Resistance Training Performed With Single and Multiple Sets Induces Similar Improvements in Muscular Strength, Muscle Mass, Muscle Quality, and IGF-1 in Older Women: A Randomized Controlled Trial

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Abstract

Cunha PM, Nunes JP, Tomeleri CM, Nascimento MA, Schoenfeld BJ, Antunes M, Gobbo LA, Teixeira D, and Cyrino ES. Resistance training performed with single and multiple sets induces similar improvements in muscular strength, muscle mass, muscle quality, and IGF-1 in older women: A randomized controlled trial. *J Strength Cond Res* XX(X): 000–000, 2018—The purpose of this study was to compare the effects between single set vs. multiple sets of resistance training (RT) on measures of muscular strength, muscle mass, muscle quality (MQ), and insulin-like growth factor 1 (IGF-1) in untrained healthy older women. Sixty-two older women were randomly assigned to 1 of the 3 groups: single-set RT (SS, $n = 21$), multiple-sets RT (MS, $n = 20$), or nontraining control (CG, $n = 21$). Both training groups performed RT for 12 weeks, using 8 exercises of 10–15 repetitions maximum for each exercise. The SS group performed only 1 set per exercise, whereas MS performed 3 sets. Anthropometry, muscle strength (1RM tests), lean soft tissue (LST), and MQ from upper limbs (UL) and lower limbs (LL), and IGF-1 were measured before and after training. Both training groups showed significant pre-training to post-training increases for UL1RM (SS: 37.1%, MS: 27.3%, CG: −3.0%), LL1RM (SS: 16.3%, MS: 21.7%, CG: −0.7%), ULLST (SS: 7.8%, MS: 8.8%, CG: −1.1%), LLLST (SS: 5.6%, MS: 6.3%, CG: −0.8%), upper-limb muscle quality (SS: 25.2%, MS: 16.7%, CG: −0.2%), lower-limb muscle quality (SS: 10.5%, MS: 15.4%, CG: −3.5%), and IGF-1 (SS: +7.1%, MS: +10.1%, CG: −2.2%). We conclude that both SS and MS produce similar increases in muscular strength, LST, and MQ of upper and lower limbs, and IGF-1 after 12 weeks of RT in untrained older women. Our results suggest that, in the early stages, the RT regardless number of sets is effective for improving muscular outcomes in this population.

Key Words aging, weight training, training volume, muscle strength

Introduction

Aging is a natural and irreversible process characterized by morphofunctional modifications, such as loss of skeletal muscle mass and strength (13,17,18,40). Reduced levels of these components are associated with a lower functional capacity, diminished performance in activities of daily living and aerobic capacity, decrease in indicators of health, greater risk of falls and fractures, metabolic decline, fat gain, and, consequently, increased risk of mortality (13,17,18,40). Aging is also associated with a decrease in anabolic hormonal concentrations, such as insulin-like growth factor (IGF-1) (17,36), which favors a catabolic state and impairs growth and remodeling of muscle tissue. To mitigate these muscle function deficits and consequences related to aging, the engagement in exercise and physical activity programs has been deemed beneficial (1). Specifically, recommendations have focused on resistance training (RT), which has proven to be a safe and effective modality for improving strength, hypertrophy, and health-related parameters in older adults (1,15,40).

In general, there is a dose-response relationship between exercise volume and gains in muscle strength and mass.

