Muscle Damage and Muscle Activity Induced by Strength Training Super-Sets in Physically Active Men

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Abstract

Brentano, MA, Umpierre, D, Santos, LP, Lopes, AL, Radaelli, R, Pinto, RS, and Kruel, LFM. Muscle damage and muscle activity induced by strength training super-sets in physically active men. *J Strength Cond Res* 31(7): 1847–1858, 2017—In strength training, muscle activity is often analyzed by surface electromyography (EMG) and muscle damage through indirect markers, such as plasma concentrations of creatine kinase (CK) after exercise. However, there is little information about the influence of the strength exercises order on these parameters. The purpose of this study is to analyze the effect of strength exercises order (super-sets) in muscle activity and indirect markers of muscle damage. Twenty men were randomly assigned to one of the strength training sessions (TS). Each TS (5 sets × 8–10 repetition maximum) consisted of 2 exercises for the knee extensor muscles and 2 exercises for the horizontal shoulder flexors performed in a different order: exercises for the same muscle group grouped (grouped exercises [GE]: $n = 10$; 26.6 ± 3.4 years; 17.4 ± 3.4 body fat) or separated (separated exercises [SE]: $n = 10$; 24.9 ± 2.6 years; 15.4 ± 5.9 body fat). Muscle activity was analyzed by surface EMG (vastus lateralis [VL], vastus medialis [VM], rectus femoris [RF], pectoralis major [PM], and anterior deltoid [AD]), and the main indirect marker of muscle damage was the CK, evaluated immediately before and after the first 5 days of each TS. There was a higher EMG activity of GE in the RF (GE: 88.4% × SE: 73.6%) and AD (GE: 176.4% × SE: 100.0%), in addition to greater concentration of CK (GE: 632.4% × SE: 330.5%) after exercise. Our findings suggest that, in physically active men, implementing super-sets with GE promotes greater muscle effort and muscle damage, wherein 5 days are not enough to recover the trained muscle groups.

Key Words pre-exhaustion, EMG, creatine kinase

Introduction

Strength training (ST) is widely used to increase muscle strength and muscle cross-sectional area in both men (9) and women (31). These training adaptations are obtained by manipulating some variables related to the intensity of ST.

One way to analyze the intensity of ST involves the level of induced muscle damage, and some indirect markers have been widely evaluated, especially in comparisons between concentric and eccentric muscle actions (10–12). In this sense, analysis of indirect markers, as well as by direct damage to the muscle fibers exercised, shows that eccentric contraction promotes the highest levels of damage (46,47), although concentric training sessions (TS) also show modifications of these markers (3,22,37).

The degree of muscle activity induced by ST is also the subject of work on the training intensity (2,39,40). Muscle activity is usually analyzed by the amplitude of electromyographic (EMG) signal during and after the TS (16,21,27) and, over more intense ST and prolonged, there is an increase in the amplitude of the EMG signal with decreased force production capacity of the agonist muscle group (21,27).

Several studies consider the load used as a relevant factor related to increases in muscle strength and muscle cross-sectional area, and high loads tend to cause increases in these parameters (9,19,20,32,35,36). However, another way to increase the training intensity involves the manipulation of the rest between sets/exercises for the same muscle group. In this context, the "superset" (grouping of exercises for the same muscle group) is cited as valid in increasing exercise intensity (6). These variations in the rest between exercises for the same

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TABLE 1. Sample characterization of the GE and SE with mean and *SD*s (mean ± *SD*).*†

Variables	Groups GE ($n = 10$)	SE ($n = 10$)
Age (y)	26.6 ± 3.4	24.9 ± 2.6
Height (cm)	178.0 ± 7.0	177 ± 6.0
Body mass (kg)	77.2 ± 5.9	76.0 ± 9.9
Fat mass (%)	17.4 ± 3.9	15.4 ± 5.9
MVC KE (N·m)	287.7 ± 26.0	313.8 ± 49.0
MVC SHF (N·m)	107.2 ± 10.5	100.0 ± 18.6
10RM bench press (kg)	52.6 ± 12.3	47.0 ± 12.0
10RM peck deck (kg)	25.5 ± 7.5	28.0 ± 6.7
10RM leg press (kg)	157.9 ± 32.9	164.0 ± 36.3
10RM knee extension (kg)	34.7 ± 4.5	38.4 ± 3.5

*GE = grouped exercise; SE = separated exercise; MVC = maximal voluntary contraction; KE = knee extensors; SHF = shoulder horizontal flexors; RM = repetition maximum.
†There were no differences between GE and SE for all variables ($p > 0.05$).

muscle group or groups with opposing functions have been consistently investigated under neuromuscular point of view, through the analysis of the EMG signal (2,4,17,21,25,26,34). However, the results involving super-sets are controversial (2,6,24) because some studies show reduced muscle activity through super-sets (2,6), whereas others show increased muscle activity (24). Furthermore, there is little or no information about the extent of damage induced by these training models.

Thus, this study aims to analyze the effects of the strength exercises order in (a) the EMG signal amplitude of the horizontal flexor muscles of the shoulder and knee extensors (KE) and (b) to analyze the response of indirect markers of muscle damage during the first 5 postexercise days due to ST sessions with exercises for the same muscle group being conducted grouped or separated.

Starting from the assumption that grouped exercises (GE) for the same muscle group promote greater effort, we hypothesized (a) a more pronounced increase in the amplitude of the EMG signal of the agonist muscle groups; and (b) a more pronounced change in indirect markers of muscle damage when compared with the session with separated exercises (SE).

