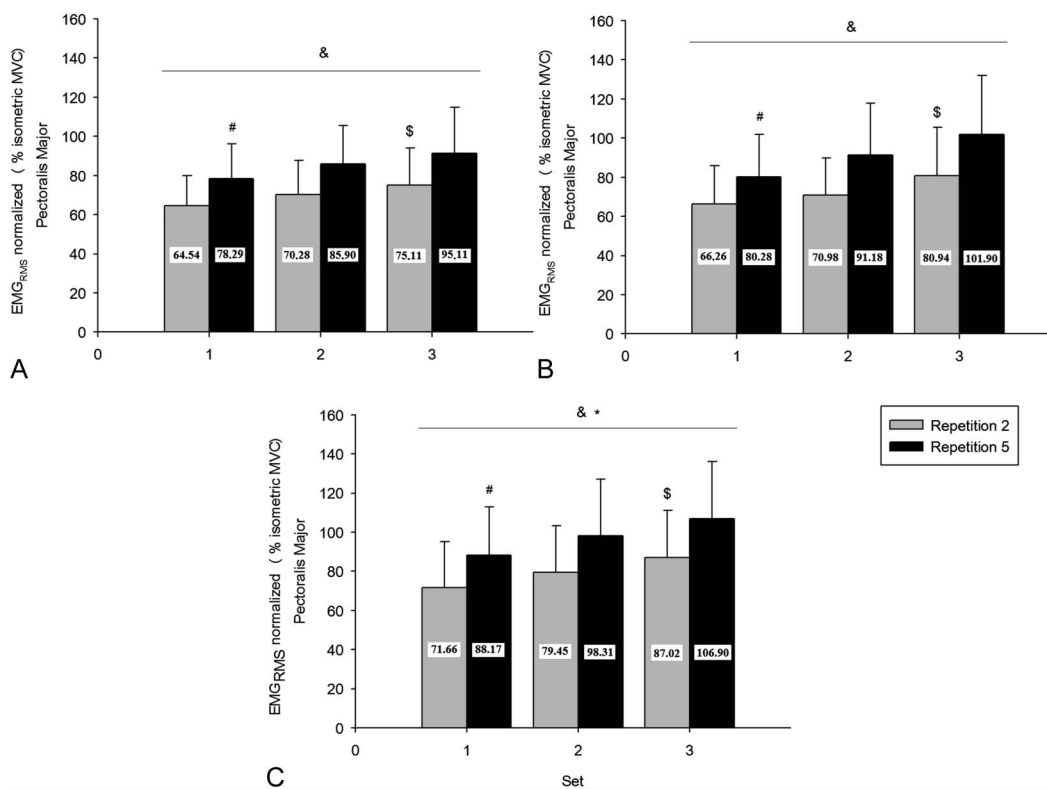
**Statistical Analyses**

Statistical analysis was performed with the software SPSS for Windows version 20.0 (SPSS, Inc., Chicago, IL, USA). Data are presented as mean  $\pm$  SD. For analysis of EMG<sub>RMS</sub> and EMG<sub>MF</sub> normalized for pectoralis major and triceps brachii muscles, the second and fifth repetitions of each set were used for all protocols. The normality and homogeneity of variances were verified using Shapiro–Wilk and Mauchly’s tests, respectively. A 3-way (protocol  $\times$  set  $\times$  repetition) ANOVA with repeated measures assessed the normalized EMG<sub>RMS</sub> and EMG<sub>MF</sub>. When necessary, a post hoc Tukey’s honest significant difference test was used to identify the differences reported in the ANOVAs. The intraclass correlation coefficient (ICC<sub>[3, k]</sub>) of the EMG (RMS and MF) found in the normalization test of experimental sessions 3, 4, and 5 was calculated. The EMG<sub>RMS</sub> intersession values were 0.94 for the pectoralis major and 0.94 for the triceps brachii. The EMG<sub>MF</sub> intersession values were 0.86 for the pectoralis major and 0.98 for the triceps brachii. In addition, eta squared ( $\eta^2$ ) values are reported to reflect the magnitude of the differences in each treatment (small = 0.01, medium = 0.06, and large = 0.14) (4).

A 1-way (protocol) ANOVA with repeated measures were used to compare repetition durations and range of motion. Finally, 2-way (protocol  $\times$  muscle action) ANOVA with repeated measures was used to compare concentric and eccentric durations in all protocols investigated. Probability was set at  $p \leq 0.05$  for statistical significance for all tests.

**RESULTS**

The protocols A (2:4), B (3:3) and C (4:2) had repetition durations of  $5.99 \pm 0.05$  second ( $2.04 \pm 0.09$  second CON;  $3.95 \pm 0.09$  second ECC),  $6.00 \pm 0.06$  second ( $2.92 \pm 0.06$  second CON;  $3.08 \pm 0.09$  second ECC), and  $5.99 \pm 0.10$  second ( $3.85 \pm 0.15$  second CON;  $2.14 \pm 0.14$  second ECC), respectively. No significant main effect for protocol was observed for the repetition duration data ( $F_{(1,16)} = 1.22, p = 0.88, \text{power} = 0.07, \eta^2 < 0.01$ ); however, there was a significant interaction effect observed between protocol and muscle action ( $F_{(2,32)} = 1,342.31, p = 0.001, \text{power} > 0.99, \eta^2 = 0.96$ ). Post hoc analysis indicated that the average muscle action durations for protocol B were different from protocols A and C. As expected, no differences were found for the average muscle action durations (2 and 4 s) between