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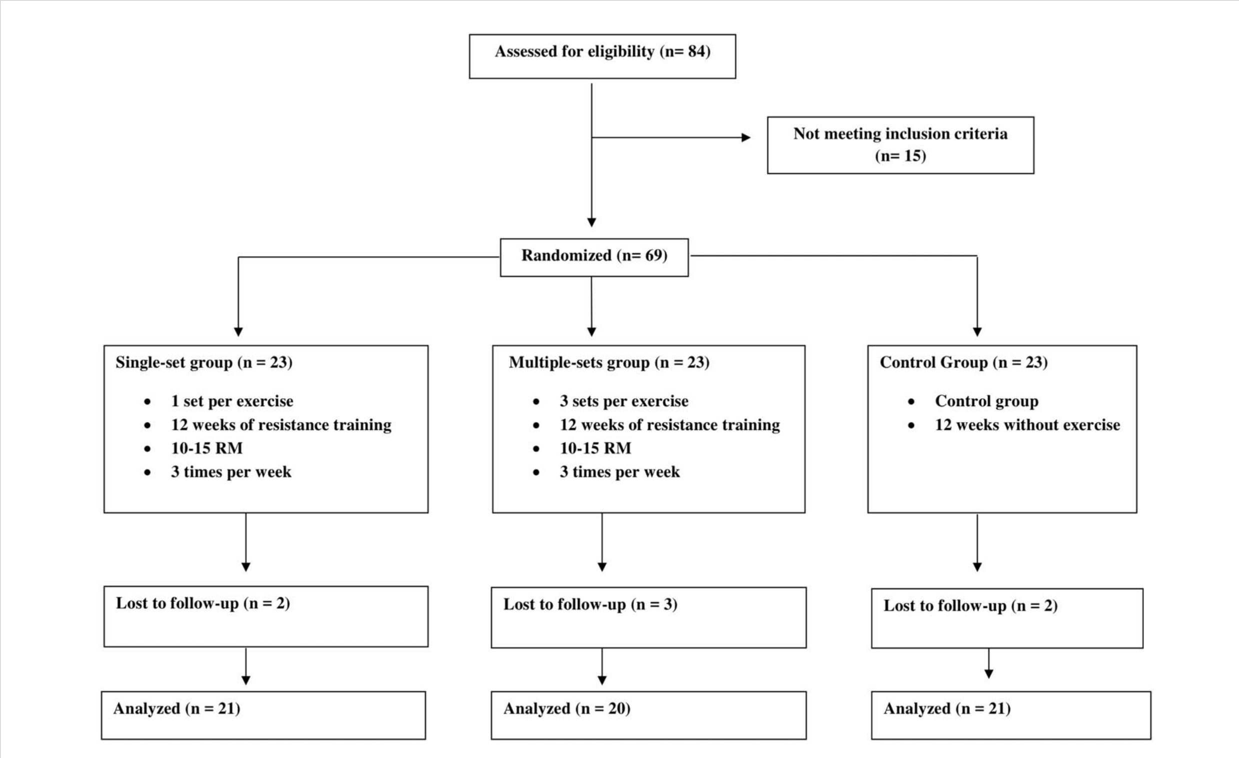

Figure 1. Flowchart of the study.

However, although it is suggested that older adults perform RT with multiple sets (MS) rather than with single sets (SS) (1), current evidence on the topic indicates the data are insufficient to draw firm conclusions (3,27,31,35). Studies directly comparing SS and MS have shown conflicting results: Some demonstrate superiority of higher volumes (16,24,29), whereas others show no statistically significant differences between conditions (6,25,26). The crucial point may be the duration of the investigations, where significant differences between SS and MS manifest over longer periods (24). The wide differences in manipulation of RT ancillary variables (e.g., weekly frequency, number of repetitions, exercise selection, etc.) between studies also are a confounding factor. Thus, additional studies on the topic are warranted.

From a health and fitness standpoint, the muscle quality (MQ), that is, the ratio between muscular strength and muscle mass (14,15), may provide valid information of RT-related adaptations and a more relevant indicator of muscle health than the variables separately (14,15). This ratio provides a validated index of muscle functionality (i.e., the capacity to produce functional movement) and is also an indicative of general state of health in older adults (15). Nonetheless, the literature about dose-response of RT on promoting changes in MQ is recent and scarce. Similarly, there is a lack of study regarding the dose-response of RT and its effect on IGF-1.

Given that training volume influences session duration, analyzing the effect of different RT volumes is important from a practical standpoint since a lack of time has been reported as a barrier to adherence to exercise programs in the elderly (2,34). Reduced training volumes would provide an attractive alternative to multiset protocols provided that the lower dose produces significant and meaningful effects in this population. Therefore, the purpose of this study was to compare the effects between SS and MS in muscle strength, muscle mass, MQ, and IGF-1 in untrained older women. We hypothesized that a higher volume of RT would be superior to a lower volume approach for improving the variables studied.