METHODS

Experimental Approach to the Problem

This study analyzed muscle activity and muscle damage induced by 2 TS: with strength exercises for the same muscle group performed in a grouped manner (super-set of pre-exhaustion) or performed separately (super-set alternating by segment). To avoid the interference of the "protective effect" caused by successive TS with similar characteristics, the individuals selected for this study were randomly divided into 2 groups, each performing one of the TS. Considering the muscle damage, the following markers were evaluated: creatine kinase (CK) activity, muscle torque, delayed onset muscle soreness (DOMS), and range of motion (ROM) of the shoulder and knee. Muscle activity was analyzed by the amplitude of the EMG signal of the vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF) (KE), pectoralis major (PM), and anterior deltoid (AD) (shoulder horizontal flexors [SHF]). The muscle damage response aimed at the development of "curves" of recovery for each of the TS, whereas the

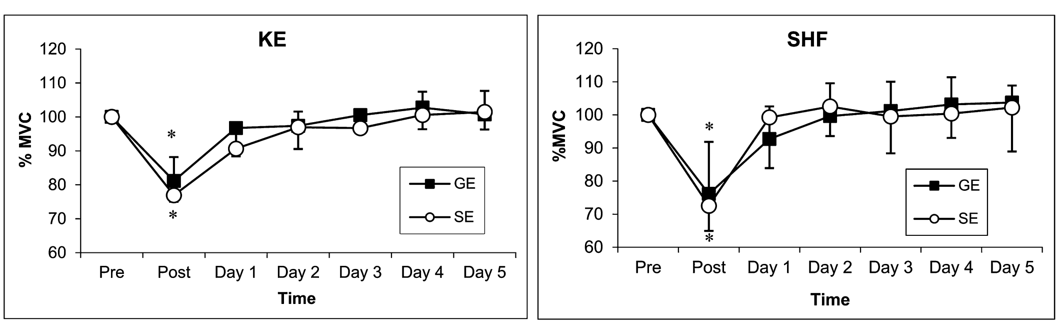

Figure 1. Mean and *SD*s of normalized maximal voluntary contraction (%MVC) of the knee extensors (KE) and shoulder horizontal flexors (SHF), before, immediately after, and during 5 days, after performing grouped exercises (GE) or separated exercises (SE). There is no difference between GE and SE. *Difference from pre-exercise ($p \leq 0.05$).

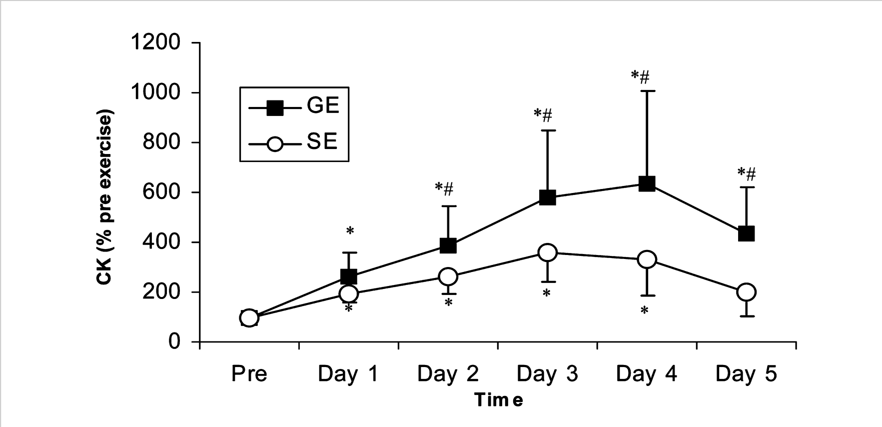

Figure 2. Mean and *SD*s of normalized plasmatic creatine kinase activity (%CK) before and during 5 days after performing grouped exercises (GE) or separated exercises (SE). #Difference between GE and SE sessions ($p \leq 0.05$). *Difference from pre-exercise ($p \leq 0.05$).

with an expected difference of 10% for the CK at 5 days post-exercise between 2 groups, it was shown that 11 subjects per group were necessary. After the selection of individuals, they were randomly divided into 2 groups, according to the muscle groups involved in each experimental session: GE (26.6 ± 3.4 years) or SE (24.9 ± 2.6 years). We chose to study 2 parallel groups to avoid interference from a "protective effect" that reduces the responses of muscle damage markers in successive workouts, with similar characteristics (10,38,54).

response of muscle activity aimed to indicate the level of muscular effort induced by each of the sessions.

Subjects

The sample consisted of 22 men. The inclusion criteria were being physically active, familiarized with strength exercises, but not on a competitive level. The exclusion criterion was to present history of neuromuscular injury. The characteristics of individuals are shown in Table 1. Before participation, all participants were informed about the procedures, risks, and benefits of the study and signed a consent form approved by the Ethics Committee of the Clinical Hospital of Porto Alegre (CEP/HCPA 08-474). The sample was obtained through dissemination of posters placed in the School of Physical Education of Federal University of Rio Grande do Sul (ESEF/UFRGS) and surrounding areas. Based on the effect size of 1, alpha level of 0.05, and a power (1-β) of 0.80,

Procedures

Before data collection, the reproducibility of main measuring instruments was evaluated into 2 separated days, whose intraclass correlation coefficients (ICCs) values ranged between $r = 0.903$ and $r = 0.979$; $p < 0.001$. Moreover, the coefficient of variation (CV) ranged between 7.4% and 28.5%.

Strength Training Sessions

The subjects performed a total of 4 exercises for upper (SHF) and lower (KE) limbs: (a) "bench press" with free weights and (b) "peck deck" (Taurus, Brazil), (c) "leg-press 45°" (Top Line, Brazil) and (d) "knee extension" (Taurus, Brazil). These four exercises were used in 2 different TS: one with exercises for the same muscle group in sequence, named grouped session (GE–exercise order a, b, c, and d) and another with the exercises for the same muscle group performed separately (SE–exercise order c, b, a, and d). Based on the characteristics

