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Research article

Effects of a 4-week eccentric training program on the repeated bout effect in young active women

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Abstract
The aim of this study was to analyze the responses of women to the repeated bout effect (RBE) and to a short eccentric training program. Twenty-four young females were randomly assigned to a training group (TG, n = 14) or a control group (CG, n = 10). They performed two identical acute eccentric bouts (120 repetitions at 70% of 1RM) in a leg-press device in an 8 weeks interval. TG followed a 4-week-eccentric-training program between the bouts. Maximal isometric contraction, range of motion, peak power and quadriceps muscle soreness were compared between and within groups before and after the two acute eccentric bouts. TG and CG presented significant losses of isometric strength and peak power, and an increment in soreness after the first bout. Isometric strength and peak power were recovered faster in CG after the second bout ($p < 0.05$) compared with TG, which showed a similar recovery of these parameters after the second bout compared with the first one. A decrease in soreness and a faster recovery of range of motion were found in TG ($p < 0.05$) following the second bout compared with the first one, but not in CG. Data indicate that a 4-week eccentric training program may prevent the RBE over those adaptations related with muscle damage (e.g. strength loss), but it may increase RBE impact on inflammatory processes (e.g. soreness).

Key words: Lengthening contraction; strength; peak power.

Introduction

Unaccustomed eccentric contractions may produce exercise-induced muscle damage, which is typically manifested as reduced maximal isometric strength and range of motion (ROM), as well as increased muscle soreness (Lavender and Nosaka, 2008; Warren et al., 1999). Nevertheless, if the eccentric bout is repeated, the exercise-induced muscle damage is reduced (Nosaka et al., 2001). This reduction in muscle damage is commonly referred to as the repeated bout effect (Nosaka et al., 2001). The repeated bout effect has been found to increase with the number of eccentric bouts performed, although the greatest relative effects are achieved after the first bout (Chen et al., 2009). Eccentric exercise and the repeated bout effect have been widely studied in men, but data concerning women are still scarce (Nie et al., 2007; Sewright et al., 2008). Data from men might not be useful for women since there are some investigations suggesting greater muscle damage in women immediately or during the first 24 h after one bout of eccentric strength exercise (Hubal et al., 2007; MacIntyre et al., 2000; Sewright et al., 2008). Furthermore, the paucity of data is even more manifested in exercise using free weights, the most commonly used methodology to train strength. Therefore, to have a better understanding of the eccentric exercise-induced muscle damage in this gender, it is important to define the responses of women to consecutive bouts of eccentric exercise.

Recent investigations have studied the effects of eccentric training on the repeated bout effect in young and older men (Garcia-Lopez et al., 2007; Jimenez-Jimenez et al., 2008), showing that this training modality provides more protection against a second bout of eccentric exercise than the repeated bout effect itself. Thus, following an eccentric training program, men present a faster recovery of jumping ability and muscle soreness, lower levels of molecular muscle damage markers (Creatine Kinase levels) and decrease expression of pro-inflammatory and oxidative stress genes after a second bout of acute eccentric exercise compared to men that only performed the two acute eccentric bouts (Garcia-Lopez et al., 2007). As indicated by others (Roig et al., 2009), only one study has focused on the response of women to non-isokinetic eccentric exercise (Ben-Sira et al., 1995), and to our knowledge, no study has approached the implications of the eccentric training on the repeated bout effect in this population. Consequently, to date scientific-based guidance regarding eccentric training for women is limited. This is somewhat surprising considering the positive effects of eccentric contractions on skeletal muscle adaptations (Colliander and Tesch, 1990; Dudley et al., 1991; Norrbrand et al., 2008) and the high number of coaches and female athletes that could benefit from this information. In addition, it could also be important for safer exercise prescriptions, including rehabilitation programs.

To assess eccentric exercise-induced muscle damage, functional tests are often used. The maximal voluntary isometric contraction (MVIC), ROM and muscle soreness are the most common tests used (Warren et al., 1999). Peak power measurements assess both physical performance and quality of life (Izquierdo et al., 2001; Thomas et al., 1996). How power evolves after eccentric exercise has been described with Wingate or jumping tests (Byrne and Eston, 2002; Garcia-Lopez et al., 2007). However, peak power with free weights has not been used to evaluate the consequences of the eccentric exercise. If an acute bout of eccentric exercise produces muscle damage, which decreases performance, then a peak power test may represent a reliable tool to assess the losses in athletic performance after a bout of eccentric exercise.