Methods

Experimental Approach to the Problem

The total duration of the study was 16 weeks, in which first 2 weeks (1–2 weeks) were used for familiarization with the RT program exercises, and pretraining measures, and the last 2 weeks (weeks 15–16) were dedicated to post-training measures. The intervention period lasted 12 weeks (weeks 3–14). The participants selected for this study were randomly assigned to 1 of the 3 groups: SS RT, MS RT, or control (CG). Participants were assessed at pre-training and post-training for measures of muscle strength, anthropometry, and body composition. The SS and MS groups were submitted to a regimented RT program for 12 weeks while CG was instructed to maintain their normal activities of daily living and not participate in any structured exercise-related program during the study period.

Subjects

Eighty-four physically independent, untrained older women (60 years and older) with no experience in RT were selected in metropolitan region of Londrina/PR (Brazil). Recruitment of the participants took place through announcements in local radio programs, and newspapers, posters, and pamphlets in the university community and in the central region of the city. The sample was preliminarily selected through an interview and clinical anamnesis. To meet initial inclusion criteria, participants had to be 60 years or older, female, physically independent, be free from cardiopathies and musculoskeletal disorders that could impede physical exercise, and not be involved in the practice of regular physical activity performed more than once a week over the last 6 months before the start of the study. In addition, participants could not be diabetic or have uncontrolled hypertension. Finally, participants had to be evaluated by a cardiologist (resting electrocardiogram test, personal interview, and treadmill stress test when deemed necessary by the physician) and released with no exclusions to exercise. After this first stage, 15 subjects were excluded for not meeting inclusion criteria.

Thereafter, a blinded researcher was responsible for generating random numbers (random.org) for all subjects; thus, with a simple randomization procedure, participants were assigned to one of 3 groups (SS, MS, or CG). After the start of the intervention, the following are criteria that resulted in participants' results being excluded from data analysis: undergoing hormone therapy; did not participate in some of the measurements; and did not participate in ≥85% of the training sessions. All participants were compliant in this regard, so no one was excluded based on exclusion criteria. However, during the intervention period, there were 7 dropouts (6 for personals reasons, and 1 due to oral surgery); thus, 62 subjects ultimately were included for analyses. Written informed consent was obtained from all participants after being provided with a detailed description of investigation procedures. This investigation was conducted according to the Declaration of Helsinki and approved by the local University Ethics Committee. Figure 1 displays a flowchart of the study.

Procedures

Anthropometry. Body mass was measured to the nearest 0.1 kg using a calibrated electronic scale (Balmak; Laboratory Equipment Labstore, Curitiba, PR, Brazil), and height was measured to the nearest 0.1 cm with a steel stadiometer attached on the scale. Participants wore light clothes and no shoes. Body mass index was calculated as body mass in kilograms divided by the square of the height in meters.

Muscular Strength. Maximal dynamic muscular strength of lower and upper limbs (UL) was evaluated using the 1 repetition maximum (1RM) tests assessed, respectively, in bilateral knee extension (NakaGym equipment, Diadema, Brazil) and barbell preacher curl, performed in this order. Testing for each exercise was preceded by a warm-up set (6–10 repetitions) with approximately 50% of the estimated weight used in the first attempt of the 1RM. This warm-up was also used to familiarize the subjects with the testing equipment and lifting technique. Three attempts per exercise were performed in each 1RM session. The testing procedure was initiated 2 minutes after the warm-up. The subjects were instructed to try to accomplish 2 repetitions with the imposed weight in 3 attempts for both exercises. The rest period was 3–5 minutes between each attempt, with 5 minutes afforded between exercises. Execution technique for each exercise was standardized and continuously monitored to ensure reliability. Two experienced researchers for greater safety and integrity of the subjects supervised all 1RM testing sessions. Verbal encouragement was given throughout each test. Three 1RM sessions were performed separated by 48 hours. Preintervention tests were performed in days 14, 12, and 10 before the first RT session, whereas the postintervention in the third, fifth, and seventh days after