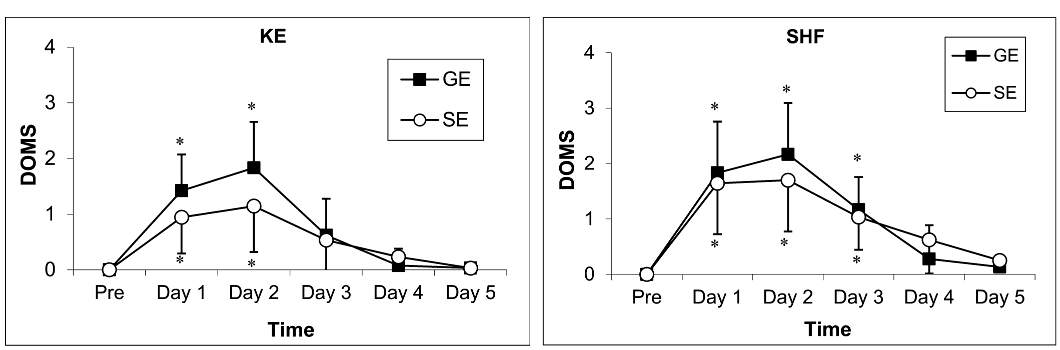

Figure 3. Mean and *SD*s of delayed onset muscle soreness (DOMS) of the knee extensors (KE) and shoulder horizontal flexors (SHF), before and during 5 days, after performing grouped exercises (GE) or separated exercises (SE). There is no difference between GE and SE. *Difference from pre-exercise ($p \leq 0.05$).

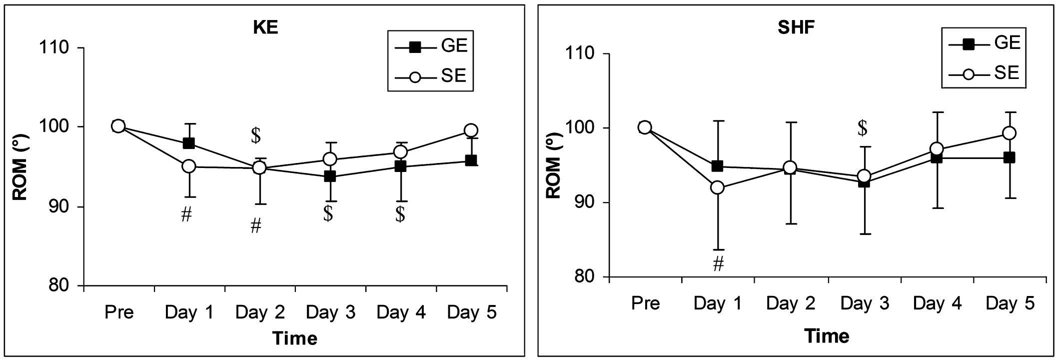

Figure 4. Mean and *SD*s of normalized range of motion (%ROM) of the knee extensors (KE) and shoulder horizontal flexors (SHF), before and during 5 days, after performing grouped exercises (GE) or separated exercises (SE). There is no difference between GE and SE. #Difference from pre-exercise in SE ($p \leq 0.05$). $Difference from pre-exercise in GE ($p \leq 0.05$).

of physically active subjects (39) and targeting a typical session for muscle hypertrophy (9), subjects performed 5 sets with 8–10 repetition maximum (RM) in each of the 4 exercises. All exercises were performed at the load obtained during the 10RM tests; therefore, both sessions were conducted with loads equivalent to 85% of 10RM.

During GE, the subjects performed one set of the "leg-press" exercise, immediately followed by one set of the "knee extension" exercise, with no rest between each exercise. After 5 sets, the subjects performed one set of the "bench press" exercise, immediately followed by one set of the "peck deck" exercise, with no rest between each exercise. During SE, the subjects performed one set of the "bench press" exercise, immediately followed by one set of the "knee extension" exercise, with no rest between each exercise. After 5 sets, the subjects performed one set of the "leg-press" exercise, immediately followed by one set of the "peck deck" exercise, with no rest between each exercise. In both GE and SE, it was used 3 minutes of rest between every 2 exercises (superset) to minimize the decrease in total work for subsequent sets (42,45,56–58).

10 Repetition Maximum Test

The adjustment of loads was performed using the 10RM test, following a protocol suggested by Simão et al. (51). The exercise order occurred as follows: leg press, bench press, knee extension, and peck deck. Subjects did up to 3 attempts for each exercise, at intervals of 5 minutes between each attempt. At the end of an exercise test, an interval of at least 10 minutes was given before the start of the next test.

Body Composition

Body weight and height were measured on a scale with a stadiometer (Asimed, Barcelona, Spain), following the recommendations of Costa (14). The sum of skinfolds was used to estimate body density of individuals (23), and body fat was estimated using the formula of Siri (52).

Indirect Markers of Muscle Damage

The indirect markers of muscle damage have been chosen according to Brentano and Kruel (8). All markers were measured immediately before the workout and during the following 5 days, approximately at the same time of the exercise session was performed. During these 5 days, no additional exercise session was allowed. We evaluated 4 indirect markers of muscle damage, as described below.

Isometric Torque (τ). Each individual was placed in the chair of the isokinetic dynamometer (CYBEX, model NORM; Lumex & Co., Ronkonkoma, NY, USA) and fixed by straps passing through the chest and pelvis. For the evaluation of the KE, hips remained in the angle 110° and the maximum torque was evaluated in the angle 70° of knee flexion (7). For the evaluation of the horizontal shoulder flexor, the maximum torque was evaluated at 30° horizontal shoulder flexion, seeking the highest torque values, according to the force × length relationship of these muscle groups (53). The joints evaluated were aligned with the axis of the dynamometer. Each maximal voluntary contraction (MVC) lasted for 3 seconds, with rest intervals of 1 minute between each one to avoid the effects of muscle fatigue.

