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Resistance training in older women: Comparison of single vs. multiple sets on muscle strength and body composition

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Abstract.
BACKGROUND: Studies are conflicting as to whether single-set resistance training (RT) are as effective as multi-set protocols with respect to promoting muscular adaptations. Several meta-analyses have shown that a clear dose-response relationship exists between RT volume and muscular adaptations. However, a majority of studies were not specific to older individuals, particularly women.
OBJECTIVE: To determine changes in strength and body composition in elderly women following 1 vs. 3 sets of RT.
METHODS: Thirty older women participated in a 12-week supervised total body RT program. Participants were randomly assigned to perform either 1 set (G1S) or 3 sets (G3S) per session. All other RT variables were held constant. Body composition was assessed by dual X-ray absorptiometry, muscle strength was evaluated by 1RM in chest press and knee extension.
RESULTS: Increases in strength were significantly ($p < 0.05$) greater in G3S versus G1S in both the chest press (+26.6%, versus +20.3%) and the knee extension (+23.9% versus +16.2%). No significant ($p > 0.05$) differences were noted in body composition components between groups.
CONCLUSIONS: Findings indicate that multiple set protocols are required to optimize strength gains in older women. Changes in body composition appear to be similar irrespective of training volume during the initial stages of RT.

Keywords: Strength training, fat-free mass, fat mass, volume

1. Introduction

Human muscle mass and force reach peak levels between the second and fourth decades of life [1]. Thereafter, it is estimated that we lose approximately $^1/_2$% of our muscle mass per year after the fourth decade of life, increasing to 1%–2% annually after the age of 50 and then accelerating to 3% annually after the age of 60 [2, 3]. This age-associated loss of muscle has been termed sarcopenia. Rates of decline are greater in sedentary individuals compared to those who are active, although leisure time physical activity has only minor effects on attenuating muscle loss [2]. The decrease in muscular strength and power associated with sarcopenia is at the root of many of health and wellness issues independent on age, size, physical activity, or co-morbidities, indicating a link between sarcopenia and generalized frailty [2]. Muscle loss contributes to a reduced ability to carry out activities of daily living, impairing the

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capacity for independent living and thereby increasing the burden to the caregiver and community [4,5]. The risk of disability is estimated to be as much as 4.6 times higher in elderly sarcopenic individuals compared to age-matched persons with normal muscle mass [6]. Often this can necessitate home healthcare, hospitalization, or placement in a nursing home [6].

Older women are particularly susceptible to the debilitating effects of sarcopenia [7]. Because women start out with lower amounts of muscle mass compared to men, the negative effects of muscle loss from aging result in greater functional deficits. To this end, studies show that between 3%–5% of individuals 65 years of age and older are admitted to a skilled-nursing facility in the United States each year and the lifetime risk of admission to a nursing home for those in this age bracket is approximately 45 percent for women and 28 percent for men [8].

Several meta-analyses have shown that a clear dose-response relationship exists between resistance training (RT) volume and muscular adaptations, whereby increased volume correlates with greater gains in muscle strength and hypertrophy at least up to a certain point [9–12]. The caveat is a majority of studies included in these analyses were not specific to older individuals. It has been demonstrated that the elderly display an altered response to RT programs compared to the young, thereby limiting generalizability between these populations [13].

Studies investigating the dose-response relationship in the elderly have produced disparate findings. Galvão and Taaffe [14] found greater increases in some measures of maximal strength with 3 sets compared to 1 set in a convenience sample of community-dwelling older men and women, but no significant differences were noted in body composition. More recently, Radaelli et al. [15] reported similar increases in muscle strength and thickness between 1- and 3-set protocols in a group of healthy older women over 13 weeks of RT. Follow-up work by the same group evaluated muscular adaptations between 1 and 3 set protocols at 6, 13, and 20 weeks of regimented RT. Results showed that increases in lower body muscle strength and thickness were significantly greater in the 3-set group compared to 1 set only at the 20 week time point; no differences were noted in upper body muscle strength or thickness [16].