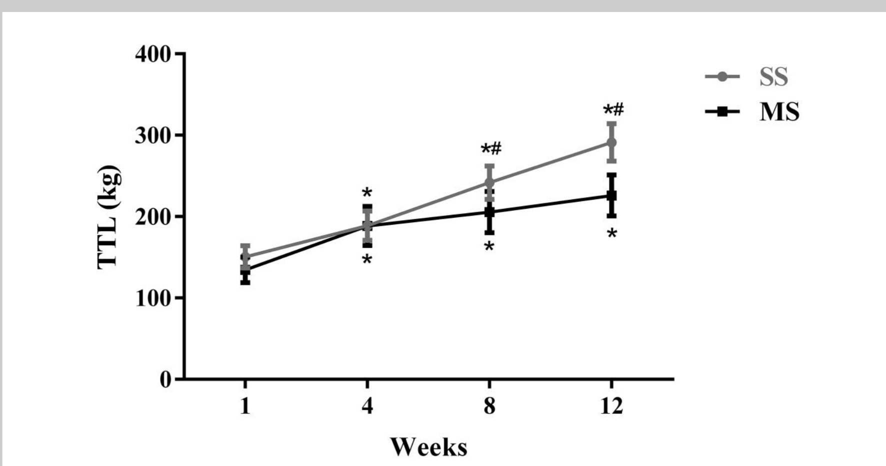

Figure 2. Total training load (TTL) performed by training groups in weeks 1, 4, 8, and 12. *$p < 0.05$ vs. last period; #$p < 0.05$ difference between groups.

Table 1. General characteristics of the participants at baseline.*†

	CG (n = 21)	SS (n = 21)	MS (n = 20)	p
Age (y)	68.04 ± 4.38	70.09 ± 5.95	68.60 ± 4.44	0.98
Body mass (kg)	63.71 ± 12.57	68.37 ± 15.31	62.61 ± 12.35	0.35
Height (cm)	155.67 ± 6.01	156.46 ± 7.68	155.12 ± 5.24	0.78
Body mass index (kg·m^{-2})	26.39 ± 4.55	27.80 ± 5.03	26.73 ± 4.79	0.60

*CG = control group; SS = single-set group; MS = multiple-sets group.
†Data are presented as mean and *SD*.

the last RT session. Intraclass correlation coefficient ≥0.96 (22). The 1RM was recorded as the heaviest weight lifted in which the subject was able to complete only 1 maximal execution and among the 3 sessions (22).

Lean Soft-Tissue Assessment. Dual energy X-ray absorptiometry (DXA) was used to measure lean soft-tissue (LST) mass of the upper and lower limbs (LL). Dual energy X-ray absorptiometry measurements were performed on a Lunar Prodigy brand GE Healthcare model ID 14739 (Madison, WI) using whole-body scanning. In preintervention measurements, subjects were measured once in the first week before the first RT session (i.e., between days 7 and 5), whereas in the postintervention, they were measured once in the second week after the last RT session (between the eighth and 10th days). Calibration of the equipment followed the manufacturer's recommendations, and both calibration and analysis were performed by a laboratory technician experienced in this type of evaluation. The participants performed the examinations in light clothes, barefoot, and without carrying any metallic objects or any other accessories next to their body. Those surveyed remained lying flat on the equipment table until finalization of the measurement. The limbs were demarcated and separated from the trunk and head by standard lines generated by the software of the equipment itself (enCORE; GE Healthcare, Madison, WI). The lines were adjusted by the technician through specific anatomical points, as shown in the equipment manual.

Muscle Quality. Upper-limb muscle quality was determined through division of the mobilized load in the preacher curl exercise by upper-limb LST, whereas lower-limb muscle quality was determined from the division of the load mobilized in knee extension by lower-limb LST (15).

Resistance Training Program. Resistance training was performed over the course of 12 weeks in the morning, 3 times per week (Mondays, Wednesdays, and Fridays), based on recommendations for RT to improve strength and muscular endurance in older adults (1). All participants were supervised throughout each training session by professionals with experience in RT (at least 1:1 participant:professional ratio) in an attempt to maintain the quality of execution of the study protocol and to ensure safety.

The RT program was performed on machines and free weights and included 8 exercises for the whole body. Exercises were performed in the following order: chest press, horizontal leg press, seated row, knee extension, preacher curl (free weights), leg curl, triceps pushdown, and seated calf raise. Participants from each group performed 10–15 repetitions maximum in SS or in MS (3 sets per exercise). The participants were instructed to inhale during the eccentric phase and to expire during the concentric phase of the exercise, maintaining the speed of movements in the proportion of 1:2 (concentric and eccentric muscular action, respectively). The rest interval between sets in the MS group was 60–120 seconds, while the interval between exercises was between 2 and 3 minutes for both groups. Each session lasted approximately 15 minutes for SS and 45 minutes for MS. The loads were adjusted individually for each exercise during the 12 weeks whenever the upper limit of programmed repetitions (15RM) was reached in 2 consecutive sessions in the SS group or in the 3 series in the MS group. Initial load for each exercise Increases in load varied from 2 to 5% for upper-limb exercises and 5–10% for lower-limb exercises, as recommended in the literature (1).