Creatine Kinase Activity. We asked subjects not to exercise in the 48 hours before experimental session, as well as not to consume alcohol or caffeine for the previous 24 hours. At rest, samples of 5 ml of venous blood were taken from the antecubital region. At the end of the TS, a new blood sample was collected from 5 ml with the same procedures. The blood samples were stored under refrigeration until centrifugation (ALC International SRL–PK 120R, Italy). The serum samples were separated and kept frozen at −70° C (−85° freezer; NuAire, Plymouth, MN, USA) to be analyzed to verify the total CK activity in the automation equipment in biochemistry Modular P with enzymatic kit (Roche

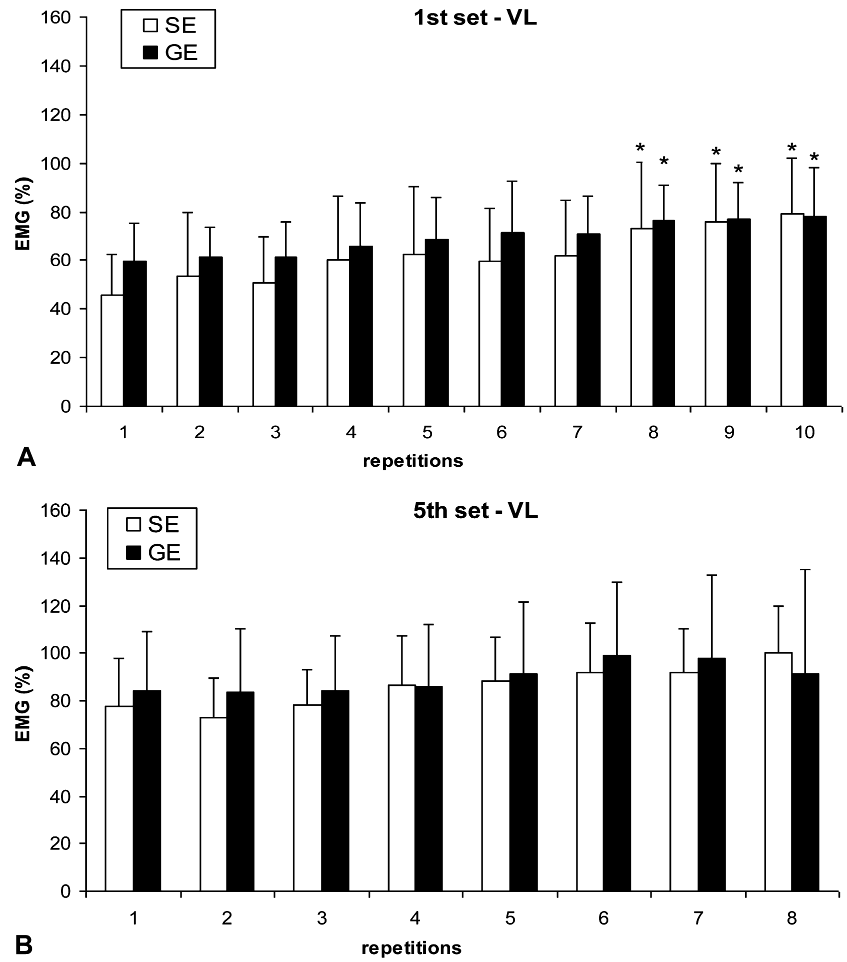

Figure 5. Mean and *SD*s of normalized electromyographic signal (%EMG) of the vastus lateralis (VL) during the first set (A) and fifth set (B) when performing grouped exercises (GE) and separated exercises (SE). There is no difference between GE and SE. *Difference from first repetition of first set ($p \leq 0.05$).

Diagnóstica, São Paulo, Brazil). The values listed in the post-exercise period were normalized by training presession resting values.

Delayed Onset Muscle Soreness. Delayed onset muscle soreness of the PM and quadriceps muscles was assessed by subjective perception using the CR10 Borg pain scale (5), ranging from 0 (absolutely nothing, no pain) to 10 (extremely strong, maximum pain). The scale was provided to each participant indicating the number corresponding to the level of pain of each muscle analyzed, after performing one repetition of knee flexion/extension and one repetition of shoulder horizontal flexion/extension.

Range of Motion. An analogical fleximeter (Sanny, São Paulo, Brazil) was used to measure the ROM of the shoulder joint (horizontal extension) and knee (flexion) of the exercised segments. The positioning of each individual has followed the instructions described by the manufacturer, and the joint amplitude values were obtained as described by Ahmadi et al. (1) *Shoulder*: each individual was supine on a stretcher with the knees bent and feet flat. Initially, the arms were raised with palms leaning against. The fleximeter was placed in the arm, above the elbow, with the display facing the examiner that was positioned above (anatomical position) the subject being evaluated. This point was considered the anatomical zero. From this position, the maximal passive shoulder horizontal extension was performed. *Knee*: in a stretcher, the subject was placed in the prone position so that the knees are suspended out of the stretcher. The fleximeter was positioned approximately on the lateral malleolus of the ankle, with the display facing the examiner. This point was considered as anatomical zero. From this position, the maximal passive knee flexion was performed. The ROM was considered as the difference between the extension/flexion and