A confounding issue with previous research is that subjects were initially unfamiliar with the exercises used as well as the concept of one repetition maximum (1RM) testing. This lack of familiarity tends to underestimate baseline scores, skewing pre- to post-study differences in strength and thus potentially obscuring the effects of volume on results [17]. The purpose of this study was to evaluate differences between 1- and 3-set RT protocols on muscular adaptations in untrained elderly women after a period of familiarization to exercise performance.

2. Methods

2.1. Participants

Thirty older women ($\geqslant 60$ years old) volunteered to participate in this study. Recruitment was carried out through newspaper and radio advertisings, and home delivery of leaflets in the central area and residential neighborhoods. Participants were randomly assigned to one of the two groups: a group that performed RT with 1 set (G1S) and a group that performed RT with 3 sets (G3S). All participants completed health history and physical activity questionnaires and met the following inclusion criteria: Non-hypertensive (systolic blood pressure < 140 mmHg and diastolic blood pressure < 90 mmHg), non-diabetic, free from cardiac or renal dysfunction, nonsmokers, not receiving hormonal replacement therapy, and were not performing any regular physical exercise for more than once a week over the six months preceding the beginning of the study. Participants passed a diagnostic, graded exercise stress test with 12-lead ECG reviewed by a cardiologist and were released with no restrictions for participation in this study. Adherence to the program was good, with all subjects participating in $>85\%$ of the total sessions. Written informed consent was obtained from all subjects after a detailed description of study procedures was provided. This investigation was conducted according to the Declaration of Helsinki, and was approved by the local University Ethics Committee.

2.2. Experimental design

The study was carried out over a period of 18 weeks, with 12 weeks directed to the RT program, 4 weeks for data collection, and 2 weeks dedicated to exercise learning. During weeks 1–2, participants underwent 6 familiarization sessions designed to acquaint them with the exercises and equipment that composed the RT program. Familiarization sessions were carried out over nonconsecutive days and involved performing 1

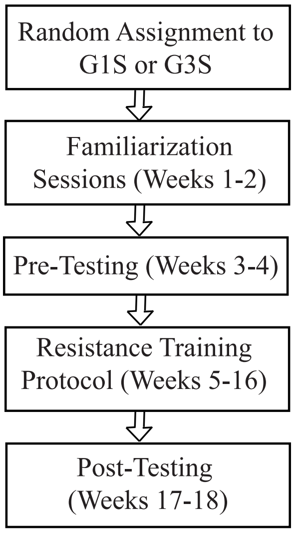


Fig. 1. Study design.

set of 10–15 repetitions of each exercise with a light load. Pre- and post-study testing was carried out at weeks 3–4 and 17–18, respectively, and comprised anthropometric, body composition and maximal dynamic strength measurements; the RT program was carried out during weeks 5–16. All sessions were supervised by fitness personnel (graduate and post-graduate students). Subjects refrained from performing any other type of physical exercise throughout the study period. The study design is displayed in Fig. 1.

2.3. *Anthropometry*

Body mass was measured to the nearest 0.1 kg using a calibrated electronic scale (Filizola, model ID 110, São Paulo, Brazil), with the participants wearing light workout clothing and no shoes. Height was measured with a wooden stadiometer to the nearest 0.1 cm with subjects standing without shoes. Body mass index was calculated as body mass in kilograms divided by the square root of height in meters.

2.4. *Body composition*

Fat-free mass (FFM) and body fat (%Fat) measurements were carried out using a dual energy X-ray absorptiometry (DXA) scan (Lunar Prodigy, model NRL 41990, GE Lunar, Madison, WI). Before scanning participants were instructed to remove all objects containing metal. Scans were performed with the subjects lying in the supine position along the table's longitudinal centerline axis. Feet were taped secured together at the toes in order to immobilize the legs while the hands were maintained in a pronated position within the scanning region. The subjects remained motionless during the entire scanning procedure. Both calibration and analysis were carried out by a skilled laboratory technician. The equipment calibration followed the manufacturer's recommendations. The software generated standard lines that set apart the limbs from the trunk and head. These lines were adjusted by the same technician using specific anatomical points determined by the manufacturer. Analyses during the intervention were performed by the same technician who was blinded to intervention time point. Previous test-retest scans of eight older women resulted in an SEM of 0.90 kg and ICC > 0.98 for %Fat, and an SEM of 0.60 kg and ICC > 0.97 for FFM.

