Resistance Training for Older Women: Do Adaptive Responses Support the ACSM and NSCA Position Stands?

EDILAINE F. CAVALCANTE[1], WITALO KASSIANO[1], ALEX S. RIBEIRO[1,2], BRUNA COSTA[1], LETÍCIA T. CYRINO[1,3], PAOLO M. CUNHA[1,4], MELISSA ANTUNES[1,3], LEANDRO DOS SANTOS[1], CRISIELI M. TOMELERI[1], HELLEN C. G. NABUCO[1,5], PAULO SUGIHARA-JÚNIOR[1], RODRIGO R. FERNANDES[1], RICARDO J. RODRIGUES[1,6], MARCELO A. S. CARNEIRO[1], FÁBIO L. C. PINA[1], MÁRCIA M. DIB[1], DENILSON C. TEIXEIRA[1], FÁBIO L. ORSATTI[7], DANIELLE VENTURINI[8], DÉCIO S. BARBOSA[8], and EDILSON S. CYRINO[1]

[1]Metabolism, Nutrition, and Exercise Laboratory. Physical Education and Sport Center, State University of Londrina, Londrina, PR, BRAZIL; [2]Center for Research in Health Sciences. University of Northern Paraná, Londrina, BRAZIL; [3]Skeletal Muscle Assessment Laboratory, School of Technology and Sciences, São Paulo State University (UNESP), Presidente Prudente, SP, BRAZIL; [4]Hospital Israelita Albert Einstein, São Paulo, SP, BRAZIL; [5]Federal Institute of Science and Technology of Mato Grosso, Cuiabá, MT, BRAZIL; [6]Heart Center, Londrina, PR, BRAZIL; [7]Applied Physiology, Nutrition and Exercise Research Group, Federal University of Triângulo Mineiro, Uberaba, MG, BRAZIL; and [8]Department of Pathology, Clinical and Toxicological Analysis, State University of Londrina, Paraná, BRAZIL

ABSTRACT

CAVALCANTE, E. F., W. KASSIANO, A. S. RIBEIRO, B. COSTA, L. T. CYRINO, P. M. CUNHA, M. ANTUNES, L. DOS SANTOS, C. M. TOMELERI, H. C. G. NABUCO, P. SUGIHARA-JÚNIOR, R. R. FERNANDES, R. J. RODRIGUES, M. A. S. CARNEIRO, F. L. C. PINA, M. M. DIB, D C. TEIXEIRA, F. L. ORSATTI, D. S. VENTURINI, D. S. BARBOSA, and E. S. CYRINO. Resistance Training for Older Women: Do Adaptive Responses Support the ACSM and NSCA Position Stands? *Med. Sci. Sports Exerc.*, Vol. 55, No. 9, pp. 1651–1659, 2023. **Purpose:** The optimal intensity of resistance training (RT) to improve muscular, physical performance, and metabolic adaptations still needs to be well established for older adults. Based on current position statements, we compared the effects of two different RT loads on muscular strength, functional performance, skeletal muscle mass, hydration status, and metabolic biomarkers in older women. **Methods:** One hundred one older women were randomly allocated to perform a 12-wk whole-body RT program (eight exercises, three sets, three nonconsecutive days a week) into two groups: 8–12 repetitions maximum (RM) and 10–15RM. Muscular strength (1RM tests), physical performance (motor tests), skeletal muscle mass (dual-energy X-ray absorptiometry), hydration status (bioelectrical impedance), and metabolic biomarkers (glucose, total cholesterol, HDL-c, HDL-c, triglycerides, and C-reactive protein) were measured at baseline and posttraining. **Results:** Regarding muscular strength, 8–12RM promoted higher 1RM increases in chest press (+23.2% vs +10.7%, $P < 0.01$) and preacher curl (+15.7% vs +7.4%, $P < 0.01$), but not in leg extension (+14.9% vs +12.3%, $P > 0.05$). Both groups improved functional performance ($P < 0.05$) in gait speed (4.6%–5.6%), 30 s chair stand (4.6%–5.9%), and 6 min walking (6.7%–7.0%) tests, with no between-group differences ($P > 0.05$). The 10–15RM group elicited superior improves in the hydration status (total body water, intracellular and extracellular water; $P < 0.01$), and higher gains of skeletal muscle mass (2.5% vs 6.3%, $P < 0.01$), upper (3.9% vs 9.0%, $P < 0.01$) and lower limbs lean soft tissue (2.1% vs 5.4%, $P < 0.01$). Both groups improved their metabolic profile. However, 10–15RM elicited greater glucose reductions (−0.2% vs −4.9%, $P < 0.05$) and greater HDL-c increases (−0.2% vs +4.7%, $P < 0.01$), with no between-group differences for the other metabolic biomarkers ($P > 0.05$). **Conclusions:** Our results suggest that 8–2RM seems more effective than 10–15RM for increasing upper limbs' muscular strength, whereas the adaptative responses for lower limbs and functional performance appear similar in older women. In contrast, 10–15RM seems more effective for skeletal muscle mass gains, and increased intracellular hydration and improvements in metabolic profile may accompany this adaptation. **Key Words:** AGING, STRENGTH TRAINING, NUMBER OF REPETITIONS, INTENSITY

Resistance training (RT) has been widely recommended for older adults because it is considered a safe and nonpharmacological strategy to attenuate or reverse the deleterious changes in different physiological systems associated with aging (1,2). Indeed, engagement in RT programs promotes numerous benefits in older adults, such as increased skeletal muscle mass (SMM) and muscular strength (3–6) and improved functional performance (7,8). In this context, many adaptative responses to RT depend on manipulating the variables that make up the training program, such as rest interval, frequency, exercise selection, volume, and intensity. For example, a higher load, such as 80% of one-repetition maximum (1RM), may contribute to a more pronounced increase in

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Address for correspondence: Edilson Serpeloni Cyrino, Ph.D., Metabolism, Nutrition, and Exercise Laboratory. State University of Londrina. Rodovia Celso Garcia Cid km 380, 86057-970, Londrina, PR, Brazil; E-mail: edilsoncyrino@gmail.com.

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muscular strength. In contrast, a wide load spectrum induces SMM gains (9).

In this regard, prestigious organizations such as the American College of Sports Medicine (ACSM) (2) and the National Strength and Conditioning Association (NSCA) (1) published position statements and guidelines providing recommendations for the effective prescription of RT programs, especially for older adults, based on the available higher level scientific evidence. For example, in its two positions in 2009, ACSM suggests using load corresponding to 8–12RM to improve strength and hypertrophy in this population (2,10). Notwithstanding, the optimal intensity to promote muscular adaptations in older adults remains a topic of investigation that allows revisiting some recommendations. In this regard, in 2011, the ACSM suggested using 10–15RM for older adults (11). Similarly, illustrating that the optimal intensity remains elusive, in its recent position statement on RT for older adults, NSCA recommends using 8–12RM or 10–15RM (1).