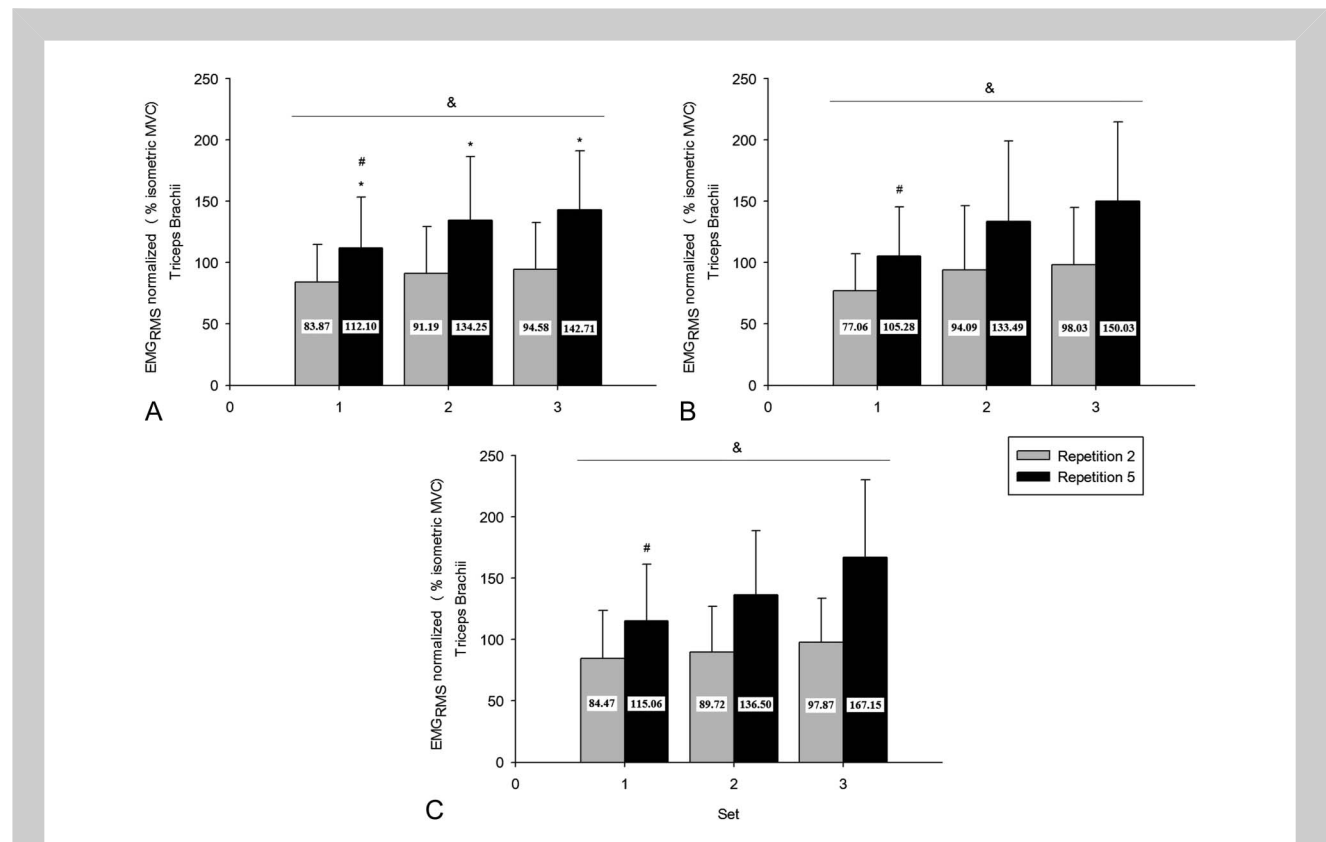
**Figure 1.** A) (protocol 2:4); (B) (protocol 3:3); (C) (protocol 4:2); mean (vertical bars); standard errors (vertical lines); repetition normalized EMG<sub>RMS</sub> of the pectoralis major muscle for each training protocol. \*Different from protocols A and B; #Different from repetition 5 in sets 2 and 3 at the respective protocol; &Repetition 5 different from repetition 2 at the respective protocol. EMG<sub>RMS</sub> = root mean square of the electromyographic signal.

protocols A and C. In addition, differences were observed between the average muscle action durations when comparing protocol B to protocols A and C. Furthermore, there was no significant difference between the concentric and eccentric durations for protocol C. Finally, no significant differences were found for the average range of motion between the protocols A, B, and C ( $59.30 \pm 11.41^\circ$ ;  $60.83 \pm 11.26^\circ$ ;  $59.86 \pm 13.92^\circ$ , respectively;  $F_{(2,32)} = 0.40$ ;  $p = 0.68$ ; power = 0.11;  $\eta^2 = 0.02$ ).

Regarding the pectoralis major normalized EMG<sub>RMS</sub> data, no significant interaction was observed between protocol, set, and repetition ( $F_{(4,64)} = 0.09$ ;  $p = 0.98$ ; power = 0.26;  $\eta^2 < 0.01$ ). Also, no significant interaction was detected between protocol and set ( $F_{(4,64)} = 1.84$ ;  $p = 0.17$ ; power = 0.37;  $\eta^2 = 0.01$ ), or between protocol and repetition ( $F_{(4,64)} = 1.73$ ;  $p = 0.179$ ; power = 0.85;  $\eta^2 < 0.01$ ). The repeated-measures ANOVA indicated a significant main effect for protocol ( $F_{(2,32)} = 5.07$ ,  $p = 0.01$ , power = 0.92,  $\eta^2 = 0.08$ ) with protocol C having higher muscle activation than the protocols A and B throughout the sets and repetitions (Figure 1). Moreover, a significant interaction effect was observed between repetition and set ( $F_{(2,32)} = 3.50$ ,  $p = 0.03$ , power = 0.72,  $\eta^2 < 0.01$ ). Tukey's test verified that

the second repetition in third set was different from the second repetition in the first and second sets. Additionally, the fifth repetition in the first set was different from the fifth repetition in the second and third sets across 3 protocols studied. Furthermore, the post hoc analysis indicated that the fifth repetition was different from the second repetition for all 3 sets and protocols investigated. The main effects for set ( $F_{(2,32)} = 5.95$ ,  $p = 0.01$ , power > 0.99,  $\eta^2 = 0.17$ ) and repetition ( $F_{(1,16)} = 555.82$ ,  $p = 0.001$ , power > 0.99,  $\eta^2 = 0.32$ ) were also significant for the pectoralis major muscle.

