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Effects of antagonist pre-load on knee extensor isokinetic muscle performance

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Abstract
The aim of this study was to evaluate and compare acute effects of a reciprocal action protocol and a super-set protocol on knee extensor performance during concentric isokinetic exercise. Fourteen men aged 29.4 ± 6.1 years were tested on three different protocols, with 1 min of rest between sets: control (3 sets of 10 isokinetic knee extension repetitions), reciprocal action protocol (3 sets of 10 repetitions of reciprocal isokinetic concentric knee flexion and knee extension repetitions), and super-set protocol (3 sets of a combination of 10 repetitions of knee flexion immediately followed by 10 repetitions of knee extension repetitions). Tests were performed at 60° · s⁻¹ and 180° · s⁻¹, randomized across 3 days and separated by at least 72 h. There were no significant differences between protocols for peak torque at 60° · s⁻¹ or 180° · s⁻¹. Total work was significantly higher during the reciprocal action protocol compared with the super-set protocol at 60° · s⁻¹. There was a significant decline in peak torque (from 240.6 to 212.9 N · m) and total work (from 2294 to 1899 J) for the control condition at 60° · s⁻¹. Also, total work declined significantly across sets for the super-set protocol at 60° · s⁻¹ (from 2157 to 1707 J). Results indicate that a reciprocal action protocol provides torque maintenance during multiple sets of isokinetic training, both at slow and high velocities.

Keywords: Muscle strength, isokinetic, resistance training, quadriceps muscle

Introduction
Resistance training has a fundamental role in physical activity programmes, and has been recommended by many major health organizations to improve general health and fitness (ACSM, 2000, 2009; Fletcher et al., 1995; Pollock et al., 2000). With the purpose of increasing muscle performance and achieving better results while reducing time spent during training sessions, many resistance training programmes have been developed, although few studies have assessed their relative effectiveness (Fleck & Kraemer, 2004).

Previous studies have shown that preloading a muscle can increase muscular force development and motor unit recruitment (Burke, Pelham, & Holt, 1999; Grabiner, 1994; Jeon, Trimble, Brun, & Robinson, 2001; Kamimura & Takenaka, 2007; Roy, Sylvestre, Katch, Katch, & Lagasse, 1990; Tillin & Bishop, 2009). Preloading the muscles may involve stretching the agonist muscle before a contraction, or activating the prime movers isometrically or eccentrically before performing a concentric action (Bosco & Komi, 1979; Bosco, Komi, & Ito, 1981; Ishikawa, Komi, Finni, & Kuittinen, 2006; McBride, McCaulley, & Cormie, 2008; Svantesson, Ernstoff, Bergh, & Grimby, 1991; Svantesson, Grimby, & Thomee, 1994). Another way to achieve preload is to perform a concentric antagonist muscle action immediately before a concentric agonist action (Jeon et al., 2001). This kind of preload, often referred to as reciprocal action, can be relevant in rehabilitation as well as in sports, as it may allow increased muscle performance and work capacity (Burke et al., 1999; Grabiner & Hawthorne, 1990; Jeon et al., 2001; Roy et al., 1990), and should also be considered as an area of future exploration for strength training research (Baker & Newton, 2005). Another way to combine agonist and antagonist muscle actions is to perform exercises with...
opposing muscle groups, training them "back-to-back" with reduced rest, a system often known as super-set (Fleck & Kraemer, 2004). During super-set, multiple repetitions of agonist muscle actions are performed after a set of multiple repetitions of antagonist muscle actions is completed.

Although most of the literature suggests that reciprocal actions may favour agonist muscle performance, these studies were conducted using single repetitions (Burke et al., 1999; Grabiner & Hawthorne, 1990; Jeon et al., 2001; Roy et al., 1990), which may not be transferred to resistance training, where multiple repetitions are performed. Results regarding the effects of super-set in muscle performance are conflicting, as previous studies have found both a decrease (Maynard & Ebben, 2003) and an increase (Baker & Newton, 2005) in agonist muscle strength following a set of multiple actions of the antagonist muscle. Also, super-set typically involves multiple sets of 8–10 or more repetitions with little or no rest between sets (Fleck & Kraemer, 2004), and previous studies have performed only one set of five maximal knee extensions in pre-fatigued and non-fatigued conditions of the hamstring group (Maynard & Ebben, 2003), or one set of eight repetitions of bench throwing after one set of bench pulling (Baker & Newton, 2005).

