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RESISTANCE TRAINING EFFECTS ON FUNCTIONAL FITNESS, MUSCULAR STRENGTH AND EXPLOSIVE POWER IN POSTMENOPAUSAL WOMEN ARE INTENSITY-DEPENDENT

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Abstract
Introduction. This study investigated the differential effects of low-intensity (LRT) versus high-intensity resistance training (HRT) on muscle strength, power, and functional fitness in community-dwelling older women, an area where the specific influence of training intensity remains unclear despite the known benefits of RT in this population. ***Material and Methods.*** Thirty-six postmenopausal women were randomly allocated, by simple randomization, to three equal groups: LRT, HRT, and sedentary control (SC). Participants in the RT groups trained three times per week for eight weeks at either 40% (LRT) or 80% (HRT) of their one-repetition maximum (1RM). Muscle strength was evaluated using 1RM test. Lower- and upper-limb explosive power was measured via countermovement jump (CMJ) and medicine ball throw (MBT), respectively. Functional fitness was further examined using the 30-second arm curl test (30s-ACT), 30-second chair stand test (30s-CST), back scratch (BS), chair sit-and-reach (CSR), stepping down test (SDT), and stepping up test (SUT). ***Results.*** In the LRT and HRT groups, functional fitness (including the 30s-ACT, 30s-CST, BS, CSR, SDT, and SUT) and muscle strength (1RM) were significantly improved at 8 weeks compared with the SC group. Only the HRT group exhibited significant enhancements in explosive power (both CMJ and MBT). Compared with the LRT, the HRT showed additional significant improvements in overall functional fitness, whole-body strength and explosive power. ***Conclusions.*** The benefits of RT on functional ability, strength, and explosive power among postmenopausal women are strongly dependent on training intensity.

Keywords: resistance training, muscle strength, explosive power, postmenopausal

Introduction

The global aging phenomenon, a pivotal concern in contemporary society, has significantly heightened focus on the well-being of the older adult population, making the extension of their health span one of the most critical global challenges as the population continues to age [1]. Global demographic projections indicate a substantial increase in the older adult population; a 2020 United Nations report estimated 728 million individuals aged 65 and over, a figure projected to nearly double to 1.5 billion by 2050 [2]. This demographic group, currently constituting 12% of the world's population, is anticipated to double its proportion by 2050 and triple by 2100 [3]. Among the multifaceted changes associated with aging, the degradation of physical function stands out as a significant concern [2]. While robust physical function is crucial for maintaining independence in older adults, alarmingly, 85% of elderly women and 70% of elderly men in the United States do not engage in regular physical activity [4]. Furthermore, similar trends are observed in Iran, where over 80% of older adults are physically inactive, with 30% of these individuals expressing no interest in participating in structured exercise programs [4]. The aging process inherently leads to a reduction in muscular strength and endurance, alongside a decline in walking speed. These changes collectively impair functional fitness and consequently interfere with the daily living activities of older adults [5, 6].

Functional fitness, essential for performing activities of daily living such as walking, jogging, running, rising from a chair, lifting, reaching, climbing stairs, bending, and kneeling, necessitates adequate levels of muscular strength, agility, endurance, and flexibility [7]. Furthermore, muscle endurance plays a significant role in the lifestyle of older adults and appears directly linked to the incidence of falls. This is underscored by the fact that muscle weakness and fatigue are commonly reported causes of falls in postmenopausal women, suggesting that developing muscle endurance is a viable strategy for this population [6]. Aging also impacts walking performance, with speeds typically decreasing by approximately 12-16% per decade after the age of seventy [4]. This decline in gait velocity is a recognized independent risk factor for increased morbidity, hospitalization, disability, and mortality in older adults [8]. Furthermore, muscle weakness in the ankles is specifically associated with a higher risk of falls during ambulation and general movement [4]. Research indicates that muscle strength can decline by as much as 50% with advancing age, contributing to the observed reduction in gait velocity [9]. Consequently, declines in functional fitness render postmenopausal women – who typically experience substantial bone mass reduction compared to men due to hormonal changes – less independent and less confident in performing daily activities, thereby increasing their susceptibility to comorbidities [5, 6, 8]. Therefore, maintaining and enhancing functional fitness is a significant societal concern [2], crucial for preventing adverse health outcomes such as falls, disability, nursing home admission, and mortality in aging populations. Thus, preventive interventions should be actively encouraged among older adults to foster beneficial adaptations in physical function [8].