Training Load. During the RT intervention, the load (kg) (i.e., weight and external load) used in all exercises was recorded individually in training logs.

Load. The load used in the 8 exercises was summed, and the resulting value was characterized as the session training load (TL). Training load for the 3 sessions performed each week was calculated as a mean, which characterized the weekly total training load (TTL). Figure 2 presents the TTL of weeks 1, 4, 8, and 12.

It is important to note that the MS group used same weight in the 3 sets, and thus, it was considered once for each exercise. As opposed to volume-load (33), the TTL as calculated herein did not take into account the volume of

Table 2. Dietary intake at week 1 and 12 of intervention.*†

	CG ($n = 21$)	SS ($n = 21$)	MS ($n = 20$)	p
Energy (kcal)				0.38
Week 1	1,054.3 ± 201.5	1,084.6 ± 258.6	1,094.0 ± 229.3	
Week 12	1,103.8 ± 182.3	1,062.7 ± 291.4	1,128.6 ± 172.4	
Energy ($kcal \cdot kg^{-1} \cdot d^{-1}$)				0.21
Week 1	16.6 ± 4.6	15.9 ± 3.5	17.7 ± 6.1	
Week 12	17.2 ± 2.9	15.6 ± 3.8	17.7 ± 4.2	
Protein ($g \cdot kg^{-1} \cdot d^{-1}$)				0.10
Week 1	0.6 ± 0.2	0.7 ± 0.1	0.7 ± 0.2	
Week 12	0.7 ± 0.2	0.9 ± 0.4	0.7 ± 0.2	
Carbohydrate ($g \cdot kg^{-1} \cdot d^{-1}$)				0.88
Week 1	2.2 ± 0.6	2.2 ± 0.6	2.5 ± 0.8	
Week 12	2.3 ± 0.4	2.0 ± 0.5	2.5 ± 0.7	
Lipids ($g \cdot kg^{-1} \cdot d^{-1}$)				0.60
Week 1	0.5 ± 0.1	0.4 ± 0.1	0.5 ± 0.3	
Week 12	0.5 ± 0.1	0.4 ± 0.1	0.5 ± 0.2	

*CG = control group; SS = single-set group; MS = multiple-sets group.
†Data are presented as mean and *SD*.

repetitions and sets performed. Analysis of the increase in training load over time has evaluated previously in the literature (28) and deemed as a viable tool to assess changes in muscular strength (7).

Volume-Load. The volume-load was calculated by the exercises' load multiplied by the total number of repetitions in all sets (i.e., volume-load = [load $_{(kg)}$ × sets $_{(no.)}$ × repetitions $_{(no.)}$]). The volume-load of all sessions of the RT program was summed, and this represented the total volume-load (TVL).

Dietary Intake. Participants were instructed by a dietitian to complete a food record on 3 nonconsecutive days (2 weeks days and 1 weekend day) in the first and last weeks of the intervention (weeks 3–14). Participants were given specific instructions regarding the recording of portion sizes and quantities to identify all food and fluid intake, in addition to viewing food models to enhance precision. Total energy intake, protein, carbohydrate, and lipid content were calculated using nutrition analysis software (Version 3.1.4; Avanutri Processor Nutrition Software, Rio de Janeiro, Brazil). All participants were asked to maintain their normal food and fluid consumption throughout the study period.

Biochemical Analysis. Two specialized laboratory technicians obtained venous blood samples from participants, and the samples were stored in 2 containing tubes. Testing took place in the morning between 7:00 and 9:00 AM after a 12-hour fast and a minimum of 48 hours after the last exercise session. Testing was performed with participants in a seated position after resting for at least 5 minutes. Ten milliliters of blood were drawn from a prominent superficial vein in the antecubital fossa using a clean vein puncture with minimal stasis, and placed in a tube containing a dipotassium ethylenediaminetetraacetic acid. All samples were centrifuged at 3.000 rpm for 15 minutes, and plasma or serum aliquots were stored at −80° C until assayed. Inter-assay and intra-assays coefficients of variation were <10% as determined in human serum. Values for IGF-1 were determined by chemiluminescence method using a LIAISON immunoassay analyzer (LIAISON; Dia-Sorin, Saluggia, VC, Italy).