Both reciprocal action and super-set training may be useful by allowing greater training volume in a shorter time. However, it is important to understand the influence of each system on muscle performance to design efficient resistance training programmes. Therefore, the purpose of this study was to evaluate and compare the acute effects of a reciprocal action protocol and a super-set protocol on knee extensor muscle performance during multiple sets of concentric isokinetic exercises.

Materials and methods

Participants

Fourteen healthy males (age 29.4 ± 6.1 years; height 1.78 ± 0.07 m; mass 82.6 ± 11.2 kg) were recruited for the study. All participants were physically active (engaged in some type of aerobic exercise, at least twice a week), but had not been resistance training for the last 6 months. Inclusion criteria were: age between 18 and 35 years and regular performance of physical activity. Participants were excluded if they presented a history of orthopaedic problems, such as fractures, surgery, and low back and lower limb pain over the past 6 months, a diagnosis of intervertebral disk herniation or cardiovascular diseases and hypertension.

All participants were notified of the research procedures, requirements, benefits, and risks before providing informed consent. The Institutional Research Ethics Committee granted approval for the study.

Dynamometry

A Biodex System 3 isokinetic dynamometer (Biodex Medical, Shirley, NY) was used for all testing. The software Biodex Advantage version 3 was used for data collection and processing. Calibration of the dynamometer was performed according to the manufacturer’s specifications before each test. Participants sat upright with the axis of rotation of the dynamometer arm oriented with the lateral femoral condyle of their dominant leg. Belts were used to secure the thigh, pelvis, and trunk to the dynamometer chair to prevent additional body movement. The hip angle was determined by chair position standardized at 100° for all participants (full extension considered as 180°). Gravity correction was obtained by measuring the torque exerted on the dynamometer resistance adapter with the knee relaxed near full extension. The chair and dynamometer settings were recorded to ensure the same positioning for all tests. Concentric contractions were performed isokinetically at 60° · s⁻¹ and 180° · s⁻¹, with an overall range of motion of 85° and full extension acting as the reference point (full extension as 0°). The knee strap was released during each rest period to ensure unrestricted blood flow to the quadriceps.

Consistent and identical verbal encouragement was provided during each test session by the same investigator. Participants were instructed to place their hands on their chest and hold the straps during the exercises (Stumbo et al., 2001), and were instructed to fully extend and flex the knee and to work maximally during each set. Total work was the sum of the work output of each repetition. Knee extensor peak torque was the highest torque output at any angle (within the load range) on each set. The angle where peak torque occurred (peak torque angle) was also recorded. All variables were used as dependent variables. The load range signals were assessed through the dynamometer DB-15 female interface (Biodex, 1998), which provides real-time analog signals of torque, angular velocity, and angular position. An adaptor was built to get the signals from the DB-15 interface into three separate BNC connectors to a digitizer board (BNC-2120, National Instruments, TX, USA), which sampled the biomechanical signals at 2000 samples per second, and converted them to digital data via a 12-bit analog-to-digital converter. The isokinetics phases for 60° · s⁻¹ and 180° · s⁻¹, using the algorithm proposed by Schwartz and colleagues (Schwartz, Bottaro, Celes, Brown, & Nascimento,
Exercise protocol

To prevent possible fatigue effects, volunteers were instructed to visit the laboratory on three different occasions, with an interval of at least 72 h between visits. In the 24 h that preceded test days, volunteers were instructed to avoid performing exercise and ingesting nutritional supplements or ergogenic aids. Prior to testing, all participants warmed up for 10 min on a cycle ergometer at 20–30 km·h⁻¹, with a resistance of approximately 25 W. Following the warm-up, participants were positioned on the dynamometer and received instructions about the test protocols and perceived exertion scale. For familiarization purposes, participants performed two sets of five repetitions of sub-maximal knee flexion–extension at 60°·s⁻¹ and 180°·s⁻¹, with 2 min rest between sets.