Resistance training (RT) proves to be a safe, cost-effective intervention that effectively combats sarcopenia and dynapenia, thereby enhancing functional performance and muscle strength in older adults [10, 11, 12, 13]. Previous studies have demonstrated significant improvements in upper- and lower--limb strength, endurance, power, flexibility, walking, and body composition among postmenopausal women and community--dwelling older adults. These benefits were observed following various RT modalities, including: elastic band-based RT [4, 14, 15, 16], combined aerobic-resistance exercise programs [17], whole-body and body-weight-based RT [1, 6], dual-task RT and RT on a body spider [2], combined resistance-balance training [8], community-based RT programs [18], and RT at heavy and moderate intensities [9]. Compared to aerobic exercise, RT interventions offers superior benefits for older adults, particularly in increasing muscular quality, lean muscle mass, and muscular contractile units [7]. Similarly, a systematic review and meta--analysis by Hu et al. demonstrated that resistance circuit training effectively improves body composition, muscle strength, cardiorespiratory endurance, blood pressure, and functional autonomy in this population [19]. Furthermore, the American College of Sports Medicine recommends that older adults engage in resistance training at least twice a week to maintain or enhance musculoskeletal function [7].

The beneficial effects of regular RT interventions on functional fitness and independent living are well-established [10, 11, 12, 13]. However, the optimal intensity for an RT program aimed at maximizing functional performance improvements in healthy older adults remains a subject of debate [9]. In a study, similar improvements in muscle strength and functional performance were observed following heavy (80% of 1 repetition maximum [1RM]) and moderate (50% 1RM) RT in older adults [20]. However, a report from another laboratory showed that 12 weeks of heavy-intensity RT (3 sets of 8 repetitions at 80% 1RM) resulted in greater gains in muscle strength and mass than moderate-intensity RT (3 sets of 15 repetitions at 60% 1RM) in inactive healthy older adults, with no significant differences in functional fitness outcomes [9]. In contrast, long-term whole--body (10 exercises, two to three sets/exercise, three and six-minute rest between sets) high-intensity resistance training (HRT) (80% 1RM) led to superior improvements in maximal strength, anaerobic power, and overall physical function compared with low-intensity resistance training (LRT) (40% 1RM) in older men [21]. A study directly comparing the effects of different RT intensities on multifaceted changes in physical function among postmenopausal older women could provide valuable insights for researchers, healthcare providers, and strength and conditioning professionals. Given the impact of aging processes, particularly following menopause, this study specifically aimed to investigate the effects of varying RT intensities on physical function and mobility in older women. We hypothesized that both LRT and HRT would enhance functional fitness, strength, power, and walking time in older adults, with high-intensity RT yielding additional benefits for postmenopausal older women.

Material and Methods

Subjects

The sample size was determined with G*Power 3.1.9, based on variance analysis with α = 0.05, power = 0.95, and a large effect size (0.40), indicating that 12 participants per group were required [22]. Participant recruitment involved extensive outreach, utilizing a combination of advertisements placed in public venues, face-to-face solicitation, and widespread promotion across social media platforms. A total of 50 individuals were initially approached, all of whom completed the medical and physical activity readiness questionnaires and underwent a physician examination. Inclusion criteria required participants to meet all of the following: be sedentary (defined as no structured strength training in the preceding six months), be postmenopausal, be available to commit to the three-month intervention period, demonstrate high motivation for participation, and be free from any metabolic, cardiovascular, or musculoskeletal conditions that would restrict participation in RT; furthermore, they had to be able to walk and exercise independently. Following this initial screening, 14 individuals were deemed ineligible and excluded from the study. The primary reasons for exclusion included: the presence of confounding cardiovascular, metabolic, or musculoskeletal disorders (n = 10); recent recovery from acute illness (n = 1); neurological conditions affecting balance (e.g., stroke, n = 1); requirement for walking aids (n = 1); or confirmed mental impairment (n=1). Consequently, 36 eligible sedentary older women (mean ± SD: 60.32 ± 2.21 years) were enrolled and subsequently randomized via simple randomization into three intervention groups: sedentary control (SC) (n = 12), LRT (n = 12), and HRT (n = 12). In addition, subjects missing three training sessions were excluded from the study [12, 13, 22]. Four participants (2 from the LRT group and 2 from the HRT group) were excluded from the per-protocol analysis because they missed more than three study sessions. Participants were required to abstain from all performance-enhancing substances and any medications or supplements known to potentially influence the study outcomes throughout the study period. Compliance with this restriction was verified through self-report questionnaires administered at each study visit, and participants were explicitly instructed to notify the research staff immediately if any restricted substance was required for medical necessity. The research received ethical approval from the University of Bojnord Research Ethics Committee. All study procedures, benefits, and potential risks were thoroughly explained, after which participants provided written informed consent. They were free to withdraw from the study at any time without penalty. Group-specific baseline demographics are depicted in Table 1.

