How to cite: Teixeira DC, Andrade AGP, Martins-Costa HC, Lacerda LT, Gomes MC, Chagas MH, et al. Impact of different training protocols on muscle synergism in maximal and submaximal strength tests in bench press exercise. Rev Bras Fisiol Exerc. 2024;23:e235589. doi: 10.33233/rbfex.v23i2.5589

RBFEx
ISSN Online: 2675-1372

Revista Brasileira de Fisiologia do Exercício

Original article

Impact of different training protocols on muscle synergism in maximal and submaximal strength tests in bench press exercise

Impacto de diferentes protocolos de treinamento no sinergismo muscular, em testes de força máxima e submáxima no exercício supino reto

Daniel Cesar Teixeira[1], André Gustavo Pereira de Andrade[1], Hugo Cesar Martins-Costa[1,2], Lucas Tulio Lacerda[1], Mateus Camargos Gomes[1], Mauro Heleno Chagas[1], Rodrigo César Ribeiro Diniz[1], Fernando Vitor Lima[1]

1. Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brazil
2. Pontifícia Universidade Católica de Minas Gerais, Belo Horizonte, MG, Brazil

ABSTRACT

Objective: This study analyzed the activation of pectoralis major and triceps brachii muscles in strength tests in bench press after 10 weeks of training. **Methods:** Thirty-three untrained individuals were divided into two experimental and one-control groups. Protocols were matched by intensity (50-55% of one repetition maximum - 1RM), frequency (3 times a week), pause between sets (3 minutes), number of sets (3 to 4 sets), and time under tension in each set (36 seconds), but with different repetition number and duration (12 repetitions vs. 3seconds / 6repetitions vs. 6seconds). **Results:** In strength endurance test both experimental groups increased amplitude of Electromyography (EMG) signal in comparison to control group, but with no difference between them. Activation was higher for triceps brachii than for pectoralis major and thus the pectoralis major/triceps brachii activation ratio significantly decreased for both groups, but with no difference between them. In the 1RM and maximum voluntary isometric contraction tests, EMG signal amplitude, activation ratio and analysis of cross-correlation did not exhibited any changes when comparing the experimental and control groups. **Conclusion:** The results showed that the fact that the protocols used dynamic actions, as well as the same time under tension (TUT), and the differences between single and multiple repetition tests, determined the responses verified.

Keywords: electromyography; muscle strength, pectoralis muscles; skeletal muscle.

RESUMO

Objetivo: Este estudo analisou a ativação dos músculos peitoral maior (PM) e tríceps braquial (TB) em testes de força no supino após 10 semanas de treinamento. **Métodos:** Trinta e três indivíduos não treinados foram divididos em dois grupos experimentais e um grupo controle. Os protocolos foram equiparados em termos de intensidade (50-55% de uma repetição máxima - 1RM), frequência (3 vezes por semana), pausa entre as séries (3 minutos), número de séries (3 a 4 séries) e tempo sob tensão em cada série (36 segundos), mas com número de repetições e duração diferentes (12 repetições vs. 3 segundos / 6 repetições vs. 6 segundos). **Resultados:** No teste de resistência de força, ambos os grupos experimentais aumentaram a amplitude do sinal eletromiográfico (EMG) em comparação com o grupo controle, mas sem diferença entre eles. A ativação foi maior para o tríceps braquial do que para o peitoral maior e, portanto, a relação de ativação do peitoral maior/tríceps braquial diminuiu significativamente em ambos os grupos, mas sem diferença entre eles. Nos testes de 1RM e de contração isométrica voluntária máxima, a amplitude do sinal EMG, a relação de ativação e a análise de correlação cruzada não apresentaram nenhuma alteração na comparação entre os grupos experimental e de controle. **Conclusão:** Os resultados mostraram que o fato de os protocolos utilizarem ações dinâmicas, bem como o mesmo tempo sob tensão (TST) e as diferenças entre os testes de repetição única e múltipla, determinaram as respostas verificadas.

Palavras-chave: eletromiografia; força muscular, músculos peitorais; músculo esquelético.

Received: April 19, 2024; Accepted: July 20, 2024.

