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Volume Load and Neuromuscular Fatigue During an Acute Bout of Agonist-antagonist Paired-set Versus Traditional-set Training

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ABSTRACT

The purpose of this study was to investigate the acute effects of performing paired-set (PS) versus traditional set (TS) training over three consecutive sets, on volume load and electromyographic fatigue parameters of the latissimus dorsi, biceps brachii, pectoralis major and triceps brachii muscles. Fifteen trained males performed two testing protocols (TS and PS) using 10-repetition maximum loads. The TS protocol consisted of three sets of bench press (BP) followed by three sets of wide-grip seated row (SR). PS consisted of three sets of BP and three sets of SR performed in an alternating manner. Volume load was calculated as load x repetitions. The electromyographic signal, time (C_{RMS}) and frequency (Cf5) domain, parameters were recorded during SR. Under the PS protocol, sets of SR were performed immediately following sets of BP. A two-minute rest interval between the completion of the set of SR and the subsequent set of BP was implemented (e.g.,, between paired sets). Under the TS protocol two-minute rest intervals were implemented between all sets. BP and SR volume loads decreased significantly from set 1 to set 2 and from set 2 to set 3 under both conditions. Volume load was greater for all sets of both exercises under PS as compared to TS. Muscle fatigue indices were greater under PS as compared to TS. In general, these results indicate that as compared to TS, PS produced a greater training volume in less time and may induce greater fatigue and thereby provide an enhanced training stimulus.

Keywords: Electromyography; muscle strength; resistance training; paired set.

INTRODUCTION

Resistance training is an efficacious method of developing muscular strength and power (1). One of the primary variables to be considered when designing a resistance training program is the training volume or volume load (VL), often calculated as number of repetitions x external load (22, 25). VL reflects the stress placed on the activated muscle group. VL is associated with neural, hypertrophic, metabolic and hormonal responses to resistance training (20). It has been suggested that increases in this variable may lead to greater gains in strength (11).

Several resistance training programs have been developed which increase VL in a time-efficient manner (7, 21). One such method is known as agonist-antagonist paired-set training (PS), and refers to the use of agonist and antagonist exercises performed in an alternating manner (24). Decreases in training time are realized by reducing the rest interval between antagonist muscle groups (22). That is, time efficiency associated with PS training is premised on the concept that antagonist exercise performed between agonist exercise sets may be done so with relatively short rest intervals between agonist and antagonist bouts without compromising outcomes (20, 23, 24). PS training differs from traditional set (TS) training in which all sets of the same exercise are performed prior to the execution of all sets of the next exercise. Previous studies have shown that as compared to TS, PS reduces the resistance training session duration (20, 22) and provides a higher level of muscle fatigue (7) and can improve muscle strength performance (6, 15).

At present, the neuromuscular responses to PS are unclear. Using an integrated electromyographic (EMG) signal, Maynard and Ebben (17) observed an increase in hamstring coactivation under PS (five knee flexions followed by five knee extensions) as compared to TS (five knee extensions). This increase in coactivation was associated with significant decreases in peak torque and peak power. In contrast, over a series of studies Robbins *et al*. (20, 21, 23, 24) observed no significant differences in a number of power-related indices, VL and EMG during PS, as compared to TS. Using reduced rest intervals, Maia *et al.* (15) observed significant increases in knee extensor performance following antagonist preloading. Under similar protocols (e.g., shortened rest intervals following antagonist preload) the authors also found significant increases in normalized root mean square (RMS) of the vastus medialis and rectus femoris muscles. Although a number of mechanisms (e.g., facilitatory stimulation of Golgi tendon organs and muscle spindles) have been suggested to explain the above-described responses to antagonist preloading, both the neuromuscular responses and underlying mechanisms remain unclear.

When planning and prescribing resistance training programs, a greater understanding of predicted outcomes and the mechanisms underlying those outcomes is beneficial. To date, studies examining the neuromuscular impact of PS have focused on EMG measures such as the root mean square (RMS) and mean or median frequency (17, 23, 24). Due to the subjective selection of boundary frequency and/or high and low-frequency bands (3), these techniques have limited ability to evaluate muscle fatigue during dynamic tasks (2, 10). EMG spectral indices have been reported to demonstrate greater sensitivity during dynamic contractions (13). To the best of our knowledge, no study has used EMG spectral indices to assess muscle fatigue during PS. The purpose of this study was to use well-suited EMG measures (e.g., the Dimitrov spectral index of muscle fatigue and amplitude) to assess muscle fatigue during a dynamic PS protocol and to provide support for the hypothesis that as compared to a TS protocol, antagonist preloading via PS may increase acute strength performance.

