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# VARIATIONS IN REPETITION DURATION AND REPETITION NUMBERS INFLUENCE MUSCULAR ACTIVATION AND BLOOD LACTATE RESPONSE IN PROTOCOLS EQUALIZED BY TIME UNDER TENSION

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## ABSTRACT

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(1): 251–258, 2016—The aim of this study was to investigate the impact of protocols equalized by the time under tension (TUT) but composed of different repetition durations and repetitions numbers on muscle activation and blood lactate concentration. Twenty-two males with previous experience in resistance training performed 2 training protocols (A and B) with the Smith machine bench press exercise, both with 3 sets, 3 minutes' rest, and 60% of 1 repetition maximum (1RM). Protocol A consisted of 6 repetitions with a 6-second repetition duration for each repetition, whereas in Protocol B the subjects performed 12 repetitions with a 3-second repetition duration for each repetition. Muscular activation was measured in the anterior deltoid, pectoralis major, and triceps brachii muscles while performing the 2 protocols, and the normalized root mean square of the electromyographic signal (EMG<sub>RMS</sub>) was calculated for each set. Blood lactate concentrations were measured during and until 12 minutes after the completion of each protocol. The results showed that the EMG<sub>RMS</sub> of all muscles increased during the sets and was higher in Protocol B when compared with Protocol A. Likewise, blood lactate concentrations also increased throughout the sets and were higher in Protocol B both during and after the completion of each training session. The data obtained in this study show that training protocols conducted

with the same TUT, but with different configurations, produce distinct neuromuscular and metabolic responses so that performing higher repetition numbers with shorter repetition durations might be a more appropriate strategy to increase muscle activation and blood lactate concentration.

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

## INTRODUCTION

The time under tension (TUT) has shown to be able to alter neurophysiological, hormonal, and metabolic responses (8,18,35), and to influence the strength gains and muscle hypertrophy caused by resistance training (35,38). During resistance training, the TUT can be structured by manipulating different training variables such as the repetition duration (time spent for the performance of a concentric and eccentric muscle action) and the repetition numbers to complete the set (36,37). Considering that these variables are often manipulated in resistance training protocols (2,39), it would be relevant to understand the effects of performing training protocols with the same TUT, but structured with different repetition durations and repetition numbers.

The neuromuscular activity during resistance training protocols has often been evaluated by recording electromyographic activity (EMG) (8,15,33,35,36). To the best of our knowledge, only the study of Tran and Docherty (36) has analyzed EMG responses provided by different training protocols equalized by the TUT. For one of the training protocols studied by these authors, the subjects performed 3 sets of 10 repetitions with a repetition duration of 7 seconds, whereas in the other experimental situation the same subjects performed 3 sets of 5 repetitions with a repetition duration of 14 seconds, totaling a TUT of 210 seconds in both situations. Maximum voluntary isometric contractions were evaluated for maximal strength and muscle activation

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through the amplitude of the EMG signal before and after 2 different training protocols. Tran and Docherty (36) reported similar reductions in muscle activation for both experimental conditions; however, the protocol that used shorter repetition durations and higher numbers of repetitions (7 seconds and 10 repetitions, respectively) produced a greater reduction in the maximal force after the training session. Although the authors manipulated the repetition duration and repetition numbers while keeping TUT equal, the EMG data was only collected before and after each experimental situation in an attempt to provide information about possible fatigue mechanisms. Collecting EMG activity during the actual training session could contribute to a better understanding of the muscle activation obtained throughout the exercise and provide insights about the chronic effects of resistance training (15,32,33,35). In this sense, further studies should also investigate EMG responses during different protocols equalized by TUT.

Another aspect that should be considered is that Tran and Docherty (36) investigated 2 protocols with repetition durations of 7 and 14 seconds, respectively, whereas in general shorter repetition durations less than 7 seconds are recommended for resistance training emphasizing muscle hypertrophy (2,39). Therefore, information about the effects of different protocols equalized by TUT but involving lower repetition durations (shorter than 7 seconds) still represents a gap in the resistance training literature.

Research that has manipulated the repetition duration and number of repetitions has also shown that the change of these variables alters other physiological responses such as blood lactate concentrations (27,29,35,38). It has been suggested that increasing the repetition duration, without changing the repetition numbers, could increase the metabolic response provided by resistance training (27,38). In addition, it has also been reported that the repetition numbers per set are important in determining metabolic stress (29). However, when analyzing the training protocols that manipulated both repetition duration and repetition numbers, no differences in blood lactate concentrations were observed (7). It should be noted that the experimental designs used in these aforementioned studies did not equalize the protocols based on TUT.

Therefore, the purpose of the present investigation was to compare the muscle activation and blood lactate responses of 2 resistance training protocols composed of different repetition durations and repetition numbers but equalized by TUT.

## METHODS

### Experimental Approach to the Problem

This study used a crossover design to examine the electromyographic and metabolic responses of resistance training protocols differentiated by repetition duration (3:3 and 1.5:1.5 seconds) and repetitions numbers (6,12). Each volunteer attended the laboratory on 4 different days (experimental

sessions 1 through 4) separated by at least 48 hours. The same data collection schedule was maintained for each subject across all sessions.