No significant interaction was observed between protocol, set, and repetition for the triceps brachii muscle normalized EMG<sub>RMS</sub> data ( $F_{(4,64)} = 0.82$ ;  $p = 0.52$ ; power = 0.71;  $\eta^2 < 0.01$ ) or between protocol and set ( $F_{(4,64)} = 1.90$ ;  $p = 0.12$ ; power = 0.44;  $\eta^2 < 0.01$ ); however, a significant interaction effect was observed between protocol and repetition ( $F_{(2,32)} = 3.49$ ;  $p = 0.03$ ; power = 0.57;  $\eta^2 < 0.01$ ) (Figure 2). Post hoc analysis indicated a higher muscle activation for protocols B and C compared with protocol A, only during the fifth repetition, with the fifth repetition having a higher muscle activations than the second repetition for all protocols. A significant main effect for repetition ( $F_{(1,16)} = 434.80$ ,



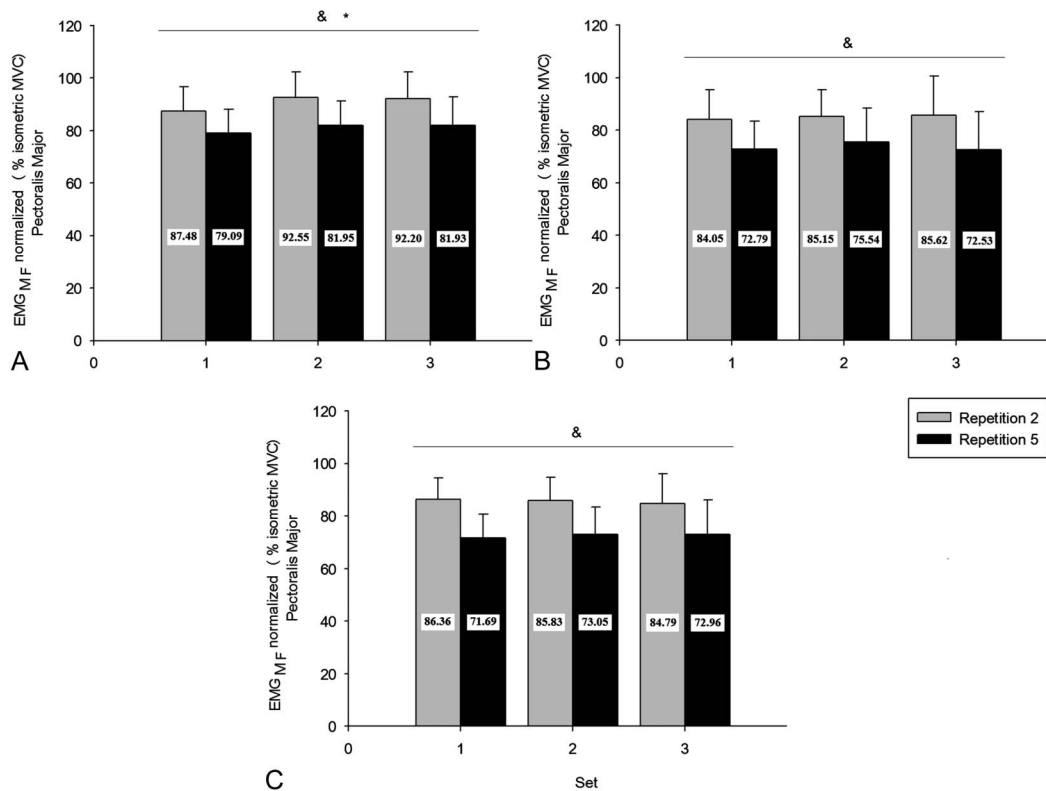
**Figure 2.** A) (protocol 2:4); B) (protocol 3:3); C) (protocol 4:2); mean (vertical bars); standard errors (vertical lines); repetition normalized EMG<sub>RMS</sub> of the triceps brachii muscle for each training protocol. \*Repetition 5 at the respective protocol different from repetition 5 from protocols B and C; #Different from repetition 5 in sets 2 and 3 at the respective protocol; &Repetition 5 different from repetition 2 at the respective protocol. EMG<sub>RMS</sub> = root mean square of the electromyographic signal.

$p = 0.001$ , power  $> 0.99$ ,  $\eta^2 = 0.39$ ) but not for protocol ( $F_{(2,32)} = 2.23$ ,  $p = 0.11$ , power = 0.19,  $\eta^2 < 0.01$ ) was observed. The repeated-measures ANOVA indicated that a significant interaction effect was detected between repetition and set ( $F_{(2,32)} = 11.02$ ,  $p = 0.001$ , power  $> 0.99$ ,  $\eta^2 < 0.03$ ). Tukey's analysis results indicated that the fifth repetition in the first set was different from the fifth repetition in the second and third sets across all 3 protocols studied, whereas no differences were observed for the second repetition throughout the sets and protocols. The post hoc analysis results indicated that the fifth repetition was different from the second repetition in all 3 sets. Finally, the main effect for set ( $F_{(2,32)} = 3.59$ ,  $p = 0.03$ , power  $> 0.99$ ,  $\eta^2 = 0.12$ ) was significant for the triceps brachii muscle.