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Therefore, the purpose of this study was to describe the repeated bout effect responses (MVIC, ROM, muscle soreness and peak power) of female subjects before and after a 4-week eccentric training program. It was hypothesized that the subjects would exhibit exercise-induced muscle damage after the first acute eccentric bout, and that the damage would be lower after the second acute eccentric bout. Moreover, based on adaptations reported in males (Garcia-Lopez et al., 2007), we assumed that 4 weeks of eccentric training would result in smaller muscle damage values compared with controls after the second acute bout.

Methods

Subjects

Twenty-four young active women (4-6 h of physical activity per week, mainly team and ball sports, for at least the last three years) were recruited and randomly assigned to either a training group (TG; n = 14; age 22.6 ± 0.3 years; height 1.65 ± 0.02 m; weight 58.4 ± 2 kg. Mean ± SEM) or a control group (CG; n = 10; age 22.1 ± 0.5 years; height 1.63 ± 0.02 m; weight 60.7 ± 2.4 kg. Mean ± SEM) before performing any test. The sample size was estimated based in data from previous studies (Garcia-Lopez et al., 2007; Jimenez-Jimenez et al., 2008) that followed a similar protocol (i.e. two acute eccentric bouts interspersed with an eccentric training period) in men. It was shown that between 7 and 10 subjects per group (considering soreness, jump performance and strength losses) were needed based on an effect size of 1, alpha level of 5% and power of 80%. There were no significant differences between groups for age, height or body mass. All subjects were sports science undergraduate students, not hormonal contraceptive users, and not involved in strength training for the last 6 months. They had no previous muscle joint or bone injuries and were considered to be healthy individuals. Subjects were requested not to perform any unaccustomed exercise or vigorous physical activity, and not to take any nutritional supplements or anti-inflammatory drugs during the experimental period. The study was approved by the Institutional Review Board of the University of León. Participants were informed of the purposes and possible risks involved in the study before giving their informed written consent for participation. Participants completed a medical and physical activity questionnaire before being interviewed by a sports physician.

Experimental design

Participants were tested for maximal isometric and dynamic strength (1RM), peak power production and ROM in a commercially available bilateral 45º-inclination leg-press device (Gerva-Sport®, Spain). Five days later participants performed an acute bout of eccentric contractions in the same leg-press device. Isometric strength, power and ROM measurements were collected immediately, 24, 48 and 168 h after the eccentric exercise bout. Quadriceps muscle soreness was collected before, immediately after, 6, 24, 48, 72, and 168 h after the bout. These time points likely allowed assessment of each dependent variable's peak value and also the recovery process after the acute eccentric bout (Chen et al., 2009; Lavender and Nosaka, 2008). Two weeks later, the training group (TG) started a 12-session-4-week training program while the control group (CG) did not follow any strength training. The length, frequency and intensity of the training have already been used successfully with eccentric overload or eccentric training programs (Garcia-Lopez et al., 2007; Jimenez-Jimenez et al., 2008; Norrbrand et al., 2008). One week after the training period, the protocol described above was repeated in the same order, and on the same time of the day. CG and TG participants were allowed to follow their physical activity routines excluding any resistance training during the length of the study.

Acute eccentric bouts

Two identical acute eccentric exercise bouts were carried out by both groups, the first one two weeks before the training period and the second bout two weeks following the last training session. The second acute bout was similar to the first one in terms of load (% of pre-training 1RM) and descent velocity. Additionally, in order to assess similarity between both acute eccentric bouts total work performed during the first and the second acute eccentric bouts was calculated for TG and CG. Time of the day was replicated between the first and the second acute eccentric bout for all the subjects. Participants completed 12 sets of 10 repetitions of eccentric contractions (Garcia-Lopez et al., 2007) at 70% of pre-training 1RM in the leg-press device described previously, with 3 min recovery between sets. The leg-press was chosen because it is a safe exercise for subjects with little experience in strength training. Participants lowered the load from full knee extension to 90º knee flexion. Thereafter, the load was lifted back by researchers with a pulley system to each participant's full knee extension. The eccentric phase lasted two seconds with the same resting time between repetitions, and the pace was set by a digital metronome (DM-22, Seiko S-Yard® Co., Ltd., Japan) and controlled by a linear encoder (Globus Real Power®, Italy), which offered real-time feedback on contraction velocity to the subjects and the research staff. Thus, instructions to the subjects were given when contraction velocity was not regular among repetitions or among sets. The number of repetitions, exercise device, and load used for the acute eccentric bouts were similar as other protocols studying the repeated bout effect and eccentric training (Garcia-Lopez et al., 2007; Jimenez-Jimenez et al., 2008; Skurvydas et al., 2011).

