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Original article

Maximal repetition performance, rating of perceived exertion, and muscle fatigue during paired set training performed with different rest intervals

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Abstract

Background/Objective: The purpose of this study was to examine rest interval length between agonist–antagonist paired set training (PS) on maximal repetition performance, rating of perceived exertion, and neuromuscular fatigue.

Methods: Fourteen trained men (age, 24.2 ± 1.1 years; height, 175 ± 5.5 cm; body mass, 76.6 ± 7.0 kg) performed two experimental protocols in random order with 2 minutes (P2) or 4 minutes (P4) between agonist–antagonist PS, which consisted of a bench press set followed immediately by a seated row set with 8-repetition maximum loads, respectively. A total of three PS were performed for each rest interval protocol. The total repetitions performed and the rating of perceived exertion were recorded for each exercise set within each rest interval protocol. Electromyography signals were recorded for the posterior deltoid, biceps brachii, pectoralis major, and triceps brachii muscles during the SR exercise. The electromyography signals were then used to calculate a fatigue index for each rest interval protocol.

Results: No significant differences were identified in the total repetitions completed between rest interval protocols for the bench press (P2 = 22.9 ± 1.3 and P4 = 22.6 ± 0.8) and seated row (P2 = 25.4 ± 1.7 and P4 = 25.1 ± 1.3). However, a significantly higher fatigue index was found for all muscles under the P2 versus the P4 protocol.

Conclusion: When performing agonist–antagonist PS, prescribing a shorter rest interval between PS may induce higher levels of fatigue, albeit with similar total repetitions versus a longer rest interval.

Keywords: Electromyography; Exercise; Recovery; Resistance training

Introduction

Several methodological variables are manipulated during the prescription of resistance training programs, such as the volume, exercise order, load intensity, training frequency, and the rest interval between sets.[1] Researchers have found that different rest intervals between sets can affect repetition performance and training volume (load × sets × repetitions).[2,3] Miranda et al[4] observed a significant reduction in the total number of repetitions completed over three consecutive sets with a 1-minute versus a 3-minute rest interval between sets for a total body resistance exercise circuit in trained men.

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A higher training volume is directly related to long-term strength adaptations.[5] Several training methods are adopted by coaches and practitioners in order to increase training volume, but in a time-efficient manner.[6] One such method is to perform agonist–antagonist paired sets (PS), which are characterized by complementary exercises performed for agonist and antagonist muscles, with or without an intervening rest interval (e.g., superset).[7] This method has been shown to increase training volume and reduce training session duration in a time-efficient manner (training volume/time), when compared to the traditional training method, in which rest intervals are adopted between all sets of each exercise.[7,8] Decreases in training time are realized as the agonist muscles are resting while the antagonist muscles are working.[7] That is, the time efficiency associated with PS training is based on the theory that exercise sets for the antagonist muscles (e.g., antagonist preloading) performed between exercise sets for the agonist muscles may be done so with relatively short rest intervals, without compromising the adaptive stimulus,[7–11] and may also increase agonist muscle strength performance in an acute manner.[12–15]

Agonist–antagonist training methods differ from traditionally structured training in which all sets of the same exercise are typically performed in succession, prior to the execution of all sets for the next exercise and so on.[16] Robbins et al[10] found no significant differences in the total repetitions completed and muscle activation for an agonist–antagonist PS protocol that alternated sets of bench pull and bench press (BP), compared to a traditional approach; adopting 4-minute rest intervals between exercises and sets, respectively. A subsequent investigation by Robbins et al[7] involving similar exercises (e.g., bench pull and BP) found that over three sets, bench pull and BP (e.g., with 4 repetition maximum loads) volume load decreased significantly from Set 1 to Set 2 and from Set 2 to Set 3 under both the PS (e.g., 4-minute rest between like sets) and traditional method (e.g., 2-minute rest between like sets) protocols. However, bench pull and BP volume load per set were significantly less for the traditional approach versus the PS protocol over all sets, with the exception of the first set (bench pull Set 1). Recently, Maia et al[15] found significant increases in repetition performance and muscle activity of the knee extensors for an agonist–antagonist PS protocol using 10-repetition maximum (RM) loads for the lying leg curl and leg extension exercises with or without a shorter rest interval (e.g., no rest, 30 seconds, or 1 minute) versus a longer rest interval (e.g., 3 minutes or 5 minutes) between paired exercises. This suggests that the rest intervals between PS may play a key role in the antagonist preloading effects.[14,17]