Participants were tested on three different protocols: (1) control protocol, (2) reciprocal action protocol, and (3) super-set protocol. During the control protocol, participants performed 3 sets of 10 repetitions of concentric isokinetic knee extension, with a rest interval of 1 min between sets. In the reciprocal action protocol, they performed 3 sets of 10 repetitions of reciprocal isokinetic concentric knee flexion and knee extension (one repetition was defined as one concentric knee flexion followed by one concentric knee extension), with 1 min rest between sets. During the super-set protocol, they performed 3 sets of a combination of 10 repetitions of knee flexion immediately followed by 10 repetitions of knee extension, with 1 min rest after the knee extension repetitions. All tests were performed at 60°·s⁻¹ and 180°·s⁻¹, with 10 min of rest between velocities. Test protocol and velocity order were randomly assigned for each participant. Participants were also asked to provide a rating of perceived exertion after each protocol using the OMNI Resistance Exercise Scale (Robertson et al., 2003).

Statistical analysis

For data analysis, we used the Statistical Package for Social Sciences (SPSS) software version 13.0. Data are expressed as means and standard deviations (mean ± s), as distribution normality was investigated using the Shapiro-Wilks test. One-way repeated-measures analysis of variance (ANOVA) was used to compare perceived exertion scores. Factorial ANOVA [protocol (control protocol, reciprocal action protocol, and super-set protocol) × sets (1, 2, and 3)] was used to test for differences in dependent variables (total work, peak torque, and peak torque angle). Mauchly’s test of sphericity was applied and, if violated, analyses were performed using a Greenhouse-Geisser correction. Multiple comparisons with confidence interval adjustment by the Bonferroni procedure were used post-hoc. Statistical significance was set at P < 0.05.

Results

There were no significant differences in perceived exertion between protocols at either velocity (P > 0.05). At 60°·s⁻¹, ratings of perceived exertion for control protocol, reciprocal action protocol, and super-set protocol were 9 ± 1, 8 ± 1, and 9 ± 1, respectively. At 180°·s⁻¹, ratings for control protocol, reciprocal action protocol, and super-set protocol were 7 ± 2, 7 ± 1, and 7 ± 1, respectively.

Between-groups comparisons are presented in Table I. There was no protocol × set interactions for peak torque at 60°·s⁻¹. However, the results exhibited a significant interaction for total work between protocols and sets for the reciprocal action protocol (P = 0.01) and super-set protocol (P = 0.02) groups but not for the control protocol group at 60°·s⁻¹. The statistics revealed that total work at 60°·s⁻¹ was significantly greater (P = 0.034) during the third set, when the reciprocal action protocol was compared with the super-set protocol. There were no interactions between protocols and sets for peak torque and total work at 180°·s⁻¹.

Within-groups comparisons are also presented in Table I. During the control protocol performed at 60°·s⁻¹, peak torque and total work showed significant decreases across sets with values for set 1 > set 2 > set 3 (P = 0.009 for set 1 vs. set 3, P = 0.003 for set 1 vs. set 2, and P = 0.001 for set 2 vs. set 3). At 180°·s⁻¹, total work in set 3 was significantly less than in sets 1 and 2 (P = 0.002). There was no difference for peak torque among sets at 180°·s⁻¹ (P > 0.05). Results for the super-set protocol performed at 60°·s⁻¹ showed that peak torque during set 3 was significantly lower than during sets 1 and 2 (P = 0.000 and P = 0.002, respectively). Total work decreased significantly with sets, with values for set 1 > set 2 > set 3 (P = 0.001 for set 1 vs. set 3, P = 0.007 for set 1 vs. set 2, and P = 0.003 for set 2 vs. set 3). During the super-set protocol performed at 180°·s⁻¹, peak torque and total work in set 1 was significantly higher than in sets 2 and 3 (P = 0.013). For the reciprocal action protocol performed at 60°·s⁻¹, peak torque did not differ between sets (P > 0.05), while total work was decreased in set 3 compared with sets 1 and 2 (P = 0.028 and P = 0.019, respectively). At 180°·s⁻¹, both peak torque and total work were
The peak torque angle was constant throughout series and did not present significant differences between protocols ($P > 0.05$). Also, there was no interaction between protocols and velocities. These findings are presented in Table I.