Eccentric training

TG participants attended 12 training sessions during 4 weeks (3 sessions per week with a minimum of 48 h between sessions). Training was carried out in the leg-press device mentioned before. Exercise intensity was progressively increased based on pre-training 1RM: 45% of 1RM in the first three sessions, 50% of 1RM in the next three sessions, and 55% of 1RM during the last six sessions. Training consisted of lowering the load in a controlled way from full knee extension to approximately 90º knee flexion, performing an eccentric contraction of two seconds. After two seconds rest, time used by researchers to lift the load to the starting position using a pulley system, the next repetition was executed. In addition, contraction velocity was controlled with a linear encoder that offered real-time feedback to subjects and researchers. Training sessions were preceded by an 8-minute warm-up on a cycle ergometer at heart rate ~120 bpm. Three sets of ten repetitions were performed per training session with 3 minutes recovery between sets. Similar training protocols in terms of intensity, number of sets and repetitions (Garcia-Lopez et al., 2007; Jimenez-Jimenez et al., 2008) and number of training sessions (Norrbrand et al., 2008) have been used with positive results in men. Submaximal intensity was chosen for the eccentric training protocol given that it has been proved to impact the repeated bout effect in young men (Garcia-Lopez et al., 2007).

One repetition maximum

This test was performed to assess any training effect in maximal dynamic strength and to establish the loads that would be used during the eccentric damaging protocol and the eccentric training. Maximal dynamic strength was measured with the 1 repetition maximum test (1RM) in the leg-press mentioned above. Participants performed one repetition from 90° to full extension (180°) with an estimated load that was increased with 10 kg if the participant succeeded or decreased 5 kg if failed. Testing ended when participants failed to overcome a given resistance in 2 successive trials. Participants achieved their 1RM between 3 and 5 attempts. To avoid possible injuries and to standardize body position, participants were asked to keep the posture described by the researchers in the leg-press and to keep their hands on the handle-bar at all times. The 1RM test was performed twice, five days before each acute eccentric bout.

Maximal voluntary isometric contraction

After warming-up (5 minutes on a cycle ergometer at heart rate ~120bpm) participants were seated in the leg-press device. The maximal voluntary isometric contraction test (MVIC) consisted of pushing against the fixed platform of the leg-press as hard as possible for 5 seconds with a knee flexion of 110º under strong verbal encouragement. A strain gauge (Globus Ergometer®, Italy; sample rate 1000 Hz) was placed in between the chains used to fix the platform of the machine, to measure the isometric strength of both legs. Data were recorded and analyzed with associated software (Globus Ergo Tester® v1.5, Italy). Each participant performed two attempts interspersed with 3 minutes recovery, and the best attempt was considered for further data analysis. The MVIC was carried out five days before the two acute eccentric bouts, and immediately after, 24, 48 and 168 h after each eccentric bout. The ICC for this test in our laboratory was between 0.958 and 0.987 for young women.

Range of movement

A loaded ROM test was carried out in the same leg-press device already described. Participants were asked to lower the leg-press platform (35 kg) with both legs slowly and smoothly from full extension to the flexion point where pain in quadriceps muscle group was experienced. Once this point was reached, researchers fixed the platform and subject's knee angle was measured with a manual goniometer (TEC®, Spain). Anatomical marks were made on the legs of subjects to increase reliability of the measurements. The test was repeated three times and the average of the three attempts was considered for further analysis. The ROM assessment was performed five days before the two acute eccentric bouts, and immediately after, 24, 48 and 168 h after each eccentric bout. The ICC for this test was between 0.931 and 0.960 for young women.