2.5. *Muscle strength*

Maximal dynamic strength was evaluated using the 1RM test assessed on chest press (CP) and knee extension (KE) performed in this exact order. Testing for each exercise was preceded by a warm-up set (6–10 repetitions), with approximately 50% of the estimated load used in the first attempt of the 1RM test. This warm-up was also used to familiarize the subjects with the testing equipment and lifting technique. The testing procedure was initiated 2 minutes after the warm-up. The subjects were oriented to try to accomplish two repetitions with the imposed load in three attempts in both exercises. The rest period was 3 to 5 min between each attempt, and 5 min between exercises. The 1RM was recorded as the last resistance lifted in which the subject was able to complete only one single maximal execution [17]. Execution technique for each exercise was standardized and continuously monitored to ensure reliability. All 1RM testing sessions were supervised by 2 experienced researchers for greater safety and integrity of the subjects. Verbal encouragement was given throughout each test. Three 1RM sessions were performed separated by 48 hours (ICC $\geqslant 0.96$). The highest load achieved among the 3 sessions was used for analysis in each exercise.

2.6. *Dietary intake*

Participants were instructed by a dietitian to complete a food record on three nonconsecutive days (two week days and one weekend day) pre- and post-training. Subjects 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 in order to enhance precision. Total dietary energy, protein, carbohydrate, and lipid content were calculated using nutrition analysis software (Avanutri Processor Nutrition Software, Rio de Janeiro, Brazil; Version 3.1.4). All subjects were asked to maintain their normal diet throughout the study period.

2.7. *Resistance training program*

The supervised RT was carried out over 12 weeks. Training took place in the morning and was based on recommendations for RT in elderly population to improve muscular endurance and strength [18,19]. All participants were personally supervised by exercise professionals with substantial experience in RT prescription throughout each training session in order to reduce deviations from the study protocol and to ensure subject safety. Subjects performed RT using a combination of free weights and machines.

The RT protocol was a whole body program with 8 exercises performed in the following order: chest press, horizontal leg press, seated row, knee extension, preacher curl, leg curl, triceps pushdown, and seated calf raise. Participants performed between 10–15 RM for each set. The participants were instructed to inspire during the eccentric phase and exhale during the concentric phase of the exercise and to maintain the speed of movements at a ratio of 1:2 (concentric and eccentric phases, respectively). The rest interval ranged between 60–120 s for sets and exercises. The instructors adjusted the loads of each exercise according to the subject's ability and improvements in exercise capacity throughout the study in order ensure that subjects were using as much resistance as possible while maintaining proper technique. Progression was planned so that when 15 repetitions were completed for two consecutive sessions, the load was increased 2–5% for the upper limb exercises and 5–10% for lower limb exercises (ACSM, 2009). At the end of each session, approximately five minutes were provided for stretching the exercised muscles.

2.8. *Statistical analyses*

Normality was checked by the Shapiro-Wilk's test. The data were expressed as mean and standard deviation. Levene's test was used to analyze the homogeneity of variances. Two-way analysis of variance (ANOVA) for repeated measures was used for within group comparisons. In variables where sphericity was violated as indicated by Mauchly's test, the analyses were adjusted using a Greenhouse-Geisser correction. When F-ratio was significant, Bonferroni's post hoc test was employed to identify the mean differences. Baseline differences comparisons were explored with an independent t-test. The effect size (ES) was calculated to verify the magnitude of the differences by Cohen's d where an ES of 0.20–0.49 was considered as small, 0.50–0.79 as moderate and $\geqslant$ 0.80 as large [20]. For all statistical analyses, significance was accepted at $p < 0.05$. The data were stored and analyzed using STATISTICA software version 10.0 (STATSOFT INC., Tulsa, OK, USA).