METHODS

Experimental Approach to the Problem

A randomized crossover design study was carried out in four test sessions on non-consecutive days (see Figures 1 and 2). Because of the familiarity of movement and widespread use as a means to develop strength, bench press (BP) and wide-grip seated row (SR) were chosen as the pulling and pushing exercises, respectively. In the week before the first session, 10 repetition maximum (RM) loads were determined for the BP and SR exercises during test and retest sessions. Moderate-intensity loads (e.g., 10-RM) performed over repeated trials have been recommended with respect to strength and hypertrophy development (1). To assess muscle fatigue and VL during a dynamic PS versus TS protocol, the following protocols were applied: (a) TS participants performed three sets to failure of BP followed by three sets to failure of SR. Two-min rest intervals were implemented between sets and exercises; (b) PS, the antagonist preloading was assessed performing a set of BP immediately followed by one set of SR. The time required for participants to change exercises was approximately 10 seconds. A two-minute rest interval was adopted before the next paired set (BP and SR). The recovery period between the experimental protocols was between 48 and 72 hours. The number of repetitions completed for all sets under both protocols was recorded. EMG signal of the latissimus dorsi (LD), biceps brachii (BB), pectoralis major (PM) and triceps brachii (TB) muscles was recorded during the SR exercise in each protocol. The EMG indices of fatigue (Cf5 and C_{RMS}) were computed to compare the neuromuscular fatigue response between TS and PS protocols. Fatigue-induced changes in non-stationary EMG signals can provide an indication of general motor unit activation and signal frequency, respectively (10).

****Figures 1 and 2 near here****

Subjects

Fifteen recreationally-trained males participated in the study. Participant descriptive data (mean ± standard deviation) are as follows: age of 22.4 ± 1.1 years, height of 175 ± 5.5 cm, weight of 76.6 ± 7.0 kg and percent body fat of 12.3% ± 2.1%. All participants had previous resistance training experience (3.5 ± 1.2 years), averaging four, 60-min sessions per week. Participants generally implemented 1- to 2-min rest intervals between sets and exercises. All participants were active in approximately 2–4 hours of recreational or competitive sports training or were active in competition 1–5 times per week. This study was conducted during the hypertrophic phase of the periodization program of all subjects. The participants included in this research did not consume dietary supplements in the form of carbohydrates, proteins or amino acids. No participants used anabolic steroids either before or while participating in this research. All test participants were informed on how to remain properly hydrated to avoid the influence of dehydration on strength performance.

The current study was approved by the Institutional Human Experimental Committee at the Federal University of Rio de Janeiro. All participants completed the Physical Activity Readiness Questionnaire (PAR-Q) and signed an informed consent before participation in this study according to the Declaration of Helsinki. All participants were instructed to avoid any upper-body exercise in the 48 hours prior to each session.

10 Repetition Maximum (10-RM) Testing

At each of the first two sessions strength was assessed using a 10-RM test for BP and SR exercises (see Figure 3) on Life Fitness equipment (Life Fitness, Rosemont, IL, USA). The 10-RM load was chosen in order to assess muscular strength. The 10-RM test was performed at a constant pace (2 s for both concentric and eccentric contractions) and was controlled by a metronome (Metronome Plus 2.0, M&M Systeme, Braugrasse, Germany) (12). If the participant did not attain 10 repetitions in the first attempt, the weight was adjusted by 4 to 10 kg, and a minimum of 5 minutes of rest was given before the next attempt. Ten-min rest intervals were adopted between exercises to test the 10-

RM loads. BP and SR exercises were alternated during test and retest. Only three trials were permitted per testing session. The test and retest sessions were conducted 48 hours apart.

In order to reduce the margin of error in testing, the following strategies were adopted (18): (a) in order that all subjects were aware of the entire data collection routine, standardized instructions were provided before the test; (b) subjects were instructed on the technical execution of the exercises; (c) the researcher carefully monitored the position adopted during the exercises; (d) consistent verbal encouragement was given in order to motivate subjects for maximal repetition performance; (e) the additional loads used in the study were previously measured with a precision scale.

****Figure 3 near here****

Procedures

Participants came to the laboratory on four different occasions, with a minimum rest interval of 72 h between visits. All tests were completed on Monday, Wednesday and Friday at the same time of the day (8 a.m. to 10 a.m.) between July and August. Subjects reported to the laboratory in the morning and then consumed a standardized breakfast (approximately 320–350 calories) with a protein to fat to carbohydrate ratio of 20:35:45 (protein, fat, carbohydrate as percentage).

Experimental protocols

During the third session, participants were assigned to the TS or PS group in a randomized fashion. The fourth session consisted of performing whichever protocol was not performed in the third session. Before each protocol, participants performed a warm-up set of 15 BP repetitions using 50%

of 10-RM loads (12, 27). A two-min rest interval was implemented following the warm-up set. 10-RM loads were used for each protocol. Under TS, participants performed three sets to failure of BP followed by three sets to failure of SR. Two-min rest intervals were implemented between sets and exercises. Under PS, participants performed one set of BP, immediately followed by one set of SR. The time required for participants to change exercises (from BP to SR) was approximately 10 seconds. A two-min rest interval was adopted before the next paired set (BP and SR). Participants performed three paired sets. The rest interval between like sets of BP and SR was approximately 170 s (the time spent to perform each exercise, plus the time to move to the next exercise, plus the 2-minute rest interval). Following the standardized warm-up, the average session duration was 16 ± 3.5 min under TS and 8.5 ± 2.3 min under PS. The number of repetitions completed for all sets under both protocols was recorded. Under each protocol, during the SR exercise, EMG activity of LD, BB, PM and TB muscles was recorded.