Recently, more divergence has emerged, indicating that lower-load (30–35RM) may be more effective for increasing SMM than higher-load (8–12RM) while promoting similar muscular strength gains in older women after 12 wk of RT (12). Also, no difference in muscular strength and SMM was found after 8 wk of RT in moderate and low load (10RM vs 15RM) in older women (13). Furthermore, given the role of SMM in regulating metabolism and as an endocrine tissue (14,15), it has been proposed that SMM increases may play a mediator role in RT-induced metabolic and endocrine adaptations. Based on this, it is reasonable to believe that RT programs that elicit greater gains in SMM could result in more favorable metabolic and endocrine adaptations. However, the studies that evaluated the potential differences between lower and higher loads on metabolic profile in older adults yield conflicting results (12,16–18).

From a broad perspective, the current scenario illustrates that the optimal intensity to elicit improvement in muscular strength, muscle mass, and metabolic parameters remains to be determined. Therefore, the purpose of the present study was to compare the effects of 12 wk of RT with two different ranges of training loads (8–12RM vs 10–15RM) on muscular strength, functional performance, SMM, and metabolic biomarkers in older women. In addition, we analyzed the hydration status (intracellular and extracellular body water) to understand the morphological adaptations' nature. We hypothesize that training with higher loads (8–12RM) might promote a superior increase in muscular strength. Also, based on the relationship between strength gains and improvement in gait speed (8), this group would experience more favorable improvements in functional performance. Conversely, lower loads (10–15RM) would elicit superior gains in SMM, and this would be accompanied by more favorable changes in cellular hydration and metabolic adaptations.

METHODS

Study overview. The present study is part of the research project "Active Aging Longitudinal Study," initiated in 2012, whose purpose is to analyze the impact of supervised, structured, and progressive RT programs on neuromuscular, morphological, physiological, metabolic, cognitive, and behavioral outcomes in older women (19). This study was carried out over 18 wk, with 12 wk dedicated to the RT program and 6 wk for data collection. We collected anthropometric, maximal dynamic strength, and body composition measurements at weeks 1 to 3 and weeks 16 to 18. Participants performed the RT program over weeks 4 to 15, and we monitored the dietary intake in the first and last 2 wk of training. Physical Education professionals supervised all training sessions. Participants were instructed not to perform any other type of physical exercise throughout the study. Based on recommendations from the current RT position statements for older adults, the sample was randomly assigned according to the relative strength in two groups (8–12RM or 10–15RM).

Participants. We recruited participants through social media (Whatsapp, Facebook, and Instagram). All participants completed health history questionnaires and met the following inclusion criteria: >60 yr; female; physically independent; had no cardiac, orthopedic, or musculoskeletal dysfunction that could impede physical exercise; not having uncontrolled diabetes mellitus or hypertension; not receiving hormonal replacement therapy; and not be involved in the practice of regular physical activity performed more than once a week over the three months before the start of the study. Participants were included in this study only after passed by a diagnostic, graded exercise stress test with a 12-lead electrocardiogram reviewed by a cardiologist. We established adherence to the program with a minimum participation of 85% of the sessions. We used previous data from our laboratory for the sample size estimation (6,20,21) using G*Power (version 3.1.9.6). The analysis indicated that at least 90 participants were needed for adequate statistical power (effect size = 0.30; power = 0.80; $\alpha = 0.05$; time = 2; groups = 2). Participants signed a written informed consent after receiving a detailed description of the investigation procedures. This study was conducted according to the Declaration of Helsinki and was approved by the local university ethics committee. A flowchart of the present study is displayed in Figure 1.

Body composition. Upper limbs (ULLST) and lower limbs lean soft tissue (LLLST) measurements were carried out by dual-energy X-ray absorptiometry (DXA) scan in a Lunar Prodigy device, model NRL 41990 (General Electric, Madison, WI, USA) to determine the appendicular lean soft tissue. Skeletal muscle mass was estimated using the following equation: $\text{SMM} = (1.13 \times \text{appendicular LST}) - (0.02 \times \text{age}) + 0.97$ (22). At the time of evaluation, the participants removed all metal objects, such as earrings, watches, chains, and bracelets, from the body before the exams started. Scans were performed with the participants lying in the supine position. The feet were taped to the toes to immobilize the legs, while the hands were held in a prone position within the scanning region. Participants remained immobile throughout the scanning procedure. A qualified and experienced laboratory technician performed the calibrations and analyses. The software generated standard lines

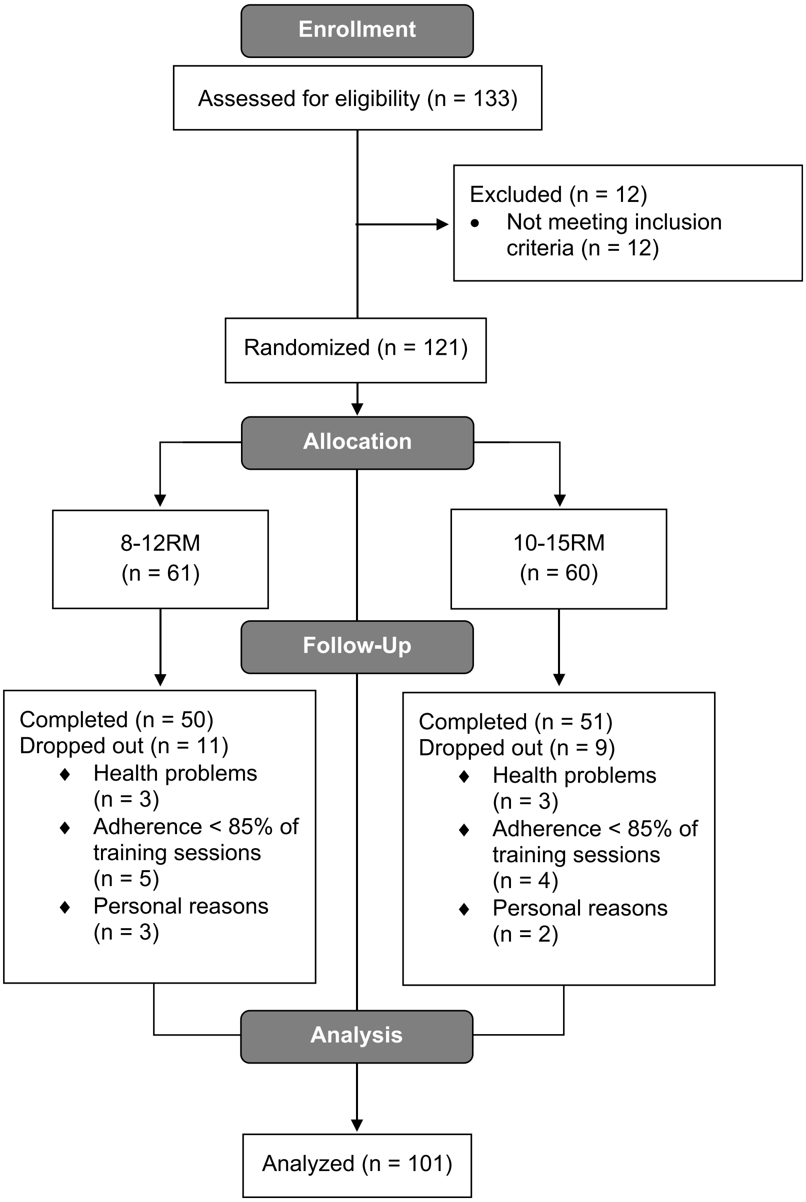

FIGURE 1—Flowchart of the study.

that separate the head, trunk, and upper and lower limb segments. These lines were adjusted by the same technician using anatomical points determined by the manufacturer. The analyses preintervention and postintervention were performed by the same technician, who was blind to the group identity of each participant. Reassessments of LST were performed at an interval of 96–120 h after the final training session. The SEM and ICC in our laboratory were calculated for ULLST (SEM = 0.1 kg; ICC = 0.99) and LLLST (SEM = 0.2 kg; ICC = 0.99).