Peak power

To complete the peak power test in the leg-press device, participants pushed the leg-press platform 3 times as fast as possible with 60% of pre-training 1RM (Thomas et al., 1996) from 90º knee flexion to full extension (180º). A linear encoder (Globus Real Power®, Italy; sample rate 300 Hz) was adapted to the platform, and associated software was used to calculate peak power for every repetition (Globus Real Power® v3.11, Italy). The best of three attempts was included in the data analysis. The peak power test was carried out five days before the two acute eccentric bouts, and immediately after, 24, 48 and 168 h after each eccentric bout. The ICC for this test was between 0.940 and 0.984 for young women.

Muscle soreness

A visual analogue scale (VAS) was used to assess soreness in the quadriceps muscle group. A 100 mm line with the legend "No pain" in the left border, and the legend "Unbearable pain" in the right limit was used. Subjects had to perform a squat movement without any additional weight and then draw a vertical line on the VAS representing their pain in the selected muscle group (Garcia-Lopez et al., 2007; Jimenez-Jimenez et al., 2008). Muscle soreness was obtained before every acute eccentric bout and immediately, 6, 24, 48, 72 and 168 h after the bout.

Statistical analyses

Data were analyzed using SPSS®17.0 (SPSS Inc., USA). Results are presented as mean ± standard error of the mean (SEM). Shapiro-Wilk normality test was used to assess data distribution. Raw values for MVIC, 1RM, peak power and ROM before the first and before the second acute eccentric bout were compared within every group by a paired Student's *T*-test to assess any training effect. To evaluate any possible difference in post test results for each group (e.g. the recovery after the first and the second acute bout) an analysis of variance (two-way ANOVA) with repeated measurements over eccentric bout (first bout and second bout) and time (baseline, post, 24, 48 and 168 h after for MVIC, ROM and peak power and baseline, post, 6, 24, 48, 72 and 168 h after for soreness) was calculated separated for TG and CG, employing normalized data for MVIC, peak power and ROM, and raw values for soreness. To compare results between TG and CG after the first and the second acute eccentric bout, a two-way ANOVA with repeated measurements for group (TG and CG) and time (baseline, post, 24, 48 and 168 h after, plus 6 and 72 h for soreness) was used. Bonferroni post-hoc test was used where appropriate. Significance was set at $p < 0.05$.

Table 1. Maximal strength, peak power and range of motion results before the first and the second acute eccentric bouts.

	MVIC (N)		1RM (kg)		Peak Power (W)		ROM (º)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
TG	2234 (188)	2476 (166) *	218 (15)	223 (14)	1209 (78)	1234 (76)	58.9 (2.1)	60.4 (1.8)
CG	2022 (186)	2007 (154)	202 (16)	212 (19)	1125 (83)	1139 (83)	57.2 (1.5)	57.2 (1.9)

Baseline maximal voluntary isometric contraction (MVIC), one repetition maximum (1RM), peak power, and range of motion (ROM) before the first and the second acute eccentric bouts (1st and 2nd, respectively) for the training group (TG) and the control group (CG). Mean (± SEM). * $p < 0.05$ compared with the first acute eccentric bout.

Results

TG and CG pretest values obtained before the first acute eccentric bout, as well as after the training period and before the second acute eccentric bout are shown in Table 1. Before the first acute bout, TG had slightly greater strength and power, but no significant differences appeared between groups in any variable ($p > 0.4$). After the training period and before the second bout, TG showed a tendency towards greater MVIC than CG counterparts ($P = 0.06$). In addition, TG significantly increased MVIC with the training program ($p < 0.02$). No changes appeared in any other variable after training period within a group ($p > 0.1$) or between groups ($p > 0.2$). The amount of work performed by TG during the first and the second acute eccentric bout was -31.1 ± 2.5 kJ and -30.3 ± 1.9 kJ, respectively, while for CG total work was -28.5 ± 2.1 kJ and -29.1 ± 2.7 kJ during the first and the second acute eccentric bout, respectively. No significant differences appeared within group or between groups for total work.