**Discussion**

The aims of this study were twofold: (1) to determine whether flexing the knee by concentric hamstrings activation immediately before knee extension (reciprocal action protocol) enhances knee extensor performance during multiple sets of isokinetic resistance exercise; and (2) to determine whether three sets of flexing the knee 10 times prior to 10 repetitions of knee extension (super-set protocol) influences knee extensor peak torque, total work, and peak torque angle. The main finding was that the reciprocal action protocol demonstrated an increased ability to maintain peak torque and total work compared with the control and super-set protocols. Also, the angle at which peak torque occurred was constant throughout series and did not show difference between protocols.

In the present study, we found no performance improvement with the reciprocal action protocol during the first set. This is in contrast to other studies that reported a performance-enhancing effect with a reciprocal action protocol (Bohannon, 1985; Burke et al., 1999; Grabiner & Hawthorne, 1990; Jeon et al., 2001). This may be due to the fact that previous studies focused on different goals, such as understanding the agonist performance during different velocities (Burke et al., 1999; Grabiner & Hawthorne, 1990; Jeon et al., 2001) or the effect of reciprocal agonist/antagonist contractions on paretic quadriceps femoris muscles (Bohannon, 1985). Despite finding no performance-enhancing effect in the first set, there was such an effect in the subsequent sets: the decline in peak torque and total work, at 60° · s$^{-1}$, from the first set to the third set during the reciprocal action protocol was almost half (5.5, 10.0, and 10.0% respectively) the decline in the control protocol (11.0, 17.0, and 18.1% respectively). One possible explanation is that participants were already fully activated in the first repetition or set, but after multiple sets central fatigue set in and influenced quadriceps activation. In this sense, it is possible that the reciprocal action protocol findings during multiple sets are the result of facilitatory influences from both the Golgi tendon organ of the different only between sets 2 and 3 ($P = 0.02$). The percent declines in peak torque and total work throughout the three sets for all exercise groups (control protocol, reciprocal action protocol, and super-set protocol) and velocities are illustrated in Figures 1 and 2.
knee flexors and the muscle spindles of the knee extensors, attributable to the preceding knee flexion (Roy et al., 1990).

Previous reciprocal action protocol studies demonstrated that one concentric action of the knee flexors (antagonist) immediately followed by one quadriceps action (agonist) leads to increases in knee extensor torque (Bohannon, 1985; Burke et al., 1999; Grabiner & Hawthorne, 1990; Jeon et al., 2001) and greater electromyographic amplitude of the quadriceps muscle (Jeon et al., 2001). Roy et al. (1990) also demonstrated that knee extensor peak torque output was greater during unilateral knee flexion immediately followed by knee extension. As Roy et al. (1990) stated, during a dynamic muscle contraction, the contracting muscle is inhibited by its own Golgi tendon organs and by the muscle spindles of its stretched antagonist. Simultaneously, facilitation from both types of receptors acts on the resting antagonist muscle and the consequences of such proprioceptive influences are that the agonist muscle becomes less excitable while its antagonist increases in excitability. Since the effects can last for a few seconds, a motor command arriving from higher motor control centres on the antagonist muscle motoneuron pool during that time interval results in the recruitment of a greater number of motor units and the generation of a correspondingly higher muscle torque output. This would support our findings during multiple sets of resistance exercise. However, comparisons between the present and previous studies may be limited by differences in study protocols, since most previous research used single sets and repetitions and, to date, this is the first

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**Figure 1.** Decline (%) in knee extensor peak torque (N · m) between sets 1, 2, and 3 for control (CON), reciprocal action (RAP), and super-set (SSP) protocols, at velocities of 60° · s⁻¹ and 180° · s⁻¹.
known study to investigate the effects of a reciprocal action protocol during multiple sets and repetitions of a resistance exercise; however, some physiological mechanisms may be similar.