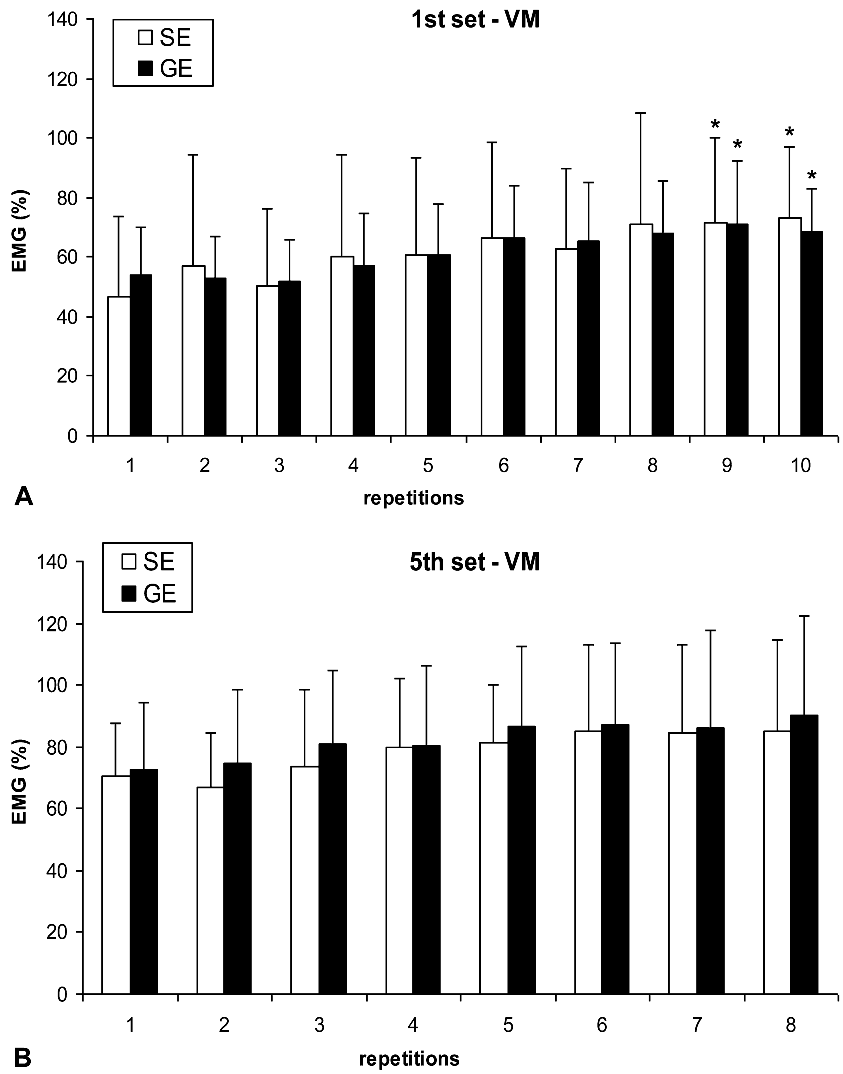

Figure 6. Mean and *SD*s of normalized electromyographic signal (%EMG) of the vastus medialis (VM) during the first set (A) and fifth set (B) when performing grouped exercises (GE) and separated exercises (SE). There is no difference between GE and SE. *Difference from first repetition of first set ($p \leq 0.05$).

horizontal flexion/horizontal extension of the knee and shoulder, respectively.

Electromyographic Signal

The EMG signal was obtained in the VL, VM, and RF (KE); PM and AD (horizontal shoulder flexors) on the first and the last set (fifth) of "peck deck" and "knee extension" in each session training, to verify a possible change of muscle activity from the beginning to the end of the TS. The EMG signal was collected in bipolar configuration, along the direction of the muscle fibers, through a 4-channel EMG (Miotool 400–Miotec) with the data acquisition program Miograph (version 1.31), and a notebook computer (AMD Turion64 2 × 1.6 GHz, 1 GB RAM, 128 MB of video). The acquisition of EMG curves had a sampling of 2,000 Hz (15).

Before data collection, the placement sites of surface electrodes (Noraxon 272; Noraxon, Scottsdale, AZ, USA) were prepared scraping the hair and cleaning by abrasion with cotton moistened with alcohol. The reference electrode (Meditrace 200; Tyco Healthcare Group LP, Mansfield, MA, USA) was placed on the tibial tuberosity or clavicle. The anatomical references to the positioning of the electrodes followed the recommendations proposed by Cogley et al. (13) for the PM muscle, Zipp (59) for the AD muscle, and Pincivero et al. (41) and Rabita et al. (43) for the VL, VM, and RF. The level of resistance between electrodes was measured, monitored, and maintained below 3,000 ohms (35), through checking performed by a multimeter.

After skin preparation and electrode placement, each subject was positioned in knee extension and peck deck

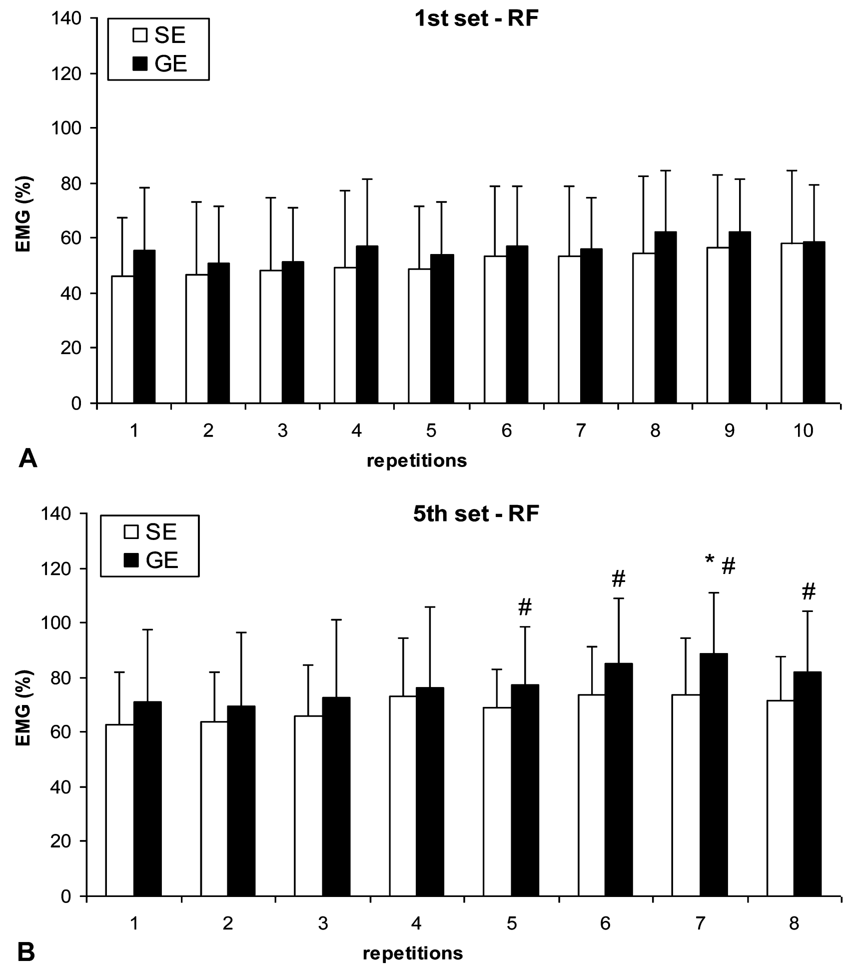

Figure 7. Mean and *SD*s of normalized electromyographic signal (%EMG) of the rectus femoris (RF) during the first set (A) and fifth set (B) when performing grouped exercises (GE) and separated exercises (SE). *Difference from first repetition of fifth set ($p \leq 0.05$). #Difference between GE and SE ($p \leq 0.05$).

