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Effects of eccentric-focused and conventional resistance training on strength and functional capacity of older adults

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Abstract The aim of the study was to assess the effect of eccentric training using a constant load with longer exposure time at the eccentric phase on knee extensor muscle strength and functional capacity of elderly subjects in comparison with a conventional resistance training program. Twenty-six healthy elderly women (age= 67±6 years) were randomly assigned to an eccentric-focused training group (ETG; n=13) or a conventional training group (CTG; n=13). Subjects underwent 12 weeks of resistance training twice a week. For the ETG, concentric and eccentric phases were performed using 1.5 and 4.5 s, respectively, while for CTG, each phase lasted 1.5 s. Maximum dynamic strength was assessed by the one-repetition maximum (1RM) test in the leg press and knee extension exercises, and for functional capacity, subjects performed specific tests (6-m walk test, timed up-and-go test, stair-climbing test, and chair-rising test). Both groups improved knee extension 1RM (24–26 %; p=0.021), timed up-and-go test (11–16 %; p<0.001), 6-m walk test (9–12 %; p=0.004), stair-climbing test (8–13 %; p=0.007), and chair-rising test (15–16 %; p<0.001), but there was no significant difference between groups. In conclusion, the strategy of increasing the exposure time at the eccentric phase of movement using the same training volume and intensity does not promote different adaptations in strength or functional capacity compared to conventional resistance training in elderly woman.

Keywords Strength training · One-repetition maximum (1RM) · Functional performance · Elderly woman

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Introduction

Aging is accompanied by a series of deleterious effects on the musculoskeletal system, such as the loss of muscle mass, reduced motor units' activation, and decline in maximal strength, muscle resistance, and power (Aagaard et al. 2010). These intrinsic muscle changes have functional implications, impairing elderly's ability to perform daily activities like lifting, sitting, and dressing (Rice and Keogh 2009; Macaluso and De Vito 2004). Since the time course of changes is directly affected by life style, mainly the physical activity level (DiPietro 2001), scientists and clinicians have focused their attention to find effective methods of exercise to prevent and/or revert the undesirable effects of aging on musculoskeletal system and functional capacity (e.g., aerobic/endurance training, strength/resistance training, and concurrent training).

Resistance training is characterized by the systematic execution of voluntary muscular contractions against external loads (ACSM 2009). Although this type of training is most commonly performed through exercises combining concentric and eccentric muscle actions (sometimes called conventional resistance training), training regimes can be executed with exclusivity or emphasis in one type of muscle action (Wernbom et al. 2007). Among the three types of contractions, the eccentric contractions induce more damages to muscles and produces a greater muscle force compared with concentric and isometric types of contraction (Westing et al. 1991). Accordingly, eccentric training has been supported as an efficient method for muscle strengthening and increased functional capacity in healthy young people (Schroeder et al. 2004), athletes (Friedmann-Bette et al. 2010), injured subjects (Lastayo et al. 2003), and elderly (Purtsi et al. 2012; Raj et al. 2012; MuellerM et al. 2011; Mueller et al. 2009; Reeves et al. 2009; Melo et al. 2008; Onambele et al. 2008; Symons et al. 2005; Valour et al. 2004; Lastayo et al. 2003).

Eccentric training programs have been traditionally performed in isokinetic or isotonic conditions (for review, see Guilhem et al. 2010). Although isokinetic dynamometers are considered an efficient and safe method for strength training, the high cost makes this equipment away from the current practice of professionals in most health centers, highlighting the significance of studies assessing the eccentric training programs in isotonic conditions. Therefore, three different approaches have been used to apply the isotonic eccentric training in elderly: (1) manual support from the researcher during the concentric phase, while the subject concentrates only on the eccentric phase (Reeves et al. 2009; Valour et al. 2004); (2) execution of the concentric phase bilaterally and the eccentric phase with only one limb (Raj et al. 2012); or (3) use of a specific equipment for eccentric exercises, such as eccentric cycle ergometers (Purtsi et al. 2012; Mueller et al. 2009, 2011; Lastayo et al. 2003) and inertial flywheel devices (Onambele et al. 2008).

