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Muscle fatigue and metabolic responses following three different antagonist pre-load resistance exercises

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ABSTRACT

Purpose: Preload of antagonist muscles can be achieved by reciprocal actions (RAs) or by opposing muscle actions. However, evidence concerning neuromuscular and fatigue responses are scarce.
Objective: To compare the effects of different knee flexor (KF) preload methods on knee extension (KE) vastus medialis muscle fatigue, based on EMG-spectral index (FI), load range (LR), total work (TW), blood lactate (LAC) and biceps femoris co-activation (BFc) during resistance exercise.
Methods: Twenty-four healthy men (23.5 ± 3.6 yrs) performed three antagonist pre-load isokinetic exercises (4 sets, 10 repetitions, $60^{\circ}\ s^{-1}$, 1 min rest between sets): RA (KF contraction immediately followed by KE); Superset (SS; one KF set immediately followed by one KE set); Multiple Set (MS; four KF sets followed by four KE sets).
Results: Total work was significantly greater in RA. There was no significant decrease in LR between sets in RA. The BFc did not differ between protocols ($p = 0.063$). However, RA presented greater biceps femoriscoactivation. The FI was greater during SS compared to RA and MS ($p < 0.05$). The SS had greater LAC when compared to MS and RA ($p = 0.005$ and $p = 0.007$, respectively).
Conclusion: It is suggested that the RA protocol is more neuromuscular and metabolic efficient during the performance of knee extension resistance exercise.

1. Introduction

Resistance exercise is considered an essential element in rehabilitation and physical conditioning programs (Ratamess et al., 2009). Also, strength gains are associated with important clinical benefits, such as muscular endurance (Kloubec, 2010), increases in functionality of the elderly (Deschenes and Kraemer, 2002), and injury prevention presumably to better dynamic joint stabilization (Warburton et al., 2006).

Numerous methods and systems of resistance training have been developed in previous years (Gentil et al., 2006; Item et al., 2011). Recently, the use of pre-activation of antagonist muscles prior to activation of the agonist methods has received increasing attention (Maynard and Ebben, 2003). Among these are the superset method (Baker and Newton, 2005; Burke et al., 1999; Kelleher et al., 2010; Maynard and Ebben, 2003; Robbins et al., 2010), and the reciprocal action method (Bohannon, 1985; Bohannon et al., 1986; Grabiner and Hawthorne, 1990; Jeon et al., 2001; Miller et al., 2000; Roy et al., 1990).

Previous studies have reported that individuals performing an antagonist pre-activation during resistance exercise seem to improve their motor performance by generating higher work levels (Carregaro et al., 2011b) and training efficiency (Robbins et al., 2010). However, evidence is still scarce and controversial, and methodological variations make it difficult to compare benefits and applications across studies (Bohannon et al., 1986; Burke et al., 1999; Maynard and Ebben, 2003). In one of the few studies that compared these two methods, the reciprocal action protocol (RA) demonstrated a higher torque (10%) when compared to the superset protocol (SS) Bohannon, 1985. In a similar recent study (Carregaro et al., 2011b) no significant differences in torque production of the agonist were reported, but RA led to greater work capacity when compared to SS.

To date, few studies have used electromyography (EMG) measurements to analyze muscle activation responses between different antagonist pre-activation methods and their results are also controversial (Jeon et al., 2001, (Maynard and Ebben, 2003), Miller et al., 2000; Robbins et al., 2010). Furthermore, most of these studies used single set protocols. One of the few studies that assessed agonist activation after antagonist activation using multiple set

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protocols reported no differences in EMG amplitude of the vastus medialis (VM) between RA and SS protocols (Carregaro et al., 2011a). On the other hand, EMG amplitude (root mean square) and spectral parameters, such as mean and median frequency, collected during dynamic contractions may affect the validity of analyzing data with the fast Fourier transformation (Dimitrov et al., 2006). This may contribute to the questionable validity of using only EMG amplitude and mean or median frequencies in the assessment of fatigue. Also, neuromuscular fatigue assessment during dynamic tasks seems to be more relevant to daily function and represents a better indicator of peripheral impairments and performance (Cairns, 2006; Gonzalez-Izal et al., 2010). Thus, due to controversy and lack of studies comparing different antagonist pre-activation methods on muscle fatigue, co-activation and metabolic responses, the purpose of this study was to evaluate the acute effects of three different antagonist pre-load resistance exercise protocols on knee extensor performance, neuromuscular fatigue and blood lactate responses.