machines, and performed an MVC (3 seconds), with each of the muscle groups of interest to normalize the EMG signal. The positioning in each exercise was based on force-length curves illustrated by Smith et al. (53) to put the muscle groups analyzed in a favorable length for greater force production.

Subsequently, the EMG signal was collected in the first and the fifth set of exercises, knee extension (VL, VM, and RF) and peck deck (PM and AD), during 8–10 repetitions. Only the concentric phase, identified with a displacement sensor (360 GN; Miotec, Porto Alegre, Brazil), was considered. Regardless of the TS performed (GE or SE), the exercises, knee extension and peck deck, were performed as the second and the fourth exercises, respectively.

After data collection, all files were analyzed in the data acquisition system SAD2 (32-bit version 2.61.05mp) as follows: (a) removal of continuum components, (b) filtering with filter type bandpass butterworth fifth order (20–500 Hz), (c) identification of the concentric phase of each repetition in the first and fifth set of exercises, (d) identification of the plateau of MVC, (e) calculation of the root mean square (RMS) at 1 second in each concentric phase of each repetition, excluding the start and the end of the muscle action, (f) calculating the RMS in 1 second during MVC of each muscle group, and (g) normalization of exercise RMS values by MVCs RMS values. The processes of "windowing" and quantification of EMG activity were similar to those used by Augustsson et al. (2) and Stoutenberg et al. (55).

Statistical Analyses

Data are expressed as mean and *SD*s. The normality and homogeneity were verified by Shapiro-Wilk and Levene tests, respectively. The reproducibility of measuring instruments was verified with the ICC and CV. Whenever normality assumptions were warranted, comparisons of numerical mean values between groups (total work, τ,

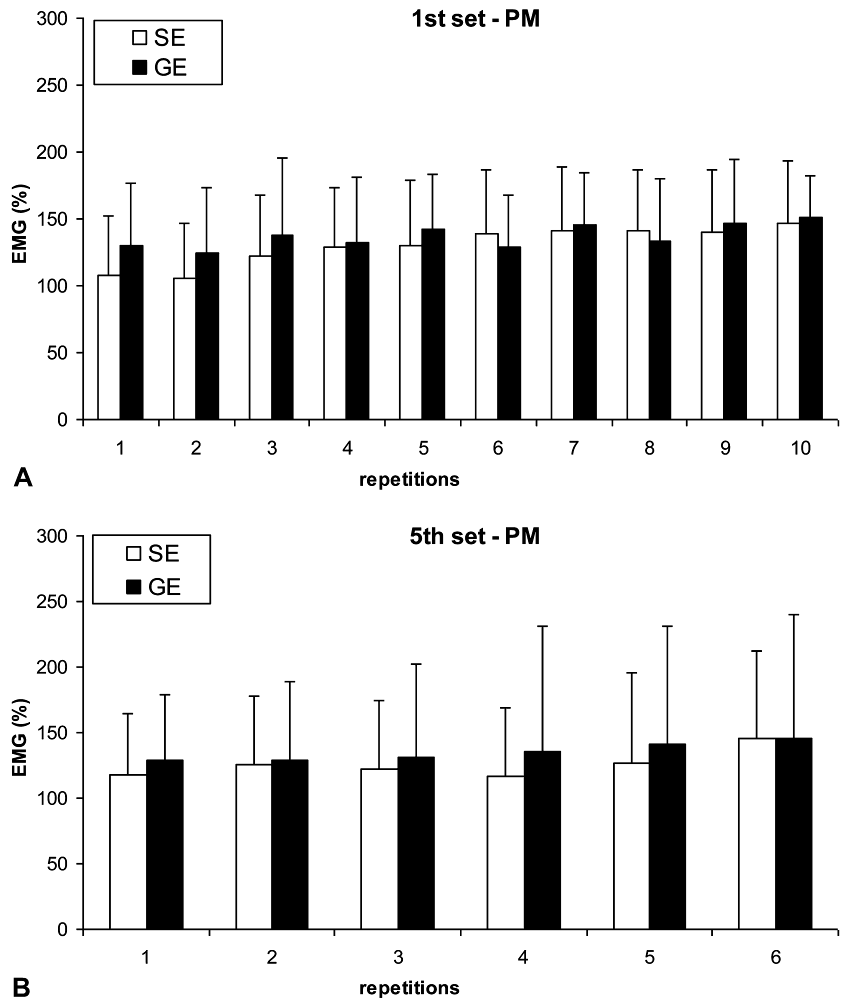

Figure 8. Mean and *SD*s of normalized electromyographic signal (%EMG) of the pectoralis major (PM) during the first set (A) and fifth set (B) when performing grouped exercises (GE) and separated exercises (SE). There is no difference between GE and SE.

ROM, DOMS, CK, and EMG) were made through an independent t-test. Intragroup differences were verified with 1-way analysis of variance for repeated measures, using the Bonferroni post hoc test as appropriate. For all analyses, statistical significance was considered whenever the alpha error was less than or equal to 5% ($p \leq 0.05$). Statistical procedures were conducted using software SPSS 18.0.

RESULTS

Twenty subjects completed the study, ten in each training group (SE and GE). One individual from each group was excluded because of the impossibility of using their EMG data. During the GE and SE sessions, groups did not differ in the total work (GE: 11,972.5 ± 2,158.94 kg × SE: 12,022.88 ± 1,812 kg) and session lengths (GE: 35min04seg ± 03min14seg × SE: 34min58seg ± 2min21seg).

