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ABSTRACT

Maia, MF, Willardson, JM, Paz, GA, and Miranda, H. Effects of different rest intervals between antagonist paired sets on repetition performance and muscle activation. J Strength Cond Res 28(9): 2529–2535, 2014—Recent evidence suggests that exercising the antagonist musculature acutely enhances subsequent performance for the agonist musculature. The purpose of this study was to examine the effects of different rest intervals between sets for exercises that involve antagonistic muscle groups, a technique referred to as antagonist paired sets (APS). Fifteen recreationally trained men were tested for knee extension (KE) exercise performance, with or without previous knee flexion (KF) exercise for the antagonist musculature. The following protocols were performed in random order with 10 repetition maximum loads for the KF and KE exercises: (a) traditional protocol (TP)—1 set of KE only to repetition failure; (b) paired sets with minimal allowable rest (PMR)—1 set of KF followed immediately by a set of KE; © P30—30-second rest between paired sets of KF and KE; (d) P1—1-minute rest between paired sets; (e) P3—3-minute rest between paired sets; and (f) P5—5-minute rest between paired sets. The number of repetitions performed and electromyographic (EMG) activity of vastus lateralis, vastus medialis (VM), and rectus femoris (RF) muscles were recorded during the KE set in each protocol. It was demonstrated that significantly greater KE repetitions were completed during the PMR, P30, and P1 protocols vs. the TP protocol. Significantly greater EMG activity was demonstrated for the RF muscle during the KE exercise in the PMR and P30 vs. the TP, P3, and P5, respectively. In addition, significantly greater EMG activity was demonstrated for the VM muscle during the PMR vs. all other protocols. The results of this study indicate that no rest or relatively shorter rest intervals (30 seconds and 1 minute) between APS might be more effective to elicit greater agonist repetition enhancement and muscle activation.

KEY WORDS: resistance training, coactivation, recovery, electromyography, strength

INTRODUCTION

Movement performance is characterized by coactivation of both agonist and antagonist muscle groups (9). Tension development in the antagonist muscle group acts as a braking mechanism and reduces the net force and movement velocity promoted by the agonist muscle group (5). Therefore, antagonist muscle groups

promote joint stability and agonist muscle groups promote joint mobility (1). A common resistance exercise technique involves alternating sets for antagonistic pairs of muscle groups, a technique referred to as antagonist paired sets (APS). It has been suggested that when a resistance exercise set for an agonist muscle group is immediately preceded by a set for the antagonist muscle group, the associated fatigue and neural inhibition of the antagonists may reciprocally facilitate increased neural activation of the agonists (5).

Maynard and Ebben (14) found that a set of isokinetic knee flexion (KF) followed immediately by a set of knee extension (KE) decreased the muscle torque and electromyographic (EMG) signal of agonists muscles compared with the protocol without preactivation of the antagonist. However, the authors adopted static stretching exercises for quadriceps as part of warm-up, which may be responsible for the reduction on knee extensor torque. Moreover, Baker and Newton (2) found a significant increase in muscle power during the ballistic bench press throw exercise that was performed 3 minutes after a set of the bench pull exercise. Additionally, Robbins et al. (19) found no significant difference in the number of repetitions completed and muscle activation for an APS protocol (bench pull and bench press with 2-minute rest between) vs. a traditional protocol (TP) in which multiple sets of each exercise were performed independently. It is noteworthy that studies have found conflicting results regarding the APS technique, and previous researchers did not use EMG to assess neural responses (2,3,5).