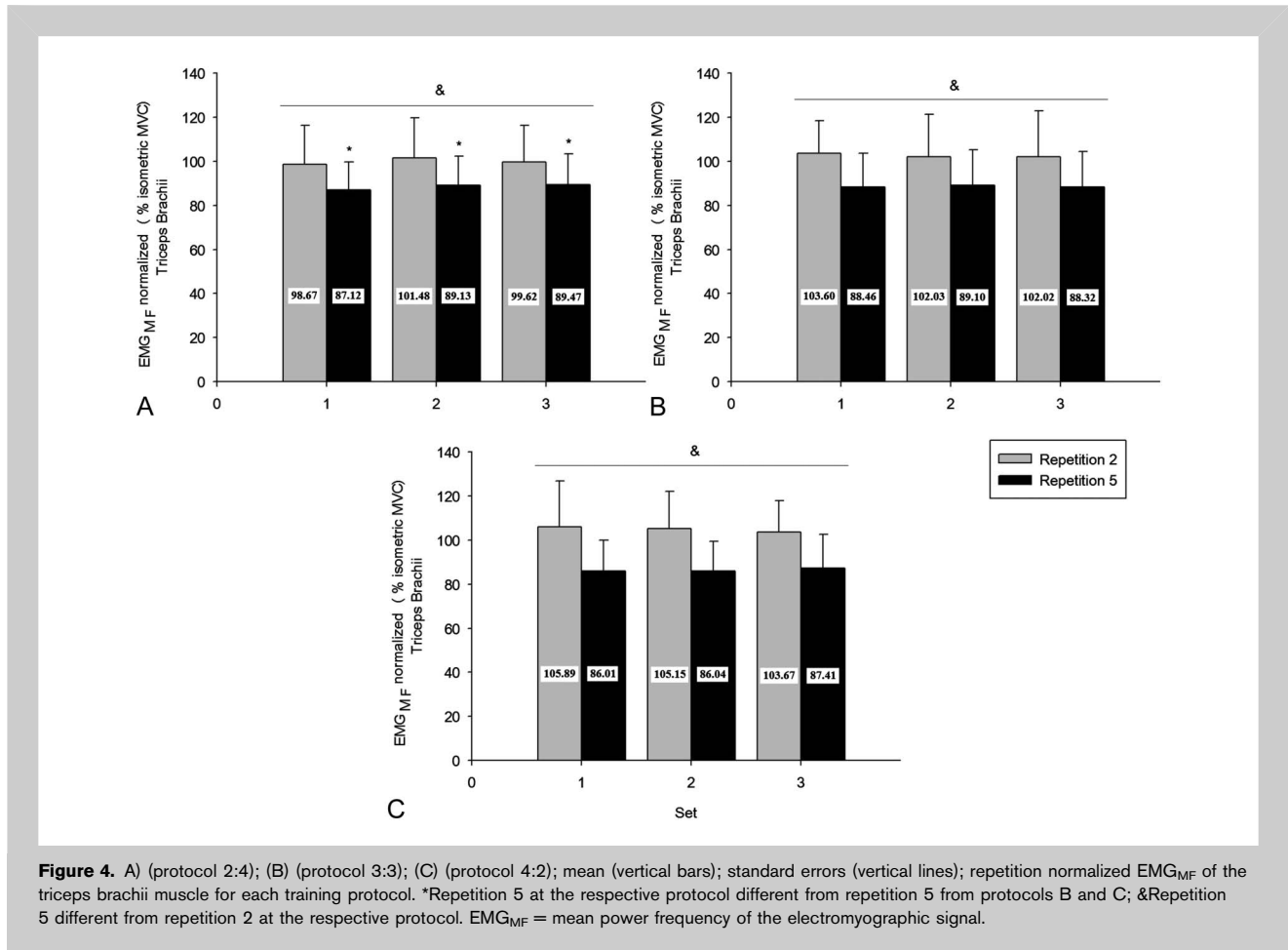
Concerning the normalized EMG<sub>MF</sub> data, no significant interaction was observed between protocol, set, and repetition for the pectoralis major ( $F_{(4,64)} = 0.83$ ;  $p = 0.51$ ; power = 0.40;  $\eta^2 < 0.01$ ) and no significant interactions were found between protocol and set ( $F_{(4,64)} = 1.98$ ;  $p = 0.11$ ; power = 0.56;  $\eta^2 < 0.01$ ), protocol and repetition ( $F_{(4,64)} = 2.80$ ;  $p = 0.06$ ; power = 0.55;  $\eta^2 < 0.01$ ) and set and repetition ( $F_{(4,64)} = 0.02$ ;  $p = 0.98$ ; power = 0.07;  $\eta^2 < 0.01$ ). The

repeated-measures ANOVA indicated a significant main effect for protocol ( $F_{(2,32)} = 7.23$ ,  $p = 0.001$ , power = 0.90,  $\eta^2 = 0.10$ ) with protocols B and C having a lower EMG<sub>MF</sub> than protocol A across the sets and repetitions (Figure 3). Additionally, a significant main effect for repetition ( $F_{(1,16)} = 340.35$ ,  $p = 0.001$ , power  $> 0.99$ ,  $\eta^2 = 0.33$ ) was also found for the pectoralis major. Tukey's test verified that the fifth repetition had a lower EMG<sub>MF</sub> than the second repetition across all sets and protocols. No significant main effect for set ( $F_{(2,32)} = 0.34$ ,  $p = 0.71$ , power = 0.25,  $\eta^2 = 0.01$ ) was observed.

No significant interaction was observed for the normalized EMG<sub>MF</sub> data between protocol, set, and repetition for the triceps brachii muscle ( $F_{(4,64)} = 0.16$ ;  $p = 0.96$ ; power = 0.10;  $\eta^2 < 0.01$ ). In addition, no significant interaction was found between protocol and set ( $F_{(4,64)} = 0.48$ ;  $p = 0.75$ ; power = 0.16;  $\eta^2 < 0.01$ ) or set and repetition ( $F_{(4,64)} = 0.50$ ;  $p = 0.61$ ; power = 0.13;  $\eta^2 < 0.01$ ); however, a significant interaction effect was observed between protocol and repetition ( $F_{(2,32)} = 3.92$ ;  $p = 0.02$ ; power = 0.78;  $\eta^2 = 0.01$ ) (Figure 4). The post hoc analysis indicated that protocols B and C had a lower EMG<sub>MF</sub> than protocol A, but only for the fifth



**Figure 3.** A) (protocol 2:4); (B) (protocol 3:3); (C) (protocol 4:2); mean (vertical bars); standard errors (vertical lines); repetition normalized EMG<sub>MF</sub> of the pectoralis major muscle for each training protocol. \*Different from protocols B and C; &Repetition 5 different from repetition 2 at the respective protocol. EMG<sub>MF</sub> = mean power frequency of the electromyographic signal.