Indirect Markers of Muscle Damage

Isometric Torque. Immediately after exercise in GE and SE groups, there was a decrease of torque both in the KE (GE: 18.9% × SE: 23.1%; $P \leq 0.05$) as in the SHF (GE: 23.9% × SE: 27.5%; $P \leq 0.05$). However, after one day, the values returned to pre-exercise levels in GE and SE. There was no difference between groups (Figure 1).

Creatine Kinase. There was an increase in CK activity post-exercise, ranging up to 632.4% of rest values in GE (P for time-effect GE = 0.013) and 330.5% in SE (P for time-effect SE = 0.045). The GE values were higher than SE 2–5 days after exercise ($P \leq 0.05$) and remained above the pre-exercise levels after 4 and 5 days for SE and GE, respectively (Figure 2).

Delayed Onset Muscle Soreness. There was an increase in the scores of DOMS in both KE (GE: 1.8 × SE: 1.1; $P \leq 0.05$)

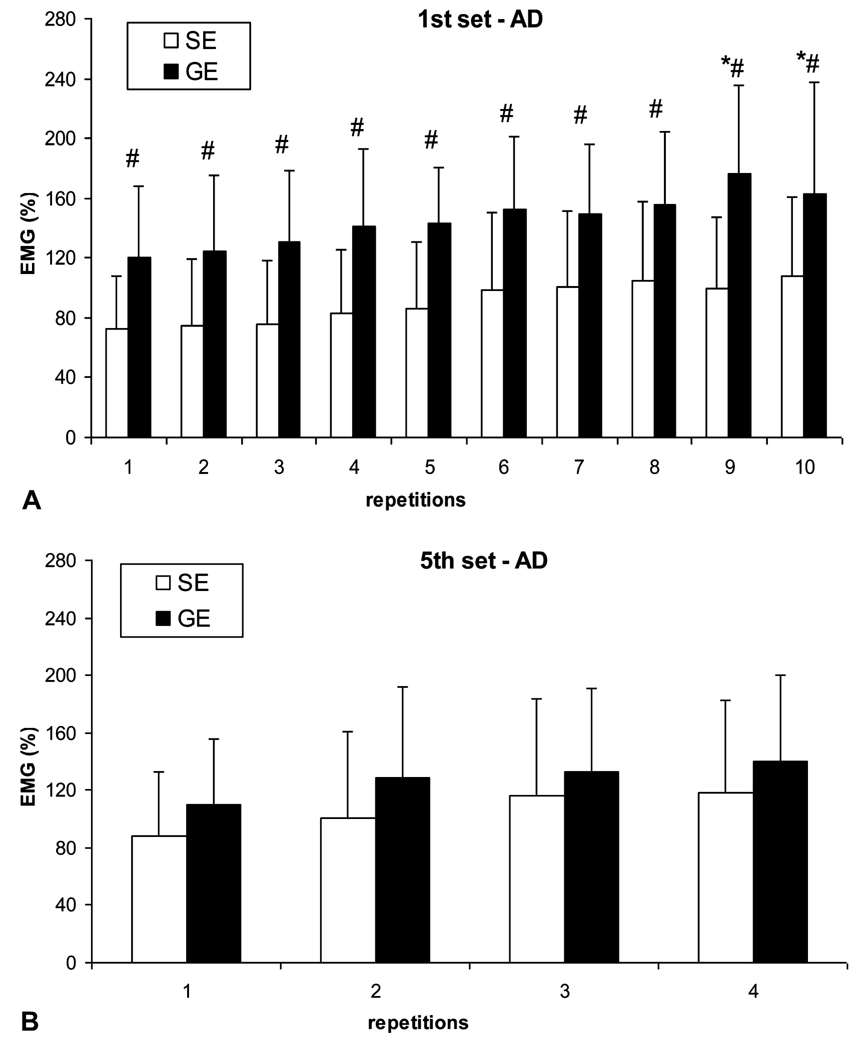

Figure 9. Mean and *SD*s of normalized electromyographic signal (%EMG) of the anterior deltoid (AD) during the first set (A) and fifth set (B) when performing grouped exercises (GE) and separated exercises (SE). *Difference from first repetition of first set ($p \leq 0.05$). #Difference between GE and SE ($p \leq 0.05$).

and the SHF (GE: 2.2 × SE: 1.7; $P \leq 0.05$). They remained above pre-exercise after 1–2 and 1–3 days for KE and SHF, respectively. There was no difference between groups (Figure 3).

Range of Motion. There was a decrease in ROM, both in KE (GE: 5.2% × SE: 5.2%; $P \leq 0.05$) and the SHF (GE: 6.3% × SE: 7.3%; $P \leq 0.05$). There was no difference between groups. However, when considering both joints, the ROM values remained bellow pre-exercise levels after 2–4 and 1–2 days for GE and SE, respectively (Figure 4).

Electromyographic Signal

There was an increase in muscle activity of VL and VM from the beginning to the end of the first set of knee extension exercises, in both GE and SE (Figures 5A and 6A). There was an increase of RF muscle activity from the beginning to the end of the fifth set of knee extension exercises, only in GE (Figure 7B). There was no change in the PM muscle activity that was observed (Figure 8). When compared with SE, there was a higher muscle activity in GE for RF (GE: 88.4% × SE: 73.6%; $P \leq 0.05$) and AD (GE: 176.4% × SE: 100.0%) in fifth and first sets, respectively (Figures 7B and 9A) and increased muscle activity of AD in the beginning to the end of the first set during the peck deck exercise (Figure 9A).

Discussion

The main findings of this study involve the larger increases in EMG activity of the muscles RF and DA, the larger increases in indirect marker of muscle damage CK in GE compared with SE, and the higher GE recovery period, observed in CK and ROM data. These results partially support our hypothesis because not all the muscle groups and indirect markers showed the same response.