To date, this is the only study that we are aware of to investigate the effect of different rest intervals between agonist–antagonist PS on repetition performance and neuromuscular fatigue. Previous studies have found conflicting results with regard to the agonist–antagonist training methods on strength performance and muscle activation, considering that different rest intervals were adopted between sets and exercises.[12,13,18] To date, only one study has investigated the effect of different rest intervals between sets and exercises during an agonist–antagonist training protocol.[15]

Thus, there is a need for further investigation examining different rest intervals in an agonist–antagonist PS type protocol with outcomes such as repetition performance and neuromuscular fatigue. The purpose of the present study was to examine how the length of the rest interval (2 minutes vs. 4 minutes) between agonist–antagonist PS affects maximal repetition performance, rating of perceived exertion (RPE), and neuromuscular fatigue.

Methods

Participants

Fourteen recreationally trained (age, 24.2 ± 1.1 years; height, 175 ± 5.5 cm; body mass, 76.6 ± 7.0 kg) men participated in this study. All were recruited from a local university using convenience sampling. All participants had previous resistance training experience (3.5 ± 1.2 years), with a mean frequency of four 60-minute sessions/wk, using 1- to 2-minute rest intervals between sets and exercises. All were assessed via the Physical Activity readiness Questionnaire[16] and signed an informed consent in accordance with the Declaration of Helsinki. The current study was approved by the Institutional Human Experimental Committee at the Federal University of Rio de Janeiro, Rio de Janeiro, RJ, Brazil. All participants were instructed to avoid any upper-body exercise in the 48 hours prior to each session.

Eight-RM testing

The 8-RM tests were conducted over 2 nonconsecutive days with at least 48 hours between sessions, in the week preceding the experiment.[4] The 8-RM tests and training sessions utilized resistance machines for the BP and wide-grip seated row (SR) exercises (Life Fitness, IL, Franklin Park, IL, USA). Repetitions were conducted at a constant velocity of 4 seconds per repetition (2 second concentric and 2 second eccentric) and controlled by a metronome (Metronome Plus 2.0; M&M System, Lich, Germany).

Experimental protocols

During the third and fourth visits, participants were assigned to two protocols conducted in random order (Figure 1). To assess the acute effects of different rest intervals between PS, the only difference between experimental protocols was resting 2 minutes (P2) or 4 minutes (P4) between agonist–antagonist PS, respectively. The agonist–antagonist PS consisted of performing a BP set to repetition failure followed immediately by a SR set to repetition failure with 8-RM loads, respectively. A total of three PS were performed for each rest interval protocol. Before each protocol, participants performed a warm-up set of 15 BP repetitions using 50% of

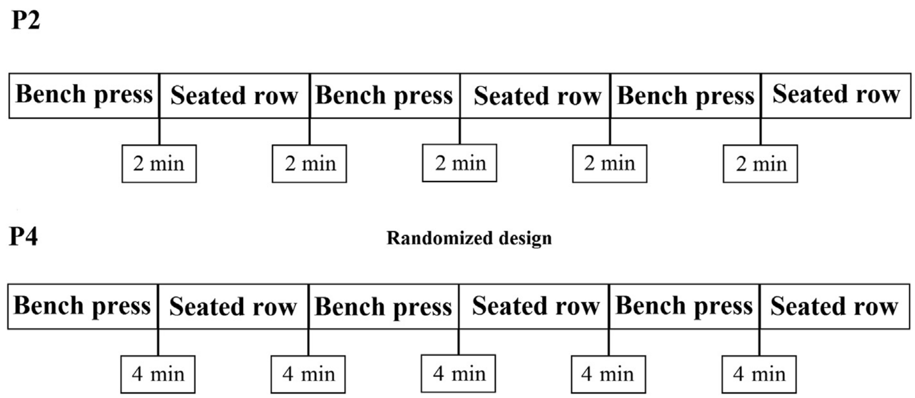

Figure 1. Study design.