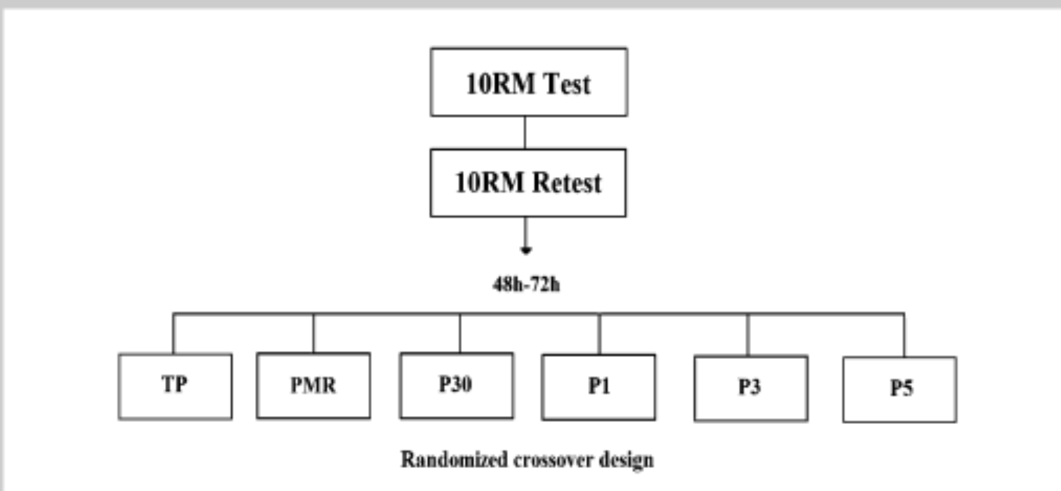

Figure 1. Summary for experimental protocol trials. TP = traditional protocol; PMR = paired sets with minimal allowable rest; P30 = protocol with 30-second rest interval; P1 = protocol with 1-minute rest interval; P3 = protocol with 3-minute rest interval; P5 = protocol with 5-minute rest interval.

The APS technique has been demonstrated to be more efficient than the traditional technique of performing sets for each exercise independently by significantly reducing the total time of a resistance training (RT) session (20,22,23). However,

with reference to the APS technique, there is still no consensus regarding the optimal rest interval between exercises that incorporate antagonist muscle groups. de Salles et al. (8) emphasized that sufficient rest time is needed between sets and exercises to allow for resynthesis of adenosine triphosphate (28). Previous studies have examined different rest intervals between traditional resistance exercise sets performed independently and demonstrated significant differences in repetition performance, hormonal, and metabolic responses (8,16,17,24,28–30).

Table 1. Subject characteristics.*†

Variables	Age (y)	Height (cm)	BM (kg)	RTE (y)	KF 10RM load (kg)	KE 10RM load (kg)
Mean ± *SD*	22.5 ± 1.9	174 ± 10.1	24.3 ± 2.14	2.7 ± 0.8	57.2 ± 7.3	63.7 ± 8.2

*Values are mean ± *SD*.
†BM = body mass; RTE = resistance training experience; KF = knee flexion; KE = knee extension.

However, to date, no studies have examined different rest intervals when using the APS technique to determine potential differences in repetition performance and Neural responses. Accordingly, the APS technique might be beneficial to optimize RT session time without compromising muscle performance (21). Therefore, the purpose of this study was to examine the effects of different rest intervals between sets for exercises involving antagonistic muscle groups (KF and KE) in the number of repetitions completed and muscle activation in trained men.

METHODS

Experimental Approach to the Problem

A randomized crossover design study was performed in 8 test sessions on nonconsecutive days (Figure 1). In the week before the first test session, 10 repetition maximum (RM) loads were determined for the KF and KE exercises during test and retest sessions. To examine the effects of different rest intervals between sets for exercises that involve antagonistic muscle groups, the following protocols were applied: (a) TP—1 set of KE only to repetition failure; (b) paired sets with minimal allowable rest (PMR)—1 set of KF followed immediately by a set of KE; (c) P30—30-second rest between paired sets of KF and KE; (d) P1— 1-minute rest interval between paired sets; (e) P3—3-minute rest between paired sets; and (f) P5—5-minute rest between paired sets. The recovery period between the experimental protocols was between 48 and 72 hours. The number of repetitions performed and the EMG activity of vastus lateralis (VL), vastus medialis (VM), and rectus femoris (RF) muscles were recorded during the KE set in each protocol.

Subjects

Fifteen recreationally trained men between 18 and 27 years old participated as subjects in this study (Table 1). All subjects had previous RT experience (2.7 6 0.8 years), with a mean frequency of four 60-minute sessions per week, using 1- to 2-minute rest intervals between sets and exercises. Subjects were on their typical diet, not permitted to use nutritional supplementation, and did not consume anabolic steroids or any other anabolic agents known to enhance performance. All subjects answered the Physical Activity Readiness Questionnaire and signed an informed consent form in accordance with the Declaration of Helsinki. Subjects who had any potential functional limitation or medical condition that could be aggravated by the tests were excluded. Subjects were encouraged to report for workout sessions fully hydrated and to be consistent in their food intake throughout the duration of the study and asked to refrain from any upper-body training in the 48 hours before each testing session. The anthropometric data included body mass (Techline BAL-150 digital scale, Sao Paulo, Brazil) and height (stadiometer Seca 208 Bodymeter, Birmingham, United Kingdom).