Correspondence: Fernando Vitor Lima, ferlima@eeffto.ufmg.br

Introduction

Among the determinants of strength performance, the synergistic activation of two or more muscles can be adjusted for greater efficiency in situations of sports performance and rehabilitation. Such determinants should be considered according to the exercise [1,2] training status [3,4], degrees of freedom of the exercise [5] the training-related variables [6,4] and exercise technique [1]. Marchetti *et al*. [1] analyzed the activation ratio between upper and lower portions of the rectus abdominis during isometric trunk and hip flexion with maximal and submaximal intensity and found significantly higher values with trunk flexion. Kristiansen *et al*. [7] compared the EMG of pectoralis major (PM) and triceps brachii (TB) in three sets at 60% of 3RM, between powerlifters and untrained individuals and suggested that different training loads and exercise techniques can result in muscle activation changing in diverse ways.

Different time under tension (TUT) can produce different results in EMG [8] and this has been manipulated by changing both the number and the duration of repetitions in training programs developed by coaches and in physical rehabilitation protocols. In bench press exercise, the PM and TB muscles may present different activation patterns and this can be verified between sets when performing this exercise with the same TUT but different number and duration of repetitions [9,8]. Sakamoto *et al*. [10] showed that PM and TB may differ in activation at different intensities and repetition durations in BP exercise.

Although in situations of maximum strength performance in single-joint exercises, muscles could be expected to reach maximum activation or close [11], it would be necessary to understand if the synergism could be changed differently in strength performance tests after training with different protocols in multi-joint exercises. In addition, it should be investigated whether synergism can be altered in dynamic and isometric maximal strength tests when only one repetition is performed compared to a test with multiple repetitions, where, in principle, a longer duration of the task could allow differentiated adjustments of muscle activations throughout of the sets to produce the best performance. This is necessary because training to improve strength performance in different manifestations (maximum and strength-endurance), aiming for maximum and/or adequate activation of the muscles is carried out with different multiple repetition protocols, with different repetitions number and duration and also different configurations of TUT. Therefore, this study aimed to investigate the effect of 10 weeks of training with protocols matched by TUT but with different number and duration of repetitions, on the activation of the PM and TB muscles in isometric and dynamic strength tests.

Methods

Sample

Thirty-three men participated in the study (age 24.1 ± 4.8 years old; body mass = 75.9 ± 10.4 kg; height 175.6 ± 6.4 cm). The sample size calculation was performed using the software G Power (version 3.1.9.2), considering an effect size of 0.48, obtained by the pre- and post-test values of the PM muscle EMG signal in young adults in the Baker *et al.* [12] study. Individuals who did not perform strength training in the last six months and did not have wrist, elbow and shoulder joint injuries were selected. This study was approved by the local Ethics Committee, and received registration and identification as a clinical trial (https://doi.org/10.17605/OSF.IO/BGJCV). All procedures were conducted according to the Declaration of Helsinki. Subjects were informed about the study aims, procedures, and risks and signed an informed consent form.

Experimental design

All tests and training procedures were carried out in the BP exercise on a Smith machine (MASTER®, Brazil). A rotary-encoder-type position sensor (BOURNS, United States; 1.2-mm precision) was coupled to the equipment and the data obtained were transformed from analog to digital signals by a converter board (BIOVISION, Germany), directed to the computer (frequency of 4,000 Hz sampling), subsequently filtered (10hz low-pass Butterworth filter, 2nd order) and analyzed using specific software (DASYLAB 11.0, United States). Volunteers lay down on the bench and placed their hands on the bar at a distance corresponding to twice the biacromial distance, using the middle finger as a reference. To ensure the same positioning in all sessions, measuring tapes were fixed on the bar and on the bench, which served as a reference to reproduce the hand and head locations.

Strength tests

Strength endurance (SE) test consisted of the maximum number of repetitions (MNR) in a single set with mass corresponding to 70% of one repetition maximum (1RM). 1RM test was performed according to the procedure used by Lacerda *et al.* [13] To determine the range of motion (ROM) in the maximum voluntary isometric contraction (MVIC) test, the bar was fixed in a position corresponding to 50% of the maximum linear displacement, which also corresponded to approximately 90° of elbow flexion; then, the volunteer should apply maximum force against the bar for 5s. Two maximum contractions were carried out, with 2-minutes rest interval.