Table 1. Group-specific baseline demographics

Variables	SC	LRT	HRT
BMI (kg/m2)	28.38 ± 2.35	27.67 ± 3.44	29.60 ± 2.88
HC (cm)	99.87 ± 6.17	98.40 ± 6.35	100.10 ± 5.46
WC (cm)	92.25 ± 6.69	93.10 ± 6.03	93.14 ± 5.07
AC (cm)	103.75 ± 7.08	102.80 ± 5.53	102.90 ± 6.10
BFP (%)	26.12 ± 1.55	25.50 ± 3.17	28.30 ± 3.46

Abbreviations: AC – Abdominal Circumference, BFP – Body Fat Percentage, BMI – Body Mass Index, HC – Hip Circumference, HRT – High-intensity Resistance Training, LRT – Low-intensity Resistance Training, SC – Sedentary Control, WC – Waist Circumference.

Intervention

The intervention's intensity in this research was regulated by 1RM [13]. Before 1RM assessment, participants were trained on correct lifting mechanics and equipment usage to mitigate injury risk and minimize initial strength gains attributable to motor learning. The testing session included a general warm-up (5 minutes on a cycle ergometer) followed by a specific warm-up using light to moderate loads. After a 3-minute recovery, suitable weight was selected allowing subjects to complete between one and ten repetitions. Epley's equation was subsequently applied to estimate 1RM [10, 11, 23].

Initially, volunteers received instructions on operating the RT devices. The RT protocols, which adhered to the overload principle, were conducted over eight weeks, three days per week, with one session per day. Each training session began with a 10-minute warm-up, consisting of cycling at 40% of maximal heart rate. Subjects in the LRT group trained at 40% of their personal 1RM, performing 2-3 sets of 12-16 repetitions per exercise, with a 3-minute rest period between sets. Participants in the HRT group trained at 80% of their personal 1RM, performing 2-3 sets of 6-8 repetitions per exercise, with a 6-minute rest period between sets [12, 21]. During each repetition, subjects were instructed to raise the weight in 2-3 seconds, pause for 2-3 seconds, and lower the weight over 2-3 seconds, with an additional 2-4 second pause mandated between each repetition [21, 23]. The total training load was equalized between both groups across the training period by meticulously calculating the Total Training Volume (V) for each participant using the formula V = Weight Lifted × Repetitions × Sets [12, 21]. The exercises were identical for both the LRT and HRT groups and consisted of biceps curl, triceps extension, bench press, lat pulldown, knee extension, knee flexion, squat, and calf raise. Furthermore, abdominal crunches and low back extensions (2–3 sets of 6 repetitions, 3 sessions per week) were included for both groups [12]. All RT sessions required the presence of a trained instructor who provided verbal encouragement to complete each workout [10]. Subjects were concurrently restricted from engaging in any supplementary exercise throughout the study duration; notably, the SC group was excluded from the RT program entirely. To ensure adherence to the SC protocol, participants in the SC group were contacted via weekly telephone calls throughout the intervention period. During these calls, participants self-reported their physical activity levels, and they were explicitly instructed to abstain from any structured or non-structured exercise, RT, or significant increase in daily activity beyond their habitual routine.

Measurements

All pre- and post-training assessments were measured and recorded by the same instructor to ensure consistency and minimize inter-rater variability [10, 11, 12, 13].

Anthropometric assessment – Subjects' height was measured to the nearest 0.1 cm by a calibrated stadiometer. Body mass (minimal clothing, fasted state, post-void) was measured to 0.1 kg using German Seca scales. Body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2). Waist-hip ratio (WHR) was determined by dividing the waist circumference (WC) (measured at the torso's narrowest point, between the umbilicus and xiphoid process) by the hip circumference (HC) (widest part of the buttocks) [24]. Abdominal circumference (AC) was measured on bare skin at the umbilicus level while standing. Body composition was assessed via the 4-site skinfold method (abdominal, triceps, thigh, suprailiac), taken in triplicate with 1-mm precision using a Japanese Yagami caliper. Body density was estimated using the Jackson and Pollock equation, from which body fat percentage (BFP) was derived via Siri's equation [3, 24].

Maximal strength assessment – Pre- and post-intervention maximal strength was evaluated using 1RM for the following exercises: biceps curl, triceps extension, bench press, lat pulldown, knee extension, knee flexion, squat, and calf raise [3].

Functional fitness assessment – Functional fitness was evaluated according to the Senior Fitness Test protocol. For the 30-second chair stand test (30s-CST), participants were instructed to perform the maximal number of complete stands within 30 seconds, with a silent count maintained by the instructor. For the 30-second arm curl test (30s-ACT), participants performed bicep curls for 30 seconds, utilizing a 2.27 kg hand weight, and the total number of curls was recorded [2, 5, 6, 25]. For the back scratch (BS) test, participants were instructed to bring their hands towards their back, with one hand reaching over the shoulder and the other from the middle of the back, attempting to touch each other. The distance between the extended middle fingers was recorded. For the chair sit-and-reach (CSR) test, participants were seated at the front edge of a chair with one leg extended and the ankle dorsiflexed. They then reached towards the toes of the extended leg, and the distance between the participant's fingers and the tips of their toes was recorded [2, 5]. For the stepping up test (SUT) and stepping down test (SDT), participants ascended or descended eight stairs while carrying a 2.3 kg weight, respectively. They were instructed to complete the task as quickly and safely as possible, with scoring based on the total time taken [21].