Ten Repetition Maximum Testing

In the week before the experiment, the 10RM load was determined for each subject for the KF and the KE exercises (Life Fitness, Rosemont, IL, USA). The 10RM load was defined as the maximum weight that could be lifted for 10 consecutive repetitions at a constant velocity of 4 seconds per repetition (2-second concentric and 2-second eccentric), but repetitions were still counted if the cadence slowed because of the effects of fatigue. The execution of the KE and KF were standardized, and pauses were not permitted between the concentric and eccentric phases. A metronome (Metronome Plus, version 2.0; M&M System, Braugrasse, Germany) was used to help control the lifting cadence. If a 10RM was not accomplished on the first attempt, the weight was adjusted by 4–10 kg and a minimum 5-minute rest was given before the next attempt. Only 3 trials were allowed per testing session. The test and retest trials were conducted on different days with a minimum of 48 hours between trials (10).

To reduce the margin of error in testing, the following strategies were adopted (15,16): (a) standardized instructions were provided before the test, so the subject was aware of the entire routine involved with the data collection; (b) the subject was 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 to motivate subjects for maximal repetition performance; (e) the additional loads used in the study were previously measured with a precision scale.

During the KE resistance exercise, subjects were instructed to extend their knees as far as possible during the concentric phase (range of motion between 908 flexion and 208 extension) and to control the descent of the leg during the eccentric phase (range of motion between 208extension and 908 flexion). For the KF resistance exercise, subjects were positioned lying prone on the machine with the knees fully

extended and the hands gripping the supporting bars in front of the head. During the concentric phase, subjects performed a KF to approximately 1208 and then controlled the eccentric phase to the initial position. A range scale was attached to the equipment to illustrate the range of motion of each subject during the resistance exercises.

Experimental Protocols

The number of repetitions performed and EMG activity of the VL, VM, and RF muscles were recorded during the KE set in each protocol. Before all protocols, warm up sets for the KF and KE exercises were performed for 10–15 repetitions with 50% of the 10RM load, and then a 2-minute interval was instituted before initiating each protocol (26). To verify the acute effect of rest interval between paired sets of agonist and antagonist muscles, 5 experimental protocols were applied as the following.

Traditional protocol: the subjects in this protocol performed a set of KE with 10RM loads until concentric failure; PMR (APS with minimal allowable rest interval): the subjects in this protocol performed a set of KF followed immediately by a set of KE. In addition, the time allowed for changing exercises (KF and KE) was fixed and controlled at 15 seconds. P30: the subjects in this protocol performed a set of KF and after 30 seconds of rest performed a set of KE; P1: the subjects performed a set of KF and after 1 minute of rest performed a set of KE; P3: the subjects in this protocol performed a set of KF and after 3-minute rest performed a set of KE; P5: the subjects in this protocol performed a set of KF and after 5-minute rest performed a set of KE. During the resistance exercises (KF and KE), the 10RM loads were adopted, and the number of repetitions completed were recorded in each protocol. The EMG signal of the VL, VM, and RF was also recorded during the KE exercise.

Maximal Voluntary Isometric Contraction

The criterion used for normalization of EMG activity was the maximal voluntary isometric contraction (MVIC). First, subjects performed 3 KE MVICs during 10 seconds against fixed resistance at a 908 knee angle, with the right leg only, separated by 20-second rest (13). For the MVICs, data analyses were conducted over a window of 4 seconds between the second and sixth seconds. The highest root mean square (RMS) value of the 3 MVICs was used for normalization (12).