Training sessions

Protocols were performed for 10 weeks, matched by the TUT in each set (36s), intensity (50-55% 1RM), training frequency (3 times a week with intervals of 48 to 72 hours between sessions), 3 min rest between sets and different duration and number of repetitions (Figure 2). Initially, three sets were performed at 50% 1RM, adding one set in the fourth week, and the intensity of 55% 1RM was adopted in the sixth week. 1RM test was performed every two weeks to adjust the intensity, 10 minutes before the protocol was started [14]. Control group was instructed not to change their daily habits throughout the study.

Electromyography

For the recording of the EMG signal, bipolar surface electrodes (Ag/AgCl) were positioned according to the procedures described by Lacerda *et al.* [9]. In PM, they were positioned horizontally at the point of greatest muscle belly with the arm positioned close to the trunk [15]. For TB, SENIAM´s (Surface Electromyography for the Non-Invasive Assessment of Muscles) guidelines were followed, determining a point corresponding to half the distance between the posterior crest of the acromion and the olecranon. After acquisition, data were amplified 500 times and then stored. They were later filtered by a second order Butterworth bandpass filter (20-500 Hz) and rectified to calculate the signal amplitude with the root mean square (RMS). In the 1RM test, the RMS of the entire repetition was used, and in the MVIC test, the 1-s RMS around the peak of activation of each muscle was considered.

Raw EMG_{RMS} values of 1RM and MVIC tests were standardized by the average EMG_{RMS} of two 5s MVIC attempts. To check the reliability of these measures, intraclass correlation coefficients (ICC) were calculated in two ways: intrasession ICC (two intrasession MVIC attempts) and intersession ICC (mean of the two measures recorded in the group's pre-test and post-test, together with the Standard Error of Measurement (SEM) [16], shown in table I.

Table I - Reliability of MVIC measurements

	N	ICC	SEM (mV)
Pre-Training Reliability			
Pectoralis Major MVIC	66	0.94	0.04
Tríceps Brachii MVIC	66	0.97	0.02
Post-Training Reliability			
Pectoralis Major MVIC	66	0.94	0.04
Tríceps Brachii MVIC	66	0.98	0.02
10-Week Reliability			
Pectoralis Major MVIC	11	0.96	0.04
Tríceps Brachii MVIC	11	0.97	0.02

n = number of measurements (2 MVIC attempts); ICC = intraclass correlation coefficient; SEM (mV) = standard error of measurement in millivolts; MVIC = maximum voluntary isometric contraction test

In the SE test, a dynamic normalization procedure was used with two repetitions, each one with 4s (2s concentric: 2s eccentric) and intensity of 70% 1RM, according to the procedure performed by Sakamoto and Sinclair [10] and Lacerda *et al.*

[9,13]. Mean EMG_{RMS} of the repetitions was used as a reference for the measurements performed during the test. To check if the EMG_{RMS} values between the sessions were reproducible, the intersession reliability during the normalization test that was performed in the second and thirteenth weeks was checked by calculating the intraclass correlation coefficient (ICC) together with the SEM [16]. Reliability and SEM data are shown in table II. Considering that in this test each volunteer performed a different NMR, to perform the analysis of the normalized EMG_{RMS}, the first, median and last repetitions of each volunteer were used.

Table II - Confiabilidade do EMG_{RMS} medidas intersecionais do teste de normalização no exercício de supino reto

	N	CCI	EPAM (mV)
PM	33	0.93	0.03
TB	33	0.78	0.04

n = number of measurements; ICC = intraclass correlation coefficient; SEM (mV) = absolute standard error of measurement; PM = pectoralis major; TB = triceps brachii

Measured variables

Pre- and post-training EMG amplitude analysis was performed to identify the influence of the protocols on muscles activation during strength tests. PM/TB ratio was determined with a mathematical ratio, by dividing the normalized EMG_{RMS} values of PM by the TB. In this study, cross correlation analysis correlated two time-variable signals comparing each other. This process involves repeatedly shifting one signal back and forth in time with the other fixed signal, with each time variation of one of the signals generating a comparison and R value for correlation. By decomposing these values, a final correlation or similarity value between the two signals was obtained [17].