### Subjects

Twenty-two males with weight training experience and aged between 18 and 30 years (mean  $\pm$  SD: age  $23.47 \pm 3.44$  years; height  $1.77 \pm 0.08$  m; body mass  $76.79 \pm 10.32$  kg; 1 repetition maximum [1RM]  $92.95 \pm 17.16$  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. Subjects were informed about the study objectives, procedures, and risks and freely signed an informed consent form. The local ethics committee of the university approved this study, which complied with international standards. The subjects' training routines were modified during the data collection period to avoid performing exercises that use the anterior deltoid, pectoralis major, or triceps brachii muscles 48 hours before sessions. 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.* After assessing anthropometric measurements, subjects were positioned on the bench of the Smith press machine and hand and head positions were standardized, as well as the range of motion. Subjects then performed 10 repetitions without any additional weight added to the bar. Subsequently, subjects performed the 1RM test for the Smith machine bench press exercise. The 1RM test was performed during the first and second sessions to familiarize the subjects with its procedures and to determine the weight for the following sessions. The 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. One repetition maximum was determined within a maximum of 6 attempts, with 5 minutes' rest periods between each attempt. Averages of  $4.4 \pm 1.0$  and  $3.5 \pm 0.8$  attempts were necessary to determine the 1RM performance for experimental sessions 1 and 2, respectively. As the last procedure of experimental sessions 1 and 2, participants were also familiarized with the use of the metronome ( $60$  or  $120$   $\text{b} \cdot \text{min}^{-1}$ ) by randomly performing the training protocols to be implemented during experimental sessions 3 and 4.

*Experimental Sessions 3 and 4.* An initial pilot study was conducted to test the feasibility of the 2 training protocols. The protocols consisted of 3 sets at 60% 1RM and 3-minute rests between sets. In Protocol A, subjects completed each set of 6 repetitions with a 6-second repetition duration

(3 seconds concentric, 3 seconds eccentric), whereas in Protocol B the subjects perform each of 12 repetitions with a 3-second repetition duration (1.5 seconds concentric, 1.5 seconds eccentric). Because we aimed to maintain the protocols' configurations so that the variables above complied with recommendations for strength training for muscle hypertrophy (2,39), neither of the protocols took subjects to momentary muscle failure during any of the sets.

An electrogoniometer was positioned on the subjects' elbow, and electrodes were fixed to the anterior deltoid, pectoralis major, and triceps brachii muscles as part of the first procedure during experimental sessions 3 and 4. The skin was marked using a semipermanent pen to reposition the electrogoniometer and electrodes during each testing session by the same researcher. After the electrodes and the electrogoniometer were fixed and the subjects rested in a seated position for 10 minutes, the first blood sample was collected to obtain resting blood lactate concentrations. The remaining blood samples were collected from the earlobe 1 minute after each set of the training protocols and every 3 minutes until 12 minutes after the completion of the training protocols. Electromyographic activity was recorded while performing each set of the training protocols.

More specifically, a calibrated electrogoniometer (Noraxon, Scottsdale, AZ, USA) was fixed on the right elbow of participants using double-sided adhesive tape and elastic bands. Once stored, 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 elbow range of motion. Additionally, muscle action and repetition duration were determined through the angular displacement time. 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 muscle action duration corresponded to the period between the minimum and maximum angular positions while the concentric muscle action duration corresponded to the maximum and minimum angular positions.

The surface electromyography procedure (Biovision, Wehrheim, Germany) followed the recommendations of Hermens et al. (21). Bipolar surface electrodes (Ag/AgCl) were placed parallel to the muscle fibers on the subjects' right anterior deltoid, pectoralis major (sternal portion), and triceps brachii (long head portion) muscles. The skin area was 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 data acquisition was amplified 500 times. After stored, these data were filtered (second-order Butterworth band-pass filter of 20–500 Hz) and rectified (full-wave) to calculate the signal amplitude through the root mean square electromyography (EMG<sub>RMS</sub>). Before commencing each experimental session, subjects were asked

to perform 2 repetitions on the Smith machine bench press exercise at 60% 1RM, using a different repetition duration (4 seconds; 2 seconds concentric, 2 seconds eccentric) to be used as reference for the normalization of the subsequent measurements. The EMG<sub>RMS</sub> was determined for each concentric or eccentric action (31), and the average of the 2 actions was determined for each muscle group (normalization test). This procedure is in accordance with recommendation of Allison et al. (1) for dynamic contractions. Finally, the mean set EMG<sub>RMS</sub> of both concentric and eccentric muscle actions obtained during the protocols was calculated, and these values were divided by the respective concentric and eccentric reference values previously described, generating the normalized EMG<sub>RMS</sub> per set. The electrogoniometer was used to separate the muscle actions in all the situations mentioned above.

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.

Blood samples were collected from a puncture to the subjects' left earlobe using sterile disposable lancets. The earlobe was cleaned with neutral soap and water and then sterilized with 70% alcohol before puncturing. A 30  $\mu$ L sample of blood was collected into heparinized capillary tubes, which were transferred into other tubes containing 60  $\mu$ L of 1% sodium fluoride and then stored in a refrigerator maintained at a temperature of  $-20^{\circ}$  C. Subsequently, the samples were thawed and analyzed in duplicates on the Yellow Springs Sport 1500 Lactate Analyzer device (YSA, Inc., Yellow Springs, OH, USA).