Total body water (TBW), extracellular water (ECW), and intracellular water (ICW) were estimated by a spectral bioelectrical impedance in a Xitron Hydra analyzer, model 4200 (Xitron Technologies Inc., San Diego, CA), in the morning hours. The device was calibrated according to the manufacturer's recommendations. Participants were instructed to refrain from consuming alcoholic and caffeinated beverages for at least 48 h, avoid strenuous physical exercise for at least 24 h, refrain from ingesting food or drink in the previous 4 h, and urinate ~30 min before the evaluation. Participants removed all metal objects from the body before the measurements began, like in body composition assessments. Measurements were performed on a table isolated from electrical conductors with participants lying supine along the table's longitudinal centerline axis, legs abducted at an angle of 45° relative to the body midline, and hands pronated. After cleaning the skin with alcohol, two electrodes were placed on the surface of the right hand and two on the right foot (23). The TBW, ECW, and ICW are expressed in liters (L). The same researcher performed the exams in the baseline and posttraining periods. Hydration parameters were reassessed 96–120 h after the final training session on the same day of DXA measurements. The ICC for all measures was ≥0.98, and the SEM was ≤0.38 L.

Muscular strength. The maximal dynamic muscular strength was determined in three exercises by the 1RM test in the following order: chest press, leg extension, and preacher curl. All tests were standardized and supervised by experienced researchers to ensure proper technique, reliability, and participants' safety and integrity. Participants performed a warm-up set (6–10 repetitions) with approximately 50% of the estimated weight used in the first attempt. The testing procedure was initiated 2 min after the warm-up. Participants attempted to perform two repetitions at the imposed weight. The weight was adjusted by 3% to 10% for the next attempt if the effort was successful (one or two repetitions completed). In contrast, the weight was removed in the same proportion if an attempt was unsuccessful. The rest period between each attempt was 3 to 5 min. The 1RM was recorded in each testing session as the maximal lifted weight in which the participant could complete only one concentric and eccentric muscular action. Three 1RM sessions were performed separated by 48 h, and the highest weight lifted in each exercise over three sessions was used for analysis (24). Verbal encouragement was provided throughout each test. The ICC from our lab for these tests is ≥0.96 with an SEM ≤ 2.0 kg.

Functional fitness. Four tests were used to determine functional performance: gait speed (4-m usual walking speed), timed-up-and-go (TUG), 30-s chair stand, and 6-min walking test (6MWT). Two evaluators used stopwatches (KIKOS, São Paulo, SP, Brazil) to measure participants' time in the 4-m usual walking speed test. Adhesive tapes on the floor demarcated this distance with additional 2-m patches before and after the 4-m main patch. Participants walked 8 m, but only the time spent walking the middle 4 m was recorded. Participants completed three attempts, with the mean value used for analysis. For the TUG test, participants were seated on a chair supported by a wall, with their back in contact with the backrest, feet fully supported on the floor, and hands rested on the thighs. Participants were requested to stand up, walk around a cone at a distance of 3 m in front of the chair, return to the chair, and sit down. Participants were instructed to complete the path as quickly as possible without running. Time was recorded to the nearest 0.01 s with a stopwatch from the initial movement to rise from the chair until returning to sit down again. Participants completed three trials, with the best value recorded for analysis. For the 30-s chair stand test, participants were seated on a chair supported by a wall, with their back in contact with the backrest, feet fully supported on the floor, and hands crossed to rest on their opposite shoulders. Participants performed the maximum sit-to-stand repetitions possible for 30 s. Two evaluators participated in the 30-s chair stand test. An recorded the time, and the other counted the number of repetitions performed. For the 6MWT, each participant was instructed to walk as far as possible, without running, for 6 min around a rectangular path (4.6 × 18.4 m; total perimeter, 46.0 m) marked with cones on the floor. An evaluator timed the test time, counted the number of laps, and calculated the total distance covered with an accuracy of 1 m.

Metabolic biomarkers. The venous blood sample was collected into a tube containing dipotassium ethylenediaminetetraacetic acid (12 mL, vacuum-sealed system; Vacutainer, England, UK) between 7:00 and 9:00 a.m. by a trained laboratory technician after an overnight fast of at least 12 h. Participants rested in a sitting position for 5 min before drawing 5 mL of blood from a prominent superficial vein in the antecubital space. All samples were centrifuged at 3,000 rpm for 15 min, and aliquots of plasma or serum were stored at −80°C until analyzed. As determined in human plasma, the between-assay and within-assay coefficients of variation were <10%. Assessments of serum levels of high-sensitivity C-reactive protein, glucose, total cholesterol (TC), high-density lipoprotein cholesterol (HDL-c), and triglycerides (TGs) were determined by standard methods in a specialized laboratory at the University Hospital. Low-density lipoprotein cholesterol (LDL-c) was calculated using the following equation: $\text{LDL-c} = \text{TC} - (\text{HDLc} + \text{TG}/5)$. Analyzes were performed using a Dimension RxL Max biochemical autoanalyzer system (Siemens Dade Behring, Erlangen, Germany) according to methods established in the literature consistent with the manufacturer's protocol.

Resistance training. The RT program was performed three times a week (Mondays, Wednesdays, and Fridays), during the morning period, in the University fitness facility, and was carried out over 12 wk. The training was based on recommendations for RT in older adults to improve muscle hypertrophy and strength (1,2,11). Physical Education professional personally supervised all participants throughout each training session to reduce deviations from the study protocol and to ensure proper technique and safety. Participants performed RT using a combination of free weights and machines. The RT protocol consisted of a whole-body program with eight exercises performed in the following order: chest press, horizontal leg press, seated row, leg extension, triceps pushdown, leg curl, preacher curl, and seated calf raise. Participants performed either three sets of 8–12RM or 10–15RM and were instructed to inspire during the eccentric phase, exhale during the concentric phase, and maintain the movement velocity at a ratio of 1:2 (concentric and eccentric phases, respectively). Rest intervals were 1–2 min between sets and 2–3 min between exercises. The supervisors adjusted the weight of each exercise according to the participant's ability and improvements in exercise capacity throughout the study to ensure maintaining intensity. When participants completed the upper limit of repetitions in all sets for two consecutive sessions, the weight was increased by 2%–5% for the upper limb exercises and 5%–10% for the exercises of the lower limbs (10). The volume load was calculated by multiplying the number of repetitions and the weight lifted in all sets in the eight exercises, including the three weekly sessions.

Dietary intake. The 24-h dietary recall method was used to analyze the food consumption. Two experienced dietitians conducted the assessments on three nonconsecutive days of the week in RT's first and last 2 wk. The dietitians provided specific instructions regarding recording portion sizes and quantities to estimate all food and fluid intake, including viewing food models to enhance portion estimate precision. Total energy intake, carbohydrate, protein, and lipid dietary content were calculated in the Virtual Nutri Plus software (Keeple®, Rio de Janeiro, RJ, Brazil). Food composition tables were used to add the items not found in the program database. All participants were asked to maintain their eating habits throughout the study.