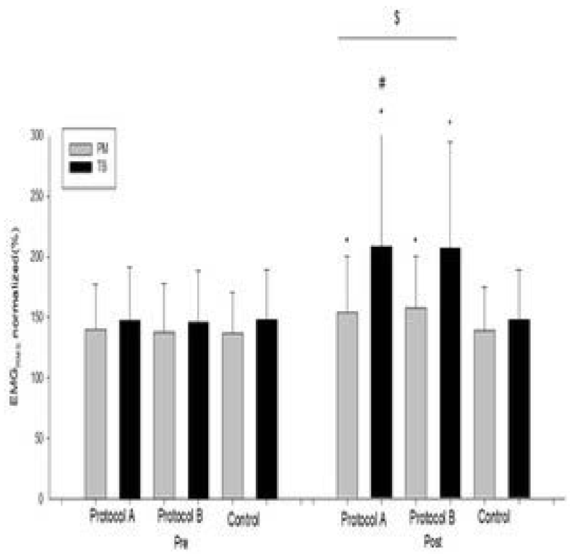
Statistical analysis

Initially, a descriptive data analysis was carried out. Normality and homogeneity were verified by using the Shapiro-Wilk and Levene tests respectively, and all study variables were shown as mean and standard deviation. Analysis of the EMG signal amplitude values of PM and TB was carried out using an ANOVA three way mixed with repeated measures (Factor 1 – Time; Factor 2 – Muscle; Factor 3 – Protocol). Two other ANOVA's two way with repeated measures (factors 1 – Time and 2 – Protocol) were carried out, one for activation ratio (PM/TB) and another for cross-correlation analysis. In the presence of a significant value of F, it was applied as post hoc of Bonferroni. For each ANOVA, the eta squared ($\eta 2$) was determined. Statistical procedures used were performed using the SPSS statistical package (version 22.0). Significance level adopted for all analyses was $p < 0.05$.

Results

EMG Signal Amplitude

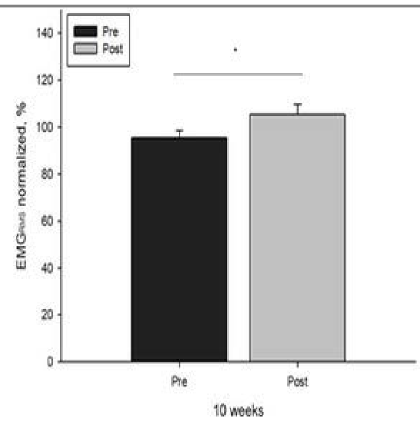
In the SE test, ANOVA three-way with repeated measures checked for an interaction between the factors: Time vs. protocol vs. muscle ($F2.46 = 4.93$, $p = 0.011$, power $= 0.78$, $\eta 2 = 0.026$). Post hoc showed no differences in normalized EMG_{RMS} between the experimental groups in the pre-test and significant increase in the post-test but with no differences between them. Values were similar between muscles in all groups in pre-test, whereas the values in TB were higher than PM in post-test for experimental groups (Figure 1).



*Post-test > Pre-test; # TB > PM; $ Protocols A and B > control; PM = Pectoralis major; TB = Triceps brachii; Protocol A =12 repetitions, 3s; Protocol B = 6 repetitions, 6s

Figure 1 - Normalized EMG_{RMS} of strength endurance test between protocols, pre- and post- training

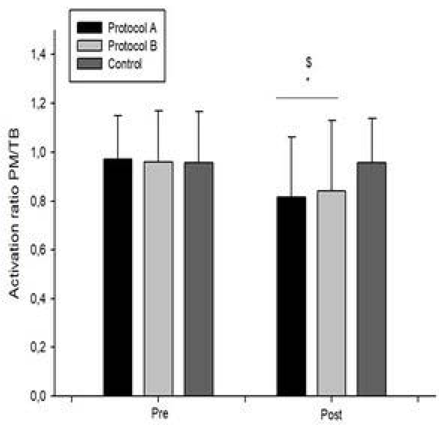
EMG_{RMS} values of the 1RM test presented no changes in experimental groups in the interactions between the factors time, muscle, and protocol. The analysis of the main effects found a significant effect of the Time factor ($F1; 9 = 6.10$; $p = 0.036$; $\eta 2 = 0.026$; power $= 0.726$), and according to the post hoc of Bonferroni, the post-test was higher than the pre-test, as shown in Figure 2. Muscle and protocol factors showed no changes. Also, no changes in the EMG_{RMS} signal amplitude in both muscles in neither of the main factors nor in the interaction between the factors was verified in MVIC test.