**Figure 4.** A) (protocol 2:4); B) (protocol 3:3); C) (protocol 4:2); mean (vertical bars); standard errors (vertical lines); repetition normalized EMG<sub>MF</sub> of the triceps brachii muscle for each training protocol. \*Repetition 5 at the respective protocol different from repetition 5 from protocols B and C; &Repetition 5 different from repetition 2 at the respective protocol. EMG<sub>MF</sub> = mean power frequency of the electromyographic signal.

repetition. Also, the fifth repetition had a lower EMG<sub>MF</sub> than the second repetition across all sets and protocols. Only the main effect for repetition ( $F_{(1,16)} = 199.82, p = 0.001, \text{power} > 0.99, \eta^2 = 0.37$ ) was significant, with no significant main effects for protocol ( $F_{(2,32)} = 0.20, p = 0.79, \text{power} = 0.09, \eta^2 < 0.01$ ) or set ( $F_{(2,32)} = 0.02, p = 0.98, \text{power} = 0.06, \eta^2 = 0.01$ ) for the triceps brachii.

### DISCUSSION

The purpose of this study was to compare the level of activation of the pectoralis major and triceps brachii muscles during the completion of equalized (based on 6-second repetition duration) training protocols with different muscle action. The results showed that the normalized EMG<sub>RMS</sub> responses were greater in protocol C than in protocols A and B for the pectoralis major across sets and repetitions. In addition, the normalized EMG<sub>MF</sub> responses were lower in protocols B and C than in protocol A throughout the sets and repetitions. Considering the triceps brachii, significantly higher normalized EMG<sub>RMS</sub> and lower normalized EMG<sub>MF</sub> for protocols B and C were found compared with protocol A, but only for the fifth repetition. Thus, protocols with longer concentric duration times placed a greater

physiological demand on the muscle compared with other protocols. The results are in agreement with the findings of Goto et al. (19) who reported that when the repetition durations are similar, the protocol performed with longer concentric duration time (5 s) had increased levels of blood lactate and serum cortisol concentrations compared with protocols with shorter concentric durations (1 s), indicating a greater metabolic demand.

The pectoralis major had a higher normalized EMG<sub>RMS</sub> for protocol C compared with protocols A and B across all sets and repetitions (protocol main effect). In addition, a medium effect size was found for the protocol main effect, reinforcing the result observed in ANOVA. This higher normalized EMG<sub>RMS</sub> in protocol C may be related to the fact that subjects spent more time in the concentric muscle action across all repetitions. To the best of our knowledge, no other studies have compared the level of muscle activation between equalized resistance training protocols with different combinations of muscle action durations; however, a possible explanation for this result seems to be related to the specific characteristics of the concentric muscular action. Previous studies that investigated isolated concentric and eccentric muscle actions have indicated that concentric

and eccentric actions differ in relation to EMG activation (10–12,41). The lower EMG activation during the eccentric action compared with the concentric action is related to the lower need for contractile tissue participation because there is a greater participation of the passive components of the muscle-tendon unit during the force production (8,10). Based on the expectation of a greater EMG activation during concentric muscle action and considering the same overall repetition duration, in the training protocols with a longer concentric duration, subjects would have spent a longer time at a higher level of EMG activation during each repetition. Thus, this higher level of muscle activation for each repetition would be required throughout the sets, resulting in a higher  $EMG_{RMS}$  for protocol C. The increased normalized  $EMG_{RMS}$  in the present study reinforces this reasoning and is an indication of the recruitment of higher threshold motor units in order to maintain the level of force production required to perform the task (24). However, other factors such as increased firing frequency and motor unit synchronization may also influence EMG amplitude (24,39) and should not be discarded in the interpretation of these results. The results of the present study regarding the  $EMG_{RMS}$  activity of the pectoralis major muscle suggest that the longer time under tension during concentric muscle actions was a determinant for a greater muscular activation as verified in protocol C compared with protocols A and B throughout the repetitions and sets.

In contrast to the results for the pectoralis major muscle, the triceps brachii exhibited a greater muscle activation for protocols B and C compared with protocol A, but only for the fifth repetition. This result indicates that the manipulation of variables within a training protocol can influence the activation of the different muscles involved in exercise. According to Kulig et al. (28), resistance training protocols performed with different velocities motion lead to distinct muscle activation responses in pennate and fusiform muscles. So, this difference in the triceps brachii (fusiform muscle) response compared with the pectoralis major (multipennate muscle) possibly would be related to anatomical characteristics between these 2 muscles. In addition, other factors as the characteristic of the investigated protocols and the Smith bench press exercise may have caused this distinct response between the investigated muscles, but the study design proposed for the present study do not allows to confirm this reasoning, being necessary further studies to elucidate these issues. However, the results of McCaw and Friday (36) reinforce the expectation that both aspects (training load and type of bench press exercise) have an influence on muscle activation. These authors verified that the differences in the activation of the muscles involved in the bench press exercise (pectoralis major, anterior and medial deltoids, and triceps brachii), when performed with free and machine weights, were higher for 60% 1RM than 80% 1RM. The results of the present study corroborate the complex behavior of the  $EMG_{RMS}$  response in relation to different muscles and training protocols.