Table 1
General characteristics of the sample. Data are expressed as mean and standard deviation

Variables	G1S ($n = 15$)	G3S ($n = 15$)	p
Age (years)	65.6 ± 4.2	67.1 ± 4.3	0.89
Body mass (kg)	63.5 ± 7.9	62.2 ± 8.5	0.80
Height (cm)	157.1 ± 6.7	154.0 ± 4.3	0.11
Body mass index (kg/m^2)	25.8 ± 3.3	26.2 ± 3.0	0.78
Relative body fat (%)	40.1 ± 6.3	36.5 ± 7.4	0.55
Absolute body fat (kg)	25.3 ± 5.9	22.5 ± 7.5	0.38
Fat-free mass (kg)	36.9 ± 3.5	37.8 ± 2.4	0.16

Note. G1S = resistance training group that performed 1 set per exercise; G3S = resistance training group that performed 3 sets per exercise.

3. Results

Table 1 shows the general characteristics of the sample at pre-training. No significant differences between groups were observed ($p > 0.05$).

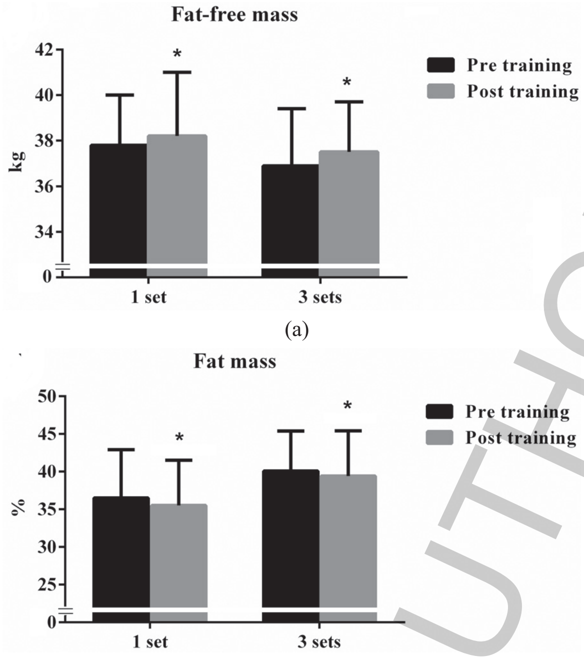
Total energy and macronutrients daily intake at pre- and post-training are shown in Table 2. There were no significant ($p > 0.05$) main effects or group vs. time interactions, indicating that the relative daily energy and macronutrients intake did not change over time.

The body composition components variations from pre- to post-training after the 12 weeks of RT for both groups are presented in Fig. 2. There were no significant group vs. time interactions for any of the components analyzed (%Fat: $F_1 = 0.25$, $p = 0.62$, FFM: $F_1 = 0.08$; $p = 0.78$). Similarly the main effect of group did not reach values of statistical significance (%Fat: $F_1 = 2.21$, $p = 0.15$, FFM: $F_1 = 0.57$; $p = 0.46$). However, for the main effect of time, statistical significance was observed for %Fat ($F_1 = 9.97$, $p < 0.05$) and FFM ($F_1 = 7.60$, $p < 0.05$), in which both the groups decreased their %Fat (G1S = −2.7%, G3S = −1.7%) and increased their FFM (G1S = +1.1, G3S

Table 2
Dietary intake at pre- and post-training (12 weeks) according to resistance training group. Data are expressed as mean and standard deviation

	G1S ($n = 15$)	G3S ($n = 15$)	Effects	F	p
Carbohydrate (g/kg)			ANOVA		
Pre	3.8 ± 1.4	3.9 ± 0.9	Group	< 0.01	0.93
Post	4.2 ± 1.6	4.1 ± 0.8	Time	2.44	0.13
			Interaction	0.24	0.62
Protein (g/kg)			ANOVA		
Pre	1.2 ± 0.5	1.0 ± 0.2	Group	2.83	0.10
Post	1.2 ± 0.4	0.9 ± 0.3	Time	2.76	0.11
			Interaction	0.43	0.51
Fat (g/kg)			ANOVA		
Pre	0.9 ± 0.3	0.8 ± 0.3	Group	0.13	2.45
Post	0.8 ± 0.2	0.7 ± 0.1	Time	1.20	0.28
			Interaction	1.12	0.30
Energy intake (kcal/kg)			ANOVA		
Pre	29.5 ± 9.6	25.6 ± 5.1	Group	2.01	0.17
Post	30.7 ± 10.5	26.0 ± 4.7	Time	1.03	0.32
			Interaction	0.31	0.58