EMG_{RMS} normalized % = normalized electromyography values through root mean square shown in percentage; * = values different from each other with a 10-week training interval ($p < 0.05$)
Figure 2 - Main effect 1RM test time

Activation ratio

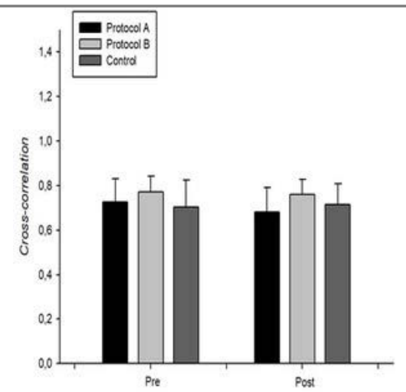
In the SE test, ANOVA three-way with repeated measures checked for an interaction between the factors protocol vs. time ($F2.46 = 4.02$, $p = 0.024$, power = 0.69, $\eta 2 = 0.05$); post hoc pointed out no significant differences in the pre-test between the groups; in the post-test, only experimental groups significantly decreased the activation ratio, but with no differences between them (Figure 3). There was no significant difference in the PM/TB ratio in the 1RM and MVIC post-tests. ANOVA two way did not detect significant differences in the main factors and their interactions



* PM/TB activation ratio Post < Pre; $ Protocols A and B < control; Protocol A = 12 repetitions, 3s; Protocol B = 6 repetitions, 6s
Figure 3 - PM/TB activation ratio between pre- and post-training protocols in the strength endurance test

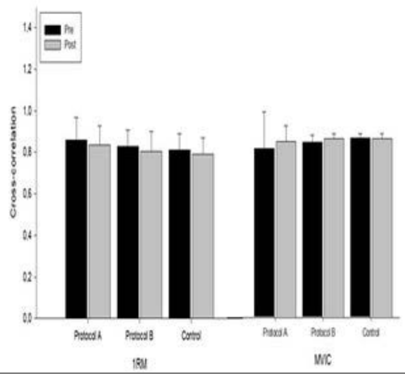
Cross-correlation

Cross-correlation analysis in SE test found no interactions between the factors: protocol vs. time ($F2.20 = 0.998$, $p = 0.386$, power = 0.199, $\eta 2 = 0.021$). There were also no main effects of time ($F1.10 = 0.571$, $p = 0.467$, power = 0.105, $\eta 2 = 0.007$) and protocol ($F2.20 = 1.823$, $p = 0.187$, power = 0.335, $\eta 2 = 0.119$) (Figure 4).



Protocol A = 12 repetitions, 3s; Protocol B = 6 repetitions, 6s
Figure 4 - Cross-correlation analysis of the strength endurance test shown as mean and standard deviation

Figure 5 shows the cross-correlation results of 1RM and MVIC tests, respectively. Mean values of all groups were 0.83 (SD = 0.08) in the pre-test, and 0.80 (SD = 0.08) in the 1RM post-test; and 0.90 (SD = 0.11) in the pre-test and 0.92 (SD = 0.04) in the MVIC post-test, with no differences in any of the analyses. ANOVA's two way found no significant differences in the main factors time and protocol and in their interactions in the 1RM test. No significant differences were identified in the main factors and interactions in the MVIC test.



Protocol A = 12 repetitions, 3s; Protocol B = 6 repetitions, 6s
Figure 5 - Cross-correlation analysis of 1RM and MVIC tests shown as mean and standard deviation; Shape analysis of the gross electromyographic signal of pectoralis major and triceps brachial muscles

Discussion

This study investigated changes in EMG signals in different strength tests after 10 weeks of training with two different protocols matched by the TUT and different number and duration of repetitions.