Explosive power assessment – Upper- and lower-limb explosive power were evaluated via the medicine ball throw (MBT) and countermovement jump (CMJ), respectively [5]. For MBT, participants sat on a chair, holding a 2 kg medicine ball at their chest (elbows flexed, shoulders abducted 90°). Following a verbal cue, the ball was propelled forward bilaterally for maximal distance, measured from the chair's base to the ball's impact point [5]. For CMJ, subjects stood with their dominant side adjacent to a wall, maintaining flat feet, and extended their dominant arm overhead to determine vertical reach. Subjects then performed a CMJ from a static, shoulder-width stance. The jump initiated with a rapid downward countermovement to approximately 90° knee flexion, followed by an immediate maximal vertical jump with an arm swing. The highest point reached by the dominant hand was recorded. CMJ height was calculated as the difference between maximal jump height and static vertical reach. Participants were familiarized with accurate testing technique. Each test began with a 5-minute general warm-up (dynamic activities and light lower limb stretching). For both MBT and CMJ, three attempts were made, and the best result was recorded [5].

Walking assessment – To quantify walking, both normal (NWT) and maximum (MWT) walking times were measured. Subjects traversed a path exceeding 10 meters in length at their habitual pace and then again at their maximal non-running speed. To ensure accuracy and minimize the influence of acceleration and deceleration, walking time was recorded with a stopwatch over an intermediate 6-meter section (from 2 to 8 meters along the path) [8].

Statistical analysis

Statistical package for social sciences software (version 16.0, Chicago, USA) was used for statistical evaluations. Data normality was assessed using the Shapiro-Wilk test. Group-specific baseline demographics were analyzed using a one-way analysis of variance. Analysis of Covariance (ANCOVA) was used to compare post-tests among the groups. When ANCOVA indicated the presence of a significant difference, the Bonferroni post-hoc tests were used for pairwise comparisons. Furthermore, paired t-test was used to compare intergroup changes. Effect sizes were computed using partial eta-squared (η_p^2) to evaluate the practical significance of the findings. The magnitude of the effects was interpreted according to conventional thresholds: ES < 0.2 as small, ES ≈ 0.5 as medium, and ES > 0.8 as large [26]. The data are depicted as the mean ± standard deviation. Significance was established at $p < 0.05$.

Results

The baseline group-specific demographics revealed no significant differences among all groups concerning BMI (F = 1.076, p = 0.356), HC (F = 0.215, p = 0.808), WC (F = 0.059, p = 0.943), AC (F = 0.061, p = 0.941), and BFP (F = 2.473, p = 0.105) (Tab. 1).

Table 2 presents changes in body composition. Inter-group comparison exhibited a remarkable reduction in BMI (p = 0.004 and p < 0.001 for LRT and HRT groups, respectively), AC (p < 0.001 for both groups), and BFP (p = 0.002 and p = 0.007 for LRT and HRT groups, respectively) in the LRT and HRT groups compared to the SC group at the end of the RT protocols. In addition, WHR was significantly lower in the HRT group than in the SC group (p = 0.007). However, no significant differences were noted between the LRT and HRT groups with respect to BMI (p = 0.066), WHR (p = 0.354), AC (p = 0.623), and BFP (p = 0.999) at the post-intervention stage.

Table 3 shows the changes in 1RM following the LRT and HRT protocols. The results indicated that 1RM for biceps curl (p < 0.001 for both groups), triceps extension (p < 0.001 for both groups), bench press (p < 0.001 for both groups), lat pulldown (p < 0.001 for both groups), knee extension (p < 0.001 for both groups), knee flexion (p = 0.003 for LRT and p < 0.001 for HRT), squat (p < 0.001 for both groups), and calf raises (p = 0.022 for LRT and p < 0.001 for HRT) was significantly greater in the LRT and HRT groups compared to the SC group. Furthermore, the inter-group comparison revealed that 1RM for all listed exercises (biceps curl, triceps extension, bench press, lat pulldown, knee extension, knee flexion, squat, and calf raises) was significantly higher in the HRT group than in the LRT group at the end of the experiment (p < 0.001 for all exercises).

Changes in power are depicted in Table 4. The results showed that CMJ was significantly greater in the HRT group compared to both the SC group (p = 0.002) and the LRT group (p = 0.007). In addition, MBT was significantly greater in the HRT group compared to both the SC group (p < 0.001) and the LRT group (p = 0.028). No significant changes were observed between the LRT and SC groups for either CMJ (p = 0.516) or MBT (p = 0.180) at the end of the interventions.