Electromyography

The EMG data of VL, VM, and RF muscles were evaluated during the KE exercise. Electrodes were placed according to the recommendation of Cram and Kasman (6). For the RF muscles, the electrodes were placed half the distance between the anterior-superior iliac spine and the superior part of the patella. For the VL muscles, the electrodes were placed twothirds the distance between the anterior-superior

iliac spine and the lateral side of the patella. For the VM muscles, the electrodes were placed at 80% of the distance between the anteriorsuperior iliac spine and the joint space on the anterior border of the medial collateral ligament. Before the placement of the electrodes, the areas were shaved and cleaned with alcohol. The EMG data were captured through passive bipolar surface electrodes (Kendal Medi Trace 200; Tyco Healthcare, Pointe-Claire, Canada) with a recording diameter of 1 mm and a distance between the electrode centers of 1 cm. The surface electrodes were placed over the muscle bellies. The electrodes were connected to an analog-to-digital converter of 16 bits (EMG System of Brazil, Sao Jose dos Campos, SP, Brazil) and acquired with the assistance of proprietary software (EMGlab, EMG System of Brazil, Sao Jose dos Campos, SP, Brazil). The EMG signals were amplified by 1.000 with a common mode rejection ratio of 100 dB. The signal was sampled at 1,000 Hz, and the signal was filtered through band pass at 10–450 Hz using a Butterworth 2 poles filter with order 4. The reference electrode was placed on the clavicle bone. A permanent marker was used to mark the location of the electrodes in the first test session for consistent electrode placement during subsequent sessions. After positioning of the electrodes, the impedance was checked and accepted when it was less than 5 kV (27).

The mean amplitude of the RMS was assessed using the custom-written software Matlab 5.02c (MathWorks TM, Natick, MA, USA). The averaging window for the RMS was 100 milliseconds, and all reported values are the mean RMS over a predetermined sampling window from the onset to the end of each contraction. The first repetition and last repetitions were excluded from analysis to avoid the effect of initial displacement of the leg support and muscle fatigue at the end of the sets (10,27). Electromyographic data were collected for the entire (concentric and eccentric phases) KE set for each protocol. Electromyographic data were expressed as a percentage relative to the largest RMS value of the EMG signal obtained in the MVICs (100%) (12).

Table 2. Number of repetitions completed in each protocol (mean ± *SD*).*†

TP	PMR	P30	P1	P3	P5
10.2 ± 0.4	13.5 ± 1.3†	12.7 ± 1.2†‡	12.9 ± 1.7†	11 ± 1.6‡§‖	10.8 ± 2.3‡§‖

*TP = traditional protocol; PMR = paired sets with minimal allowable rest; P30 = protocol with 30-second rest interval; P1 = protocol with 1-minute rest interval; P3 = protocol with 3-minute rest interval; P5 = protocol with 5-minute rest interval.
†Significant difference vs. TP.
‡Significant difference vs. PMR.
§Significant difference vs. P30.
‖Significant difference vs. P1.

Statistical Analyses

The10RM test-retest reliability was calculated through the intraclass correlation coefficient (ICC = [MSb 2 MSw]/ [MSb + {k 2 1}$MSw]), where MSb = mean-square between, MSw = mean-square within, and k = average group size. The normality and homoscedasticity of the data was analyzed by the Shapiro-Wilk and Bartlett's criterion. All variables presented normal distribution and homoscedasticity. A one-way analysis of variance with repeated measures was used to evaluate differences in repetition performance between experimental protocols and muscle activation during the KE exercise. Significant main effects were subsequently evaluated using Bonferroni's post hoc. A probability value of p # 0.05 was used to establish the significance of all comparisons. Statistical analysis was performed with the software SPSS version 20.0 (SPSS, Inc., Chicago, IL, USA).

RESULTS

The ICCs for the 10RM tests were KF = 0.97 and KE = 0.91. The number of repetitions completed in each protocol is presented in Table 2.

Significantly greater repetitions were demonstrated for the PMR (p = 0.001), P30 (p = 0.002), and P1 (p = 0.023) protocols vs. the TP protocol. Significantly fewer repetitions were demonstrated for the P30 (p = 0.021), P3 (p = 0.012), and P5 (p = 0.001) protocols vs. the PMR protocol. Significantly fewer repetitions were demonstrated for the P3 (p = 0.021) and P5 (p = 0.043) protocols vs. the P30 protocol, as well as for the P3 (p = 0.03327) and P5 (p = 0.041) protocols vs. the P1 protocol (Table 3).