Statistical Analyses

Sample size was estimated using G*Power (version 3.0.10; Universitat Kiel, Kiel, Germany). Data from previous studies from our laboratory, in which RT was the exercise intervention model and effects on muscle mass, MQ, muscular strength were determined, were used for the sample size estimation (10,29,30). We based the calculation on an effect size of 0.30, an α level of 0.05, and a power ($1 - \beta$) of 0.80. The sample size estimation indicated that it would be necessary to include at least 45 volunteers (15 subjects per group). Considering the potential for dropouts, we recruited 69 older women who were randomly assigned into 1 of 3 groups of the study.

Normality was checked by the Shapiro-Wilk's test. The data were expressed as mean values and *SD*s. Levene's test was used to analyze the homogeneity of variances. To examine differences among groups on changes in body fat, muscular strength, muscle mass, MQ, IGF-1, and dietary intake, an analysis of covariance for repeated measures was

Table 3. Muscle strength, body and muscle mass, muscle quality, and IGF-1 of the groups at baseline and after intervention.*

	CG ($n = 21$)	SS ($n = 21$)	MS ($n = 20$)
Body mass (kg)			
Pre	63.71 ± 12.57	68.37 ± 15.31	62.61 ± 12.35
Post	64.13 ± 12.09	68.33 ± 15.65	63.60 ± 12.31
Δ%	+0.7	−0.1	+1.5
Upper-limb muscle strength (kg)			
Pre	18.90 ± 2.66	17.47 ± 2.82	17.90 ± 3.24
Post	18.33 ± 3.15	23.95 ± 4.03†‡	22.80 ± 3.73†‡
Δ%	−3.0	+37.1	+27.4
Lower-limb muscle strength (kg)			
Pre	47.80 ± 8.67	47.23 ± 10.90	44.40 ± 9.88
Post	47.47 ± 9.00	54.95 ± 11.49†‡	54.05 ± 9.68†‡
Δ%	−0.7	+16.3	+21.7
Appendicular LST (kg)			
Pre	14.03 ± 2.28	17.07 ± 2.67	14.33 ± 2.08
Post	13.91 ± 2.71	18.13 ± 2.78†‡	15.32 ± 2.02†‡
Δ%	−0.9	+6.2	+6.9
Upper-limb LST (kg)			
Pre	3.57 ± 0.65	4.34 ± 0.95	3.51 ± 0.64
Post	3.53 ± 0.64	4.68 ± 0.91†‡	3.82 ± 0.61†‡
Δ%	−1.1%	+7.8	+8.8
Lower-limb LST (kg)			
Pre	10.46 ± 1.68	12.73 ± 1.91	10.81 ± 1.51
Post	10.38 ± 2.27	13.44 ± 2.00†‡	11.49 ± 1.51†‡
Δ%	−0.8	+5.6	+6.3
Upper-limb muscle quality			
Pre	5.36 ± 0.87	4.16 ± 0.96	5.14 ± 0.72
Post	5.36 ± 1.11	5.21 ± 0.97†‡	6.0 ± 0.84†‡
Δ%	−0.2	+25.2	+16.7
Lower-limb muscle quality			
Pre	4.61 ± 0.73	3.71 ± 0.67	4.10 ± 0.75
Post	4.45 ± 0.67	4.10 ± 0.71†‡	4.73 ± 0.77†‡
Δ%	−3.5	+10.5	+15.4
IGF-1 ($ng \cdot ml^{-1}$)			
Pre	109.63 ± 30.70	106.80 ± 28.89	100.25 ± 25.58
Post	107.23 ± 30.20	114.33 ± 25.81†‡	110.36 ± 27.61†‡
Δ%	−2.2	+7.1	+10.1

*CG = control group; SS = single-set group; MS = multiple-sets group; LST = lean soft tissue; IGF-1 = insulin-like growth factor 1.
†$p < 0.05$ vs. pre.
‡$p < 0.05$ vs. CG.

performed with baseline scores used as a covariate to eliminate any possible influence of initial score variances on training outcomes (37,38). When the *F*-ratio was significant, the Bonferroni's post hoc test was used to identify the differences between pre-training and post-training raw data. For all analyses, a *p*-value of ≤0.05 was accepted as statistically significant. The data were stored and analyzed using Statistica software version 10.0 (Statsoft, Inc., Tulsa, OK).