Changes in walking time are depicted in Table 5. The results showed that NWT was significantly improved in the HRT group compared to both the SC group (p < 0.001) and the LRT group (p < 0.001). No significant changes were observed in NWT between the LRT and SC groups at the end of the interventions (p = 0.754). Both LRT and HRT significantly improved MWT (p = 0.001 for both groups) when compared to the SC group. Furthermore, the improvement in MWT was significantly greater in the HRT group than in the LRT group (p = 0.002).

Changes in functional fitness are depicted in Table 6. Both LRT and HRT significantly improved performance in 30s-ACT (p < 0.001 for both groups), 30s-CST (p = 0.007 in LRT and p < 0.001 in HRT), BS (p = 0.019 in LRT and p = 0.005 in HRT), CSR (p < 0.001 in LRT and p < 0.001 in HRT), SUT (p = 0.025 in LRT and p < 0.001 in HRT), and SDT (p = 0.033 in LRT and p < 0.001 in HRT) when compared to the SC group. Moreover, the improvement in performance for 30s-ACT (p < 0.001), 30s-CST (p = 0.022), SUT (p = 0.044), and SDT (p = 0.024) was significantly greater in the HRT group than in the LRT group. No significant changes were observed between the LRT and HRT groups for BS (p = 0.559) and CSR (p = 0.574) at the end of the interventions.

Table 2. Post-intervention changes in anthropometric features across LRT, HRT, and SC groups

Variables	Group	Pre-intervention	Post-intervention	Within-group	Between-group
BMI (kg/m^2)	SC	28.38 ± 2.35	29.56 ± 3.63	t = 2.195, p = 0.064	F = 18.150, p < 0.001, η_p^2 = 0.60
	LRT	27.67 ± 3.44	27.27 ± 3.51 *#	t = 3.498, p = 0.007	
	HRT	29.60 ± 2.88	28.45 ± 3.15 *#	t = 5.932, p < 0.001	
WHR	SC	0.91 ± 0.021	0.91 ± 0.025	t = 0.012, p = 0.999	F = 5.889, p = 0.008, η_p^2 = 0.31
	LRT	0.94 ± 0.020	0.92 ± 0.019 *	t = 6.708, p < 0.001	
	HRT	0.92 ± 0.004	0.89 ± 0.012 *#	t = 5.715, p < 0.001	
AC (cm)	SC	103.75 ± 7.08	104.38 ± 7.13	t = 1.930, p = 0.095	F = 17.741, p < 0.001, η_p^2 = 0.60
	LRT	102.80 ± 5.53	102.01 ± 5.27 *#	t = 4.015, p = 0.003	
	HRT	102.90 ± 6.10	101.70 ± 6.51 *#	t = 6.001, p < 0.001	
BFP (%)	SC	26.12 ± 1.55	26.37 ± 1.76	t = 1.528, p = 0.170	F = 8.980, p < 0.001, η_p^2 = 0.43
	LRT	25.50 ± 3.17	23.01 ± 3.33 *#	t = 4.792, p < 0.001	
	HRT	28.30 ± 3.46	25.60 ± 3.13 *#	t = 4.263, p = 0.002	

Abbreviations: AC – Abdominal Circumference, BFP – Body Fat Percentage, BMI – Body Mass Index, HRT – High-intensity Resistance Training, LRT – Low-intensity Resistance Training, SC – Sedentary Control, WHR – Waist to Hip Ratio. * – Significant difference from pre-intervention, # – Significant difference from SC.

Table 3. Post-intervention changes in maximal strength measures across LRT, HRT, and SC groups.