SE test showed a significant increase in EMG_{RMS} values in the post-test with no differences between the protocols. Our study observed a significant increase in MNR in post-test in both protocols and this can result in a greater EMG amplitude, especially when repetitions until muscle failure are performed [18]. To compensate for the drop in nerve impulse conduction speed due to fatigue, more motor units

(MU) tend to be recruited [18]. It was not verified differences in muscle activation in pre-training situation between groups of untrained individuals for SE testing, but training can change it regardless of the number an duration of repetitions if the TUT is equalized. However, activation in TB increased more than in PM. Stastny *et al*. [19] demonstrated that the TB is more sensitive than PM to changes in training load, thus presenting greater variability in its activation. Although Lacerda *et al*. [9] did not make comparisons between muscles, they verified higher variations in TB than in PM after three sets in BP exercise. Van Den Tillar *et al*. [20] verified a higher capacity to produce force at the beginning of the concentric action in BP until it reaches the sticking point, and PM does not change activation throughout ROM, but TB presents continuous increase in activation. TB muscle has greater pennation angles and, consequently, a greater capacity to produce torque throughout the concentric ROM [21], and could remain more activated at this muscle action. This difference in favor of TB can explain the decrease in PM/TB ratio in SE, indicating a change in relative activation of TB compared to PM; activation ratio is commonly used to estimate the relative activation between muscles in an exercise [1,22]. However, no difference was found between protocols, suggesting that the similar TUT between the protocols was decisive in this response, despite the different number and duration of repetitions.

Higher EMG_{RMS} values in 1 RM post-test corroborates Sampson and Groeller [23] who verified, after 12 weeks of training with different repetition durations, an increase in EMG in 1RM test of elbow flexors but without differences between protocols. Van der Tillaar *et al*. [20] verified greater muscle activation in the dynamic 1RM test compared to another isometric test, but pointed out that it was not possible to explain this result. The highest values in this study may be related to greater recruitment and MU synchronization to produce the higher strength performance in post-test. However, this did not occur with MVIC in both studies, which suggests that these changes are due to the dynamic nature of training and would not be carried over to an isometric action. Clark *et al*. [24] also did not see changes in EMG signal in PM and TB during MVIC after 5 weeks of training in bench press exercise in different ROM.

No differences were verified in PM/TB ratio in both 1RM and CVIM tests. Van der Tillaar *et al*. [20] found that the EMG activity were higher in 1RM compared to isometric acute test, but this was the only difference verified in EMG activity between these two different tests. Our study analyzed two muscles in two different joints in the same exercise. According to Prilutsky [25], the analysis of synergism must consider the differences between exercises that require muscles with different actions in different joints and others with more than one muscle acting in two joints. This author states that during the control of the force exerted on a proximal or distal segment, or when external resistance is applied to two or more joints, the activation of multi-joint muscles seems to strongly depend on the direction of the moments of force on the joints. Although training can induce adjustments in the coordinated activation of the muscles aiming at greater efficiency, this does not seem to be the case in our study. It can be suggested that in only one repetition, dynamic or isometric, there would be little time for adjustments in the coordination between the muscles, even more so in situations of maximum strength and muscle activation demands.

No significant differences were found in the cross-correlation analysis, both between pre- and post-test and between protocols. The effect of 5 weeks of training on the synergism of 13 muscles, including PM and TB, in BP exercise were analysed and no differences was verified in cross-correlation between the experimental and control groups [4]. High cross-correlation value with no differences between two tasks was verified in two portions of rectus abdominis muscle, identifying a common pattern in the activation of these portions [1]. In the same way and considering that the cross correlation measure refers to the variation of activation over time, in our study, it appears that regardless of the demand, when the muscles are jointly producing force there seems to be some constant pattern of activation along time and this happens regardless if the performance is short with only one repetition or longer with multiple repetitions, and this may not be influenced by some different training protocols that induce strength gain, even in multi joint exercise. Furthermore, it must be considered that there would be differences in muscle coordination patterns depending on strength demand. For example, in situations of maximum effort, not all muscles can be activated to their maximum, that is, even the muscles that can contribute to maximum force production may not be activated to their full potential [26].

This study showed the impact of training on the activation ratio between the PM and TB muscles in a strength test with multiple repetitions but not in the tests of only one repetition. It is unknown whether these differences arise from the variability of the adjustments in the degrees of freedom of the elbow during movement, which could occur in multiple repetitions. Moreover, it could be considered that the limited degrees of freedom of the Smith machine would not have allowed significant changes in trajectories of elbows in both protocols, whether single or multiple sets, also contributing to the smaller differences verified in the results. However, in a 1RM test, the EMG_{RMS} recorded no differences in the comparison between these two equipment's [27]. In a similar study, Schick *et al*. [28] analyzed the EMG of PM using Smith machine and free weights in two strength tests (70% and 90% 1RM) and found no differences in the amplitudes of the EMG signal. Perhaps, the difference observed only in the SE test is closer to the similarity with the training protocols than to a possible variability in the movement between repetitions.