Results

The general characteristics of participants are described according to groups in Table 1. There were no significant differences between groups at pre-training for any variable analyzed (Table 1), and no significant differences were found between or within groups in regard of the scores of dietary intake during intervention (Table 2).

Table 3 presents values of muscular strength, body mass, LST, and MQ of the upper limbs and lower limbs (LL), appendicular LST, and IGF-1 at pre-training and post-training. With the exception of body mass ($F = 1.312$, $p = 0.377$), an interaction effect (time × group) was observed for all variables, where both SS and MS significantly increased their values from pre-training to post-training with no significant difference between them, and the CG presents no significant alteration from baseline.

The TVL (load × sets × repetitions) was greater in MS group (105.84 ± 11.52 ton) comparing with the SS group (40.95 ± 3.21 ton) ($F = 616.501$, $p < 0.0001$).

Figure 2 presents values of the TTL at weeks 1, 4, 8, and 12. Both SS and MS groups started with the same training loads ($p > 0.05$). There were significant differences at weeks 8 and 12, in which SS trained with greater TTL than MS ($p < 0.05$).

Discussion

The main findings of this study were that both RT protocols (single set and multiple sets) produced similar improvements in the variables analyzed. We showed that 12 weeks of RT, regardless of the training volume used, promoted increases in muscular strength, muscle mass and quality, and IGF-1 in a cohort of untrained older women. To our knowledge, this is the first study that compares the effects of single vs. MS on IGF-1 levels and presents the analysis of training load progression throughout the weeks, includes a control group, and is only the second study (29) to evaluate nutritional intake during such an intervention.

With respect to muscular strength, our results showed that both SS and MS produced similar improvements for upper-body and lower-body exercises, which corroborate the findings of other studies (6,25,26), but contrasts with other studies that showed a superiority to higher training volumes (16,19,24,29). Discrepancies in findings would seem to be related to numerous differences in study designs including variations in exercise number and selection (19), study duration (6,16,24), repetition range and training frequency (24), age and sex (16,19), initial training status (19), and tools used to assess muscle strength and mass (16,19,24,29). Of particular importance is difference in the duration of studies on the topic. The studies by Galvão and Taaffe (16) and Radaelli et al. (24) showed that only after 20 weeks of RT was it possible to note a significant increase in muscle strength, indicating that low training volumes are effective for muscle strength gains in the early stages of RT. After this initial period, a greater stimulus would seemingly become necessary to realize continued increases in strength, consistent with ACSM guidelines (1).

Moreover, the analysis of the progression of the load contributes to the understanding of why some previous studies (16,19,24,29) differed in the gains of strength, whereas in this, our study did not. As shown in Figure 2, the TTL progressed across sessions to a greater extent in SS than MS. Because muscular strength, as measured by the 1RM test, is highly influenced by the SAID principle (specific adaptations to imposed demands) (5,20,23), the more times subjects are exposed to high loads the greater the odds of increasing the 1RM-strength (5,20,23) (i.e., in this case, favoring the MS group, which trained with 3-fold greater number of sets). However, by the same SAID-principle rationale, as the SS group trained with higher loads (Figure 2), this may have helped to minimize any differences in strength adaptations between conditions. Furthermore, these findings physiologically suggest that neurological adaptations at the muscle level that do not result in growth seem to be responsible for the increased strength induced by training (11,20).