Variables	Group	Pre-intervention	Post-intervention	Within-group	Between-group
Biceps curl (kg)	SC	17.56 ± 2.79	17.87 ± 2.87	t = –1.488, p = 0.180	F = 32.149, p < 0.001, η_p^2 = 0.73
	LRT	17.05 ± 1.38	22.65 ± 3.44*#	t = 6.332, p < 0.001	
	HRT	18.65 ± 2.05	28.40 ± 2.57*#†	t = 10.601, p < 0.001	
Triceps extension (kg)	SC	12.12 ± 2.37	12.16 ± 2.19	t = 0.163, p = 0.875	F = 41.223, p < 0.001, η_p^2 = 0.76
	LRT	11.85 ± 2.01	15.80 ± 2.74*#	t = 7.614, p < 0.001	
	HRT	13.45 ± 2.24	20.65 ± 2.52 *#†	t = 10.854, p < 0.001	
Bench press (kg)	SC	19.87 ± 2.41	20.01 ± 2.61	t = 0.685, p = 0.685	F = 30.702, p < 0.001, η_p^2 = 0.72
	LRT	20.65 ± 3.02	25.30 ± 3.26 *#	t = 5.329, p < 0.001	
	HRT	23.35 ± 3.67	33.30 ± 4.47*#†	t = 10.021, p < 0.001	
Lat pulldown (kg)	SC	25.50 ± 4.17	26.12 ± 4.82	t = 1.256, p = 0.250	F = 136.310, p < 0.001, η_p^2 = 0.92
	LRT	25.40 ± 2.98	30.60 ± 3.62*#	t = 17.894, p < 0.001	
	HRT	27.60 ± 4.08	36.30 ± 4.13*#†	t = 40.761, p < 0.001	
Knee extension (kg)	SC	36.50 ± 6.04	37.01 ± 5.70	t = 0.624, p = 0.553	F = 65.571, p < 0.001, η_p^2 = 0.85
	LRT	35.70 ± 5.20	40.50 ± 5.62*#	t = 9.798, p < 0.001	
	HRT	37.60 ± 5.77	47.40 ± 6.05*#†	t = 25.210, p < 0.001	
Knee flexion (kg)	SC	17.62 ± 3.77	17.87 ± 4.45	t = 0.509, p = 0.626	F = 34.509, p < 0.001, η_p^2 = 0.74
	LRT	18.30 ± 3.09	22.90 ± 3.66*#	t = 9.662, p < 0.001	
	HRT	19.70 ± 3.68	29.70 ± 4.62*#†	t = 9.214, p < 0.001	
Squat (kg)	SC	26.25 ± 4.46	26.75 ± 4.52	t = 0.798, p = 0.451	F = 60.662, p < 0.001, η_p^2 = 0.84
	LRT	26.80 ± 4.02	32.20 ± 5.02*#	t = 12.650, p < 0.001	
	HRT	28.60 ± 5.50	37.01 ± 5.27*#†	t = 21.017, p < 0.001	
Calf raises (kg)	SC	26.37 ± 3.46	26.87 ± 3.31	t = 1.528, p = 0.170	F = 34.168, p < 0.001, η_p^2 = 0.74
	LRT	25.30 ± 2.35	29.40 ± 2.87*#	t = 4.379, p = 0.002	
	HRT	26.20 ± 2.78	35.80 ± 3.29*#†	t = 11.529, p < 0.001	

Abbreviations: HRT – High-intensity Resistance Training, LRT – Low-intensity Resistance Training, SC – Sedentary Control. * – Significant difference from pre-intervention, # – Significant difference from SC, † – Significant difference from LRT.

Table 4. Post-intervention changes in explosive power measures across LRT, HRT, and SC groups.

Variables	Group	Pre-intervention	Post-intervention	Within-group	Between-group
CMJ (cm)	SC	5.56 ± 1.16	5.60 ± 1.27	t = 0.341, p = 0.743	F = 7.345, p = 0.003, η_p^2 = 0.38
	LRT	4.99 ± 1.23	5.13 ± 1.38	t = 0.929, p = 0.377	
	HRT	5.58 ± 1.41	6.20 ± 1.36*#†	t = 13.286, p < 0.001	
MBT (m)	SC	2.17 ± 0.40	2.14 ± 0.41	t = 0.814, p = 0.442	F = 6.705, p = 0.005, η_p^2 = 0.36
	LRT	2.11 ± 0.39	2.15 ± 0.44	t = 0.937, p = 0.373	
	HRT	2.30 ± 0.47	2.47 ± 0.46*#†	t = 6.530, p < 0.001	

Abbreviations: CMJ – Countermovement Jump, HRT – High-intensity Resistance Training, LRT – Low-intensity Resistance Training, MBT – medicine ball throw, SC – Sedentary Control. * – Significant difference from baseline, # – Significant difference from SC, † – Significant difference from LRT.

Table 5. Post-intervention changes in walking time measures across LRT, HRT, and SC groups.

Variables	Group	Pre-intervention	Post-intervention	Within-group	Between-group
NWT (s)	SC	4.35 ± 0.46	4.32 ± 0.50	t = 0.715, p = 0.498	F = 11.694, p < 0.001, η_p^2 = 0.49
	LRT	4.23 ± 0.47	4.21 ± 0.48	t = 1.081, p = 0.308	
	HRT	4.12 ± 0.44	3.94 ± 0.46*#†	t = 9.073, p < 0.001	
MWT (s)	SC	3.40 ± 0.24	3.44 ± 0.26	t = 1.598, p = 0.154	F = 33.493, p < 0.001, η_p^2 = 0.74
	LRT	3.46 ± 0.45	3.35 ± 0.43*#	t = 8.516, p < 0.001	
	HRT	3.27 ± 0.49	3.06 ± 0.46*#†	t = 9.249, p < 0.001	

Abbreviations: HRT – High-intensity Resistance Training, LRT – Low-intensity Resistance Training, MWT – Maximum Walking Time, NWT – Normal Walking Time, SC – Sedentary Control. * – Significant difference from baseline, # – Significant difference from SC, † – Significant difference from LRT.

Table 6. Post-intervention changes in functional fitness measures across LRT, HRT, and SC groups.