TABLE 3. RMS average of EMG amplitude for the muscles evaluated in each protocol (%MVIC).*

	TP	PMR	P30	P1	P3	P5
RF	70.1 ± 10.9	75.9 ± 9.8†	74.2 ± 12.1†	71.8 ± 10.2	67.9 ± 13.1‡§	69.2 ± 13.9‡§
VL	81.3 ± 12.1	89.0 ± 10.1	81.1 ± 12.1	79.2 ± 12.1	82.1 ± 13.8	79.1 ± 10.1
VM	86.0 ± 10.1	90.2 ± 12.1†	82.3 ± 11.1‡	84.2 ± 10.3‡	81.2 ± 10.3‡	80.0 ± 12.1‡

*RMS = root mean square; EMG = electromyography; TP = traditional protocol; PMR = paired sets with minimal allowable rest; P30 = protocol with 30-second rest interval; P1 = protocol with 1-minute rest interval; P3 = protocol with 3-minute rest interval; P5 = protocol with 5-minute rest interval; RF = rectus femoris; VL = vastus lateralis; VM = vastus medialis.

†Significant difference vs. TP.

‡Significant difference vs. PMR.

§Significant difference vs. P30.

Significantly greater activity of the RF was demonstrated for PMR protocol vs. the TP (p = 0.001), P3 (p = 0.003), and P5 (p = 0.012) protocols; and also for P30 protocol vs. the TP (p = 0.021), P3 (p = 0.011), and P5 (p = 0.023) protocols. No significant differences were demonstrated among the TP, P1, P3, and P5 protocols. Similarly, for the VM, significantly greater activity was demonstrated for the PMR protocol vs. the TP (p = 0.001), P30 (p = 0.031), P1 (p = 0.011), P3 (p = 0.031), and P5 (p = 0.041) protocols. Additionally, no significant differences were found among the experimental protocols for the VL.

DISCUSSION

The key finding from this study was the significant increase in repetition performance and muscle activation in the RF and VM muscles when the KE exercise was preceded by antagonist preactivation through the KF exercise. Furthermore, the greatest effects in repetition performance and muscle activation were evident when the KE exercise was performed immediately after the KF exercise without rest between APS. The increase in repetition performance after antagonist preactivation was consistent with previous studies examining the manipulation of the antagonist musculature as a preactivation stimulus to facilitate greater performance in the agonist musculature (2–4,11,25). Perhaps surprisingly, no significant increase in repetitions was evident for the KE in the 3- and 5-minute rest protocols vs. the TP that did not involve the antagonist manipulation.

This study was the first to our knowledge to evaluate different rest intervals between APS (e.g., KF and KE). Collectively, greater KE repetitions were demonstrated during the PMR, P30, and P1 protocols vs. the TP, P3, and P5 protocols. These data suggested that limited or minimal rest between APS provides the optimal window to enhance repetition performance and muscle activation for the agonist musculature. The longer rest intervals in this study (e.g., P3 and P5) seemed to negate the potentiation effects demonstrated in repetition performance and muscle activation.

The significantly greater muscle activation observed in the RF and VM muscles for the PMR and P30 protocols might be associated with the increased number of repetitions completed for these conditions. Croce et al. (7) found a significant decrease in hamstring torque (average and peak) and EMG activity after reciprocal KE and KF actions compared with a hamstring MVIC. According to authors, the preactivation of antagonist muscles may reduce the force production of antagonist muscles and compromise the joint stabilization role of the hamstrings during KE. In contrast to the study of Croce et al. (7) that used isokinetic equipment, this study and other studies used conventional RT machines with protocols more applicable to practical settings. In particular, Remaud et al. (18) found greater quadriceps activity in isoinertial KE movements vs. isokinetic KE movements. These researchers also observed lesser VL activation compared with RF and VM during the KE, similar to the results observed in this study.

The mechanisms underlying APS training are still unclear. Alteration of the triphasic coactivation pattern (i.e., shortening of the antagonist braking period) as a result of antagonist preactivation has been indicated as a possible mechanism responsible for the increase in strength performance (2). The influence of triphasic pattern are usually associated to ballistic movements, whereby there is an initial burst from the agonist musculature, followed by a burst from the antagonist muscles, and then a final burst from the agonist muscles (21). Arguably, a shortening of the antagonist braking burst would allow for a larger aggregate agonist firing period and could conceivably result in performance enhancement

(19).