#### Statistical Analyses

The normality and homogeneity of variances were verified using Shapiro-Wilks and Levene tests, respectively. These tests were performed using the Statistical Package for the Social Sciences (SPSS 20.0; SPSS, Inc., Chicago, IL, USA). The normalized EMG<sub>RMS</sub> showed significant deviations from normality; therefore, the median was used as an indicator of central tendency and the quartile indicated the dispersion of the normalized EMG<sub>RMS</sub> across experimental sessions. A nonparametric procedure (analysis of variance [ANOVA]-type statistics) suggested by Brunner et al. (4) and Brunner and Langer (5) was used to check the response of the normalized EMG<sub>RMS</sub> during the training protocols for the main effects of protocol and sets, as well as the interactions between these factors. The ANOVA-type statistics were performed using package nparLD in R software. Additionally, a post hoc Dunn's test was used to identify the differences reported in the nonparametric procedure. This procedure was performed using R software. The intraclass correlation coefficient (ICC<sub>[3,k]</sub>) of the concentric and eccentric EMG found in the normalization test of experimental sessions 3 and 4 was calculated; these intersession values

were 0.93 and 0.95 for the anterior deltoid, 0.87 and 0.91 pectoralis major, 0.81 and 0.77 for the triceps brachii, respectively. In addition, partial eta squared ( $\eta_p^2$ ) values are reported to reflect the magnitude of the differences in each treatment (small = 0.01, medium = 0.06, and large = 0.14) (11).

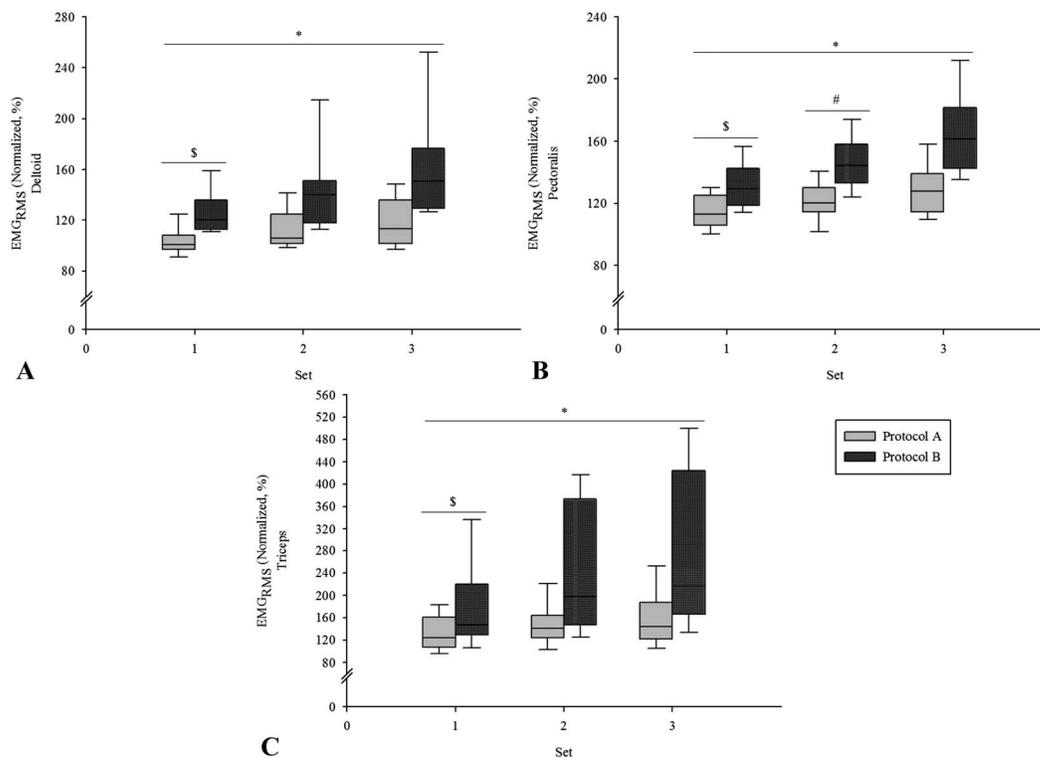
A 2-way (protocol  $\times$  time) ANOVA with repeated measures assessed lactate concentrations during and after the training (STATISTICA 7.0). Normality and homogeneity of variances were verified using Shapiro-Wilks and Levene tests, respectively. When necessary, a post hoc Tukey honest significant difference test was used to identify the differences reported in the ANOVAs. Finally, paired-sample *t*-tests were used to compare repetition durations, TUT (concentric and eccentric), and ranges of motion. Probability was set at  $p \leq 0.05$  for statistical significance for all tests.