the 8-RM load, followed by a 2-minute rest interval before beginning the workout.[19] The total repetitions and RPE were recorded for each protocol along with electromyographic (EMG) signals during the SR (2^{nd} exercise in each PS) for the posterior deltoid (PD), biceps brachii (BB), pectoral major (PM), and triceps brachii (TB) muscles. During the experimental protocols, the RPE was assessed using the OMNI-Resistance Exercise Scale (OMNI-RES).[20]

Surface EMG

The EMG signal was captured through passive bipolar surface electrodes (Kendal Medi Trace 200; Tyco Healthcare, Pointe-Claire, Quebec, Canada), acquired by a data acquisition system (EMG System of Brazil, Sao Jose dos Campos, SP, Brazil). The signals were amplified by 1000 (CMRR > 100 dB), and sampled at 1000 Hz after being band-pass filtered (10−500 Hz). Some precautions were taken in order to increase the validity of the EMG measurement, such as in the placement and location of the electrodes in accordance with standardized procedures.[21] The skin surface was shaved, slightly abraded, and cleaned with alcohol swabs before placement of the EMG surface electrodes. The electrodes were placed on the corresponding muscle belly in alignment with the fiber direction in accordance with Cram and Kasmam[22] recommendations. The impedance between electrode pairs was < 5 kΩ using a 25-Hz signal through the electrodes.

Data analysis

Traditionally, the root mean square together with the mean and/or median frequency of the EMG power spectrum has been used to evaluate muscle fatigue.[23] However, to overcome the limitation of low sensitivity in these spectral parameters, a spectral index with greater sensitivity, called the FInsm5, was adopted to assess changes in muscle EMG during fatigue.[24] Conventional fast Fourier transformation 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 Eq. (1):

$$M_k = \int_{f\min}^{f\max} f^k . PS(f) . df \qquad (1)$$

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 order 1 and order 5 for each exercise repetition (Eq. 2). The fatigue index (increases representing greater fatigue) was 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:

$$\frac{FI^5_{nsm5}}{FI^1_{nsm5}} \times 100 \quad (n = 1,\ 2,\ \text{and}\ 3) \qquad (2)$$

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 comparison between protocols.[14] All digital processing procedures were performed using the custom-written software Matlab5.02c (Mathworks, Natick, MA, USA).

Statistical analyses

All data are presented as mean ± standard deviation. The Shapiro-Wilk and homoscedasticity (Bartlett criterion) tests indicated that all variables presented homoscedasticity and normal distribution, except for the RPE, which was nonparametric. Test−retest reliability of the 8-RM loads and EMG spectral parameters were assessed 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. The data were analyzed using a 2-way ANOVA [2 (rest intervals) × 3 (sets)] with repeated measures to assess main effects and interactions between protocols (P2 and P4) in the total repetitions performed. EMG data were analyzed using a 3-way ANOVA [2 (rest interval) × 3 (sets) × 4 (muscles)] with repeated measures to assess main effects and interactions between protocols

Table 1
Bench press repetitions for each protocol.

	Set 1	Set 2	Set 3	Total
P4	8.0 ± 1.1	7.7 ± 0.5	6.8 ± 0.6*	22.6 ± 0.8
P2	7.9 ± 1.2	7.6 ± 0.7	6.6 ± 0.8*	22.9 ± 1.3

Data are presented as mean ± standard deviation.
* Significant differences for Set 1 ($p < 0.05$).

(P2 and P4) and sets (1, 2, and 3) for each muscle (PM, PD, BB, and TB). *Post hoc* tests with the Bonferroni correction were employed in the case of significant main effects and interactions. A paired t test was used to compare the total repetitions completed over three sets between the protocols for each exercise. To assess differences in the RPE between protocols and exercises, the Wilcoxon test was used, respectively. The level of statistical significance was set at $p < 0.05$ for all comparisons. The statistical analysis was performed with SPSS version 20.0 (SPSS Inc., Chicago, IL, USA).