In a previous study, lower ICC values in the reproducibility analysis of the EMG activity for the triceps brachii compared with the pectoralis major for the bench press during normalization tests performed during different training sessions were reported (30). The ICC reflects the magnitude of the variability between subjects and the consistency in different measures in the same test. Thus, lower ICC values indicate the differences between subjects do not remain stable when the same test condition is repeated, which may favor the occurrence of a type 2 error (44). However, the ICC results of the present study showed similar intersession ICC values for the pectoralis major and triceps muscles ( $ICC = 0.94$ ) and therefore makes it unlikely that a type 2 error was committed. On other hand, the normalized  $EMG_{RMS}$  for the triceps brachii in present study did have a greater variability (large standard deviation values) compared with pectoralis major. These data are in agreement with other studies that investigated the EMG responses during the bench press exercise (9,30,34). Additionally, inconsistent patterns in the relationship between EMG amplitude and the force responses for biarticular movements compared with monoarticular muscles have been reported (33). These authors speculate that the different anatomical functions performed by biarticular muscles would result in a high degree of variability in the EMG amplitude and force responses. Therefore, although variability in the muscle activation during resistance training protocols has often been reported in the literature (17,31), this fact may explain the distinct EMG amplitude responses between the triceps brachii and pectoralis major muscles.

Furthermore, the normalized  $EMG_{RMS}$  response increased across repetitions and sets for all protocols and muscles. However, a small effect size was observed for the analysis of the interaction effect between repetition and set. Nevertheless, this small effect size contrasts with the large effect size found for the main effects (set and repetition) points out that there is an increase of muscle activation across sets and repetition. Although the current study verified this response and agrees with previous studies (14,43), the experimental designs of these studies were not intended to verify the impact of the manipulation of a certain variable related to the training load on the EMG activity during the sets, and for this reason, the authors did not equate the training loads used between the different protocols. To the best of our knowledge, no studies have been found that investigated EMG activation across multiple sets in matched training protocols. Because of this limitation, data from a single-set protocol related to EMG activation may provide insights for a multiset protocol analysis. Sakamoto and Sinclair (38) investigated the EMG activity in single-set protocols (different intensities and repetition durations) and found an increase in EMG amplitude at the end of the sets. Although speculative, this result may indicate a possible explanation for the increase in normalized  $EMG_{RMS}$  verified over the course of the sets. Thus, considering that this



response also occurred at the end of the first set for the Sakamoto and Sinclair study; in the present study, it is possible that some motor units may not have fully recovered for participation in the subsequent set (second set), thus requiring the recruitment of additional motor units in the second and again in the third set of the protocol. This response may be associated with the characteristics of the training protocols (volume, intensity, rest, and repetition duration), and the maintenance of the 6 second repetition duration may have been a difficult task for volunteers who were not used to training with this duration. Recent research by Diniz et al. (7) reinforces this perspective. These authors analyzed equalized and similar resistance training protocols as those used in the present study and demonstrated that protocols with 6 second repetition duration produced significantly higher subjective perceived exertion values when compared to protocols with 4 second or self-paced repetition durations across all 3 sets.

Similar to  $EMG_{RMS}$  measurements obtained during the training sessions, no studies were found that analyzed the  $EMG_{MF}$  responses when manipulating the concentric duration while equalizing the repetition duration. In this study, the normalized  $EMG_{MF}$  responses were lower in protocols B and C than in protocol A for the pectoralis major throughout the sets and repetitions. In addition, a medium effect size for protocol main effect was verified, reinforcing the result found by ANOVA. A lower normalized  $EMG_{MF}$  was observed for the triceps brachii for protocols B and C compared with protocol A, only for the fifth repetition, but it is worth note to highlight that a small effect size for interaction effect between repetition and protocol was found. These results indicate the differences between protocols for normalized  $EMG_{MF}$  for the triceps brachii in present study are not as evident as for the normalized  $EMG_{MF}$  pectoralis major. This fact was probably because of a greater activation variability for triceps brachii muscle. The  $EMG_{MF}$  response during an actual training session could contribute to a better understanding of the neuromuscular fatigue accumulated throughout the exercise and provide insights about the chronic effects of resistance training (25,38,43). It has been suggested that decreases in  $EMG_{MF}$  during fatiguing protocols are caused by shifts in the power spectrum EMG toward lower frequencies (6,22). The fatigue-induced shifts in the EMG power spectrum have been attributed to decreases in intramuscular pH (3). Therefore, at least in part, the higher percent decreases in  $EMG_{MF}$  observed during the protocols performed with greater time under tension in the concentric muscle action in the present study (protocols B and C) may be related to a greater metabolic product accumulation (25). Also, it is known that an increased intramuscular acidity with a reduced sarcoplasmic reticulum  $Ca^{2+}$  uptake may promote an impairment of muscle contractile function (37). Results of the study by Goto et al. (19) are in agreement with the reasoning presented. A lower number of maximal repetitions and a higher concentration of blood

lactate were observed after a protocol with a longer concentric duration (5 s) compared to a protocol with a shorter duration of this muscle action (1 s), considering protocols with the same 6 second repetition duration. However, further studies are needed to investigate whether comparable protocols, but with smaller differences in muscle action durations (e.g., similar to those investigated in the present study), are capable of providing greater metabolic responses (e.g., intramuscular pH). Moreover, the reduction in  $EMG_{MF}$  with fatigue seems to be primarily because of decreases in muscle fiber conduction velocity associated with decline in intramuscular pH (3), changes in action potential shape (22), and decreases in firing rate of fatigued fast motor units (6,18).

In the present study, a normalized  $EMG_{MF}$  decrease accompanied by a progressive increase of the normalized  $EMG_{RMS}$  across the repetitions for all protocols and muscles was also found. These results were reinforced to the large effect size for repetition main effect. Decreases in EMG frequency during exercise in parallel with increases in EMG amplitude have been observed during sustained submaximal isometric (15) and dynamic exercise contractions (18,35). Studies report that the progressive decline in EMG frequency together with the increase in EMG amplitude with fatigue may be related to an increased synchronization of motor units firing frequency (5,43,46) rather than the recruitment of additional motor units to partially compensate for the loss of force of the motor units active throughout the repetitions (15,24). Therefore, these mechanisms could be the muscle activation strategy to maintain work output across the repetitions (43). These results show that different ways of organizing muscle action durations result in distinct muscular activation and neuromuscular fatigue, indicating a possible alternative for the variation of the training stimulus.