In contrast with the reciprocal action protocol, we found similar declines in peak torque and total work from the first set to the third set in the super-set protocol (14.2 and 21.0% respectively) and control protocol (11.0 and 17.0% respectively). Maynard and Ebben (2003) reported a decrease in strength capacity and power on the subsequent muscle action during a single set of five maximum repetitions of knee flexion followed by five repetitions of knee extension (a similar super-set protocol) in 20 college-aged male wrestlers. On the other hand, Baker and Newton (2005) reported that power output was increased as a result of a set of eight repetitions of bench pulls prior to five repetitions of bench press throws in a power test in 24 college-aged rugby league players. They suggested that the power output augmentation was due to a neural strategy of enhanced reciprocal inhibition of the antagonist musculature, which prevented agonist fatigue and potentiated performance. The differences between Baker and Newton (2005) and our study may be related to the protocol used. Baker and Newton examined the acute effect on power output of alternating agonist and antagonist muscle exercises.
during typical complex power training, also known as contrast training. They used rapid upper-body pulling movements alternated with rapid throwing movements. We used a typical hypertrophy resistance exercise protocol (ACSM, 2009). Also, they had 3 min of rest between antagonist and agonist actions whereas no rest was allowed in the present study. These differences may have resulted in a more fatiguing protocol during the present study.

During the reciprocal action protocol performed at 180° · s⁻¹, total work presented a significant decline only between sets 2 and 3, demonstrating that the participants had significant decreases in training volume only at the end of the session. This finding may have important practical applications, as Munn and colleagues (Munn, Herbert, Hancock, & Gandel, 2005) demonstrated that a higher volume of resistance training can produce approximately twice the increase in strength, inducing further strength adaptations even in the acute phase of training. Although there were no significant differences in our study between exercises (except for total work at 60° · s⁻¹, between the reciprocal action protocol and super-set protocol at the third set), it is important to emphasize that participants worked with appropriate intensity on both exercises, thus the lower decrease in total work output observed during the reciprocal action protocol performed at 180° · s⁻¹ appears to be beneficial for the production of optimal muscular performance (Hatfield et al., 2006).

The velocities adopted in our study were based on practical concerns (velocities close to those used in isoinertial or free-weight conditions) and findings from other authors, which demonstrated that for reciprocal actions, participants were able to generate high torques at velocities ranging from 30° · s⁻¹ to 150° · s⁻¹ (Grabiner & Hawthorne, 1990; Jeon et al., 2001). The velocity of 180° · s⁻¹ was based on results from Baker and Newton (2005), who reported increased power output as a result of reciprocal agonist/antagonist training during bench pulls. Nonetheless, future studies should address the effects of different velocities on the torque and work output of these exercises, both in short-term and long-term training, and also consider if these effects differ between lower and upper body muscle groups.

Results from reciprocal actions of agonist/antagonist muscles may promote advantages in muscle performance, which should be confirmed in chronic studies. Exercise regimens performed using a reciprocal action protocol, as in the present study, may also be less time-consuming and could be of interest in clinical practice of physical therapy as well as sports training (Brown & Whitehurst, 2003; Coburn et al., 2006). In this sense, short-term and chronic studies are necessary to elucidate if individuals performing a reciprocal action protocol can achieve greater gains in strength and total work output compared with a control protocol or super-set protocol. Furthermore, torque maintenance during multiple sets of resistance exercise has relevant practical applications for strength gains, since a total work decline in individuals performing a reciprocal action protocol at 60° · s⁻¹ was about half that (10.0%) in both a control protocol (17.0%) and a super-set protocol (21.0%).

Conclusion

The present results indicate that immediate agonist/antagonist reciprocal action exercise provides torque maintenance at both 60° · s⁻¹ and 180° · s⁻¹ during multiple sets of isokinetic exercise. These findings also suggest that the reciprocal action exercise provides a smaller decline in resistance training work output. It is recommended that these methods be compared in chronic experimental strength training studies.

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