The execution of eccentric exercises with support during the concentric phase (Reeves et al. 2009) is limited to the need for a researcher/clinician sufficiently strong to manually lift the load, which it is not easy for some lower limb exercises (e.g., leg press or knee extension machines). In addition, the execution of the eccentric phase unilaterally (Raj et al. 2012) may be uncomfortable for some subjects, and eccentric cycle ergometers (Purtsi et al. 2012; Mueller et al. 2009, 2011; Lastayo et al. 2003) and inertial flywheel devices (Onambele et al. 2008) are not widespread in health centers. Therefore, innovative approaches to eccentric training in isotonic conditions are needed.

The execution of the eccentric phase with longer duration than the concentric phase, as proposed by Schoenfeld (2010), seems an interesting strategy for eccentric training because it mitigates the need for assistance and for the use of special devices, but we were unable to find studies assessing this training method. Therefore, the aim of this study was to evaluate the effect of an eccentric-focused training, using a constant load and longer exposure time at the eccentric phase, on the knee extensor muscle maximal strength and functional capacity of elderly subjects, and compare this training regime with a conventional resistance training program.

Methods

Subjects

Sample size was determined using a statistics software (G*Power version 3.0.10) and was based on a power of the test of 90 %, and statistical significance level was set at 5 %. Thus, the estimated sample size for our study was 20 participants (assigned in each group in even proportion, i.e., 10 per group). In order to anticipate for potential drop outs, the study started with more subjects.

Twenty-six healthy elderly women (mean ± SD 67± 6 years) who have not been engaged in any regular or systematic training program in the previous 12 months volunteered for the study after completing an informed consent. Subjects were carefully informed about the design of the study with special information on the possible risks and discomfort related to the procedures. Subsequently, subjects were randomly assigned by drawing lots in two groups: eccentric-focused training group (ETG, n=13) who performed a resistance training program with longer duration at the eccentric phase of movement and conventional training group (CTG, n=13) who performed a conventional resistance training program with balanced time of execution between concentric and eccentric phases. The study was approved by the Ethics Committee of Faculty of Serra Gaúcha (Círculo-FSG, no. 68257), Rio Grande do Sul, Brazil.

Experimental design

Before starting the training program, subjects completed two familiarization sessions with their respective training method: eccentric-focused or conventional. During these sessions, they were familiarized with the equipment and the angular velocity of each exercise. Thereafter, subjects underwent 12 weeks of resistance training twice a week. In each session, subjects performed specific muscle stretching and a specific warm up with very light loads for the upper and lower body lasting 10 min. The training was composed of the following exercise sequence: leg press, seated row, knee extension, bench press (Ajustmaq, 1 kg resolution), and abdominal exercises. The rest interval between sets ranged from 2 to 3 min. Specific muscle stretching was performed at the end of each session.

For the ETG, concentric and eccentric phases were performed using 1.5 and 4.5 s, respectively. For CTG, a conventional angular velocity of execution was enforced, i.e., 1.5 s for the concentric phase and 1.5 s for the eccentric phase. The rhythm was monitored using a metronome with audible feedback. Exercises for the upper limbs were performed with conventional timing between the concentric and eccentric phases in both groups in order to provide a complete training for the subjects. For both groups, every 2 weeks, the Borg's rating of perceived exertion (RPE) scale with values from 13 to 18 was used for upper limb load adjustment (Tiggemann et al. 2010). For the lower limbs, load was adjusted by the percentage of the baseline one-repetition maximum (1RM) (Brown and Weir 2001). The resistance training load was conducted according to American College of Sports Medicine (Garber et al. 2011). During weeks 1 and 2, subjects performed two sets of 12 repetitions with 45 % of pre-training 1RM, increasing their load to 50 % of pre-training 1RM with the same training volume in weeks 3 and 4. In weeks 5 and 6, subjects performed two sets of 10 repetitions with 55 % of pre-training 1RM, progressing to 60 % of pre-training 1RM in weeks 7 and 8. In weeks 9 and 10, subjects performed three sets of eight repetitions with 65 % of pre-training 1RM, advancing to 70 % of pre-training 1RM in weeks 11 and 12. The evaluation protocols (strength and functional capacity) were performed before the training (test and re-test with a 1-week interval) and after 6 and 12 weeks of training.