**RESULTS**

Regarding the concentric normalized EMG<sub>RMS</sub> data, ANOVA-type statistics indicated a significant main effect for protocol in the anterior deltoid ( $H_1 = 48.06, p = 0.0001, \text{power} = 1.00, \eta_p^2 = 0.63$ ), pectoralis major ( $H_1 = 49.25,$

$p = 0.0001, \text{power} = 1.00, \eta_p^2 = 0.76$ ), and triceps brachii ( $H_1 = 31.54, p = 0.0001, \text{power} = 0.99, \eta_p^2 = 0.52$ ) so that the Protocol B showed higher muscle activation in all comparisons (Figure 1). Also, significant effects were observed for the sets in the anterior deltoid ( $H_2 = 8.66, p = 0.0003, \text{power} = 1.00, \eta_p^2 = 0.52$ ), pectoralis major ( $H_2 = 17.20, p = 0.0001, \text{power} = 1.00, \eta_p^2 = 0.71$ ), and triceps brachii ( $H_2 = 5.21, p = 0.005, \text{power} = 1.00, \eta_p^2 = 0.55$ ). The post hoc analysis results indicated the occurrence of an increase in muscle activation across the sets in all 3 muscles studied. Dunn's test identified differences between the first and third sets in the anterior deltoid and triceps brachii muscles, whereas differences were observed in concentric normalized EMG<sub>RMS</sub> data between all sets in the pectoralis major. No significant interactions (protocol  $\times$  sets) were observed for the anterior deltoid ( $H_2 = 1.61, p = 0.20$ ), pectoralis major ( $H_2 = 2.45, p = 0.08$ ), and triceps brachii ( $H_2 = 1.72, p = 0.18$ ).

Regarding the eccentric normalized EMG<sub>RMS</sub> data, ANOVA-type statistics indicated a significant main effect for protocol in the anterior deltoid ( $H_1 = 15.35, p = 0.0001, \text{power} = 1.00, \eta_p^2 = 0.65$ ), pectoralis major ( $H_1 = 81.27, p = 0.0001, \text{power} = 1.00, \eta_p^2 = 0.77$ ), and triceps



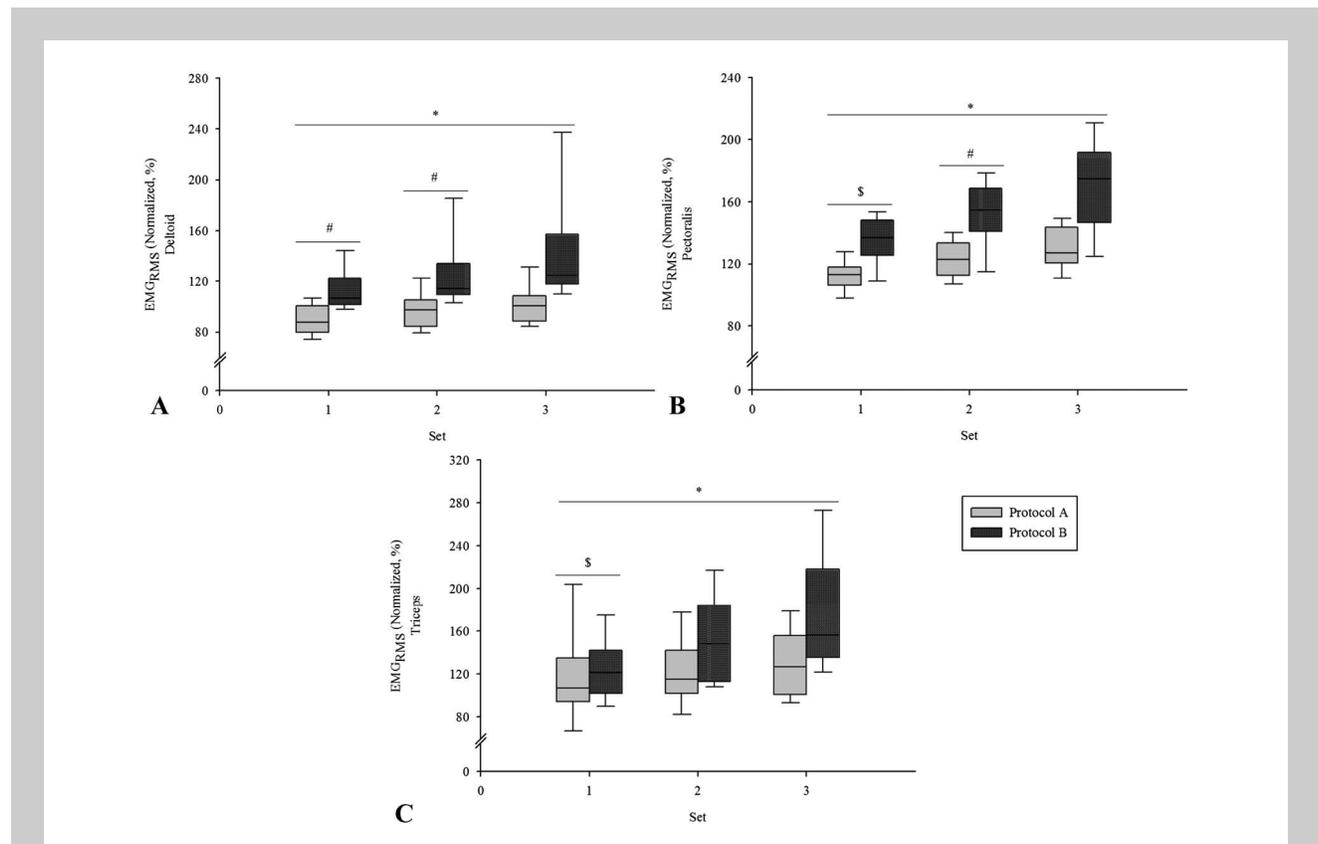
**Figure 1.** Median (horizontal line within the box); first and third quartiles (lower and upper box limits); minimum and maximum (whiskers) concentric normalized EMG<sub>RMS</sub> of the anterior deltoid (A), pectoralis major (B), and triceps brachii (C) muscles for each training protocol. \*Protocol B different from Protocol A (main effect); \$Different from sets 2 and 3 in the respective protocol; #Different from set 3 in the respective protocol. EMG<sub>RMS</sub> = root mean square of the electromyographic signal.