2. Methods

2.1. Participants

Twenty-four healthy men (23.5 ± 3.6 years; 1.80 ± 0.10 m; 79.1 ± 11.9 kg; and 25.1 ± 2.9 kg/m^2) participated in the study. Participants were selected at random from respondents to fliers distributed over the university campus, and by word-of-mouth. They were instructed not to perform any type of strenuous physical activity during the study period. Inclusion criteria were: (1) age between 18 and 35 years and (2) physically active (engaged in some kind of physical exercise at least twice a week). Subjects were excluded if they had: (1) history of orthopedic problems such as trauma, lower back and lower limb pain over the last 6 months; (2) musculoskeletal surgery of the lower limbs and spine; (3) cardiovascular disease or diagnosed arterial hypertension. All participants were notified of the research procedures, requirements and benefits, and were invited to participate by signing an informed consent. The Institutional Research Ethics Committee granted approval for the study (FS/UnB, protocol n. 161/2008).

2.2. Isokinetic dynamometer

A Biodex System 3 isokinetic dynamometer (Biodex Medical, Shirley, NY) was used. Calibration was performed according to the specifications in the manufacturer's manual, and gravity correction was obtained by measuring the torque exerted by the resistance arm and the subject's leg (relaxed) in the terminal knee extension position. Each subject was positioned on the chair allowing for free and comfortable movement of knee flexion and knee extension. To prevent knee hyperextension, a range of motion of 80° flexion/extension (excursion between 10° and 90°, with 0° being full knee extension) was used. Hip position was standardized at 100° of flexion (position of the chair) for all subjects. The lateral epicondyle of the femur was used as a reference point for the knee rotation axis and used for alignment with the rotation axis of the dynamometer. Height of the chair, backrest tilt, dynamometer and length of the resistance arm were recorded and replicated each day to guarantee standardization and reliability between sessions.

2.3. Procedures

Participants came to the laboratory on four different occasions, with a minimum rest interval of 72 h between visits.

On the first visit, participants were familiarized with the exercise protocols and performed two sets of four maximal repetitions at 60° s^{-1} (in each protocol), with 1 min rest between sets. Between protocols, there was a period of 5 min rest. Familiarization with maximal voluntary isometric contraction testing was also performed, in which all participants performed two maximal contractions for five seconds, with a rest interval of 2 min. All exercises were performed with the dominant limb (leg used to kick a ball).

On the second, third and fourth visits, subjects performed the isokinetic exercise protocols at 60° s^{-1}, in a counterbalance order. All protocols had the same exercise volume consisting of four sets of 10 knee extensions and four sets of 10 knee flexions. Also, the protocols had the same knee extension and knee flexion time under tension. The only difference between protocols was the antagonist pre-activation order (knee flexion). The three antagonist pre-activation protocols were: (1) reciprocal action protocol (RA): one repetition of concentric knee flexion immediately followed by one repetition of knee extension. The RA had four sets and each set (10 repetitions) was characterized by 10 reciprocal knee flexion/knee extension actions and 1 min rest interval between sets (Parcell et al., 2002); (2) superset protocol (SS): one set (10 repetitions) of concentric knee flexion followed (no rest between sets) by one set (10 repetitions) of knee extension. During knee flexion, knee extension was performed passively and vice versa; and (3) multiple set protocol (MS): four sets of 10 repetitions of concentric knee flexion (1 min rest interval between sets). After the four sets of knee flexion, the subject performed four sets of 10 repetitions of concentric knee extension (1 min rest interval between sets). During knee flexion, knee extension was performed passively and vice versa.

Before performing the exercise procedures on the dynamometer, all subjects underwent 10 min warm up on a stationary cycle with no load. During each exercise protocol, participants were asked to keep their arms crossed against their chest (Stumbo et al., 2001). Verbal encouragement and visual feedback using the computer screen were given in an attempt to achieve the maximum level of effort. After each set of exercise, for all protocols, participants were asked to provide a rating of perceived exertion using the OMNI Resistance Exercise Scale (Robertson et al., 2003). All procedures were performed by the same investigator for all sessions.

2.4. Surface electromyography

The recording and processing of electromyographic signals (EMG) were based on recommendations of the International Society of Electrophysiology and Kinesiology (Merletti, 1999). Placement of the electrodes was based on the guidelines of the SENIAM project (Hermens et al., 2000). A portable device measuring eight channels of surface electromyography (*Miotool, Miotec-Biomedical equipments*®), with 14 bits resolution, noise level <2LSB (ADC range 1.9 μV RMS) and common mode rejection of 110 db was used. A sampling rate of 2000 Hz and a gain of 1000 times were utilized. 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. Muscles evaluated were the vastus medialis (VM) and biceps femoris (BF). The reference electrode was attached to the bony prominence of the seventh cervical vertebra (C7).

Electrodes were positioned over the belly of the VM and BF, in parallel to the muscle fibers (Basmajian and Deluca, 1985). Before placing electrodes, the area was shaved and lightly abraded with 70% alcohol. Placement of the electrodes was identified on the first day of testing and an indelible pen mark was made on the skin to ensure the same position was used on subsequent days.

On each visit, all subjects performed a maximum voluntary isometric contraction (MVIC) with their knee joint positioned at 60° –