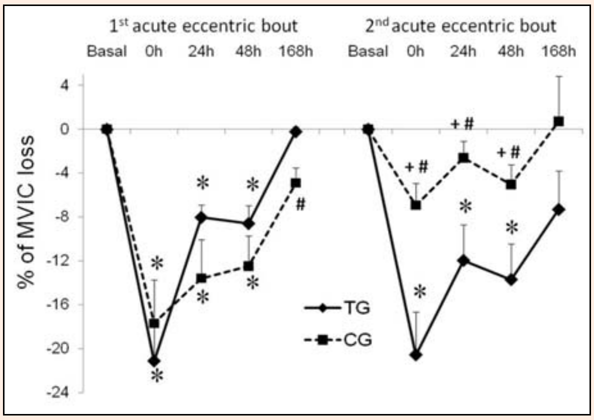

Figure 1. Normalized changes in maximal voluntary isometric contraction (MVIC, mean ± SEM) from baseline at immediately after (0), 24, 48 and 168 h following the first and the second acute eccentric bout for the training group (TG) and the control group (CG). *: Significant difference from baseline value; +: Significant difference from the first acute eccentric bout within a group; #: Significant difference from TG. Significance was set at $p < 0.05$.

The MVIC recovery after each acute bout (normalized values) for TG and CG is shown in Figure 1. The response to the first bout was fairly similar between TG and CG from immediately after to 72 h after the bout ($p > 0.2$). However, CG showed significantly more strength losses 168 h after the bout ($p < 0.01$) compared with TG. The MVIC recovery following the second acute eccentric bout was faster for the CG, presenting lower strength losses than TG immediately ($p < 0.02$), 24 h ($p < 0.03$) and 48 h ($p < 0.05$) after the second bout. Isometric strength losses for TG were significant following both acute bouts immediately, 24 h and 48 h after the bouts ($p < 0.03$).CG showed MVIC losses only after the first acute bout (immediately, 24 and 48 h, $p < 0.04$). In addition, CG showed significantly lower decreases ($p < 0.02$) in MVIC immediately, 24 h and 48 h after the second eccentric bout when compared with MVIC losses suffered after the first bout.

Figure 2 shows normalized ROM results for TG and CG after the first and the second acute eccentric bouts. No differences between groups appeared in the recovery of neither the first nor the second acute eccentric bout. Significant differences between baseline and post 48 h after the first eccentric bout appeared for TG ($p < 0.05$). TG presented lower losses of ROM in the recovery of the second acute eccentric bout immediately (0 h) and 24 h after the bout when compared with the first bout ($p < 0.05$). No differences between the first and the second bout were found for CG.

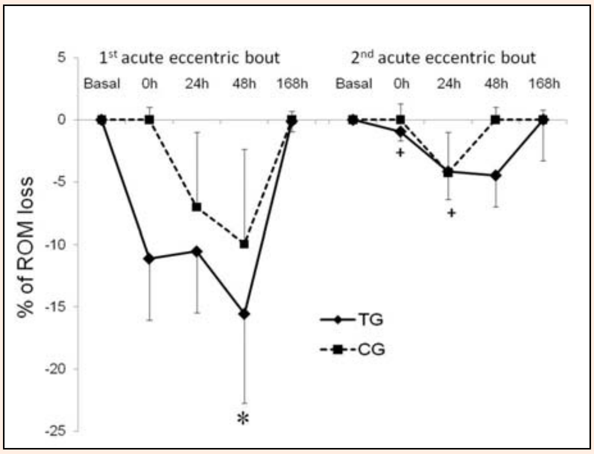

Figure 2. Normalized changes in range of motion (ROM, mean ± SEM) from baseline at immediately after (0), 24, 48 and 168 h following the first and the second acute eccentric bout for the training group (TG) and the control group (CG). *: Significant difference from baseline value; +: Significant difference from the first acute eccentric bout within a group. Significance was set at $p < 0.05$.

The normalized pre- and post-test peak power results for the acute eccentric bouts are shown in Figure 3. There were no differences between groups after any acute bout. Peak power from TG decreased in all post-tests after the first bout ($p < 0.05$), while it was significantly lower only immediately after the second bout ($p < 0.02$). CG presented a decrease in peak power from immediately to 48 h after the first bout ($p < 0.04$), while the decrease after the second eccentric bout was evident only immediately after the bout. Interestingly, CG recovered peak power faster after the second acute eccentric bout than after the first one from 24 h to 168 h after the bout ($p < 0.02$). This faster recovery after the second bout was not seen in TG.