Surface Electromyography

The EMG signal was captured through passive bipolar surface electrodes (Kendal Medi Trace 200, Tyco Healthcare, Pointe-Claire, Canada), acquired by a dedicated data acquisition system (EMG System of Brazil, Sao Jose dos Campos, SP, Brazil). The signals were amplified by 1,000 (CMRR > 100dB), and sampled at 1,000 Hz after being band-pass-filtered (10–500 Hz). The simple differential active electrodes (input impedance of 10^{10}Ohm; passband prior sampling of 0.1–500 Hz) had polyethylene foam with hypoallergenic medical adhesive, solid stick gel, bipolar contact of Ag/AgCl and a between poles distance of 20 mm. Precautions were taken in order to avoid the dynamic EMG limitations. Skin surface was shaved, slightly abraded, and cleaned with alcohol swabs before placing the EMG surface electrodes. In order to avoid the possibility of crosstalk, electrodes were placed on the corresponding muscle belly aligned with the fiber direction, according to SENIAM standards (26). Placement and location of the electrodes was made in accordance with surface EMG for the non-invasive assessment of muscles Cram and Kasman (9) recommendations.

The PM electrode was placed at the midpoint between the acromion process and the xiphoid process. The LD electrode was placed lateral to the inferior angle of the scapula. The BB electrode was placed on the line between the medial acromion and the cubit fossa. The TB electrode was placed half way between the acromion process and the olecranon process at 2 finger widths below the medial line. The reference electrode was placed on the clavicle bone. The impedance between electrode pairs was less than 5 kΩ using a 25-Hz signal through the electrodes. All these procedures were performed by the same investigator. Placement of the electrodes was identified on the first day of testing, and an indelible pen mark was made on the skin to ensure that a similar electrode position was used on the subsequent day.

Following recommendations for muscle testing function proposed by Cram and Kasman (9), at each visit, all subjects performed a maximum voluntary isometric contraction (MVIC) for PM, LD, BB and TB in a randomized design. The MVIC was performed for two sets of 5 s each, with a rest interval of 2 min (7). The EMG analysis was conducted with a MatLab sub-routine specially designed for this study. The EMG signal was normalized using the MVIC. In the normalization procedure, the MVIC repetition with the highest RMS value across the three middle seconds of the signal was used as a reference. A ten-minute rest interval was adopted before beginning the experimental protocols.

Data Processing

Commonly, the RMS together with the mean and/or median frequency of the EMG power spectrum has been used to evaluate muscle fatigue (28). To overcome the problem of low sensitivity of those spectral parameters during dynamic contractions, a new highly sensitive spectral index called FInsm5 was adopted in order to quantify the spectral changes of muscle EMG during fatigue. This method is in accordance with the procedure of Dimitrov *et al.* (10). The conventional Fast Fourier

Transformation (FFT) was applied to calculate the spectrum density. The spectral moments were then used to extract the features of the spectral density of the EMG signal using equation 1:

$$M_k = \int_{f\,\min}^{f\,\max} f^k . PS(f) . df \quad \text{Eq. 1}$$

Where M_k is the spectral moment of order K, PS(f) the EMG power spectrum, as a function of frequency f of the signal bandwidth, fmin to fmax (20–450 Hz). The fatigue index was calculated as the ratio between spectral moments of orders 1 and 5 for each exercise repetition (equation 2). The fatigue index changes (increases representing greater fatigue) were based on a comparison between the first and subsequent repetitions within each set. The first set was always referred to as 100% and subsequent sets were based on the equation:

$$\frac{FI^{5}_{nsm5}}{FI^{1}_{nsm5}} x100 \qquad \text{(n = 1, 2 and 3)} \qquad \text{Eq. 2}$$

The FInsm5 was calculated for each repetition and muscle. Those values, together with the time duration of each contraction, were used to perform a linear regression, from which the coefficient (Cf5) was used for further comparisons (7). The RMS was calculated for each entire contraction (concentric and eccentric) during the seated row exercise, with the beginning and ending of each contraction selected visually from the EMG signal. A linear regression was performed of the series formed by all values obtained and the corresponding time duration of each value. The coefficient of this regression (C_{RMS} - uV/min), together with Cf5, was taken as the parameter to be compared across the experimental protocols. All digital processing procedures were performed by using the custom-written software Matlab5.02c (Mathworks™, Natick, USA).

Statistical analyses

All data are presented as mean ± SD. The Shapiro-Wilk normality test and a homoscedasticity test (Barlett criterion) were used to test the normal distribution of the data. All variables presented a normal distribution and homoscedasticity. The dependent variables were: EMG indices of fatigue (Cf5 and C_{RMS}) and volume load (repetition x load). Test-retest reliability of 10-RM loads and EMG spectral parameters was conducted using the intraclass correlation coefficient (ICC = (MSb – MSw)/[MSb + (k-1)MSw)]), where MSb = mean-square between, MSw = mean-square within, and k = average group size. These data were analyzed using a 2-way analysis of variance (ANOVA) [protocols x sets] with repeated-measures and paired t-tests to determine whether there were significant main effects or interactions for the type of training (TS and PS) and the sets (1, 2, and 3). EMG data were analyzed using a 2-way ANOVA (2 x 3) with repeated measures to determine whether there were significant main effects or interactions for the type of training (TS and PS) and sets (1, 2 and 3). Post-hoc tests using the Bonferroni correction were employed when necessary. The VL (load x repetitions) for each set was calculated for bench press and seated row. Paired T-tests were used to compare the session VL (load x repetitions for entire session) between protocols for each exercise. The level of statistical significance was set at $p \leq 0.05$ for all tests. The effect size was also computed following Rhea (19) recommendations for recreationally trained individuals (Trivial: < 0.35; Small: 0.35 – 0.80; Moderate: 0,80 – 1.50; Large: >1.5). The statistical analyses were performed with SPSS version 20.0 (Chicago, IL, USA).