Variables	Group	Pre-intervention	Post-intervention	Within-group	Between-group
30s-ACT (n)	SC	19.75 ± 3.10	19.62 ± 2.55	t = 0.261, p = 0.802	F = 38.415, p < 0.001, η_p^2 = 0.76
	LRT	20.90 ± 3.14	23.10 ± 2.68*#	t = 5.659, p < 0.001	
	HRT	20.60 ± 2.76	25.40 ± 2.83*#†	t = 12.075, p < 0.001	
30s-CST (n)	SC	11.75 ± 2.12	11.62 ± 2.26	t = 0.314, p = 0.763	F = 19.067, p < 0.001, η_p^2 = 0.61
	LRT	12.50 ± 2.71	13.70 ± 2.49*#	t = 4.811, p < 0.001	
	HRT	12.10 ± 2.84	14.50 ± 2.59*#†	t = 9.056, p < 0.001	
CSR (cm)	SC	3.90 ± 1.72	3.80 ± 1.48	t = 0.424, p = 0.685	F = 24.818, p < 0.001, η_p^2 = 0.67
	LRT	3.70 ± 2.21	5.60 ± 2.45*#	t = 10.585, p < 0.001	
	HRT	4.10 ± 1.79	6.20 ± 2.20*#	t = 9.011, p < 0.001	
BS (cm)	SC	-9.90 ± 3.68	-10.40 ± 4.37	t = 0.935, p = 0.381	F = 5.271, p = 0.013, η_p^2 = 0.92
	LRT	-10.60 ± 3.20	-9.80 ± 3.04*#	t = 3.207, p = 0.011	
	HRT	-9.80 ± 3.79	-8.70 ± 3.88*#	t = 3.973, p = 0.003	
SUT (s)	SC	7.42 ± 1.30	7.62 ± 1.25	t = 1.273, p = 0.243	F = 14.408, p < 0.001, η_p^2 = 0.55
	LRT	7.60 ± 1.35	7.06 ± 1.16*#	t = 2.414, p = 0.039	
	HRT	7.52 ± 1.13	6.37 ± 1.20*#†	t = 9.197, p < 0.001	
SDT (s)	SC	7.13 ± 1.17	7.06 ± 1.23	t = 0.582, p = 0.579	F = 15.169, p < 0.001, η_p^2 = 0.56
	LRT	6.90 ± 1.23	6.42 ± 1.17*#	t = 5.726, p < 0.001	
	HRT	7.03 ±1.19	6.13 ± 1.21*#†	t = 7.894, p < 0.001	

Abbreviations: 30s-ACT – 30-second Arm Curl Test, 30s-CST – 30-second Chair Stand Test, BS – Back Scratch, CSR – Chair Sit and Reach, HRT – High-intensity Resistance Training, LRT – Low-intensity Resistance Training, SC – Sedentary Control, SDT – Stepping Down Test, SUT – Stepping Up Test. * – Significant difference from baseline, # – Significant difference from SC, † – Significant difference from LRT.

Discussion

Age-related alterations in the neuromuscular system, muscle loss, and progressive fiber denervation reduce muscle strength, power, and mobility, leading to functional limitations [21]. This study investigated the effects of eight weeks of RT regimens at different intensities on muscle strength, power, walking time, and functional fitness in postmenopausal older women. The findings from this randomized controlled trial support our hypothesis that, compared with LRT, HRT intervention yields additional benefits in overall functional fitness, whole-body strength, walking time, and explosive power – factors that are clinically significant for preventing frailty, functional decline, and related geriatric syndromes.

Aging causes functional and strength deficits due to sarcopenia [19]; however, RT favorably alters body composition. Our LRT/HRT interventions specifically improved BMI, WHR, AC, and BFP, corroborating Yoon et al. (2017), who found high-speed, elastic band power training reduced weight, BMI and BFP over slow-speed training [14]. This is further supported by Hu et al., showing only high-intensity circuit RT significantly reduced fat mass/BMI/weight in older adults, unlike low/moderate circuit [19]. Syed-Abdul et al. (2022) also confirmed significant reductions in body weight and fat mass following an eight-week community-based RT regimen [18]. Additionally, RT has proven as effective as aerobic exercise in reducing fat mass in postmenopausal women, with low-intensity circuit RT lowering total, subcutaneous, and abdominal fat [27]. Given that our current study's whole-body, long-duration exercise sessions stressed major muscle groups, the continuous movement likely supported body composition improvements. Our finding of similar reductions in body composition between 8-week LRT and HRT contrasts with studies showing greater weight and subcutaneous fat loss with 24-week HRT (80% 1RM) compared to LRT (40% 1RM) in elderly men [21]. This suggests that intervention duration may influence results. Additionally, RT benefits may be limited to obese or overweight individuals, with no significant effects in normal-weight participants [28]. While HRT is often proposed as superior for weight/BMI reduction due to higher energy expenditure, our subjects performed equal workloads. Lastly, although combined aerobic and RT programs improve body composition in older adults, long-term training in older women may lead to metabolic adaptations and lower metabolic rates [29], indicating that optimal weight loss intensity depends on individual fitness, health status, and age.