Statistical analyses. Shapiro–Wilk's test verified data distribution. Levene's test checked the homogeneity of the variances. The *t* test was used to compare the general characteristics of the variables at the baseline between the groups. Repeated-measures two-way ANOVA was used for within- and between-group comparisons for dietary intake variables, a weekly average of the number of repetitions, load, and volume load accumulated per session. The effects of 8–12RM and 10–15RM on primary outcomes (i.e., muscular strength, physical performance, skeletal muscle mass, and metabolic parameters) were compared using the analysis of covariance (ANCOVA) of the raw difference between pretraining and posttraining measures with baseline values as a covariate. The effect of time was interpreted from the 95% confidence interval (CI) of the mean difference pretraining to posttraining (i.e., when the 95% CI of the change delta did not overlap the 0, there was a difference between the baseline score). The effect size was calculated to verify the magnitude of the differences by Cohen's *d*, where an effect size of 0.00 to 0.19 was considered trivial; 0.20 to 0.49, small; 0.50 to 0.79, moderate; and ≥0.80 large (25). In addition, we calculated the percentage change (Δ%) as posttraining mean minus pretraining mean, divided by pretraining multiplied by 100. For all statistical analyses, significance was accepted at $P < 0.05$. The data are presented as mean and standard deviations, mean difference, and 95% CI. The data were stored and analyzed in Jeffreys' Amazing Statistics Program (JASP), version 0.11.1 (University of Amsterdam, Amsterdam, NL).

RESULTS

Baseline characteristics and dietary intake. One hundred one participants completed the intervention (8–12RM: $n = 51$, age = 69.5 ± 6.9 yr, body mass = 64.5 ± 11.4 kg, stature = 154.1 ± 5.5 cm; 10–15RM: $n = 50$, age = 67.7 ± 5.3 yr, body mass = 64.7 ± 11.5 kg, stature 155.5 ± 5.6 cm). No between-groups differences were revealed for these variables at baseline ($P > 0.05$). Also, no difference was found for total energy, carbohydrate, protein, and lipid in the comparisons between or intra-groups over intervention ($P > 0.05$). Dietary intake data in RT's first and last 2 wk are presented in Supplemental Table 1 (Supplemental Digital Content, Energy and macronutrient intake at the first and last week of resistance training program, http://links.lww.com/MSS/C845).

Number of repetitions, load, and volume load. The weekly average of the number of repetitions, load, and volume load at weeks 1 and 12 for each exercise are presented in Table 1. The number of repetitions was higher in the 10–15RM group in all exercises at weeks 1 and 12 ($P < 0.05$). Conversely, the load was higher in the 8–12RM group in all exercises at weeks 1 and 12 ($P < 0.05$). At week 1, the volume load was higher for the 8–12RM in seated leg curl and seated calf raise ($P < 0.05$), with no difference in the rest of the exercises. At week 12, the volume load was higher for the 10–15RM in leg press, triceps pushdown, seated leg curl, and seated calf raise ($P < 0.05$), with no difference in the rest of the exercises.

Muscular strength and functional performance. Changes in chest press, leg extension, preacher curl, gait speed, TUG, 30-s chair stand, and 6MWT are presented in Table 2. Both 8–12RM and 10–15RM groups increased muscular strength ($P < 0.01$) according to the results in 1RM tests at baseline. Changes were superior for the 8–12RM group in chest press (8–12RM = +23.2%, ES = 1.27 vs 10–15RM = +10.7%, ES = 0.55; $P < 0.01$) and preacher curl (8–12RM = +15.7%, ES = 0.88 vs 10–15RM = +7.4%, ES = 0.38; $P < 0.01$) exercises, but the magnitude of changes did not differ between them for leg press (8–12RM = +14.9%, ES = 0.54 vs 10–15RM = +12.3%, ES = 0.48; $P > 0.05$). Similarly, both groups significantly improved ($P < 0.05$) the performance in the gait speed test, with no difference between them (8—2RM = +4.6%, ES = 0.41 vs 10–15RM = +5.6%, ES = 0.41; $P > 0.05$). None of the groups experienced significant changes in the performance of the TUG test (8–12RM = −1.3%, ES = −0.15 vs 10–15RM = −2.6%, ES = −0.20; $P > 0.05$). Both groups increased the number of repetitions in the 30-s chair stand test, with no difference between them (8–12RM = +5.9%, ES = 0.28 vs 10–15RM = +4.6%, ES = 0.17; $P > 0.05$). Similarly, both groups enhanced the performance in the 6MWT, with no difference between them (8–12RM = +7.0%, ES = 0.66 vs 10–15RM = +6.7%, ES = 0.52; $P > 0.05$).

Body composition. Changes in ULLST, LLLST, SMM, ICW, ECW, and TBW for the 8–12RM and 10–15RM groups are shown in Table 3. Although both groups increased ULLST, LLLST, and SMM after 12 wk of RT, changes were superior in the 10–15RM group for ULLST (8–12RM = +3.9%, ES = 0.24 vs 10–15RM = +9.0%, ES = 0.58; $P < 0.01$), LLLST (8–12RM = +2.1%, ES = 0.13 vs 10–15RM = +5.4%, ES = 0.40; $P < 0.01$), SMM (8–12RM = +2.5%, ES = 0.16 vs 10–15RM = +6.3%, ES = 0.44; $P < 0.01$). However, only the 10–15RM group improved the hydration status after the intervention period according to the results found for ICW (8–12RM = −0.8%, ES = 0.06 vs 10–15RM = +2.1%, ES = 0.19; $P < 0.01$), ECW (8–12RM = −1.0%, ES = −0.11 vs 10–15RM = +2.8%, ES = 0.17; $P < 0.01$), and TBW (8–12RM = −0.9%, ES = −0.09 vs 10–15RM = +2.4%, ES = 0.21; $P < 0.01$).

Metabolic biomarkers. Glucose, glycated hemoglobin, HDL-c, LDL-c, total cholesterol, triglycerides, and C-reactive protein concentrations for both groups at baseline and posttraining also are presented in Table 4. Only the 10–15RM group decreased glucose (10–15RM = −4.9%, ES = −0.28 vs 8–12RM = −0.2%, ES = −0.01; $P < 0.05$) and increased HDL-c (8–12RM = −0.2%, ES = −0.01 vs

TABLE 1. Weekly average of number of repetitions, load, and volume-load at the first and last week of RT program.