Results

Eight-RM loads for BP and SR exercises were 90 ± 4.4 kg and 69.2 ± 3.4 kg, respectively. The ICCs for the test and retest of 8-RM were 0.92 for the BP and 0.95 for the SR exercises. The test−retest ICC of the EMG measures for the four monitored muscles ranged between 0.91 and 0.92. The average session duration was 20 minutes for the P4 protocol and 10 minutes for the P2 protocol. No significant differences in total BP repetitions were observed between protocols ($F = 1.349$; $p = 0.266$; Table 1). However, for both protocols, a significant reduction in BP repetitions was observed between Set 1 and Set 3 ($p = 0.0001$).

Similarly, for the SR exercise (2nd exercise in each agonist−antagonist paired set), no significant differences in total repetitions were observed between protocols ($F = 0.252$; $p = 0.62$; Table 2). However, for both protocols, a significant reduction in SR repetitions was observed between Set 1 versus Sets 2 and 3 ($p = 0.0001$). There were no significant interactions between sets and protocols.

A significant interaction was observed between sets and protocols for the index of muscle fatigue (Cf5) in the PD ($F = 78.569$; $p = 0.0001$) and BB ($F = 65.453$; $p = 0.0001$). Significant increases were found for the indices of fatigue (Cf5) in the PD muscle during Set 2 ($p = 0.0001$) and Set 3 ($p = 0.02$) for the P2 protocol versus the P4 protocol (Figure 2). Similar results were found during Set 2 ($p = 0.0001$) and Set 3 ($p = 0.03$) in the BB muscle.

Regardless of differences in the EMG activity for the antagonist muscles, significant interactions between sets and protocols were observed in the PM ($F = 53.343$; $p = 0.001$) and TB ($F = 35.332$; $p = 0.001$). Significant increases were found in the level of fatigue (Cf5) for the PM muscle during Set 2 ($p = 0.001$) and Set 3 ($p = 0.003$) during the P2 protocol versus the P4 protocol (Figure 3). Similar results were found during Set 2 ($p = 0.001$) and Set 3 ($p = 0.003$) for the TB muscle. Additionally, there was no difference in the RPE between sets and protocols for the BP and SR exercises (Figure 4).

Table 2
Seated row repetitions for each protocol.

	Set 1	Set 2	Set 3	Total
P4	9.5 ± 0.9	8.3 ± 0.4*	7.2 ± 0.6*	25.1 ± 1.3
P2	10 ± 0	7.3 ± 0.5*	7 ± 0.8*	25.4 ± 1.7

Data are presented as mean ± standard deviation.
* Significant differences for Set 1 ($p < 0.05$).

Discussion

Previous research has indicated that shorter rest intervals between sets promote lower repetition performance versus longer rest intervals over multiple sets.[3,25,26] The results of the current study demonstrated similar repetition performance with agonist−antagonist training PS protocols that utilized either 2- or 4-minute rest intervals between PS and with a moderate load (e.g., 8-RM). However, the elevated fatigue indices (Cf5) observed for the agonist and antagonist muscles groups under P2 during the SR exercise, suggests that a shorter rest interval (e.g., 2 minutes) may promote greater levels of muscle fatigue, but without compromising repetition performance, when compared to a longer rest interval between PS (e.g., 4 minutes).

Greater increases in the EMG spectral fatigue index (Cf5) were noted for the P2 protocol compared to the P4 protocol. These increases in the EMG spectral fatigue index (Cf5) might be associated with an additional recruitment of motor units and/or increased spatial or temporal synchronization of motor units due to muscle fatigue.[27] In contrast to the present study, Robbins et al[11] found similar EMG parameters of fatigue (root mean square and median frequency) for the bench pull and BP conducted in a traditional format for each exercise independently versus a PS approach during which sets of the bench pull (involving antagonists for the BP: latissimus dorsi and posterior deltoid) were alternated with sets of the BP (agonists: pectoralis major and anterior deltoid). Robbins et al[11] suggested that their results might have been related to the fiber-type composition of the antagonist muscles for participants in their study, whose muscles may have consisted of fatigue resistant fiber types. A greater proportion of fatigue-resistance fibers would have resulted in greater maintenance of performance measures irrespective of the workout format (e.g., traditional or PS).[10]