RESULTS

The reliability study determined that ICCs and %TE for average and total VL over 3 sets for BP and SR ranged between 0.92 (5.9%) and 0.95 (9.4%), respectively. Paired sample t-tests revealed no significant (p <0.001) differences between the 2 testing occasions. The test-retest ICC of the EMG measures for the 4 monitored muscles ranged between 0.91 and 0.92. Mean and SD of the 10-RM loads was 83 ± 3.4 kg for BP and 68.5 ± 3.4 kg for SR exercises.

Significant reductions in VL were found for BP and SR exercises between sets 1 and 2, and sets 2 and 3 under both protocols. VL for SR was significantly lower under the TS, as compared to PS, over the 3 sets. VL was significantly lower for BP under TS, as compared to PS, for sets 2 and 3. Session VL was greater under PS, as compared to TS, for both BP and SR. Session VL was higher for PS (1328 ± 27.5 kg) as compared to TS (1188.4 ± 115 kg; p = 0.002) for BP exercise. This was also true for the SR exercise TS (960.5 ± 100.1kg) and PS (1249.4 ± 135.5 kg; p = 0.0001).The percentage change in VL from set 1 to set 3 was significantly less under PS, as compared to TS, for BP exercise. There was no significant difference in the percentage change between protocols for SR exercise. VL data, percent changes and effect sizes are shown in Table 1. Higher repetition performance was noted for SR exercise under PS for set 1 (p = 0.0001), 2 (p = 0.001) and 3 (p = 0.0001) when compared to the TS protocol (see Figure 4). Similar results were noted for BP exercise for set 2 (p = 0.001) and 3 (p = 0.0001)

****Table 1 near here****

**** Figure 4 near here****

Significant increases in LD and BB amplitude coefficient (C_{RMS}) were noted from set 1 to 2 and 2 to 3 for both protocols. As compared to TS, increases in LD muscle activity (C_{RMS}) were observed under PS during sets 1, 2 and 3. Augmentation of BB muscle activity was only observed for set 3 under PS, as compared to TS. Reduced PM muscle activity was observed in sets 1, 2 and 3 under PS, as compared to TS. Reduced muscle activity was also observed for the TB muscle in sets 1 and 2 under PS, as compared to TS. No differences were noted between sets and protocols for the TB muscle (see Figure 5).

****Figure 5 near here****

Significant increases in the fatigue index (C_{RMS} and Cf5) were noted from set 1 to set 2, and set 2 to set 3, during SR exercise for all muscle groups evaluated under both PS and TS. The LD muscles showed a higher fatigue index (e.g., Cf5) under PS, as compared to TS, during sets 1, 2 and 3 (see Figure 6). The EMG fatigue index was also higher for the BB muscle for sets 2 and 3under PS, as compared to TS. This result was also observed for the PM muscle during sets 1, 2 and 3. The TB muscle showed a higher fatigue index during sets 2 and 3 under PS, as compared to TS.

****Figure 6 near here****

DISCUSSION

Previous research has suggested that PS training is a time-efficient method by which to maintain VL in an acute setting (20, 21, 23, 24). The results of the present study indicate that antagonist preloading via PS (with minimal allowable rest) may allow for increased VL in a time-efficient manner. VL was greater for both BP and SR under PS, as compared to TS. This, in conjunction with the elevated fatigue indices (EMG) observed for agonist and antagonist muscles groups during SR under the PS protocol, suggests PS, as compared to TS, may provide significant increases in acute muscle strength performance.

Of the six comparisons of VL (three sets each of BP and SR) only the first set of BP was not significantly different. Given that this set of exercise was preceded by nothing other than the standardized warm-up, this is not surprising. Each of the other five comparisons yielded significantly greater VL under PS as compared to TS. These data are in disagreement with some previous studies which suggested that PS yields similar VL in a time-efficient manner (7, 8, 20). One possible explanation is that the time between like sets of exercise was greater under PS as compared to TS in the present study, as compared to those implemented in previous studies. Robbins et al. (20) implemented 2-min rest intervals between like sets. In the present study the rest interval following the BP or SR set was approximately 120 s. Thus, under the PS protocol the effective rest between like sets was approximately 10 s to move from BP to SR plus the time to complete the set of SR or BP exercises of approximately 40 s (e.g., 10 repetitions at a cadence of 2 s concentric and 2 s eccentric contractions). That is, under PS the rest interval between like sets was two min and 50 s. This longer rest interval of approximately 50 s (42% greater) between like sets under PS, as compared to TS, may have allowed for greater recovery and greater VL.