		8–12RM (*n* = 51)		10–15RM (*n* = 50)				
Exercises	**Variables**	**Week 1**	**Week 12**	**Week 1**	**Week 12**	***P* Time**	***P* Group**	***P* Interaction**
Chest press	Reps (n°)	35.9 ± 0.1	35.4 ± 2.6	41.0 ± 3.3**	44.0 ± 1.7*,**	<0.001	<0.001	<0.001
	Load (kg)	26.0 ± 4.3	30.5 ± 5.0*	23.5 ± 3.8**	25.6 ± 4.6*,**	<0.001	<0.001	<0.001
	VL (kg)	937.5 ± 156.2	1084.0 ± 202.7*	968.9 ± 186.4	1133.1 ± 222.7*	<0.001	0.265	0.464
Leg press	Reps (n°)	34.6 ± 2.1	35.3 ± 1.5	44.6 ± 0.9**	44.3 ± 1.6**	0.361	<0.001	0.014
	Load (kg)	58.6 ± 12.5	69.2 ± 14.0*	42.2 ± 10.4**	61.9 ± 14.0*,**	<0.001	<0.001	<0.001
	VL (kg)	2037.3 ± 478.2	2453.5 ± 532.8*	1890.4 ± 475.7	2750.7 ± 649.2*,**	<0.001	0.448	<0.001
Seated row	Reps (n°)	35.4 ± 0.7	34.0 ± 2.2*	42.9 ± 2.4**	41.2 ± 3.0*,**	<0.001	<0.001	0.563
	Load (kg)	24.2 ± 4.9	29.0 ± 5.5*	18.6 ± 3.2**	26.3 ± 4.7*,**	<0.001	<0.001	<0.001
	VL (kg)	860.4 ± 175.5	990.3 ± 215.8*	806.6 ± 154.7	1088.7 ± 217.7*	<0.001	0.519	< 0.001
Leg extension	Reps (n°)	35.6 ± 0.4	35.1 ± 1.1	42.5 ± 2.1**	40.8 ± 2.6*,**	<0.001	<0.001	0.020
	Load (kg)	20.7 ± 6.5	31.4 ± 8.4*	14.5 ± 4.4**	24.5 ± 7.4*,**	<0.001	<0.001	0.480
	VL (kg)	742.2 ± 232.1	1105.7 ± 309.1*	618.6 ± 199.3	1004.0 ± 314.6*	<0.001	0.024	0.478
Triceps pushdown	Reps (n°)	35.8 ± 0.4	35.1 ± 1.2*	44.4 ± 1.2,**	43.7 ± 1.9*,**	<0.001	<0.001	0.931
	Load (kg)	21.5 ± 2.8	26.6 ± 4.1*	16.5 ± 2.4**	24.4 ± 3.8*,**	<0.001	<0.001	<0.001
	VL (kg)	773.7 ± 105.9	936.0 ± 158.5*	734.8 ± 112.0	1071.1 ± 180.6*,**	<0.001	0.053	<0.001
Seated leg curl	Reps (n°)	35.1 ± 1.0	33.9 ± 1.4*	43.1 ± 1.9**	41.5 ± 3.0*,**	<0.001	<0.001	0.450
	Load (kg)	31.5 ± 5.0	36.0 ± 5.6*	23.3 ± 3.5**	32.7 ± 4.6*, **	<0.001	<0.001	<0.001
	VL (kg)	1111.5 ± 191.9	1225.1 ± 214.8*	1009.8 ± 166.1**	1362.7 ± 213.6*,**	<0.001	0.612	<0.001
Preacher curl	Reps (n°)	35.7 ± 0.8	34.3 ± 2.0*	43.8 ± 1.8**	41.9 ± 2.6*,**	<0.001	<0.001	0.344
	Load (kg)	17.9 ± 3.7	21.7 ± 4.3*	12.9 ± 2.6**	19.5 ± 4.1***	<0.001	<0.001	<0.001
	VL (kg)	640.5 ± 137.0	746.7 ± 163.1*	567.5 ± 123.8	817.5 ± 175.0*	<0.001	0.968	< 0.001
Seated calf raise	Reps (n°)	35.7 ± 0.6	33.9 ± 1.6*	44.6 ± 1.9**	43.9 ± 1.5**	<0.001	<0.001	0.016
	Load (kg)	34.0 ± 7.9	38.8 ± 8.2*	20.0 ± 4.2**	34.6 ± 7.0*,**	<0.001	<0.001	< 0.001
	VL (kg)	1212.8 ± 275.9	1295.7 ± 360.2	898.5 ± 195.8**	1524.2 ± 316.0*,**	<0.001	0.401	< 0.001

The VL was calculated by multiplying the number of repetitions and the weight lifted.
**P* < 0.05 vs week 1.
***P* < 0.05 vs 8–12RM at the same period.
Reps, number of repetitions; VL, volume load.

10–15RM = +4.7%, ES = 0.17; $P < 0.01$). Both groups decreased ($P < 0.05$) glycated hemoglobin (8–12RM = −7.9%, ES = −0.77 vs 10–15RM = −6.5%, ES = −1.33), LDL-c (8–12RM = −10.9%, ES = −0.38 vs 10–15RM = −5.0%, ES = 0.18), total cholesterol (8–12RM = −5.3%, ES = −0.24 vs 10–15RM = −3.4%, ES = 0.17), and C-reactive protein (8–12RM = −16.7%, ES = −0.28 vs 10–15RM = −16.1%, ES = −0.25; $P > 0.05$), with no differences between them ($P < 0.05$). For triglycerides, only the 10–15RM group significantly decreased, but the magnitude of changes did not differ between groups (8–12RM = +5.6%, ES = 0.10 vs 10–15RM = −11.3%, ES = −0.28; $P > 0.05$).

DISCUSSION

The main findings of the present study were: (a) Twelve weeks of RT resulted in increased muscular strength, improved functional fitness, and SMM gains in both 8–12RM e 10–15RM groups; (b) a greater increase in upper limb muscular strength occurred in the 8–12RM group, but no difference was observed for lower limb muscular strength increases between the 8–12RM and 10–15RM groups; (c) a higher increase in ULLST, LLLST, SMM, TBW, ECW, and ICW was found in the 10–15RM group; and (d) both groups experienced an improvement in metabolic profile, but 10–15RM elicited more favorable changes in glucose, HDL-c, and triglycerides. Therefore, results found in this study partially confirmed our initial hypothesis on muscular strength and functional fitness since 1RM performance increases favored the 8–12RM group in the upper. Moreover, the results support our hypothesis about greater hypertrophy in the lower load group, since 10–15RM was more effective than 8–12RM for SMM gains. Interestingly, this result was accompanied by increased intracellular hydration, a potential mechanism for muscle hypertrophy (26,27), and improved metabolic profile.

Regarding muscular strength and functional fitness, we observed an increase of higher magnitude in the chest press and

TABLE 2. Muscular strength and functional fitness at pretraining and posttraining.

	8–12RM (*n* = 51)			10–15RM (*n* = 50)			
Variables	**Pretraining**	**Posttraining**	**Δ (95% CI)**	**Pretraining**	**Posttraining**	**Δ (95% CI)**	**ANCOVA Effects**
Chest press (kg)	42.0 ± 8.6	51.9 ± 10.9*	9.7 (8.4 to 11.0)	42.0 ± 6.8	46.3 ± 7.1*,**	4.2 (2.9 to 5.5)	<0.001
Leg extension (kg)	53.8 ± 14.9	60.9 ± 14.6*	7.0 (4.3 to 9.6)	50.4 ± 11.0	56.8 ± 13.2*	5.8 (3.2 to 8.4)	0.479
Preacher curl (kg)	21.9 ± 3.6	25.1 ± 3.7*	3.3 (2.5 to 4.0)	21.1 ± 3.6	22.5 ± 3.8*,**	1.3 (0.5 to 2.0)	<0.001
Gait speed ($m \cdot s^{-1}$)	1.22 ± 0.13	1.28 ± 0.19*	0.05 (0.01 to 0.09)	1.26 ± 0.16	1.32 ± 0.19*	0.06 (0.03 to 0.10)	0.594
TUG (s)	6.50 ± 1.11	6.36 ± 1.06	−0.16 (−0.34 to 0.00)	6.84 ± 0.75	6.65 ± 0.76	−0.16 (−0.33 to 0.01)	0.940
30-s chair stand (reps)	14.1 ± 2.4	14.9 ± 2.9*	0.7 (0.1 to 1.3)	13.8 ± 3.4	14.3 ± 3.9*	0.5 (0.0 to 1.1)	0.671
6MWT (m)	482.5 ± 47.2	517.1 ± 75.4*	34.7 (21.1 to 48.4)	475.0 ± 58.1	502.3 ± 61.3*	30.4 (18.8 to 42.0)	0.585

Pretraining and posttraining data are presented as mean and standard, whereas mean difference as mean and 95% confidence interval.
**P* < 0.05 vs pretraining.
***P* < 0.05 vs 8–12RM based on baseline-adjusted ANCOVA.