## PRACTICAL APPLICATIONS

This study showed that training protocols conducted with the same repetition duration, but with different configurations of muscle action durations, produced distinct muscle activation and neuromuscular fatigue responses, suggesting that performing longer concentric durations could be a more appropriate strategy to increase muscle activation and neuromuscular fatigue.

All 3 protocols investigated in the present study are shown to be effective in stimulating the neuromuscular system based on the EMG amplitude results across sets and repetitions and the decreases in EMG frequency throughout repetitions, and these responses are strategies used to maintain work output. However, greater responses were observed in the protocols with longer concentric durations. Given the expectation that the activated muscle fibers are those that adapt to training, protocols which show higher EMG amplitude and greater decreases in EMG frequency would present greater potential to promote increases in

strength and muscle hypertrophy. Therefore, considering the impact of increasing muscle activation and neuromuscular fatigue responses to chronic adaptations to resistance training, physical trainers and coaches could opt for these longer concentric durations training as an attempt to obtain better results.

#### ACKNOWLEDGMENTS

This study received support from the FAPEMIG; CAPES (Brazil); and PRPq da Universidade Federal de Minas Gerais.

#### REFERENCES

- American College of Sports Medicine. American College Sports Medicine position stand: Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 41: 687–708, 2009.
- Bigland-Ritchie, BR, Dawson, NJ, Johansson, RS, and Lippold, OC. Reflex origin for the slowing of motoneurone firing rates in fatigue of human voluntary contractions. *J Physiol* 379: 451–459, 1986.
- Brody, LR, Pollock, MT, Roy, SH, De Luca, CJ, and Celli, B. PH induced effects on median frequency and conduction velocity of the myoelectric signal. *J Appl Physiol* (1985) 71: 1878–1885, 1991.
- Cohen, J. The Analysis of Variance. In: 2nd, ed. J Cohen, ed. *Statistical Power Analysis for the Behavioral Sciences*. Hillsdale, NJ: Lawrence Erlbaum Associates, 1988. pp. 273–406.
- Dartnell, T, Nordstrom, MA, and Semmler, JG. Motor unit synchronization is increased in biceps brachii after exercise-induced damage to elbow flexor muscles. *J Neurophysiol* 99: 1008–1019, 2008.
- De Luca, CJ. Towards Understanding the EMG Signal. In: J.V. Basmajian, ed. *Muscles Alive*. Baltimore, MD: Lippincott, Williams and Wilkins, 1985. pp. 53–78.
- Diniz, RC, Martins-Costa, HC, Machado, SC, Lima, FV, and Chagas, MH. Repetition duration influences ratings of perceived exertion. *Percept Mot Skills* 118: 261–273, 2014.
- Duchateau, J and Enoka, RM. Neural control of shortening and lengthening contractions: Influence of task constraints. *J Physiol* 586: 5853–5864, 2008.
- Dunnick, DD, Brown, LE, Coburn, JW, Lynn, SK, and Barillas, SR. Bench press upper-body muscle activation between stable and unstable loads. *J Strength Cond Res* 29: 3279–3283, 2015.
- Enoka, RM. Eccentric contractions require unique activation strategies by the nervous system. *J Appl Physiol* (1985) 81: 2339–2346, 1996.
- Enoka, RM and Fuglevand, A. Motor unit physiology: Some unresolved issues. *Muscle Nerve* 24: 4–17, 2001.
- Fang, Y, Siemionow, V, Sahgal, V, Xiong, F, and Yue, GH. Greater movement-related cortical potential during human eccentric versus concentric muscle contractions. *J Neurophysiol* 86: 1764–1772, 2001.
- Fatela, P, Reis, JF, Mendonca, GV, Avela, J, and Mil-Homens, P. Acute effects of exercise under different levels of blood-flow restriction on muscle activation and fatigue. *Eur J Appl Physiol* 116: 985–995, 2016.
- Finn, HT, Brennan, SL, Gonano, BM, Knox, MF, Ryan, RC, Siegler, JC, and Marshall, PW. Muscle activation does not increase after a fatigue plateau is reached during 8 sets of resistance exercise in trained individuals. *J Strength Cond Res* 28: 1226–1234, 2014.
- Fuglevand, AJ, Zackowski, KM, Huey, KA, and Enoka, RM. Impairment of neuromuscular propagation during human fatiguing contractions at submaximal forces. *J Physiol* 460: 549–572, 1993.
- Gillies, EM, Putman, CT, and Bell, GJ. The effect of varying the time of concentric and eccentric muscle actions during resistance training on skeletal muscle adaptations in women. *Eur J Appl Physiol* 97: 443–453, 2009.
- Glass, SC and Armstrong, T. Electromyographical activity of the pectoralis muscle during incline and decline bench presses. *J Strength Cond Res* 11: 163–167, 1997.
- Gorostiaga, EM, Navarro-Amézqueta, I, González-Izal, M, Malanda, A, Granados, C, Ibáñez, J, Setuain, I, and Izquierdo, M. Blood lactate and sEMG at different knee angles during fatiguing leg press exercise. *Eur J Appl Physiol* 112: 1349–1358, 2012.
- Goto, K, Ishii, N, Kizuka, T, Kraemer, RR, Honda, Y, and Takamatsu, K. Hormonal and metabolic responses to slow movement resistance exercise with different durations of concentric and eccentric actions. *Eur J Appl Physiol* 106: 731–739, 2009.
- Headley, SA, Henry, K, Nindl, BC, Thompson, BA, Kraemer, WJ, and Jones, MT. Effects of lifting tempo on one repetition maximum and hormonal responses to a bench press protocol. *J Strength Cond Res* 25: 406–413, 2011.
- Hermens, HJ, Freriks, B, Disselhorst-Klug, C, and Rau, GJ. Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol* 10: 361–374, 2000.
- Hermens, HJ, Bruggen, TA, Baten, CT, Rutten, WL, and Boom, HB. The median frequency of the surface EMG power spectrum in relation to motor unit firing and action potential properties. *J Electromyogr Kinesiol* 2: 15–25, 1992.
- Hollander, DB, Kraemer, RR, Kilpatrick, MW, Ramadan, ZG, Reeves, GV, Francois, M, Hebert, EP, and Tryniecki, JL. Maximal eccentric and concentric strength discrepancies between young men and women for dynamic resistance exercise. *J Strength Cond Res* 21: 34–40, 2007.
- Hunter, SK, Duchateau, J, and Enoka, RM. Muscle fatigue and the mechanisms of task failure. *Exerc Sport Sci Rev* 32: 44–49, 2004.
- Jenkins, ND, Housh, TJ, Bergstrom, HC, Cochrane, KC, Hill, EC, Smith, CM, Johnson, GO, Schmidt, RJ, and Cramer, JT. Muscle activation during three sets to failure at 80 vs. 30 % 1RM resistance exercise. *Eur J Appl Physiol* 115: 2335–2347, 2015.
- Jones, B and Kenward, G. Design and Analysis for Three or More Treatments. In: B. Jones and G. Kenward, eds. *Design and Analysis of Cross-over Trials*. London, England: Chapman & Hall, 2003. pp. 189–241.
- Keogh, J, Wilson, G, and Weatherby, R. A cross-sectional comparison of different resistance training techniques in the bench press. *J Strength Cond Res* 13: 247–258, 1999.
- Kulig, K, Powers, CM, Shellock, FG, and Terk, M. The effects of eccentric velocity on activation of elbow flexors: Evaluation by magnetic resonance imaging. *Med Sci Sports Exerc* 33: 196–200, 2001.
- Kwatny, E, Thomas, DH, and Kwatny, HG. An application of signal processing techniques to the study of myoelectric signals. *IEEE Trans Biomed Eng* 17: 303–313, 1970.
- Lacerda, LT, Martins-Costa, HC, Diniz, RCR, Lima, FV, Andrade, AGP, Tourino, FD, Bembem, MG, and Chagas, MH. Variations in repetition duration and repetition numbers influence muscular activation and blood lactate response in protocols equalized by time under tension. *J Strength Cond Res* 30: 251–258, 2016.
- Lagally, KM, McCaw, ST, Young, GT, Medema, HC, and Thomas, DQ. Ratings of perceived exertion and muscle activity during the bench press exercise in recreational and novice lifters. *J Strength Cond Res* 18: 359–364, 2004.
- Looney, DP, Kraemer, WJ, Joseph, MF, Comstock, BA, Denegar, CR, Flanagan, SD, Newton, RU, Szivak, TK, DuPont, WH, Hooper, DR, Häkkinen, K, and Maresh, CM. Electromyographical and perceptual responses to different resistance intensities in a squat protocol: Does performing sets to failure with light loads produce the same activity? *J Strength Cond Res* 30: 792–799, 2016.
- Luera, MJ, Stock, MS, and Chappell, ADW. Electromyographic amplitude vs. concentric and eccentric squat force relationships for monoarticular and biarticular thigh muscles. *J Strength Cond Res* 28: 328–338, 2014.