brachii ( $H_1 = 16.96$ ,  $p = 0.0001$ , power = 0.82,  $\eta_p^2 = 0.30$ ). Similar to concentric normalized EMG<sub>RMS</sub> data, Protocol B also showed higher muscle activation in all comparisons performed for the eccentric normalized EMG<sub>RMS</sub> data (Figure 2). Also, significant effects were observed for the sets for the anterior deltoid ( $H_2 = 11.98$ ,  $p = 0.001$ ; power = 0.99,  $\eta_p^2 = 0.45$ ), pectoralis major ( $H_2 = 21.43$ ,  $p = 0.0001$ , power = 1.00,  $\eta_p^2 = 0.75$ ), and triceps brachii ( $H_2 = 6.84$ ,  $p = 0.001$ , power = 1.00,  $\eta_p^2 = 0.58$ ). The post hoc analysis results indicated the occurrence of an increase in muscle activation across the sets in all 3 muscles studied. Dunn's test verified that the first and second sets were different from the third set in anterior deltoid. In the triceps brachii, differences were verified between the first and second sets, whereas differences were observed in eccentric normalized EMG<sub>RMS</sub> between all sets in the pectoralis major (Figure 2). No significant interactions (protocol  $\times$  sets) were observed for the anterior deltoid ( $H_2 = 3.13$ ,  $p = 0.21$ ), pectoralis major ( $H_2 = 2.43$ ,  $p = 0.08$ ), and triceps brachii ( $H_2 = 3.00$ ,  $p = 0.07$ ).

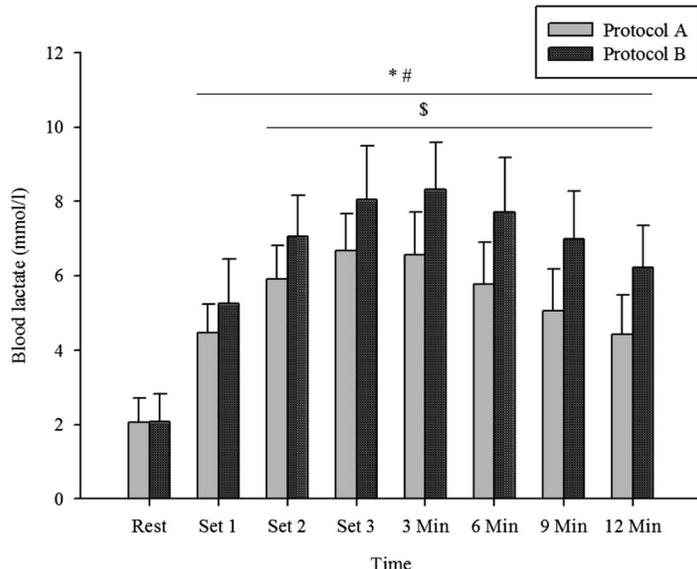
The main effects of protocol and set were significant regarding blood lactate concentration. In addition, repeated-measures ANOVA indicated that a significant

interaction effect was observed between protocol and time ( $F_{(7,133)} = 26.97$ ;  $p < 0.001$ ; power = 1.00,  $\eta_p^2 = 0.59$ ). Figure 3 shows the blood lactate concentrations for different training protocols. Post hoc analysis indicated higher blood lactate concentrations for Protocol B in all times, except in the pre-exercise condition. In addition, the blood lactate concentrations increased for both protocols throughout the sets. Tukey post hoc analysis also indicated that blood lactate concentrations were reduced after 3 minutes in Protocol A and after 6 minutes in Protocol B.

As expected, Protocol B showed shorter mean repetition duration than Protocol A ( $3.01 \pm 0.05$  seconds vs.  $5.94 \pm 0.07$  seconds;  $p < 0.001$ ; coefficient of variation  $< 1.6\%$  for both protocols). No differences were found on the average range of motion between Protocols A and B ( $76.01 \pm 12.01^\circ$  vs.  $74.24 \pm 12.21^\circ$ , respectively;  $p = 0.148$ ). No differences were also found on the average concentric TUT between Protocols A and B ( $17.54 \pm 0.63$  seconds vs.  $17.69 \pm 0.57$  seconds, respectively;  $p = 0.129$ ). However, differences were found on the average eccentric TUT between Protocols A and B ( $18.19 \pm 0.41$  seconds vs.  $18.43 \pm 0.58$  seconds,



**Figure 2.** Median (horizontal line within the box); first and third quartiles (lower and upper box limits); minimum and maximum (whiskers) eccentric normalized EMG<sub>RMS</sub> of the anterior deltoid (A), pectoralis major (B), and triceps brachii (C) muscles for each training protocol. \*Protocol B different from Protocol A (main effect); \$Different from sets 2 and 3 in the respective protocol; #Different from set 3 in the respective protocol. EMG<sub>RMS</sub> = root mean square of the electromyographic signal.