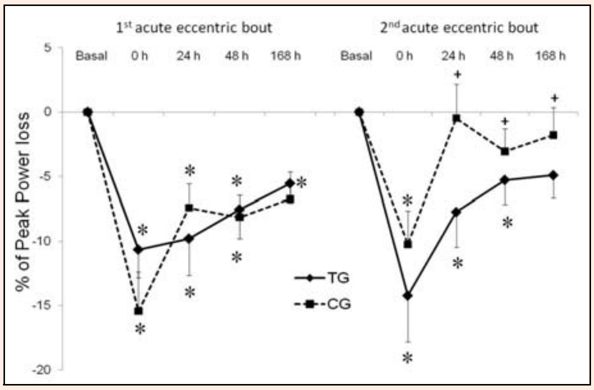

Figure 3. Normalized changes in peak power (mean ± SEM) from baseline at immediately after (0), 24, 48 and 168 h following the first and the second acute eccentric bout for the training group (TG) and the control group (CG). *: Significant difference from baseline value; +: Significant difference from the first acute eccentric bout within a group. Significance was set at $p < 0.05$.

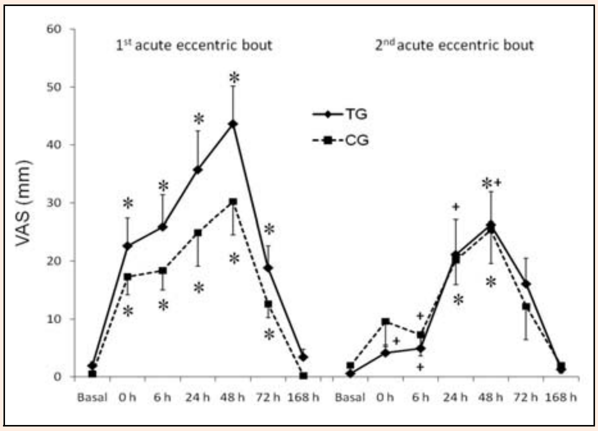

Figure 4. Soreness response to the first and second acute eccentric bouts for training group (TG) and control group (CG) (mean ± SEM). *: Different from basal value; +: Different from first acute eccentric bout within a group. Significance was set at $p < 0.05$.

Muscle soreness results are shown in Figure 4. No significant differences arose between groups after any of the eccentric bouts. TG subjects reported more soreness from immediately to 72 h after the first bout ($p < 0.02$). However, soreness after the second bout in TG was significantly greater ($p < 0.02$) only 48 h after the bout. Interestingly, a training effect was seen in TG, showing a faster recovery with less soreness after the second bout than after the first one from immediately to 48 h after the eccentric bout ($p < 0.001$ for immediately and 6 h after the bout, and $p < 0.05$ for 24 and 48 h after the bout). Comparing with basal values, CG showed greater soreness ($p < 0.04$) from immediately to 72 h after the first bout. Significantly higher values of soreness were reported 24 h and 48 h after the second eccentric bout ($p < 0.04$) compared with basal values. CG showed less ($p < 0.01$) soreness only 6h after the second bout when compared with the first acute eccentric bout.

Discussion

This is the first study that aims to determine the influence of an eccentric training program on the repeated bout effect in young women. Contrary to our initial hypothesis, the main finding of this investigation indicates that the eccentric training program carried out here decreases the repeated bout effect when assessed with MVIC and peak power tests in young women. However, as we hypothesized, the eccentric training increased the repeated bout effect impact if assessed with muscle soreness. The present results suggest that, in young active women, eccentric training may prevent the repeated bout effect in adaptations related with the initial mechanical stress or muscle damage (e.g. strength loss), but, on the other hand, it may increase the repeated bout effect impact on the secondary damage, more related with the inflammatory response (e.g. soreness). These are important findings that increase the knowledge concerning the effects of eccentric training programs in women.

The response of TG and CG to the MVIC after the first acute eccentric bout showed a decrease of ~20% just after finishing the bout and a progressive recovery thereafter. Jimenez-Jimenez and coworkers (2008) showed a similar strength loss after an acute eccentric bout of similar characteristics in old men. Despite the similar initial response, the MVIC loss developed by CG at 168 h was significantly greater than TG. A possible explanation could be a higher number of “high responders” (Hubal et al., 2007), although in a previous study the differences between high- and low- responders were seen only within the 48 h following the acute eccentric bout (Hubal et al., 2007).