34. Martins-Costa, HC, Diniz, RCR, Lima, FV, Machado, SC, Almeida, RSV, Andrade, AGP, and Chagas, MH. Longer repetition duration increases muscle activation and blood lactate response in matched resistance training protocols. *Motriz* 22: 35–41, 2016.
35. Masuda, K, Masuda, T, Sadoyama, T, Inaki, M, and Katsuta, S. Changes in surface EMG parameters during static and dynamic fatiguing contractions. *J Electromyogr Kinesiol* 9: 39–46, 1999.
36. McCaw, ST and Friday, JJ. A comparison of muscle activity between a free weight and machine bench press. *J Strength Cond Res* 8: 259–264, 1994.
37. Place, N, Bruton, JD, and Westerblad, H. Mechanisms of fatigue induced by isometric contractions in exercising humans and in mouse isolated single muscle fibres. *Clin Exp Pharmacol Physiol* 36: 334–339, 2009.
38. Sakamoto, A and Sinclair, PJ. Muscle activations under varying lifting speeds and intensities during bench press. *Eur J Appl Physiol* 112: 1015–1025, 2012.
39. Suzuki, H, Conwit, R, Stashuk, D, Santarsiero, L, and Metter, E. Relationships between surface-detected EMG signals and motor unit activation. *Med Sci Sports Exerc* 34: 1509–1517, 2002.
40. Tanimoto, M, Sanada, K, Yamamoto, K, Kawano, H, Gando, Y, Tabata, I, Ishii, N, and Miyachi, M. Effects of whole-body low-intensity resistance training with slow movement and tonic force generation on muscular size and strength in young men. *J Strength Cond Res* 22: 1926–1938, 2008.
41. Tanimoto, M and Ishii, N. Effects of low-intensity resistance exercise with slow movement and tonic force generation on muscular function in young men. *J Appl Physiol* 100: 1150–1157, 2006.
42. Tesch, PA, Dudley, GA, Duvoisin, MR, Hather, BM, and Harris, RT. Force and EMG signal patterns during repeated bouts of concentric or eccentric muscle actions. *Acta Physiol Scand* 138: 263–271, 1990.
43. Walker, S, Davis, L, Avela, J, and Häkkinen, K. Neuromuscular fatigue during dynamic maximal strength and hypertrophic resistance loadings. *J Electromyogr Kinesiol* 22: 356–362, 2012.
44. Weir, JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J Strength Cond Res* 19: 231–240, 2005.
45. Wernbom, M, Augustsson, J, and Thomeé, R. The influence of frequency, intensity, volume and mode of strength training on whole muscle cross-sectional area in humans. *Sports Med* 37: 225–264, 2007.
46. Yao, W, Fuglevand, RJ, and Enoka, RM. Motor-unit synchronization increases EMG amplitude and decreases force steadiness of simulated contractions. *J Neurophysiol* 83: 441–452, 2000.