**Figure 3.** Mean  $\pm$  SD blood lactate concentration at rest, after each set, and until 12 minutes after completing protocols A and B. \*Different from the rest, in the respective protocol; #Protocol B different from Protocol A, in the respective time; \$Different from the anterior moment, in the respective protocol.

respectively;  $p = 0.036$ ), although the magnitude of the difference between mean values was less than 1.4%.

## DISCUSSION

This study examined whether protocols with different configurations of repetition durations and repetition numbers would result in different electromyographic and blood lactate responses in resistance training protocols equalized by TUT. The results showed that the normalized EMG<sub>RMS</sub> responses for concentric and eccentric actions were greater in Protocol B than in Protocol A for the anterior deltoid, pectoralis major, and triceps brachii muscles. Furthermore, normalized EMG<sub>RMS</sub> response increased across the sets for both protocols. Blood lactate concentrations were also higher in Protocol B both during and after completion of the training session. The results are in agreement with the findings of Tran and Docherty (36), because these authors have shown that, when there is equivalence of TUT, protocols performed with higher repetition numbers and shorter repetition durations led to increased levels of fatigue (reduced ability to generate force), indicating a greater physiological demand during its execution.

Previous studies have analyzed muscle activation while performing resistance training protocols characterized by different repetition durations and repetition numbers (8,30,31). One of these studies, which manipulated only the repetition duration (8), demonstrated that increasing the repetition duration may result in a greater EMG response. However, it must be emphasized that in their

investigation the repetition numbers performed in the training protocols were kept constant, thus longer repetition durations could provide a higher TUT, a factor capable of altering EMG amplitude (23,34). However, this study aimed to compare the EMG responses to different protocols equalized by TUT, verifying that shorter repetition duration added to the higher repetition numbers and provoked greater EMG amplitude. Similar results were observed in the study of Sakamoto and Sinclair (30), although the protocols performed by the subjects in that study were performed until lifting failure (maximum repetition number) and did not allow for the equalization of TUT. By analyzing this type of information, it is possible to understand that a combination

of shorter repetition duration and higher repetition numbers in resistance training protocols plays an important role in increasing the muscle activation response. This statement is based on the fact that EMG amplitude was higher in protocols with shorter repetition duration and higher repetition numbers regardless of whether the set was equalized by TUT as in this study, or not, as in the Sakamoto and Sinclair study (30). At least in part, the higher amplitude of the EMG signal in Protocol B is indicative of the occurrence of an increased recruitment of motor units (10,23,34), which in turn has been pointed out as an important neuromuscular response related to an increased hypertrophy adaptation and an increase in muscle strength (26,32). However, it should be noted that other factors, such as the increased firing frequency and synchronization of motor units, may also influence the EMG amplitude (23,34).

The increased normalized EMG<sub>RMS</sub> of Protocol B can be explained by the greater peak force generation needed to accelerate the bar when higher movement speeds are produced, thus requiring greater motor unit recruitment (30). This acceleration demand could occur at the beginning of the concentric muscle action. Regarding the normalized EMG<sub>RMS</sub> eccentric action, the increased response in Protocol B may also be related to the greater requirement for force production during the braking phase of the movement, which probably was greater during faster movement velocities. Similar results were reported by Sampson et al. (31) that showed shorter eccentric actions during training protocols involving the elbow flexors exercise, which produced

greater EMG signal amplitude when compared with longer eccentric protocols. In fast eccentric actions, it is possible that contractile mechanisms would increase force generation because of a higher level of activation (increase in the fraction of cross-bridges formed) during the preactivation period (3). However, it still needs to be clarified whether movement velocities similar to those performed during Protocol B (no ballistic condition) would potentialize the neurophysiological mechanisms (preactivation and myotatic reflex response) and consequently EMG responses compared with Protocol A. Additionally, the fact that Protocol B resulted in twice the repetition numbers must also be considered. Although no studies have specifically examined the effects of repetition numbers on muscle activation level while performing resistance training protocols, it is expected that this factor could contribute to the present results of both muscle actions. It should also be noted that Harwood and Rice (19) reported that the fast movements of human limbs would benefit from a single set of activation parameters capable of generating greatest amount of torque in the shortest possible time. Thus, it has been suggested that there is a reduction in the motor unit recruitment threshold for faster dynamic actions (19), particularly during the eccentric phase of the movement (24). Considering the need to produce faster movements in Protocol B compared with Protocol A, a possible reduction of motor unit recruitment thresholds in this situation would have promoted an additional recruitment of fast motor units and consequently a greater EMG. However, specific additional studies are necessary to investigate these mechanisms in resistance training protocols similar to those used in this study.