TABLE 3. Regional lean soft tissue, skeletal muscle mass, and hydration at pretraining and posttraining.

	8–12RM ($n = 51$)			10–15RM ($n = 50$)			
Variables	**Pretraining**	**Posttraining**	**Δ (95% CI)**	**Pretraining**	**Posttraining**	**Δ (95% CI)**	**ANCOVA Effects**
ULLST (kg)	3.71 ± 0.58	3.85 ± 0.55*	0.13 (0.08 to 0.19)	3.69 ± 0.58	4.02 ± 0.59*,**	0.31 (0.26 to 0.37)	<0.001
LLLST (kg)	11.70 ± 1.70	11.93 ± 1.57*	0.20 (0.03 to 0.37)	11.91 ± 1.67	12.60 ± 1.74*,**	0.64 (0.47 to 0.81)	<0.001
SMM (kg)	17.0 ± 2.5	17.4 ± 2.3*	0.37 (0.15 to 0.60)	17.2 ± 2.4	18.3 ± 2.5*,**	1.08 (0.85 to 1.30)	<0.001
ICW (L)	17.5 ± 1.6	17.4 ± 1.4	−0.18 (−0.41 to 0.05)	17.8 ± 1.5	18.1 ± 1.6*,**	0.38 (0.13 to 0.62)	<0.001
ECW (L)	12.0 ± 1.8	11.8 ± 1.7	−0.16 (−0.36 to 0.04)	12.2 ± 1.7	12.5 ± 1.8*,**	0.33 (0.12 to 0.54)	<0.001
TBW (L)	29.6 ± 3.4	29.3 ± 3.2	−0.34 (−0.78 to 0.09)	30.0 ± 3.2	30.7 ± 3.4*,**	0.71 (0.25 to 1.17)	<0.001

Pretraining and posttraining data are presented as mean and standard, whereas mean difference as mean and 95% confidence interval.

*$P < 0.05$ vs pretraining.

**$P < 0.05$ vs 8–12RM based on baseline-adjusted ANCOVA.

preacher curl exercises favorably to the 8–12RM; however, without between-group differences in the 1RM leg extension and functional tests. Our findings may be explained, at least in part, by the principle of specificity, which suggests that the higher the load intensity adopted in training, the strength gains tend to be higher (28). Indeed, this helps explain our results since the load lifted by the 8–12RM group was greater than that of the 10–15RM group in all exercises (see Table 1). Notably, 8–12RM elicited superior strength gains in the upper limbs, but not in the lower limbs. A possible explanation for these findings may lie in the difference in adaptability between upper and lower limbs. For example, reports are pointing to greater adaptability of the upper limbs relative to the lower limbs for the same RT scheme (29–31). Thus, it is reasonable to suggest that higher intensities may be needed to optimize lower limb strength gains. Regarding functional fitness, we initially hypothesized that strength gains could favor performance in motor tests based on a linear relationship between a 1RM leg extension increase and an improvement in the gait speed (8). Given the similarity of lower limb strength gains between groups, this result helps to contextualize the similar improvement in functional performance (e.g., gait speed, 30-s chair stand test) between the groups.

Regarding the changes in SMM, we observed that 10–15RM elicited greater gains than 8–12RM. A possible explanation for this result may be in the characteristics of the muscle tissue of the older adults since it has a lower number and size of myosin heavy chain (MHC) II fibers (32) and, consequently, their responsiveness to RT with higher load. For instance, a recent meta-analysis found an inverse relationship between higher intensity and magnitude of hypertrophy in MHC II fibers ($\beta = -0.39$, $P = 0.01$) in older adults (33). Given that the size of MHC II fibers is reduced to a greater magnitude with increasing age (32), the 8–12RM group (higher load, ~60%–80% of 1RM) may have experienced lower hypertrophy of MHC II fibers and, consequently, lower whole muscle growth than the 10–15RM group (low-to-moderate load, ~40%–60% of 1RM). In addition, 10–15RM may have stimulated hypertrophy of both types of fibers (32,34). Indeed, a recent meta-analysis found that moderate-training intensities elicited the highest increases in whole muscle following RT in older adults (34). Parallel to this, 10–15RM allowed for performing more repetitions (see Table 1). Notably, higher RT volume frequently results in greater gains in muscle mass (12,35). Therefore, this factor may have contributed to the superiority in SMM gains elicited by lower load over the higher load group.

Our study revealed that the 10–15RM group increased ICW, ECW, and TBW more than the 8–12RM group. In this regard, cell hydration or cell swelling has been identified as a possible mechanism of muscle hypertrophy because it favors an increase in protein myofibrillar synthesis and a reduction in proteolysis (27). Cell swelling may be optimized by exercise that relies heavily on glycolysis and protocols that induce an increased glycogen storage capacity (27), such as higher repetitions/lower loads. This phenomenon seems to occur because one glycogen molecule attracts ~3 g of water (27,36). Muscle fibers, especially type II fibers, are sensitive to osmotic changes related to their high concentration of water transport channels named aquaporin-4 (27). This water transport channel may facilitate plasma entry into the cell (37), resulting in higher cell swelling. Given that the 10–15RM group performed a greater number of repetitions, this may have contributed to adjustments favorable to the increase in intracellular hydration, which in turn promoted a more anabolic cellular environment, ultimately inducing a superior rise in SMM.

TABLE 4. Metabolic profile in older women at pretraining and posttraining.