Maximal dynamic strength

Maximum dynamic strength measurement followed the guidelines proposed by Brown and Weir (2001) and was performed by the 1RM test in the leg press and knee extension exercises. One week prior to the pre-training test session, subjects were familiarized with all procedures in two sessions (Levinger et al. 2009). On the testing session, subjects performed muscle stretching and a warm up with specific movements for the exercise test. Each subject's maximal load was determined with no more than five attempts with a 4-min recovery between attempts.

Functional capacity

Subjects performed a battery of four functional tests based on daily activities. All subjects received instructions about test procedures and were familiarized to each test. All functional tests were performed with continuous verbal encouragement by the researchers. They are described below:

6-m walk test The test involved walking for 6 m at full speed. On the ground, there were four marks: one located 3 m away from the start of timing (called point −3) at point 0 being the start of timing, in section 6 at the end of timing (with a distance of 6 m between the point 0 and point 6), and finally at the end of the walk (point 9) 3 m of the end of timing. There were two attempts with a resting time of 3 min between them, computing the fastest performance time (Cuoco et al. 2004; Kalapotharakos et al. 2005).

Timed up-and-go test Subjects started the test sitting on a chair with 43 cm of height, with back support. They should rise (without using their hands), travel a distance of 2.43 m, turn around a cone positioned at the end of the route, return, and sit down again at the chair (leaning back and not using their hands as support). There were two attempts with 3 min of resting time, recording the fastest time for completing the test (Hanson et al. 2009; Serra-Rexach et al. 2011).

Stair-climbing test The test consisted on climbing eight steps without using the handrail. Each step had 17 cm of height and 31 cm of length, requiring a step by step pattern, where the timer was activated when the first contact was made at the first step and ended when the contact occurred at the last step. Two trials were conducted with 3 min of rest between them, recording the fastest performance time (Galvão and Taaffee 2005; Seynnes et al. 2004).

Chair-rising test Subjects should get up and sit from a chair with 43 cm of height and flat seat. They should perform five repetitions, where the test started (while subjects were seated) and finished after the fifth repetition. During testing, subjects kept their arms crossed over their chest, raised until full extension was observed at trunk and lower limb joints, and return with their back fully supported at the back of the chair. Two trials with 3 min of rest between each were conducted, and the fastest performance time was recorded (Henwood and Taaffe 2005; Galvão and Taaffee 2005).

Statistical analysis

Shapiro-Wilk and Levene tests were used for verification of data normality and homogeneity, respectively. A two-way ANOVA [group (ETG × CTG) vs. time (baseline vs. post-6 vs. post-12)], followed by a LSD post hoc test, was used to compare absolute values of leg press 1RM, knee extension 1RM, timed up-and-go test, stair-climbing test, 6-m walk test, and chair-rising test. Percent changes between baseline and post-12 evaluations were compared between ETG and CTG through independent sample *t* tests. All statistical analyses were conducted using a statistical package (SPSS 17.0, Chicago, USA) using a significance level of $p<0.05$.

Results

Throughout the 12-week resistance training program, seven volunteers dropped out for personal reasons (i.e., four from ETG and three from CTG). Therefore, statistical analysis was performed with nine elderly at the ETG (65.6±5.6 years old, 70.3±9.8 kg, 156.9±4.5 cm), and 10 at the CTG (67.8±6.5 years old, 67.5±13.6 kg, 158.8±7.1 cm). There were no significant differences between groups for age ($p=0.433$), body mass ($p=0.615$), or height ($p=0.515$).

The two-way ANOVA test indicated no significant group-time interaction ($p>0.05$ for all variables). No group effect was observed ($p>0.05$), while time effect was verified for knee extension 1RM ($p=0.021$), timed up-and-go test ($p<0.001$), 6-m walk test ($p=0.004$), stair-climbing test ($p=0.007$), and chair-rising test ($p<0.001$) for both groups.

Six weeks of training was sufficient for reaching significant improvements in knee extension 1RM (Fig. 1), as well as timed up-and-go, 6-m walk, and chair-rising tests (Fig. 2) for the assessed subjects. No further increases were observed in these parameters between the sixth and the twelfth training weeks (Figs. 1 and 2). Subjects had significant improvements in stair-climbing test only after 12 weeks of training (Fig. 2), while leg press 1RM did not change significantly throughout the study (Fig. 1). Percent change values from baseline to post-12 evaluations were similar ($p>0.05$) between ETG and CTG for all variables assessed in this study (Table 1).