With respect to muscle mass, both SS and MS were sufficient for promoting increases in ULLST and LLLST in untrained older women. Although our findings conflict with those of Radaelli et al. (24), this potentially can be explained, at least in part, by the fact that the duration of the Radaelli et al. study was substantially longer than ours (20 vs. 12 weeks, respectively). In the study by Radaelli et al. (24), it was reported significant difference in results only after the 20th week of RT, suggesting that our study may have been too short to detect a divergence between SS and MS groups. Therefore, it can be speculated that a set of RT may induce benefits over the initial weeks of training, and thereafter, a progression in the number of sets may be necessary to promote subsequent muscular adaptations in this population. Moreover, Radaelli et al. (24) did not report the dietary intake of the subjects. It therefore is possible that their results may have been influenced by a difference in protein or calorie intake between groups, which would have confounded the ability to determine the effects of volume on hypertrophic changes. Given that no differences were found in food intake before and after the study period (Table 2), it can be inferred that nutritional factors did not influence the increases in muscle mass found herein. However, it should be noted that the reported total daily protein intake in both training groups was far below what has been shown to be optimal for maximizing muscular adaptations to RT (21). It is possible that higher volumes may require greater protein intake to promote additional gains in muscle mass. This hypothesis warrants further investigation.

In addition to eliciting gains in hypertrophy and strength, RT may also improve muscle functionality, herein represented by MQ and defined as a muscle's ability to produce strength, power, or function (14). Improvement in MQ may be due to an improvement in muscle strength and by increases in muscle mass. We found increases in MQ of the upper and lower limbs in both groups (SS and MS), which may be considered a more important predictor of performance and/or function than either muscle strength or body composition alone (12,15). Importantly, we observed that these early-phase improvements occurred regardless of the training volume. Possible mechanisms that may explain such results are those associated with increased muscle mass and strength such as improvements in contractile efficiency, intramuscular and inter-muscular coordination, motor unit recruitment, neural drive, and motor unit synchronization.

We also observed that RT is sufficient to augment basal levels of IGF-1 in older women irrespective of training volume. This result is consistent with others studies that observed RT-induced increases in circulating IGF-1 in the elderly (8,9). Moreover, the finding of an increase in IGF-1 levels consequent to 12 weeks of RT raises the possibility that subjects were perpetually in a higher anabolic state and thus better able to synthesize proteins for long-term accretion of muscle mass. However, although the IGF-1/AKT/PI3K pathway is obligatory for hypertrophy during human maturation, the extent of its involvement in muscular adaptations to regimented RT remains unclear (32). In this sense, further research is warranted to determine mechanistic insights into the role of chronic RT-induced IGF-1 elevations and its influence on muscle development.

This study has several limitations that must be taken into consideration when attempting to extrapolate findings to practice. First, the sample of untrained older women makes it difficult to extrapolate our findings to trained ones or other demographics. As previously noted, other studies have shown that the need for higher training volumes increases when subjects have attained a degree of RT experience (24). Second, and in a similar vein, the relatively short study duration precludes the ability to determine whether single-set RT programs would be effective in generating positive adaptive responses over longer time frames. Third, the use of food records to evaluate nutritional habits has been shown to be problematic, with a tendency for individuals to underestimate actual intake (39); however, as no differences were observed between groups, this suggests that any within-group alterations did not influence between-group comparisons. Fourth, the use of DXA, while a reference standard for measuring muscle mass (4), lacks the sensitivity to detect RT-induced changes compared with direct imaging modalities such as computed tomography and magnetic resonance imaging. Fifth, the medication intake and physical activity levels of participants were not controlled, which might have confounded the results. Finally, strength tests were performed using task-specific tests (1RM); the lack of other methods to assess strength gains (i.e., peak-torque in isokinetic/isometric equipment) hinders the ability to draw further strength-related inferences from the data (5). On the other hand, the study has a number of strengths that deserve highlighting. In addition to those already mentioned in the first paragraph of this section, training sessions were individually supervised by physical education professionals with experience in RT, ensuring proper compliance of the protocol. Finally, the sample was larger than most previous studies on the topic, thereby affording good statistical power.

Therefore, we conclude that 12 weeks of RT using either a SS or MS protocol is sufficient to increase IGF-1, muscular strength, LST, and MQ of the upper and lower limbs in untrained older women.

Practical Applications

The results of this study further our understanding as to the manipulation of resistance exercise variables when developing programs for older women. Similarity in the response of all outcomes between conditions allows for RT prescription to be more flexible in this population. Moreover, since time constraints may be a barrier to exercise practice, especially in elderly, it is important to note that SS RT can be a viable strategy to improve exercise adherence. Thus, untrained elderly individuals who wish to enter into an RT program can start with a low volume routine to adapt/adhere to the regimen, and then perhaps progressively increase volume to reap continuous benefits over time.

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