Indirect markers of muscle damage: previous studies showed increases in indirect markers of muscle damage, after performing strength exercises (10–12,28). Although most studies suggest that mechanical load to the active muscle group in eccentric contractions is crucial to the highest degree of injury induced by ST, concentric contractions also show changes in these markers (3,22,37). Particularly in relation to CK, increasing its plasma levels is related to a threshold intensity (mechanical load) to promote rupture of the sarcolemma and Z lines of contractile units (sarcomeres) by increasing the membrane permeability transition and providing a substantial amount of CK for circulation by the lymphatic system (28).

In the exercises with free weights and conventional ST machines, in which the same load is used in concentric and eccentric phases of the exercise, when we consider the effect of time of rest between exercises for the same muscle group, few studies have addressed the indirect markers of muscle damage response, and the results are controversial (29,33,50). Mayhew et al. (33) showed that short rests (1 minute) between 10 sets (10 repetitions with 65% of 1RM) leg press promoted greater increase in CK compared with long intervals (3 minutes). Machado and Willardson (29), using the same rests, had similar results in the higher responsive subjects. However, Silva et al. (50) found no differences between short rest (30 seconds) and long rest (90 seconds) between 5 sets (85% 1RM until concentric failure) of "arm curls." In agreement with previous findings (29,33), our study shows that the degree of damage induced by a ST session can be influenced by the order in which the exercises are performed because GE had a higher increase in CK levels compared with SE. However, our study seems to be the first to assess the degree of muscle damage induced by super-sets of pre-exhaustion in ST; and our findings suggest a higher degree of muscle damage resulting from this training strategy.

In our study, we used an identical percentage of maximum effort for GE and SE, equaling the mechanical load in the 2 TS. Thus, one explanation for the difference in CK values could be related by higher muscle fatigue in GE, suggested by the increased muscle activity (EMG) in lower limbs and upper limbs. However, the role of fatigue in the muscle damage remains inconclusive.

It is important to point out that SE took 4 days for CK return to baseline levels, whereas in GE, after 5 days the CK values had not yet returned to resting levels. Similar results were observed in ROM (1–2 × 2–4 days), indicating that sessions with exercises grouped per body segment may require more days of recovery compared with SE. As seen earlier, shorter intervals are associated with increased muscle damage induced by exercise, especially considering the findings related to changes in CK (29,33).

However, successive sessions of ST with the same characteristics promote a "protective effect" that causes the lower response of indirect markers of muscle damage over time (30). In our study, we have only the acute response of one TS with super-sets. It is likely that, in subsequent sessions, the response of these markers was attenuated, as observed previously during 8 weeks of concentric or eccentric ST (37). Thus, it was inferred that the pre-exhaustion promotes greater muscle damage and recovery period, indefinitely; it is a statement with fragile support.

Muscle activity: the premise of using training systems to group exercises for the same muscle group is the greater recruitment of motor units, fatiguing the muscle group of interest (18). However, previous studies failed to show increased muscle activity in super-sets (2,6). Other findings suggest increased activity of the agonist muscle in supersets with moderate loads (24) or the accessory muscles (18). Augustsson et al. (2) found no increased muscle activity of the quadriceps to perform knee extension just before leg-press, when compared with leg-press, alone. Brennecke et al. (6) observed lower muscle activity of the triceps brachii in the pre-exhaustion model, compared with traditional exercises. These authors suggest that when muscle group is under fatigue, other muscle groups would be recruited (accessories). Thus, the traditional pre-exhaustion model would not be indicated. From the results of Augustsson et al. (2) and Brennecke et al. (6), the superset used in GE of our study was different; putting the exercises to the largest muscle group immediately before exercise for muscle group of interest (leg-press × knee extension and bench press × peck deck) may have induced the increased muscle activity. Junior et al. (24) added that moderate loads optimize the effect of the pre-exhaustion because of the low inhibitory effect that higher loads would provide in the traditional model. However, we used loads equivalent to 85%–90% 10RM which are considered high loads. Therefore, the mechanism suggested by Junior et al., (24) cannot be used as a justification to our results.

Previous studies have also evaluated the effect of the exercises order on the total work of the TS (44,48,49). Sforzo and Touey (49) showed that the exercises performed earlier in the session are less influenced by muscle fatigue, as compared with those exercises performed toward the end of the session, independently of multijoint or single-joint exercises. However, their training model did not involve super-sets. Recently, it was suggested that pre-exhaustion supersets where single-joint exercises are performed before multijoint exercises allow the performing of a higher total work with lower limbs (48) and with upper limbs (44). Regardless of exercises order, our findings showed the same total work, therefore confirming the results of Sforzo and Touey (49). One possibility for the discrepancy with previous studies involving supersets is that our session involved both lower and upper limbs and this may have increased the session effort level as a whole, compared with independent sessions, as proposed by Salles et al. (48) and Ribeiro et al. (44).

There are some limitations in our study. Increasing the amplitude of the EMG signal indicates increased muscle activity; however, does not show the degree of fatigue induced in both groups analyzed (GE and SE). A fatigue protocol, considering the time domain and the frequency domain, would show more clearly the intensity of each workout session. Furthermore, the direct analysis of muscle damage could provide more consistent information about the damage response and recovery time resulting from pre-exhaustion during ST.

In summary, our findings suggest that, in physically active men, implementing the supersets with GE can promote greater muscle activity of the upper limbs and lower limbs. Super-sets promote a long period recovery of muscle (more than 5 days) and possibly higher degree of muscle damage. Therefore, sessions with this training model should be administered with caution to promote the proper recovery of trained muscle groups.

Practical Applications

Our findings suggest that training with super-sets of pre-exhaustion in the early sessions deserves greater attention in relation to the interval between sessions. The increased muscle activity and the higher number of days that some indirect markers of muscle damage remained above baseline levels suggest that training with pre-exhaustion demands greater effort and greater recovery period than other models with longer intervals between exercises for same muscle group.

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