Discussion

The aim of this study was to verify if increased exposure time at the eccentric phase during a resistance training program in older adults would result in larger gains in strength and functional capacity compared to conventional resistance training. Although both training regimes led to improvements in elderly's conditioning, no significant differences were observed between ETG and CTG.

We observed improvements in knee extension muscle strength and in three of the four functional performance

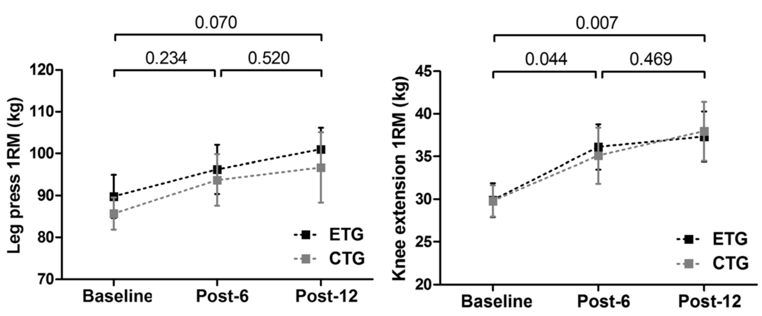

Fig. 1 Absolute values (mean ± SEM) of 1RM test in leg press and knee extension from eccentric training group (ETG) and conventional training group (CTG) throughout the study

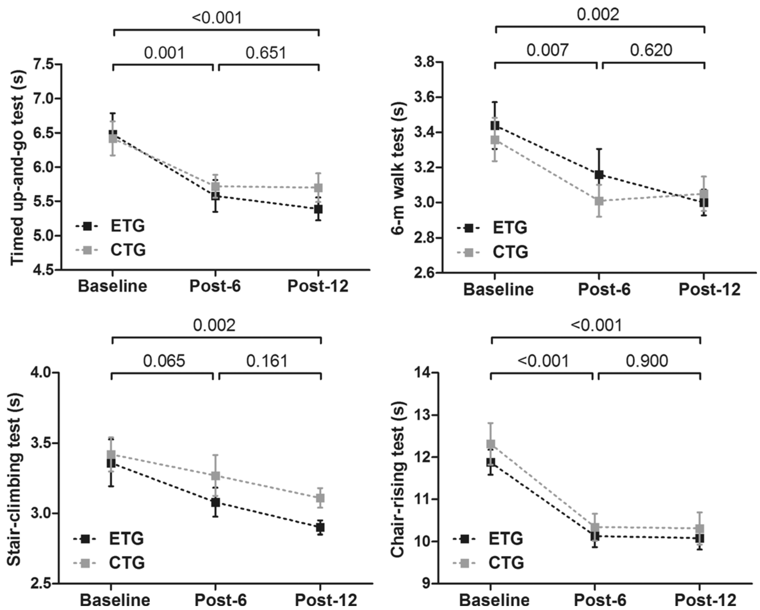

Fig. 2 Absolute values (mean ± SEM) of timed up-and-go, 6-m walk, stair-climbing, and chair-rising tests from eccentric training group (ETG) and conventional training group (CTG) throughout the study

tests for both groups after 6 weeks of training, but no additional effects were found after 12 training weeks. This early improvement response is mainly attributed to neural adaptations, such as increased motor unit recruitment and reduced co-activation (Cadore et al. 2012). Studies have shown a fast increase in maximum strength after a few weeks of training, followed by a stabilization of the strength gains (Cadore et al. 2012; Häkkinen and Pakarinen 1994; Hickson et al. 1994). This study did not investigate the mechanisms responsible for the time course of muscle adaptations in each group, but our findings suggest that few weeks of conventional or eccentric-focused training are equally able to significantly change elderly's strength. With regards to functional capacity, Pinto et al. (2013) also found that 6 weeks of conventional training are sufficient to promote improvements in both chair-rising and timed up-and-go tests, agreeing with findings from our study.