However, the increase in repetition performance found in this study is in agreement with the mechanisms proposed by Roy et al. (25). They suggested that the preactivation characteristic of APS training has a positive effect on agonist muscles because of the facilitatory stimulation of Golgi tendon organs of knee flexor muscles and muscle spindles of extensor muscles. In this study, the work for the antagonist hamstrings group preceding work for the agonist quadriceps group may have desensitized muscle spindles for the hamstrings group and neurally facilitated greater contractile performance in the quadriceps group. Apart from this, Aagaard et al. (1) observed that antagonist hamstring movements counteract the anterior tibial shear and excessive internal tibial rotation induced by the contractile forces of the quadriceps near full KE. However, it has been shown that antagonist activation may not affect the performance of a standard isokinetic fatigue test. Thus, the decrease in the resultant joint moment after fatigue could be attributed to changes in agonist (knee extensor) muscle force-generation capacity rather than an altered moment of force exerted.

An interesting feature of this study was the use of conventional RT machines. Other studies to date on the APS technique used isokinetic equipment. In this study, the significant increases demonstrated in EMG activity of the RF and VM muscles may account for the improvement in the number of repetitions completed during the PMR, P30, and P1 protocols vs. the P3 and P5 protocols. However, other previous studies examining aspects of the APS technique have demonstrated decreases in agonist performance (14), no differences in EMG activity and performance (5,22,23), and/or improvement in strength performance (2–4).

Previous studies have consistently demonstrated that during a training session, longer rest intervals between sets ($2 minutes) allowed for significantly greater repetitions vs. shorter rest intervals between sets (,2 minutes). However, when using the APS technique little to no rest between exercises for opposing muscles groups might be the best strategy from a time efficient standpoint and a neuromuscular standpoint. Considering the influence of the exercise order in strength performance, Balsamo et al. (3) observed that when multiple sets of the KF exercise were performed before multiple sets of the KE exercise (3 sets; 10RM load; 90-second rest between sets) resulted in significantly greater volume vs. the inverse order (e.g., KE to KF). Additionally, this increasing in the repetition performance observed in this study during APS training with limited or shorter rest intervals (30 seconds–1 minute) may be associated to the stretchshortening cycle. The shortening cycle has been suggested to be involved in agonist-antagonist movement pairs (1,3–5); however, the characteristics of APS training are in disagreement with the involvement of such mechanisms because the time between agonist and antagonist contractions necessary to elicit responses associated with stretch-shortening cycle movements is ,1 second (21).

Similarly, the results of this study can be applied using conventional RT machines

with recreationally trained subjects. However, acute and longitudinal studies are necessary to evaluate the effects of different rest intervals when using the APS and also to elucidate the mechanisms that may promote greater gains in strength vs. a traditional training model during which sets for each exercise are performed in succession and independently.

One of the limitations of this study was the use of a single APS for opposing muscle groups in the lower extremities. Also, the EMG activity of hamstrings muscles was not recorded. According to Robbins et al. (21), studies that investigated the APS technique had several limitations such as use of a heterogeneous sample, different training levels, loads (intensity), and muscle actions. Thus, this type of training may not be applicable to multijoint exercises such as squats, deadlifts, and cleans because of the nature of these multiphase movements which the muscles involved are working as synergists. However, this study contributes additional information to prompt further study on the mechanisms promoting greater agonist performance through antagonist manipulation, which may be large applicable to isolated muscles groups during single-joint exercises.

PRACTICAL APPLICATIONS

Exercise models performed using a reciprocal antagonist/ agonist protocol, as in this study, might be less time consuming and could be useful in clinical practice as well as sports performance training. Significantly greater muscle activity was evident for the agonist muscles (e.g., KE) after the antagonist resistance exercise (e.g., KF) protocols vs. the TP without antagonist manipulation. Additionally, significant differences were evident for the number of maximum repetition completed, especially when little or no rest was used between exercises. Nevertheless, this study provides some justification for practitioners to experiment with antagonist manipulation over multiple sets using the APS technique to potentially improve acute agonist performance.

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