Perhaps more surprising was the different responses of CG and TG in MVIC after the second acute eccentric bout. Thus, after the second bout CG showed less strength losses and a faster recovery than after the first bout, possibly due to the repeated bout effect (Howatson et al., 2007; Nosaka et al., 2001; Skurvydas et al., 2011). However, the decrease in strength losses in CG immediately after the second acute eccentric bout may seem unusual since some investigations have shown that the repeated bout effect does not affect strength losses immediately after the bout (Nosaka et al., 2001; Paschalis et al., 2008). Nevertheless, a recent investigation (Skurvydas et al., 2011) reported that strength losses immediately after an eccentric bout with the leg extensor muscles was attenuated by 10% the second time the eccentric bout was performed, results supported by our data. Nosaka and coworkers (2001) and Paschalis and coworkers (2008) chose the elbow flexors and the knee flexors, respectively, for their protocols, while Skurvydas et al. (2011) and the present study analyzed the knee extensors. Thus, it is possible that differences may exist in the adaptative responses to the repeated bout effect when comparing different muscle groups or joint movements, something recently described for a single bout of eccentric exercise (Chen et al., 2011).

The most novel and unexpected finding were the values presented by TG after the second acute eccentric bout. As mentioned above, our hypothesis was that the repeated bout effect manifestations would improve following eccentric training. Not only was this not fulfilled, but the eccentric training in young women also prevented the faster recovery of MVIC provided by the repeated bout effect. To our knowledge, this is the first investigation to describe this response, which will be discussed further.

Peak power is a critical factor in muscular performance (Baker and Nance, 1999; Sleivert and Taingahue, 2004) and it has been established that it is reached with loads ranging from 50 to 70% of 1RM (Izquierdo et al., 2001; Thomas et al., 1996) using similar protocols as in this study. It has been demonstrated that humans present less peak power on a cycle ergometer after carrying out an eccentric exercise (Byrne and Eston, 2002). Moreover, a study with mice (Widrick and Baker, 2006) reported decreased power in an isolated muscle after an eccentric contraction series due to a loss in strength and a slower muscle shortening speed. In the present study, peak power decreased significantly from immediately post-exercise to 48 h after the eccentric bout in both groups after the first acute eccentric bout, and also at 168 h for TG. However, after the second acute eccentric bout peak power decreased only immediately after the exercise in both groups, although significant differences between the first and the second eccentric bouts emerged only for CG from 24 h to 168 h, i.e. recovering the peak power faster. The faster recovery of peak power after the second eccentric bout in CG may represent the repeated bout effect, although this effect was not evident in TG. Again, it seems that a short eccentric training program might avoid the repeated bout effect impact. These data also support that the repeated bout effect can be evaluated with a peak power test. Since losses in peak power can be due to a decrease in strength or to a slower muscle fiber shortening speed (Widrick and Baker, 2006), a deeper analysis of both parameters is needed to understand the mechanisms that determine the loss in peak power after an acute eccentric exercise.

Considering TG results of MVIC and peak power, it could be proposed that certain eccentric training protocols would prevent the adaptations given by consecutive eccentric exercise bouts over the exercise-induced muscle damage in females. Some investigations (Hubal et al., 2007; Sewright et al., 2008) have shown that women suffer greater muscle damage after eccentric exercise. This greater damage may also influence the adaptation process and the recovery after an acute eccentric bout and the response of women to eccentric training. Since the results of this study differ from those carried out in men (Garcia-Lopez et al., 2007; Jimenez-Jimenez et al., 2008), investigations comparing eccentric training and its adaptative responses between genders are needed to clarify the possible differences.

A recent study by Falvo et al. (2009) showed that resistance trained subjects did not present a repeated bout effect for MVIC, but they did for self-assessed muscle soreness. According to the ideas proposed by the authors of that study, the training protocol used in the present investigation may have generated neural adaptations responsible for the absence of the repeated bout effect (Falvo et al., 2009), considering that TG and CG participants had similar physical-activity background. However, the light load employed for the training program would make these adaptations difficult to appear. Another hypothesis that may help to explain our results is suggested by Choi and Widrick (2009). They concluded that fatigue may reduce the long-term power and force losses associated with lengthening contractions. According to this hypothesis, TG may have developed less fatigue during the second acute eccentric bout due to the training that they followed. Thus, the muscle fibers would have been more susceptible to suffering from the muscle damage generated by the second acute bout. On the other hand, fatigue would have worked as a protection mechanism in CG, losing less MVIC and peak power after the second acute eccentric bout.