While the present study is in disagreement with some previous research (7, 17, 20), it does seem to support that of Maia et al. (15). Those researchers observed greater repetition performance (with 10-RM loads) when performing a set of knee extension immediately following a set to failure of lying leg curl (e.g. antagonist preloading), when compared to knee extension without antagonist preloading. The authors observed this potentiated effect using 30-s and 1-minute rest intervals, but not when implementing longer rest intervals (e.g. 3- and 5-minute rest interval). This suggests that the rest interval between PS exercises may play an important role. This is supported by previous studies which adopted longer rest intervals and did not find differences in agonist muscle strength performance (7, 8, 20, 21, 23, 24). It is possible that antagonist preloading using minimal rest intervals may potentiate subsequent agonist exercise.

A variety of mechanisms (e.g., neural adjustment of GTO's, increased elastic energy storage, alteration of triphasic neural pathways) have been proposed to explain antagonist-pre-load-induced performance (4-7). It is also possible that the changes in Cf5 observed for BB and LD under both protocols may be partially related to an increase in the duration of the motor unit action potential waveform and subsequent decrease in muscle fiber conduction velocities (10). According to Woods, Furbush and Bigland-Ritchie (29) motor neurons firing rates are inhibited by some reflex originating from the muscle, generated in response to either the mechanical or metabolic changes that accompany fatigue. Martin *et al*. (16) observed that when comparing elbow extensor and flexor maximal sustained contractions, motor neurons are not uniformly affected by inputs from group III and IV afferents, when preceded by antagonist preloading. Those researchers also found that if inhibitory influences from these afferents are more pronounced on extensor motor neurons then, all other things being equal, these muscles will require greater cortical output to generate a given force during fatigue (14).

In the present study, the muscle fatigue index was able to detect performance variations between protocols. Significant increases in the fatigue index (Cf5 and C_{RMS}) were noted over the 3 sets of SR exercise for the LD, BB, PM muscles under both protocols. Increases in Cf5 were observed for the TB muscle under both protocols. PS presented higher levels of muscle fatigue, as compared to TS, for the LD, BB, PM and TB muscles. This lower fatigue index in the TS protocol may be due to the order of the antagonist preloading, which may lead to a higher degree of muscle recovery between like sets. The increased EMG amplitude observed during PS (C_{RMS}) might be primarily attributed to additional motor unit recruitment and/or increased spatial (2) or temporal motor unit synchronization (3), presumably to compensate for muscle fiber fatigue (13). An increase in the fatigue index (Cf5) has previously been associated with changes in spectral moment of order 1 across repetitions (10), emphasizing the changes in the low and ultra-low frequencies in the EMG spectrum (3). Spectral moment of order 5 conferred greater magnitudes of change at high frequencies (13). Such outcomes have previously been attributed to the increased duration of the intracellular action potentials and decreased action potential propagation (28).

This study has limitations that warrant mentioning. Due to factors such as muscle speed, fiber and length, the interpretation of the EMG signal during dynamic tasks may increase the non-stationary characteristics of the EMG signal. Additionally, the current study only examined two upper body resistance exercises, whereas resistance training sessions typically include various exercises performed over multiple sets.

A secondary finding of the present study was the observed decreases in VL for both BP and SR across sets under both protocols. These data suggest that a 2-min rest interval was inadequate to maintain VL. This finding is consistent with previous PS research in which VL was not maintained when using rest intervals of 1-4 minutes between like exercises sets (18, 23, 24).

PRACTICAL APPLICATIONS

The results of the present study suggest that upper body antagonist preloading via PS may increase muscle strength performance in acute manner and may be a practical alternative to TS with respect to increasing VL in a time-efficient manner. The elevated fatigue indices observed during PS could be useful in developing muscle strength and hypertrophy for both antagonist and agonist muscle groups. PS may be useful for coaches and athletes who are seeking to enhance acute muscle performance and increase VL and/or reduce the training session duration.

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Figure Legends

Figure 1. Schematic representation of TS protocol.

10-RM: 10 repetition maximum
BP: bench press
SR: seated row

Figure 2. Schematic representation of PS protocol.

10-RM: 10 repetition maximum
BP: bench press
SR: seated row

Figure 3**.** Bench press (A) and wide-grip seated row (B) being performed.

Figure 4. Repetition performance of each participant performed in bench press and wide-grip seated row exercises between paired-set and traditional protocols.
§ Significant difference as compared to traditional set protocol.

Figure 5. Coefficient of root mean square linear regression (values in percentages) for agonist and antagonist muscles during the performance of wide-grip seated row between paired set and traditional protocols. Curves represent the average between sets.

*Significant difference for set 1. § Significant difference as compared to traditional set protocol.

Figure 6. Fatigue index (values in percentages) for agonist and antagonist muscles during the performance of wide-grip seated row between paired-set and traditional protocols. Curves represent the average between sets.
*Significant difference for set 1. § Significant difference as compared to traditional set protocol.