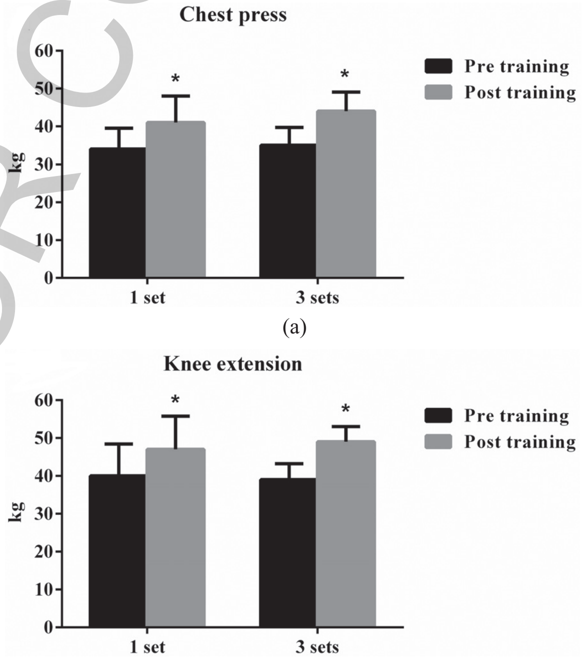
Note. G1S = resistance training group that performed 1 set per exercise; G3S = resistance training group that performed 3 sets per exercise.



(a)

(b)

Fig. 2. Variations from pre- to post-training on relative body fat and fat-free mass after the 12 weeks of resistance training in older women ($n = 30$) according to the number of sets performed. $^*p < 0.05$ vs. pre-training. There is no group by time interaction. Data are expressed as mean and standard deviation.



(a)

(b)

Fig. 3. Muscular strength (1RM) in chest press and knee extension at pre- and post-training in older women ($n = 30$) according to the number of sets performed during 12 weeks of resistance training. $^*p < 0.05$ vs. pre-training. There is a group by time interaction for both chest press and knee extension. Data are expressed as mean and standard deviation.

= +1.6%). ES of small magnitude was observed only for FFM in both the groups (ES = 0.2).

Figure 3 shows pre- and post-study results for the 1RM in CP and KE for both the groups. There was significant group vs. time interaction for CP 1RM ($F_1 = 10.22$, $p < 0.05$) and for KE 1RM ($F_1 = 7.13$, $p < 0.05$), in which the G3S had higher increases than the G1S (CP: G3S = +26.6%, G1S = +20.3%; KE: G3S = +23.9%, G1S = +16.2%) after the 12 week RT program. The ESs for BP 1RM and KE 1RM were considered large (G1S = 0.8, G3S = 2.2).

4. Discussion

The main findings of the present study were that a 3 set RT protocol produced superior increases in muscular strength compared to a 1-set protocol after 12 weeks in elderly women, but improvements in body composition were similar regardless of the number of sets performed. We had hypothesized that a higher training volume would lead to greater improvements in muscular strength and body composition. This hypothesis was confirmed for the muscular strength outcomes, which is consistent with the dose-response relationship between volume and strength reported in several meta-analyses [9–12]. Given that subjects were untrained, differences between groups may be attributed to greater improvements in neural adaptations (i.e., increases in motor-unit recruitment and rate coding of motor units, improved synergistic or fixator contribution, and reductions in the coactivation of antagonists muscles) brought about by an increased exposure to exercise performance in those performing multiple sets. Neural adaptations have been determined to be the primary factor responsible for strength gains during the early phase of RT [21]. Hypothetically, performing a greater number of sets should lead to greater motor learning over time, thereby providing an advantage to the 3-set group.