Similar to EMG measurements obtained during the training sessions, no studies were found analyzing blood lactate responses when manipulating the repetition duration and repetition numbers while equalizing TUT. In this study, blood lactate concentrations were greater for the protocol using shorter repetition durations and higher repetition numbers (Protocol B) and these higher concentrations remained higher than Protocol A for until 12 minutes after the completion of the training protocol. Only 1 previous study examined the effects of simultaneously manipulating the repetition duration and repetition numbers on blood lactate responses while maintaining the same relative intensity of training (%IRM). As in the study of Sakamoto and Sinclair (30), Buitrago et al. (7) compared training protocols with different repetition durations and repetition numbers to volitional lifting failure. All protocols produced similar responses; however, as mentioned earlier, the absence of the exact equivalence of TUT for the protocols may have been a confounding factor in the results of the observed metabolic response because previous studies (27,35) have suggested that the increased TUT in resistance training protocols produces higher blood lactate concentrations.

The blood lactate responses in this study may also be related to the mechanical characteristics of the 2 protocols, considering that higher maximal forces would be expected

to accelerate the bar during every repetition in Protocol B (20). With the production of higher maximal forces in Protocol B, additional motor units with higher glycolytic capacities were presumably recruited (6,17,28), which might promote an increase in blood lactate production compared with Protocol A. This hypothesis is supported by the EMG data from this study. Additionally, it is important to note that the realization of higher repetition numbers in Protocol B should also be taken into account, considering that some investigations have found a greater mechanical work that provides a higher metabolic response (6,12,22).

In this study, the actual measurement of the changes in force applied to the bar during each protocol was not possible, which may be noted as a limitation of this investigation. It is known that the torque variation in dynamic muscle actions (13), as well as changes in the acceleration of the bar, may change the EMG signal (14) and blood lactate response (9). Knowledge of the changes in force during the acceleration and deceleration phases of the bar movement in the bench press exercise could result in a better understanding of changes in EMG (31) and blood lactate responses (12). Furthermore, the data indicate a large variability in the EMG<sub>RMS</sub> responses (large interquartile range values), especially for Protocol B. It is possible that during Protocol B the higher variation in muscle activation may be due to the need for greater acceleration of the bar in a shorter time period compared with Protocol A. However, variability in the EMG responses during strength training protocols has often been reported in the literature (16,25).

In conclusion, the data obtained in this study show that training protocols equalized by TUT, but with different configurations, produce different physiological demands. Specifically, a protocol with shorter repetition durations and higher repetition numbers produced greater neuromuscular and metabolic responses compared with a different protocol with the same TUT. Nevertheless, further studies are encouraged to compare other training protocols with different numbers of repetitions and repetition durations and to understand the impact of these protocols in chronic training responses.

## PRACTICAL APPLICATIONS

This study showed that training protocols conducted with the same TUT, but with different configurations, produced distinct neuromuscular and metabolic responses so that performing higher repetition numbers with shorter repetition durations might be a more appropriate strategy to increase muscle activation and blood lactate concentration.

Although both protocols resulted in increases in muscle activation and lactate across the sets, greater responses were observed in the protocol with higher repetition numbers and shorter repetition durations. Therefore, considering the importance of neuromuscular responses to chronic adaptations to resistance training, coaches could opt for this type of protocol training to obtain better results.