Conclusion

The results showed that the fact that the protocols used dynamic actions, as well as the same TUT in both protocols and the differences between single and multiple repetition tests, appeared to play a significant role in the responses.

The complexity of understanding synergism may require additional analyzes beyond those performed in the present study. In addition, performance can also be evaluated in different ways, as well as in different exercises with different combinations of muscle groups. Thus, it appears that care must be taken when interpreting these results and further studies should be carried out before concluding information on this topic.

Academic affiliation
This article represents part of Daniel Cesar Teixeira's master's thesis, supervised by professor Dr. Fernando Vitor Lima (UFMG)

Conflict of interest
The authors declare no conflicts of interests.

Funding
There was no funding.

Authors' contributions
Conception and experimental design: Teixeira DC, Lima FV, Chagas MH, Martins-Costa HC, Lacerda LT, Diniz RCR; Data acquisition: Teixeira DC, Gomes MC; Data analysis and interpretation: Teixeira DC, Gomes MC, Andrade AGP, Diniz RCR, Martins-Costa HC; Statistical analysis: Teixeira DC, Andrade AGP; Manuscript writing: Teixeira DC, Lima FV; Critical revision of the manuscript and intellectual content: Lima FV, Chagas MH

References

1. Marchetti PH, Kohn AF, Duarte M. Selective activation of the rectus abdominis muscle during low--intensity and fatiguing tasks (Ativação seletiva do músculo reto abdominal durante tarefas de baixa intensidade e fadiga). J Sports Sci Med. 2011;10:322-27.
2. Jaberzadeh S, Yeo D, Zoghi M. The effect of altering knee position and squat depth on VMO: VL EMG durante exercícios de agachamento. Physiother Res Int 2015;21(3):164-73. doi: 10.1002/pri.1631
3. Kutch JJ, Kuo AD, Bloch AM, Rymer WZ. As flutuações de força do ponto final revelam padrões flexíveis, em vez de sinérgicos, de cooperação muscular. J Neurophysiol. 2008;100:2455-71. doi: 10.1152/jn.90274.2008
4. Kristiansen M, Samani A, Madeleine P, Hansen, EA. Effects of 5 weeks of bench press training on muscle synergies: a randomized controlled study. J Strength Cond Res. 2015;30(7):1948-59. doi: 10.1519/JSC.0000000000001282.
5. Kornecki S, Kebel A, Siemienski A. Muscular co-operation during joint stabilization, as reflected by EMG. Eur J Appl Physiol. 2001;84:453-61. doi: 10.1007/s004210100401
6. Wong YM, NG G. Resistance training alters the sensorimotor control of vasti muscles. J Electromyogr Kinesiol. 2010;20:180-84. doi: 10.1016/j.jelekin.2009.02.006
7. Kristiansen, M, Madeleine P, Hansen EAM, Samani A. Inter-subject variability of muscle synergies during bench press in power lifters and untrained individuals. Scand J Med Sci Sports. 2013;25:89-97. doi: 10.1111/sms.12167
8. Martins-Costa HC, Diniz RCR, Lima FV, Machado SC, Almeida, RSV, Andrade AGP, Chagas MH. Longer repetition duration increases muscle activation and blood lactate response in matched resistance training protocols. Motriz: Rev Educ Fis. 2016;22(1):35-41. doi:10.1590/S1980-65742016000100005
9. Lacerda L, Martins-Costa H, Diniz R, Lima F, Andrade A, Tourino F, *et al*. 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. 2016;30:251-58. doi: 10.1519/JSC.0000000000001044
10. Sakamoto A, Sinclair PJ. Muscle activations under varying lifting speeds and intensities during bench press. Eur J Appl Physiol. 2012;112:1015-25. doi: 10.1007/s00421-011-2059-0
11. Noorkoiv M, Nosaka K, Blazevich, AJ. Neuromuscular adaptations associated with knee joint angle-

-specific force change. Med Sci Sports Exerc. 2014;46(8):1525–37. doi: 10.1249/MSS.0000000000000269