However, previous authors have suggested that the median frequency variable is limited in the ability to assess the extent of muscle fatigue during dynamic tasks due to a lower sensitivity in identifying changes in the spectral moment.[24] Thus, changes in the spectral moment from order 1 to order 5 across repetitions within a set,[28] have previously been attributed to increases in muscle fatigue (Cf5) due to decreased propagation of action potentials.[29]

Considering the effect of different rest intervals between agonist−antagonist PS training protocols, Maia et al[15] found significant increases in muscle activation for the rectus femoris and vastus lateralis muscles, when the leg extension was

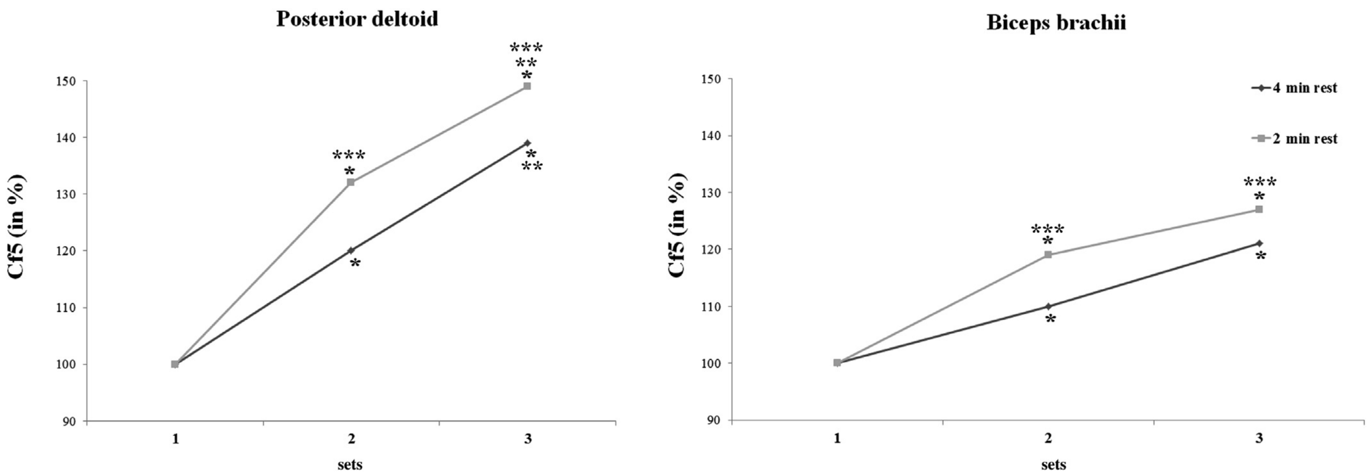

Figure 2. Coefficient of linear regression (Cf5) of FInsm5 presented as the percentage change between protocols for the posterior deltoid and biceps brachii muscles (agonists) during the seated row exercise. * Significant intraset difference for Set 1 ($p < 0.05$). ** Significant intraset difference for Set 2 ($p < 0.05$). *** Significant difference for 4-minute rest protocol ($p < 0.05$).