	8–12RM ($n = 51$)			10–15RM ($n = 50$)			
Variables	**Pretraining**	**Posttraining**	**Δ (95% CI)**	**Pretraining**	**Posttraining**	**Δ (95% CI)**	**ANCOVA Effects**
Glucose ($\text{mg}\cdot\text{dL}^{-1}$)	103.5 ± 29.7	103.3 ± 25.7	−0.3 (−2.5 to 1.8)	105.6 ± 19.3	100.4 ± 18.4*,**	−5.2 (−7.1 to −3.3)	<0.001
Glycated hemoglobin ($\text{mg}\cdot\text{dL}^{-1}$)	6.3 ± 0.6	5.8 ± 0.7*	−0.5 (−0.5 to −0.4)	6.2 ± 0.3	5.8 ± 0.3*	−0.3 (−0.4 to −0.2)	0.223
HDL-c ($\text{mg}\cdot\text{dL}^{-1}$)	62.8 ± 17.1	62.7 ± 15.5	−0.1 (−2.4 to 2.2)	59.1 ± 16.0	62.7 ± 17.4*,**	3.6 (1.6 to 5.6)	0.032
LDL-c ($\text{mg}\cdot\text{dL}^{-1}$)	117.0 ± 34.9	104.3 ± 31.5*	−12.8 (−17.8 to −7.7)	118.4 ± 33.5	112.5 ± 32.4*	−5.9 (−10.3 to −1.6)	0.206
Total cholesterol ($\text{mg}\cdot\text{dL}^{-1}$)	200.8 ± 44.0	190.2 ± 39.7*	−10.6 (−17.3 to −3.9)	203.6 ± 39.5	196.7 ± 42.5*	−7.0 (−12.7 to −1.1)	0.390
Triglycerides ($\text{mg}\cdot\text{dL}^{-1}$)	104.4 ± 73.9	110.2 ± 42.9	5.7 (−9.0 to 20.6)	117.6 ± 52.0	104.3 ± 43.9*	−13.0 (−25.9 to −0.2)	0.107
C-reactive protein ($\text{mg}\cdot\text{dL}^{-1}$)	3.0 ± 2.0	2.5 ± 1.6*	−0.4 (−0.9 to −0.0)	3.1 ± 2.2	2.6 ± 1.8*	−0.5 (−0.9 to −0.1)	0.859

Pretraining and posttraining data are presented as mean and standard, whereas mean difference as mean and 95% confidence interval.

*$P < 0.05$ vs pretraining.

**$P < 0.05$ vs 8–12RM based on baseline adjusted ANCOVA.

Despite this, it is essential to note that although it is a plausible hypothesis, additional investigations are necessary to elucidate underlying mechanisms for such differences in SMM gains between different loads/repetitions schemes in older women.

Regarding metabolic biomarkers, we observed more favorable adaptations in the 10–15RM group. More specifically, greater glucose reductions and HDL-c increases were found in this group. Furthermore, only 10–15RM elicited triglycerides reduction. A body of evidence has led to the hypothesis that SMM gains may be a mediator of RT-induced improvement in metabolic function (38). Given that the 10–15RM group showed superior SMM gains, it is reasonable to believe that this adaptation contributed to higher glucose uptake and utilization (39). Also, more significant amounts of SMM may have been essential in reducing triglycerides via increased resting energy expenditure (39,40).

Furthermore, we do not rule out the role of muscle contractions on increases glucose and lipids uptake (e.g., for energy production) and improving insulin sensitivity. Thus, the greater number of repetitions performed by the 10–15RM group may have played an essential role in the more favorable metabolic adaptations in the lower load group (38). Specifically, regarding the changes in HDL-c levels, a potential explanation may be an improvement in the lipoprotein profile due to better functioning of the enzymatic processes involved in lipid metabolism (e.g., increase in enzymes lecithin-cholesterol-acyltransferase and lipoprotein lipase) (41). Notably, this argument is valid for higher and lower load schemes. Thus, the exact mechanisms by which the 10–15RM group optimized the HDL-c increase still need to be determined since current evidence is inconsistent regarding the role of RT in increasing HDL-c (42). Therefore, confirmatory work is required.

The present study has strengths and limitations that should be considered. First, the results observed were in untrained older women and should not be extrapolated to other populations. Second, we did not assess free-living physical activity and sedentary behavior, so the extent to which any changes occurring in these variables may have affected the present findings is unknown. However, all participants were instructed not to engage in any other physical exercise program throughout the investigation. In contrast, some positive points of the present study deserve to be highlighted. The design adopted with a randomized sample and balanced according to the relative strength of the participants allowed the groups to be similar at the beginning of the study. Notably, the absence of a nontraining control group makes it difficult to assess how much of the changes were due to learning effects or other potential confounding factors. Thus, future studies may consider including a nontraining control group to quantify the net effects of different loading schemes on strength, physical performance, SMM, and metabolic adaptations. Another positive point of our study is the methods for evaluating morphological changes. Both DXA and bioelectrical impedance are valid methods and highly recommended to assess SMM and hydration, respectively, in the older population because they are considered noninvasive, accurate, and can provide additional information on other health parameters, such as bone mineral density, body fat, fat distribution, and phase angle (43). In addition, we monitored the food consumption in the first and last 2 wk of RT. The maintenance of eating habits in both groups strengthens the adaptive responses found in the present study, especially SMM gains. The supervision in all RT sessions by physical education professionals allows adequate control da exercise execution, with individualized monitoring, attenuating the risk of injuries and favoring the progression of the RT program (44).

CONCLUSIONS

Our results suggest that 12 wk of RT with loads corresponding to 8–12RM and 10–15RM promote increases in muscular strength and improve functional fitness, SMM gains, and improvements in the metabolic profile of physically independent older women. Notably, the superior augment of muscular strength in upper limbs occurs with 8–12RM but not in lower limbs, whose responses at 8–12RM or 10–15RM are similar. In contrast, the highest gain in SMM occurs at 10–15RM, and this adaptation may be accompanied by increased intracellular hydration and more favorable changes in metabolic profile. Therefore, based on the present study, future recommendations on RT for older adults, at least for older women, should consider individual objectives and needs when suggesting loading schemes.

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REFERENCES

1. Fragala MS, Cadore EL, Dorgo S, et al. Resistance training for older adults: position statement from the National Strength and Conditioning Association. *J Strength Cond Res*. 2019;33(8):2019–52.
2. American College of Sports Medicine, , Chodzko-Zajko WJ, Proctor DN, et al. American College of Sports Medicine position stand. Exercise and physical activity for older adults. *Med Sci Sports Exerc*. 2009;41(7):1510–30.
3. Botero JP, Shiguemoto GE, Prestes J, et al. Effects of long-term periodized resistance training on body composition, leptin, resistin and muscle strength in elderly post-menopausal women. *J Sports Med Phys Fitness*. 2013;53(3):289–94.
4. Dos Santos L, Ribeiro AS, Cavalcante EF, et al. Effects of modified pyramid system on muscular strength and hypertrophy in older women. *Int J Sports Med*. 2018;39(8):613–8.
5. Ribeiro AS, Schoenfeld BJ, Souza MF, et al. Traditional and pyramidal resistance training systems improve muscle quality and metabolic biomarkers in older women: a randomized crossover study. *Exp Gerontol*. 2016;79:8–15.