12. Baker D, Wilson G, Carlyon R. Periodização: The effect on strength of manipulating volume and intensity. J Strength Cond Res. 1994;8(4):235-42. doi: 10.1519/00124278-199411000-00006

13. Lacerda L, Marra-Lopes R, Diniz RCR, Lima FV, Rodrigues SA, Martins-Costa H, *et al*. Is performing repetitions to failure less important than volume for muscle hypertrophy and strength? J Strength Cond Res. 2020;34(5):1237-48. doi: 10.1519/JSC.0000000000003438

14. Wakahara T, Miyamoto N, Sugisaki N, Murata K, Kanehisa H, Kawakami, *et al*. Association between regional differences in muscle activation in one session of resistance exercise and in muscle hypertrophy after resistance training. Eur J Appl Physiol. 2012;112:1569-76. doi: 10.1007/s00421-011-2121-y

15. Lagally KM, McCaw ST, Young GT, Medema HC, Thomas DQ. Ratings of perceived exertion and muscle activity during the bench press exercise in recreational and novice lifters. J Strength Cond Res. 2004;18(2):359-364. doi: 10.1519/R-12782.1

16. Portney LG, Watkins MP. Foundations of clinical research: applications to practice. 3rd ed. Upper Saddle River: F.A. Davis Company; 2008.

17. Wren TAL, Do KP, Rethlefsen, SA, Healy, B. Cross-correlation as a method for comparing dynamic electromyography signals during gait. J Biomech. 2006;39:2714-18. doi: 10.1016/j.jbiomech.2005.09.006

18. Looney DP, Kraemer WJ, Joseph MF, Comstock BA, Deneger CR, Flanagan SD, Newton RU. 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. 2015;30(3):792–99. doi: 10.1519/JSC.0000000000001109

19. Stastny P, Golas A, Blazek D, Maszczyk A, Wilk M, Pietraszewski P, *et al*. A systematic review of surface electromyography analyses of the bench press movement task. PlosOne 2017;12. doi: 10.1371/journal.pone.0171632

20. Van Den Tillar R, Saeterbakken AH, Ettema G. Is the occurrence of the sticking region the result of diminishing potentiation in bench press? J Sports Sci. 2012;30(6):591-99. doi: 10.1080/02640414.2012.658844

21. Murray WM, Buchanan TS, Delp SL. The isometric functional capacity of muscles that cross the elbow. J Biomech. 2000;33(8):943-52. doi: 10.1016/s0021-9290(00)00051-8

22. Matheson JW, Kernozek TW, Fater DC, Davies GJ. Electromyographic activity and applied load during seated quadriceps exercises. Med Sci Sports Exerc. 2001;33(10): 1713-25. doi: 10.1097/00005768-200110000-00016

23. Sampson JA, Groeller H. Is repetition failure critical for the development of muscle hypertrophy and strength? Scand J Med Sci Sports. 2016;24(4):375-83. doi: 10.1111/sms.12445

24. Clark RA, Humphries B, Hohmann E, Bryant AL. The influence of variable range of motion training on neuromuscular performance and control of external loads. J Strength Cond Res. 2011;25(3):704-11. doi: 10.1519/JSC.0b013e3181c6a0ff

25. Prilutsky BI. Coordination of two- and one-joint muscles: funcional consequences and implications for motor control. Motor Control 2000;4:1-44. doi: 10.1123/mcj.4.1.1

26. Wakeling JM, Blake OM, Wong I, Rana M, Lee SSM. Movement mechanics as a determinate of muscle structure, recruitment and coordination. Philos Trans R Soc Lond B Biol Sci. 2011;366(1570):1554-64. doi: 10.1098/rstb.2010.0294

27. Saeterbakken AH, Van Den Tillaar R, Fimland MS. A comparison of muscle activity and 1-RM strength of three chest-press exercises with different stability requiriments. J Sports Sci. 2011;29(5):533-38. doi: 10.1080/02640414.2010.543916

28. Schick EE, Coburn, JW, Brown LE, Judelson DA, Khamoui AV, Tran TT, Uribe BP. A comparison of muscle activation between a Smith machine and free weight bench press. J Strength Cond Res. 2010;24(3):779-84. doi: 10.1519/JSC.0b013e3181cc2237