Figures

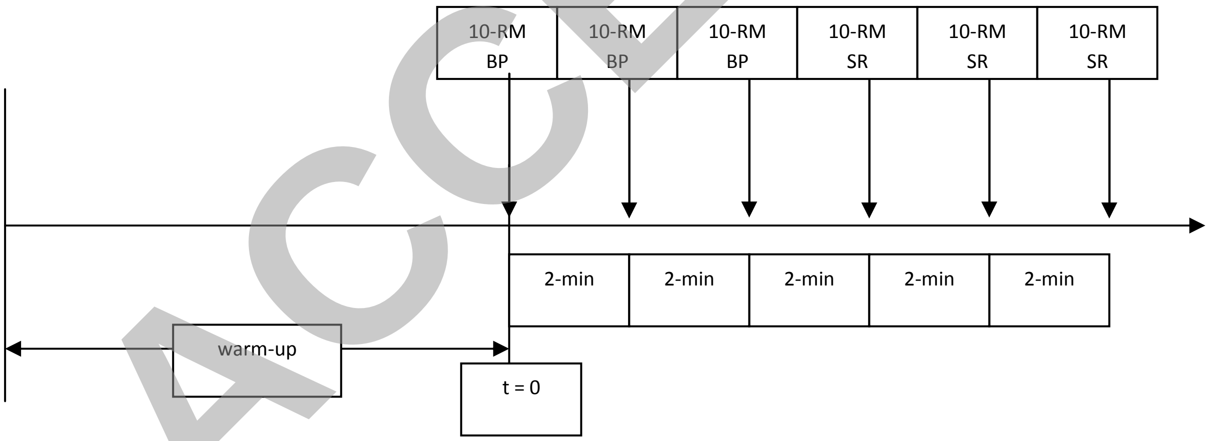

Figure 1. Schematic representation of TS protocol.

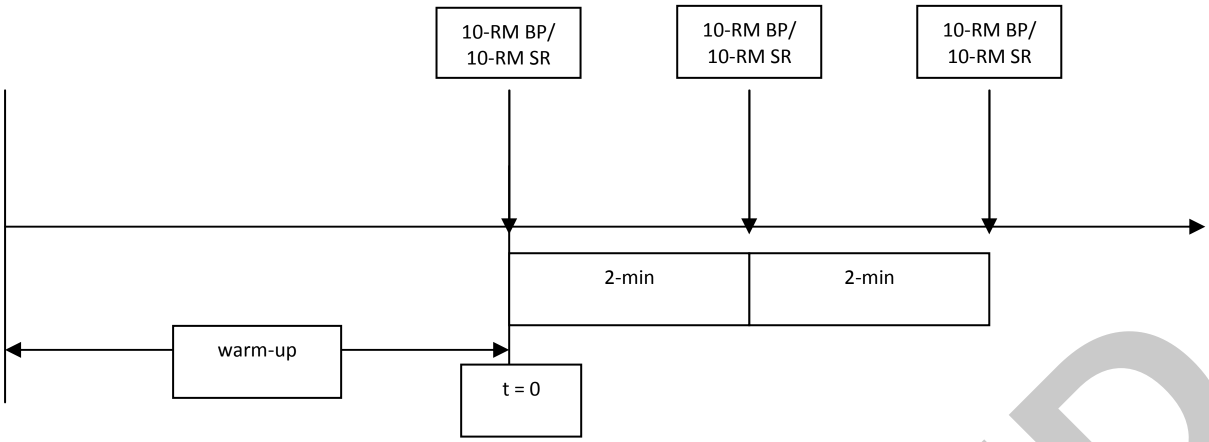

Figure 2. Schematic representation of PS protocol.

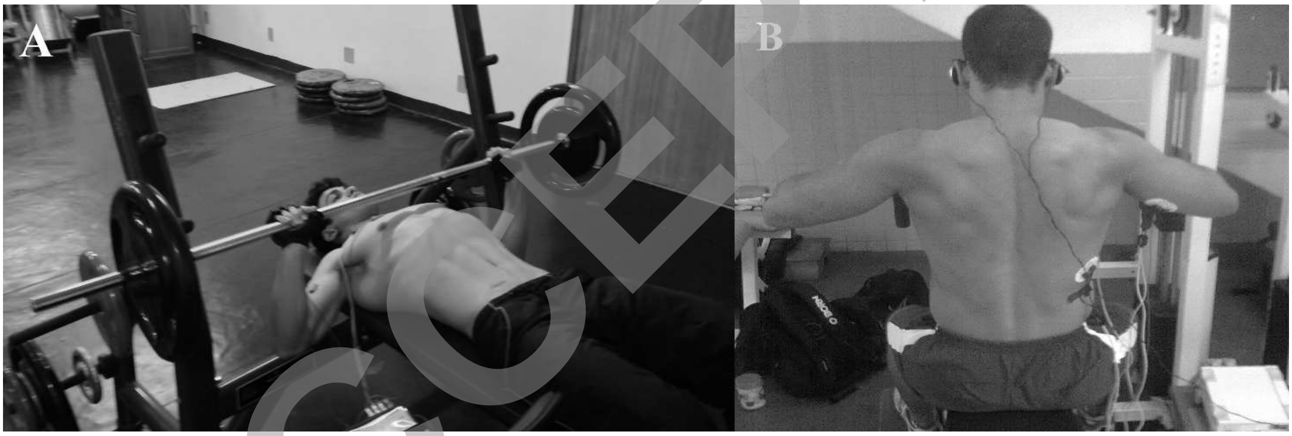

Figure 3. Bench press (A) and wide-grip seated row (B) being performed.