6. Kassiano W, Costa B, Nunes JP, et al. Does resistance training promote enough muscular strength increases to move weak older women to better strength categories? *Exp Gerontol*. 2021;149: 111322.
7. Dib MM, Tomeleri CM, Nunes JP, et al. Effects of three resistance exercise orders on muscular function and body composition in older women. *Int J Sports Med*. 2020;41(14):1024–31.
8. Santos L, Ribeiro AS, Schoenfeld BJ, et al. The improvement in walking speed induced by resistance training is associated with increased muscular strength but not skeletal muscle mass in older women. *Eur J Sport Sci*. 2017;17(4):488–94.
9. Schoenfeld BJ, Grgic J, Ogborn D, Krieger JW. Strength and hypertrophy adaptations between low- vs. high-load resistance training: a systematic review and meta-analysis. *J Strength Cond Res*. 2017; 31(12):3508–23.
10. American College of Sports Medicine. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc*. 2009;41(3):687–708.
11. Garber CE, Blissmer B, Deschenes MR, et al. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc*. 2011;43(7):1334–59.
12. Carneiro MAS, de Oliveira Júnior GN, de Sousa JFR, et al. Effects of resistance training at different loads on inflammatory biomarkers, muscle mass, muscular strength, and physical performance in postmenopausal women. *J Strength Cond Res*. 2022;36(6):1582–90.
13. Ribeiro AS, Picoloto A, Nunes JP, Bezerra ES, Schoenfeld BJ, Cyrino ES. Effects of different resistance training loads on the muscle quality index in older women. *J Strength Cond Res*. 2022;36(5): 1445–9.
14. Pedersen BK. Muscles and their myokines. *J Exp Biol*. 2011;214(Pt 2):337–46.
15. Pedersen BK, Febbraio MA. Muscle as an endocrine organ: focus on muscle-derived interleukin-6. *Physiol Rev*. 2008;88(4):1379–406.
16. Carneiro MAS, Oliveira Júnior GN, de Sousa JFR, et al. Effect of whole-body resistance training at different load intensities on circulating inflammatory biomarkers, body fat, muscular strength, and physical performance in postmenopausal women. *Appl Physiol Nutr Metab*. 2021;46(8):925–33.
17. Njemini R, Forti LN, Mets T, et al. Sex difference in the heat shock response to high external load resistance training in older humans. *Exp Gerontol*. 2017;93:46–53.
18. Forti LN, Van Roie E, Njemini R, et al. Load-specific inflammation mediating effects of resistance training in older persons. *J Am Med Dir Assoc*. 2016;17(6):547–52.
19. Kassiano W, Costa B, Nunes JP, et al. Muscular strength and skeletal muscle mass in 511 physically independent older women aged 60–88 years. *Exp Gerontol*. 2022;166:111867.
20. Cunha PM, Nunes JP, Tomeleri CM, et al. 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*. 2020;34(4):1008–16.
21. Ribeiro AS, Aguiar AF, Schoenfeld BJ, et al. Effects of different resistance training systems on muscular strength and hypertrophy in resistance-trained older women. *J Strength Cond Res*. 2018;32(2): 545–53.
22. Kim J, Wang Z, Heymsfield SB, Baumgartner RN, Gallagher D. Total-body skeletal muscle mass: estimation by a new dual-energy X-ray absorptiometry method. *Am J Clin Nutr*. 2002;76(2):378–83.
23. Sardinha LB, Lohman TG, Teixeira PJ, Guedes DP, Going SB. Comparison of air displacement plethysmography with dual-energy X-ray absorptiometry and 3 field methods for estimating body composition in middle-aged men. *Am J Clin Nutr*. 1998;68(4):786–93.
24. Amarante do Nascimento M, Januario RS, Gerage AM, Mayhew JL, Cheche Pina FL, Cyrino ES. Familiarization and reliability of one repetition maximum strength testing in older women. *J Strength Cond Res*. 2013;27(6):1636–42.
25. Cohen J. A power primer. *Psychol Bull*. 1992;112(1):155–9.
26. Schoenfeld BJ. Potential mechanisms for a role of metabolic stress in hypertrophic adaptations to resistance training. *Sports Med*. 2013; 43(3):179–94.
27. Schoenfeld BJ. The mechanisms of muscle hypertrophy and their application to resistance training. *J Strength Cond Res*. 2010;24(10): 2857–72.
28. Schoenfeld BJ, Grgic J, Van Every DW, Plotkin DL. Loading recommendations for muscle strength, hypertrophy, and local endurance: a re-examination of the repetition continuum. *Sports (Basel)*. 2021; 9(2):32.
29. Antunes M, Kassiano W, Silva AM, et al. Volume reduction: which dose is sufficient to retain resistance training adaptations in older women? *Int J Sports Med*. 2022;43(1):68–76.
30. Sousa N, Mendes R, Abrantes C, Sampaio J. Differences in maximum upper and lower limb strength in older adults after a 12 week intense resistance training program. *J Hum Kinet*. 2011;30:183–8.
31. Rønnestad BR, Egeland W, Kvamme NH, Refsnes PE, Kadi F, Raastad T. Dissimilar effects of one- and three-set strength training on strength and muscle mass gains in upper and lower body in untrained subjects. *J Strength Cond Res*. 2007;21(1):157–63.
32. Lexell J, Taylor CC. Variability in muscle fibre areas in whole human quadriceps muscle: effects of increasing age. *J Anat*. 1991;174: 239–49.
33. Straight CR, Fedewa MV, Toth MJ, Miller MS. Improvements in skeletal muscle fiber size with resistance training are age-dependent in older adults: a systematic review and meta-analysis. *J Appl Physiol (1985)*. 2020;129(2):392–403.
34. Borde R, Hortobagyi T, Granacher U. Dose-response relationships of resistance training in healthy old adults: a systematic review and meta-analysis. *Sports Med*. 2015;45(12):1693–720.
35. Franco CMC, Carneiro MADS, Alves LTH, Júnior GNO, de Sousa JFR, Orsatti FL. Lower-load is more effective than higher-load resistance training in increasing muscle mass in young women. *J Strength Cond Res*. 2019;33(Suppl 1):S152–8.
36. Chan ST, Johnson AW, Moore MH, Kapadia CR, Dudley HA. Early weight gain and glycogen-obligated water during nutritional rehabilitation. *Hum Nutr Clin Nutr*. 1982;36(3):223–32.
37. Frigeri A, Nicchia GP, Verbavatz JM, Valenti G, Svelto M. Expression of aquaporin-4 in fast-twitch fibers of mammalian skeletal muscle. *J Clin Invest*. 1998;102(4):695–703.
38. Sardeli AV, Tomeleri CM, Cyrino ES, Fernhall B, Cavaglieri CR, Chacon-Mikahil MPT. Effect of resistance training on inflammatory markers of older adults: a meta-analysis. *Exp Gerontol*. 2018;111: 188–96.
39. Consitt LA, Dudley C, Saxena G. Impact of endurance and resistance training on skeletal muscle glucose metabolism in older adults. *Nutrients*. 2019;11(11):2636.
40. Zampino M, Semba RD, Adelnia F, et al. Greater skeletal muscle oxidative capacity is associated with higher resting metabolic rate: results from the baltimore longitudinal study of aging. *J Gerontol A Biol Sci Med Sci*. 2020;75(12):2262–8.
41. Rader DJ. Molecular regulation of HDL metabolism and function: implications for novel therapies. *J Clin Invest*. 2006;116(12): 3090–100.
42. Kelley GA, Kelley KS. Impact of progressive resistance training on lipids and lipoproteins in adults: a meta-analysis of randomized controlled trials. *Prev Med*. 2009;48(1):9–19.
43. Ceniccola GD, Castro MG, Piovacari SMF, et al. Current technologies in body composition assessment: advantages and disadvantages. *Nutrition*. 2019;62:25–31.
44. Lacroix A, Hortobágyi T, Beurskens R, Granacher U. Effects of supervised vs. unsupervised training programs on balance and muscle strength in older adults: a systematic review and meta-analysis. *Sports Med*. 2017;47(11):2341–61.