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## REFERENCES

- Allison, GT, Marshall, RN, and Singer, KP. EMG signal amplitude normalization technique in stretch-shortening cycle movements. *J Electromyogr Kinesiol* 3: 236–244, 1993.
- 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.
- Bobbert, MF, Gerritsen, KG, Litjens, MCA, and Vansoest, AJ. Why is countermovement jump height greater than squat jump height? *Med Sci Sports Exerc* 28: 1402–1412, 1996.
- Brunner, E, Domhof, S, and Langer, F. *Nonparametric Analysis of Longitudinal Data in Factorial Experiments*. (1st ed.). New York, NY: Wiley, 2002.
- Brunner, E and Langer, F. Nonparametric analysis of ordered categorical data in designs with longitudinal observations and small sample sizes. *Biom J* 42: 663–675, 2000.
- Buitrago, S, Wirtz, N, Flenker, U, and Kleinöder, H. Physiological and metabolic responses as function of the mechanical load in resistance exercise. *Appl Physiol Nutr Metab* 39: 345–350, 2014.
- Buitrago, S, Wirtz, N, Kleinöder, H, and Mester, J. Effects of load and training modes on physiological and metabolic responses in resistance exercise. *Eur J Appl Physiol* 112: 2739–2748, 2012.
- Burd, NA, Andrews, RJ, West, DW, Little, JP, Cochran, AJ, Hector, AJ, Cashaback, JGA, Gibala, MJ, Potvin, JR, Baker, SK, and Phillips, SM. Muscle time under tension during resistance exercise stimulates differential muscle protein sub-fractional synthetic responses in men. *J Physiol* 590: 351–362, 2012.
- Caruso, JF, Hari, P, Leeper, AE, Coday, MA, Monda, JK, Ramey, ES, Hastings, LP, Golden, MR, and Davison, SW. Impact of acceleration on blood lactate values derived from high-speed resistance exercise. *J Strength Cond Res* 23: 2009–2014, 2009.
- Christie, A, Inglis, JG, Kamen, G, and Gabriel, DA. Relationships between surface EMG variables and motor unit firing rates. *Eur J Appl Physiol* 107: 177–185, 2009.
- Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*. (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc., 1988.
- Denton, J and Cronin, JB. Kinematic, kinetic, and blood lactate profiles of continuous and intraset rest loading schemes. *J Strength Cond Res* 20: 528–534, 2006.
- Duchateau, J and Enoka, RM. Neural control of shortening and lengthening contractions: Influence of task constraints. *J Physiol* 586: 5853–5864, 2008.
- Elliott, BC, Wilson, GJ, and Kerr, GK. A biomechanical analysis of the sticking region in the bench press. *Med Sci Sports Exerc* 21: 450–462, 1989.
- Fahs, CA, Loenneke, JP, Thiebaut, RS, Rossow, LM, Kim, D, Abe, T, Beck, TW, Feeback, DL, Bembien, DA, and Bembien, MG. Muscular adaptations to fatiguing exercise with and without blood flow restriction. *Clin Physiol Funct Imaging* 35: 167–176, 2015.
- 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.
- González-Badillo, JJ, Rodríguez-Rosell, D, Sánchez-Medina, L, Gorostiaga, EM, and Pareja-Blanco, F. Maximal intended velocity training induces greater gains in bench press performance than deliberately slower half-velocity training. *Eur J Sport Sci* 14: 772–781, 2014.
- Goto, K, Takahashi, K, Yamamoto, M, and Takamatsu, K. Hormone and recovery responses to resistance exercise with slow movement. *J Physiol Sci* 58: 7–14, 2008.
- Harwood, B and Rice, CL. Changes in motor unit recruitment thresholds of the human anconeus muscle during torque development preceding shortening elbow extensions. *J Neurophysiol* 107: 2876–2884, 2012.
- Hatfield, DL, Kraemer, WJ, Spiering, BA, Hakkinen, K, Volek, JS, Shimano, T, Spreuwenberg, LPB, Silvestre, R, Newton, RU, and Maresh, CM. The impact of velocity of movement on performance factors in resistance exercise. *J Strength Cond Res* 20: 760–766, 2006.
- 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.
- Hunter, GR, Seelhorst, D, and Snyder, S. Comparison of metabolic and heart rate responses to super slow vs. traditional resistance training. *J Strength Cond Res* 17: 76–81, 2003.
- Hunter, SK, Duchateau, J, and Enoka, RM. Muscle fatigue and the mechanisms of task failure. *Exerc Sport Sci Rev* 32: 44–49, 2004.
- Ivanova, T, Garland, SJ, and Miller, MJ. Motor unit recruitment and discharge behavior in movements and isometric contractions. *Muscle Nerve* 20: 867–874, 1997.
- 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.
- Loenneke, JP, Wilson, GJ, and Wilson, JM. A mechanistic approach to blood flow occlusion. *Int J Sports Med* 31: 1–4, 2010.
- Mazzetti, S, Douglass, MS, Yocum, A, and Harber, M. Effect of explosive versus slow contractions and exercise intensity on energy expenditure. *Med Sci Sports Exerc* 39: 1291–1301, 2007.
- Pareja-Blanco, F, Rodríguez-Rosell, D, Sánchez-Medina, L, Gorostiaga, EM, and González-Badillo, JJ. Effect of movement velocity during resistance training on neuromuscular performance. *Int J Sports Med* 35: 916–924, 2014.
- Rogatzi, MJ, Wright, GA, Mikat, RP, and Brice, G. Blood ammonium and lactate accumulation response to different training protocols using the parallel squat exercise. *J Strength Cond Res* 28: 1113–1118, 2014.
- Sakamoto, A and Sinclair, PJ. Muscle activations under varying lifting speeds and intensities during bench press. *Eur J Appl Physiol* 112: 1015–1025, 2012.
- Sampson, JA, Donohoe, A, and Groeller, H. Effect of concentric and eccentric velocity during heavy-load non-ballistic elbow flexion resistance exercise. *J Sci Med Sport* 17: 306–311, 2014.
- Schoenfeld, BJ. Is there a minimum intensity threshold for resistance training-induced hypertrophic adaptations? *Sports Med* 43: 1279–1288, 2013.
- Schoenfeld, BJ, Contreras, B, Willardson, JM, Fontana, F, and Tiryaki-Sonmez, G. Muscle activation during low- versus high-load resistance training in well-trained men. *Eur J Appl Physiol* 114: 2491–2497, 2014.
- 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.
- 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* (1985) 100: 1150–1157, 2006.
- Tran, QT and Docherty, D. Dynamic training volume: A construct of both time under tension and volume load. *J Sports Sci Med* 5: 707–713, 2006.
- Tran, QT, Docherty, D, and Behm, D. The effects of varying time under tension and volume load on acute neuromuscular responses. *Eur J Appl Physiol* 98: 402–410, 2006.
- Watanabe, M, Tanimoto, A, Ohgane, K, Sanada, K, Miyachi, M, and Ishii, N. Increased muscle size and strength from slow movement, low-intensity resistance exercise and tonic force generation. *J Aging Phys Act* 21: 71–84, 2013.
- 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.