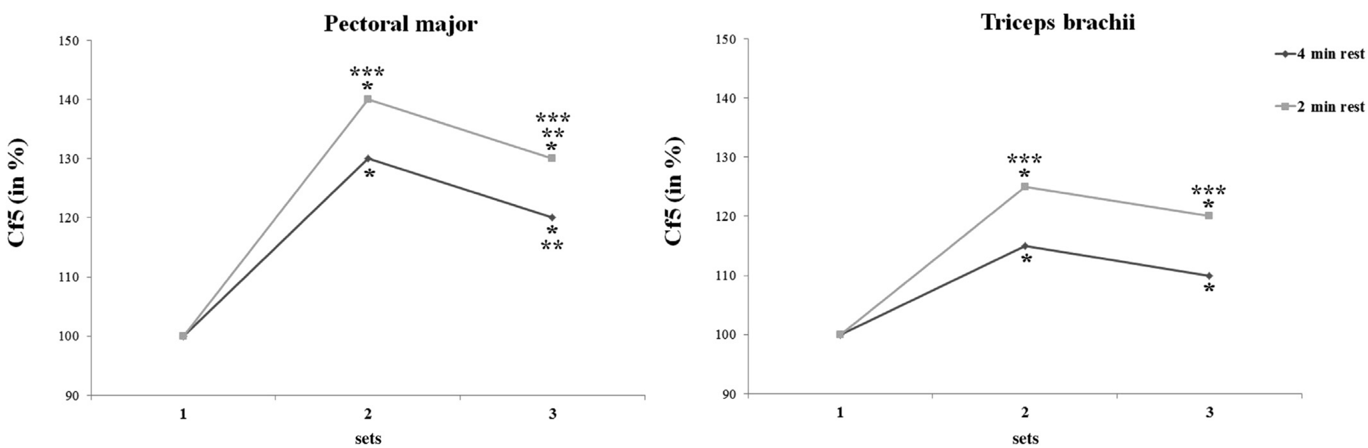

Figure 3. Coefficient of linear regression (Cf5) of FInsm5 presented as the percentage change between protocols for the pectoral major and triceps brachii muscles during the seated row exercise. * Significant intraset difference for Set 1 ($p < 0.05$). ** Significant intraset difference for Set 2 ($p < 0.05$). *** Significant difference for 4-minute rest protocol ($p < 0.05$).

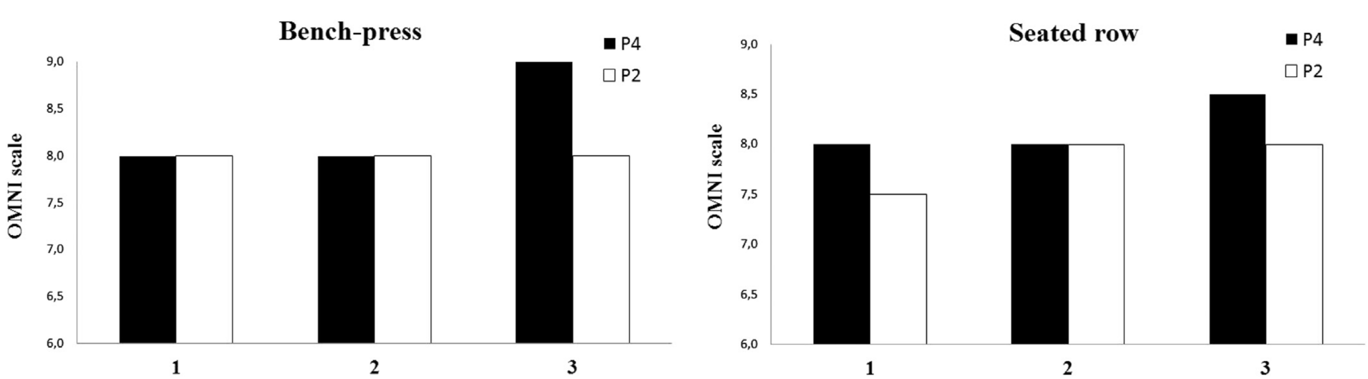

Figure 4. Rating of perceived exertion values (median) following the OMNI-RES recorded after each set of the seated row exercise. P4 = agonist−antagonist superset with 4-minute rest interval; P2 = agonist−antagonist superset with 2-minute rest interval.

performed immediately following or with shorter rest intervals (30 seconds and 1 minute) versus longer rest intervals (3 minutes or 5 minutes) following a leg curl exercise. The authors attributed this response to the fatigue induced in the hamstrings muscles during the leg curl that facilitated greater activation in the agonist muscles during the subsequent leg extension. In the present study, despite the similar RPE found between protocols, the fatigue indices suggested that the P2 protocol induced significantly greater fatigue versus the P4 protocol. For the agonist muscles (PM and TB), the EMG-spectral index of fatigue was greater for the P2 protocol versus the P4 protocol for Sets 2 and 3. However, significant increases in fatigue indices were noted from Set 2 to 3 for both protocols.