The results of our study are at odds with several studies that examined the effects of performing 1 versus 3 sets on strength outcomes in elderly women. Both Cannon and Marino [22] and Radaelli et al. [15] found similar strength gains following performance of 1 versus 3 sets per exercise in elderly women. A possible explanation for the disparate findings between these studies and ours is that we provided a two-week familiarization period whereby subjects learned performance of the exercises prior to undertaking 1RM tests. In addition, current literature indicates that several 1RM sessions are beneficial in achieving accurate maximal strength baseline scores [17,23], thus the three 1RM sessions applied in our investigation may be considered a strong point, because such procedure can ensure the 1RM load stabilization prior intervention. For example, Amarante do Nascimento et al. [17] investigated the number of 1RM testing sessions were necessary to achieve consistent 1RM load in older women, and they observed that the stabilization of the load occurred between sessions 2 and 3, which confirms the needed of several trials of 1RM to achieve a consistent evaluation. The fact that familiarization session were not provided in the aforementioned studies suggests the possibility that initial 1RM values were underestimated thereby skewing pre- to post-study results.

Single-set training has been recommended as a starting point for beginners engaged in RT [18,24]. With respect to FFM outcomes, our results lend support to such recommendations since single- and multiple-sets routines resulted in similar body composition outcomes. A meta-analysis by Krieger [9] found that ESs were 40% greater with performance of multi- compared to single-set protocols in both trained and untrained subjects. However the meta-analysis did not account for age as a covariate in regression, limiting generalizability to the present investigation. The results of our study are in agreement with previous findings in untrained older women, suggesting single sets are equally as effective as multi-set protocols for increasing muscle mass during the initial weeks of RT in this population [14,15]. However, it should be noted that our study had duration of only 12 weeks. Radaelli et al. [16] reported that differences in quadriceps hypertrophy between 1- versus 3-set protocols were not evident in elderly women until 20 weeks of RT, at which point multiple sets displayed a significant advantage. Therefore, while single-set RT programs can provide a time-efficient alternative for older women to develop muscle mass, it appears that increasing the number of sets is necessary to sustain greater hypertrophic increases over time. Future research should seek to better determine the dose-response relationship between volume and hypertrophy in this population so that program design can be optimized to counteract sarcopenia and maximize the accretion of functional muscle mass.

Previous research has shown reductions in body fat in elderly women after a period of RT [25–27]. Although training with a higher volume may allow for a greater energy expenditure during the RT session, we observed similar reductions in body fat between groups. These results may be partly attributed to similar increases in lean tissue, given that FFM has been shown to increase resting metabolic rate by approximately 7–8% [28–30]. Another factor to consider is that single set protocols have been shown to produce similar increases in excess post-exercise oxygen consumption compared to multi-set protocols in the 72-hour period following RT [31]. Thus, any additional calories expended during the RT session itself with higher volume RT may have been overshadowed by the increased energy expenditure following each exercise bout. It should be noted that the body compositions improvements observed in this investigation occurred without alterations in the food habits of the individuals of both groups.

It is important to point out that this study has several limitations. First, results are specific to 12-week RT duration. Second, results are specific to untrained, older women and cannot be necessarily generalized to other populations. Therefore, our body composition findings must be interpreted with some degree of caution. Follow-up work using direct imaging modalities to assess hypertrophy is recommended. Finally, our findings are limited to 1 versus 3 sets of exercise.

5. Conclusion

We conclude that an RT protocol comprising 3 sets is superior to 1 set for promoting increases in muscle strength after 12 weeks of RT in elderly women; however, the higher training volume does not induce better improvements in body composition. Taken together, our results indicate that elderly women can take a flexible approach to program design during the early stages of RT. If the individual's goal is to maximally increase muscle strength then a multiple set protocol would be recommended. However, if the goal is specifically to improve body composition, a single-set protocol would be adequate and can be accomplished in less time.

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