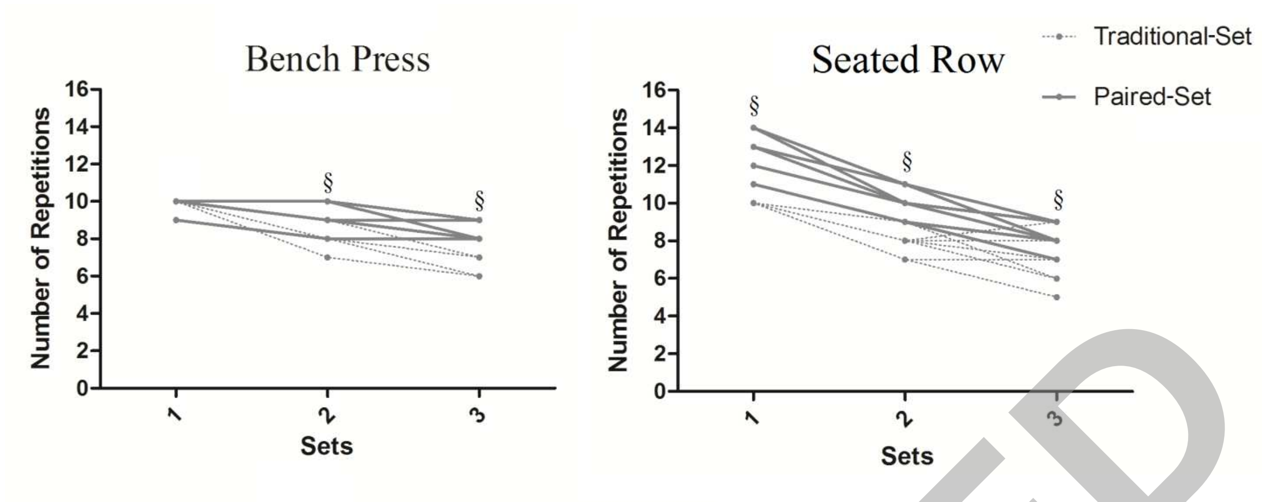

Figure 4. Repetition performance of each participant performed in bench press and wide-grip seated row exercises between paired-set and traditional protocols. § Significant difference as compared to traditional set protocol.

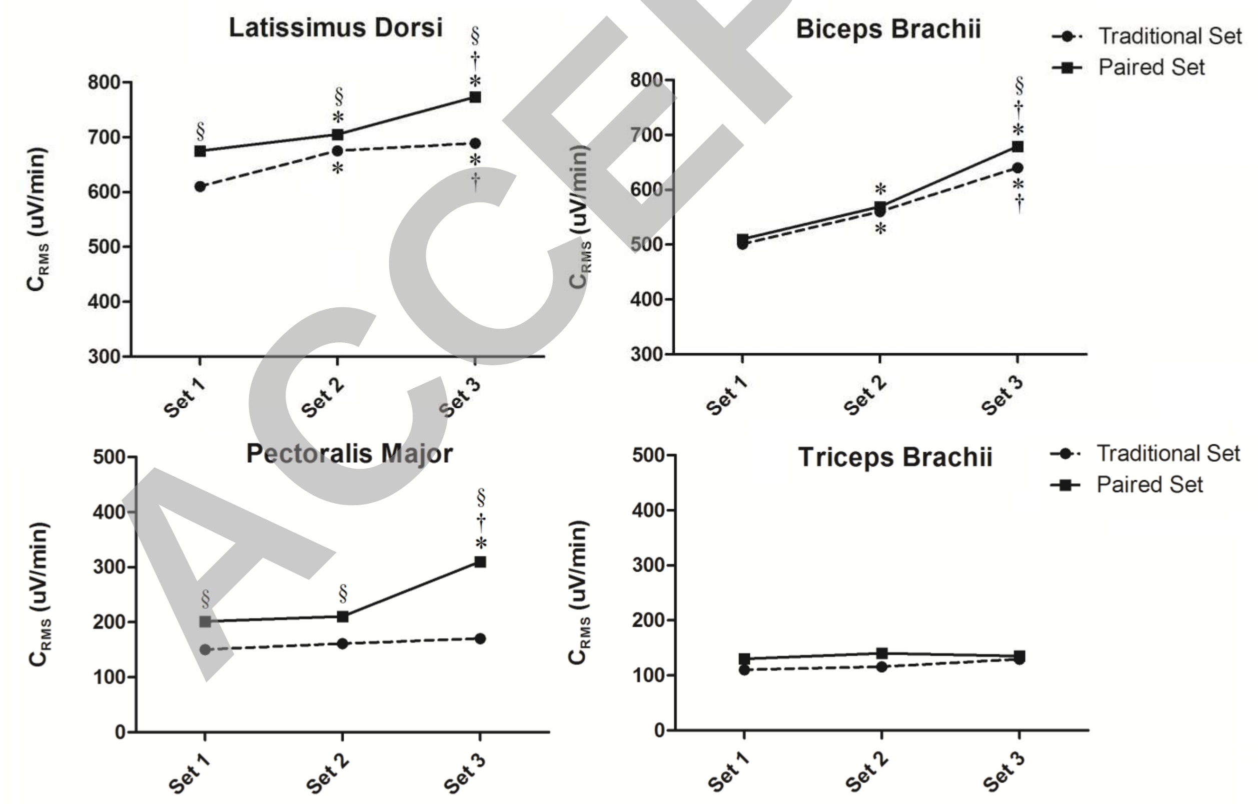

Figure 5. Coefficient of root mean square linear regression (values in percentages) for agonist and antagonist muscles during the performance of wide-grip seated row between paired set and traditional protocols. Curves represent the average between sets. *Significant difference for set 1. § Significant difference as compared to traditional set.