Table 1 Percent changes (mean ± SD) from baseline to post-12 in eccentric training group (ETG) and conventional training group (CTG)

	ETG (Δ%)	CTG (Δ%)	*p* Value
Leg press 1RM	13.35±12.42	12.19±22.97	0.892
Knee extension 1RM	24.17±9.67	25.96±22.05	0.820
TUG test	−15.89±8.82	−11.02±4.60	0.165
6-m walk test	−11.83±9.40	−8.54±10.65	0.484
Stair-climbing test	−12.60±9.27	−8.19±10.74	0.349
Chair-rising test	−15.02±5.95	−15.99±7.47	0.756

The strength and functionality baseline values found in this study are similar to those in previous studies to 1RM knee extension (Peiffer et al. 2010) and leg press (Hanson et al. 2009), TUG (Hanson et al. 2009), and chair-rising test (Peiffer et al. 2010; Tiedemann et al. 2008). Only in stair-climbing test the subjects of our study had a shorter time to perform the test compared to baseline values of other studies (Peiffer et al. 2010; Hanson et al. 2009; Tiedemann et al. 2008). However, part of the difference may be associated with the equipment and protocols used. Previous studies involving eccentric training in older adults found increments in maximal strength tests ranging between 8 and 60 % (Raj et al. 2012; Reeves et al. 2009; Mueller et al. 2009; Melo et al. 2008; Onambele et al. 2008; Valour et al. 2004; Lastayo et al. 2003), as well as improvements in functional tests: 5–55 % in stair-climbing (Raj et al. 2012; Gür et al. 2002), 4–21 % in stair descent (Raj et al. 2012; Lastayo et al. 2003), 5–29 % in timed up and go (Raj et al. 2012; Mueller et al. 2009; Lastayo et al. 2003), 7 % in step time (Symons et al. 2005), and 23 % in chair-rising (Gür et al. 2002). Taken together, these evidence suggest that improvements in conditioning could be reached with eccentric training in elderly, independent of training regimes including isokinetic dynamometers (Symons et al. 2005; Melo et al. 2008), conventional gym machines (Reeves et al. 2009; Valour et al. 2004;

Raj et al. 2012), eccentric cycle ergometers (Purtsi et al. 2012; Mueller et al. 2009; Lastayo et al. 2003), or inertial flywheel devices (Onambele et al. 2008).

A meta-analysis study conducted by Roig et al. (2009) showed that gains in strength and muscle mass in healthy adults aged 18–65 years are higher in exclusively eccentric compared to exclusively concentric training programs. However, Symons et al. (2005) was the only showing that, in elderly subjects, the eccentric isokinetic training group did not demonstrate gains in voluntary strength superior to those of the isometric and concentric groups. In addition, looking for studies comparing eccentric and conventional resistance training, we found only two studies and their results are controversial (Reeves et al. 2009; Raj et al. 2012). Reeves et al. (2009) found that eccentric torque increased significantly for the eccentric training group, but not for the conventional group, while concentric torque increased significantly for the conventional group, but not for the eccentric group. On the other hand, Raj et al. (2012) observed no significant difference between training regimes for most of the maximal strength tests.

Differences in resistance training methods should be taken into account for an appropriate interpretation and comparison of findings. In Reeves' study, conventional and eccentric training groups trained with loads correspondent to 80 % of the conventional or eccentric five-repetition maximum (5RM), respectively. In Raj et al.'s study, the so-called eccentrically biased training involved concentric lifts at 50 % of 1RM with the eccentric portion of repetitions performed unilaterally, alternating between limbs with each repetition, while conventional training involved exercises at 75 % of 1RM. Therefore, the training method used in our study is different from those used by these previous studies (Reeves et al. 2009; Raj et al. 2012), but our results corroborate those reported by the Raj et al.'s study regarding the absence of difference between enhanced-eccentric and conventional training on maximal strength tested by 1RM test.