Studies with male participants (Howatson et al., 2007; Lavender and Nosaka, 2008) show that ROM decreases after an acute bout of eccentric exercise, presenting lower losses the second time the acute bout is performed. This is commonly explained by the repeated bout effect. In the present study only the group of women that followed the eccentric training program presented a significant decrease in ROM losses after the second acute eccentric bout when compared with the first one (immediately and 24 h after the bout). Apart from a possible training effect, it should also be considered that perhaps the loaded ROM assesses this variable in a different way compared with active or passive ROM. Therefore, research comparing different methods to assess ROM is warranted.

Soreness assessment is one of the most utilized indirect methods to evaluate exercise-induced muscle damage (Warren et al., 1999). TG and CG soreness values after the first acute eccentric bout followed the pattern already described in men by other authors (Howatson et al., 2007; Paschalis et al., 2008; Vissing et al., 2008), presenting significantly higher values than baseline from immediately to 72 h after the first bout, which would confirm the idea that soreness is similar for men and women after an acute eccentric bout (MacIntyre et al., 2000; Dannecker et al., 2005). When the acute bout is performed the second time by men, soreness tends to be lower which is commonly explained by the repeated bout effect (Garcia-Lopez et al., 2007). CG showed a similar trend, but significant differences between the first and the second eccentric bouts were only found 6 h after the bout, reporting less soreness on the second bout. However, TG showed significantly less soreness after the second acute eccentric bout when compared with the first one. This response points out that the training program followed by TG had a protective effect over muscle soreness, since the repeated bout effect alone did not lower soreness in CG. Paschalis et al. (2008) reported a repeated bout effect in soreness results for females, but methodological discrepancies between Paschalis et al. (2008) and the present investigation (isokinetic vs. varying speed eccentric actions, respectively) may partly explain the different results obtained.

The hypothesis that soreness is an indicator of inflammation (Smith et al., 1991), which would represent a secondary cascade of tissue damage, while strength losses would represent primary muscle fiber damage or initial mechanical stress has been defended in recent works (Chen et al., 2009; Parr et al., 2009). This would suggest that the adaptation processes are different between the skeletal muscle fibers and the extracellular matrix (Chen et al., 2009). Thus, the eccentric training protocol herein carried out may have induced different adaptations between the muscle fiber damage and the inflammation processes, preventing the adaptations associated with muscle fiber damage (losses in MVIC) and increasing the adaptations related with inflammation (less soreness). We speculate that this could explain the different patterns of MVIC and soreness in TG after the second acute eccentric bout. However, it should be taken into account that results from this study must be analyzed with caution since the response of TG and CG was not completely similar (although not significantly different between groups) after the first acute eccentric bout. This may represent a confounding factor when making inferences about the subsequent interventions carried out in this investigation.

Conclusion

In conclusion, the results of the present study show that women develop muscle damage after an acute eccentric bout. Furthermore, women present less muscle damage when the bout is repeated. Results from TG indicate that a 4-week eccentric training program of 12 sessions may prevent some of the adaptations provided by the repeated bout effect, specifically those adaptations related with muscle damage. On the other hand, the eccentric training program may have an additional effect together with the repeated bout effect in the adaptations related with the inflammation process.

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Key points

- An acute bout of eccentric exercise induces losses of strength, peak power and range of motion, and increases muscle soreness in young active women.
- When the acute eccentric bout is repeated by young women, the losses of strength and power are smaller, indicating less muscle damage. However, muscle pain and range of motion do not present any difference with the results obtained after the first bout, which would indicate that the repeated bout effect does not affect inflammatory response after acute eccentric exercise.
- Four weeks of eccentric training is enough to increase maximal isometric strength, but not dynamic strength (1RM) or peak power. Furthermore, this training seems to prevent those adaptations provided by the repeated bout effect related with muscle damage. On the other hand, the eccentric training seems to be a positive tool to decrease muscle soreness, and thus the inflammatory response, associated to a repeated acute eccentric bout.

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