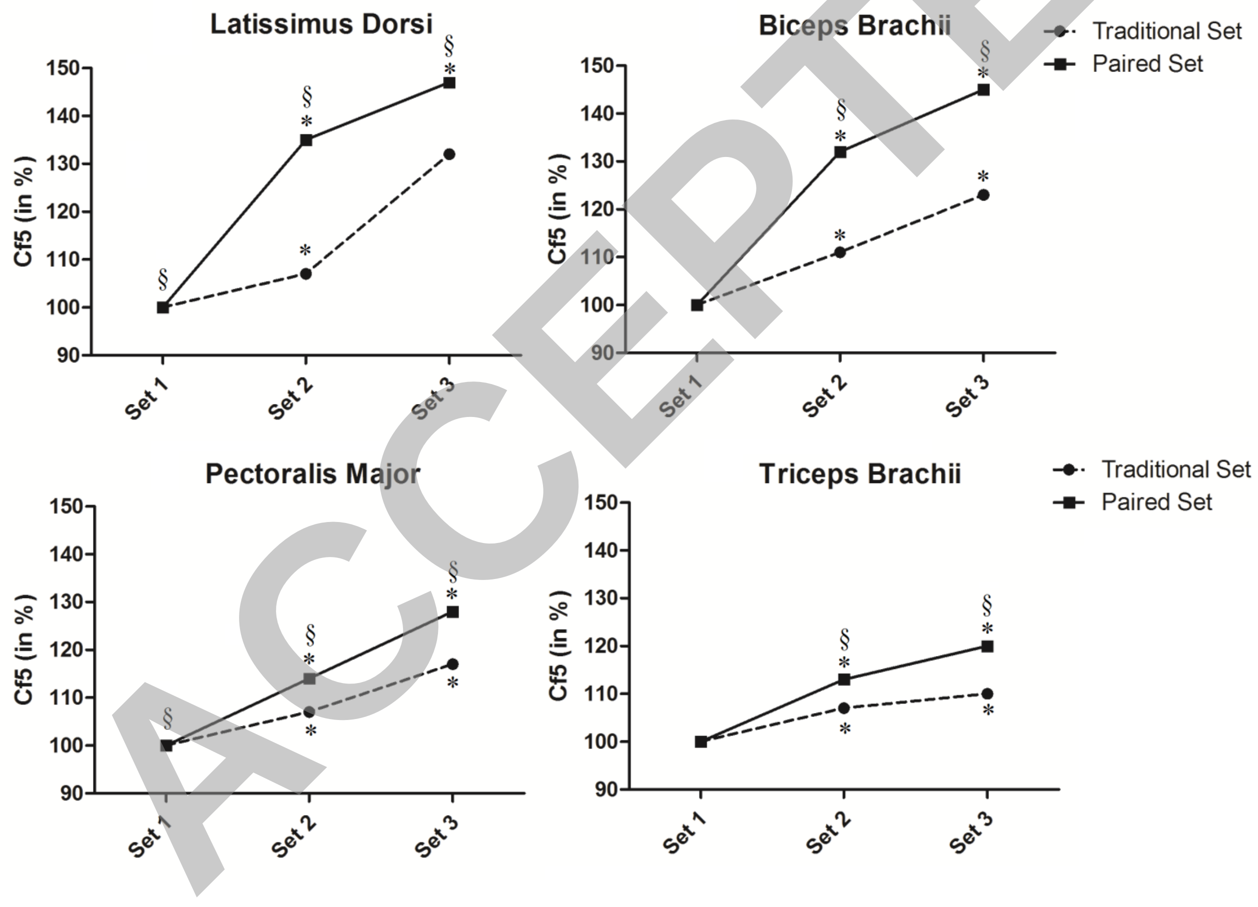

Figure 6. Fatigue index (values in percentages) for agonist and antagonist muscles during the performance of wide-grip seated row between paired-set and traditional set protocols. Curves represent the average between sets. *Significant difference for set 1. § Significant difference as compared to traditional set.

Tables

Table 1. Volume load (kg) completed in each set for agonist-antagonist paired-set (PS) and traditional set (TS) protocols (Mean and SD) and effect size data. The Δ% represents the decrease from the 1st to the 3rd set. Mean (SD) (N = 15).

Exercise	Protocol	Set 1	Set 2	Set 3	Δ%
Bench press	TS	480.0 ± 34	417.4 ± 60.3*	352 ± 55.6*	-26%
	PS	476.8 ± 36.2	448.6 ± 50.2*§	382.8 ± 72.2*§	-19.7%§
	effect size	-0.09 (Trivial)	0.51 (Small)	0.57 (Small)	-
Seated row	TS	382.3 ± 31.2	313.5 ± 39.5*	264.6 ± 45.3*	-30.7%
	PS	484.9 ± 50.1¥	385.1 ± 37.8*§	318.4 ± 35*§	-34.3%
	effect size	3.28 (Large)	1.81 (Large)	1.18 (Moderate)	-

*Significant difference as compared to previous set 1 ($p < 0.05$); § Significant difference as compared to TS ($p < 0.05$).