A secondary finding of the present study was that there was no difference in the total repetitions performed for the BP and SR exercises between the P2 and P4 protocols. That is, the rest interval between like sets was 2 minutes under the P2 and 4-minutes under the P4 protocol, respectively. This longer rest interval of ~4 minutes (100% greater) between like sets under P4, as compared to P2, was not necessary given the similar repetition performance between protocols. Robbins et al[7] found similar repetition performance over three sets of the bench pull and BP for a traditional approach versus a PS approach when utilizing 4-RM loads and 4 minutes between like sets. In another study utilizing the same exercises, Robbins et al[11] also found similar training volume for a traditional approach versus a PS approach when utilizing 8-RM loads and 4-minute rest intervals between like sets and exercises. The authors suggested that the PS approach might be an interesting alternative to reducing the session duration, without compromising repetition performance and the potential for strength adaptations. The time-efficient characteristics of PS method are often associated with protocols in which the rest interval is only applied after the PS.[7,8] However, the outcomes induced by the different rest intervals adopted between PS in the current study might be restricted to strength performance parameters, considering that similar rest intervals were adopted between like sets and exercises, respectively.

Mechanisms underlying the unique physiological responses during agonist–antagonist PS protocols are still unclear. Alteration of the triphasic coactivation pattern (e.g., decrease in the antagonist braking period) as a result of antagonist preactivation has been indicated as a possible mechanism responsible for a subsequent increase in strength performance for the agonist musculature.[17] The influence of the triphasic pattern has usually been connected to the neuromechanics of ballistic movements designed to develop muscular power (e.g., vertical jump or BP throw).[8] Although it is perhaps counterintuitive that the more fatiguing of the two protocols yielded similar repetition performance, this may be explained by the above-described difference in the rest interval between like sets (e.g., the greater rest interval allowed for more complete recovery). Alternatively, it may be that antagonist preloading yields potentiation of the subsequent agonist exercise under the right conditions (e.g., timeline, load, exercise). However, the EMG assessment was not applied during the BP exercise, which limits the interpretation of the effects of co-activation mechanisms on strength and fatigue parameters of performance. It is also possible that the changes in Cf5 observed for PD and BB 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.[23,27]

Considering chronic effects of agonist–antagonist training methods, Mackenzie et al[30] found significant increases in strength (5.8%) and EMG activity (18.5%) of elbow flexor muscles when compared to a control limb, following 6-weeks of an antagonist training protocol for elbow extensor muscles. The results of the current study should be considered as an interesting acute perspective of the potential adaptations associated with antagonist manipulation based on the hybrid training concept, in which agonist–antagonist groups can be simultaneously activated and also generate opposing torques about a joint.[31]

It is important to recognize the limitations of the current study. Latissimus dorsi muscle activity was not measured; this muscle has an essential role during rowing and pulling exercises, and the absence of measures in the present study may compromise the interpretation of fatigue parameters between the protocols applied. In future studies, this would be an important muscle to be analyzed during pulling exercises, considering latissimus dorsi role in shoulder adduction and extension. Thus, the interpretation of the EMG during dynamic tasks is complicated and requires caution. For instance, it is not possible to extrapolate the results obtained for people with different training levels or clinical conditions.

When planning a resistance training session, understanding the causes and mechanisms behind fatigue are essential to achieve optimal results. Resistance exercise workouts that involve pairing of exercises for agonist–antagonist muscle groups might represent an interesting and effective alternative for coaches and practitioners with the intent of reducing training session duration, without compromising the potential for increasing in muscular strength. Therefore, when performing agonist–antagonist PS, prescribing a shorter rest interval (2 minutes) will induce higher levels of neuromuscular fatigue, albeit with similar total repetitions versus a longer rest interval (e.g., 4 minutes). Due to the greater neuromuscular fatigue that was evident with the 2-minute rest protocol; training sessions that place an emphasis on consistently high repetition velocity might necessitate resting 4 minutes between PS.

Conflicts of interest

All contributing authors declare no conflicts of interest.

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