It is important to note that we matched the progression of the training intensity between groups by the results of the 1RM test performed at the baseline evaluation. Therefore, the load used by the conventional and the eccentric-focused training groups was the same throughout the training program. Additionally, concentric phase of movement was equally performed by volunteers of each experimental group (1.5 s); thus, the only difference occurred in the exposure time to eccentric contraction: 1.5 s for conventional group and 4.5 s for eccentric group. Therefore, since 1RM test is a measure of maximal concentric strength, not a maximal eccentric strength, it seems reasonable that two groups trained with the same stimulus (load and velocity) at the concentric phase of movement, leading to similar strength gains. Following that, it was expected that the larger exposure time at eccentric muscle actions would promote more prominent gains in eccentric strength capacity. Unfortunately, an isokinetic dynamometer was not available to test subjects' maximal eccentric capacity in our laboratory, as used by Reeves et al. (2009), for example, and the eccentric 1RM did not appear to be a reliable test in our pilot studies. Therefore, we had no isolated measurements of eccentric strength capacity in this study, and possible differences between groups at this variable remain unclear.

The functional tests used in this study are closely related with muscle power (e.g., timed up-and-go test, stair-climbing test, 6-m walk test, and chair-rising test). These specific muscular responses were not trained in eccentric-focused or conventional training groups, so the improvements at the functional tests further support the training transfer, which means that the extent to which a response in one task or trained situation affects the response in another task or untrained situation (Issurin 2013). For the elderly population, functional capacity seems to be more important than maximal (concentric or eccentric) strength, and scientists and clinicians have a frequent concern in proposing really efficient and applicable training programs to improve functional status in this population. Unfortunately, our results further support previous studies (Gault et al. 2012; Symons et al. 2005) suggesting that eccentric training programs have no additional effects on functional performance of elderly. However, for many tasks that involve a high risk of falls, the majority of the work is performed eccentrically, like stairs descent. Therefore, further assessment of eccentric priority tasks (e.g., stairs descent) should highlight the potential benefits from the training conducted by the eccentric training group. Furthermore, functional tests were performed at maximum speed making it difficult to identify differences between groups. For balance tests, we expect that the eccentric training group could present better performance because balance generally involves rapid responses from muscle spindles and other proprioceptors to a sudden increase in length of muscles (Ellaway et al. 2015) which is similar to observed during eccentric loading (Brockett et al. 2001).

A review by Gault and Willems (2013) suggested that eccentric exercise has been investigated by the possibility of applying larger mechanical load with a low metabolic demand in elderly adults, with or without clinical conditions, to improve quality of life. These characteristics of eccentric training were evident in Reeves et al. (2009) study, where subjects from the eccentric training group used loads ~50 % higher and presented lower levels of perceived exertion. On the other hand, our study used the same load for both training groups, while training groups from Raj et al. (2012) were matched for total work. Interestingly, Reeves et al. (2009) found advantages at the eccentric training program, while we and Raj et al. (2012) observed no differences for most of the strength and functional tests. Therefore, we believe that the higher loads supported during eccentric compared to concentric contractions may be the key factor to the benefits of eccentric training. Since we used intensities of 50–70 % of baseline 1RM (a concentric test), maximal eccentric capacity from our volunteers throughout the training program was underestimated, and the higher exposure time to eccentric phase of movement did not represent a sufficient stimulus to generate additional adaptations in strength or functional tests.

Although we found no differences between training groups, it is important to inform that ETG subjects reported muscle pain and discomfort more often. This factor suggests that the strategy to increase the duration of eccentric loading has the potential to increase muscle damage even when load is kept constant. Possibly, repeated ECC contractions prevent re-integration of actin and myosin and result in a reduced ability of the sarcoplasmic reticulum to open their Ca^{2+} release channels leading to greater muscle damage (Gault and Willems 2013).

The test used to assess the maximum force (1RM) was possibly the main limitation from this study, since it did not evaluate eccentric force. Additionally, a load progression based on the pre-training 1RM tests could have been different, since the basic principle of progressive resistance exercise is to periodically adjust the resistance based on an individual's strength at that time. We believe that this progression method may have impaired maximal strength gains in the eccentric-focused training group. Further research is needed to determine if a longer training (more than 12 weeks) and/or higher load increments could help to find differences between eccentric and conventional training. In addition, incorporating these factors with an isokinetic evaluation should be investigated.

Conclusion

We conclude that using the same volume and intensity of training, eccentric-focused training through the strategy of increasing the exposure time at the eccentric phase of movement does not promote additional adaptations in strength and functional capacity compared to conventional resistance training.

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