Muscle mass declines roughly 2% yearly post-age 50, with strength loss accelerating after 60 [3]. Our current study confirms that both LRT and HRT proportionally increase maximal strength and explosive power across all muscle groups, intensity-dependently. Given that peak strength optimization often requires intensities near 80% 1RM, significant strength gains from HRT are well-documented [9, 21]. This intensity effect was observed directly, where long-term HRT (80% 1RM) yielded greater gains in upper/lower-body strength and anaerobic power in older men than LRT (40% 1RM) [21]. Supporting this, 12 weeks of heavy RT (3 × 8 reps at 80% 1RM) resulted in superior lower-body strength gains over moderate training (3 × 15 reps at 60% 1RM) in inactive older adults [9]. Moreover, this superiority of heavy training aligns with findings showing that heavy RT regimen creates superior strength and power improvements compared to moderate RT regimen [3], and matches results from diverse RT protocols in inactive older women [5]. In addition, short-term RT protocols (8 weeks, 3 × 8 reps at 50-75% 1RM) significantly enhanced strength in older women, aligning with these results [30, 31]. Initial increments in strength and explosive power under both LRT and HRT regimens might reflect the subjects' low baseline physical activity and strength levels [9]. Despite this, evidence confirms that low and very low-load RT protocols are also effective in enhancing muscle strength [21]. A key confounding factor is the disparity in total mechanical work between LRT and HRT; however, when total work was standardized across both methods, HRT still yielded substantially greater strength improvements than LRT [21]. Consequently, while LRT induces comparatively smaller strength gains, it remains a potent stimulus for strength development in sedentary older adults. The greater improvement in maximal strength and subsequent explosive power can be attributed to the higher training intensity, as muscle strength tends to reach its maximum during more intense workouts. This occurs due to enhanced recruitment and synchronization of motor units, as well as the inhibition of antagonistic muscles and the Golgi tendon organ [5].

Walking is fundamental for daily independence, and even marginal gains in walking performance are associated with enhanced longevity in older women. Therefore, targeted RT protocols are critical for mitigating mobility challenges and enhancing functional well-being [14]. In this study, both HRT and LRT resulted in clinically meaningful gains in MWT and NWT, with HRT showing greater improvements. These results align with prior evidence demonstrating that RT – whether applied to specific lower limb muscle groups using elastic bands [4] or executed as whole-body training at moderate to heavy intensities [9] – enhances dynamic balance and, consequently, walking performance in older individuals. Similarly, Wang et al. observed improved gait speed, swing and double support phases as a result of greater strength and balance adaptations following both combined cognitive instability RT and isolated lower limb training in older women [22]. Further confirmation comes from Jiang et al., who reported concurrent gains in walking, agility, and dynamic balance after sustained moderate intensity RT with or without a balance component [8]. These findings underscore the well established role of RT in optimizing neuromuscular coordination and functional mobility, which are critical for efficient walking [22]. The greater strength gains observed in HRT suggest that exercise intensity is the principal factor driving these benefits. Clinically, structured RT can substantially enhance gait stability and efficiency and support functional independence in aging women [22]. Given that maximal walking requires greater cognitive and balance demands than normal walking [8], it serves as a sensitive measure of overall functional capacity, highlighting HRT's specific positive impact on maximal walking performance.

Decreases in flexibility and joint range of motion due to age-related disuse significantly compromise mobility, balance, and the execution of daily activities in older adults [16]. Conversely, the present investigation demonstrates that both LRT and HRT protocols elicited significant enhancements in upper- and lower-body flexibility. Specifically, LRT and HRT led to increases in BS scores of 7.5% and 11.22%, and CSR scores of 51% each. These improvements align with prior research showing flexibility gains after progressive short- [2, 7, 18] and long-term RT intervention [5]. Notably, our finding that LRT and HRT regimens conferred equivalent flexibility benefits in healthy, inactive older individuals echoes earlier work [9]. These results underscore RT as a vital non-pharmacological strategy for mitigating age-related motor disabilities [16]. According to the findings from the present study, it has been concluded that both RT regimens may enhance the range of motion in the synovial joint, due to the fact that the exercises are performed through the full range of motion. In addition, both agonist and antagonist muscles are trained during the intervention [7, 9].

Training-induced enhancements in strength and explosive power were accompanied by marked improvements in functional fitness, with HRT eliciting greater achievements. Upper-extremity muscular endurance, assessed via the 30s-ACT, improved by 10.52% in LRT and 23.30% in HRT. Similarly, lower-extremity endurance, measured by the 30s-CST, increased by 9.6% and 19.83% in LRT and HRT, respectively. Furthermore, performance times on the SUT (7.10% and 15.29% for LRT and HRT, respectively) and SDT (6.95% and 12.80% for LRT and HRT, respectively) improved in both experimental groups. Consistent with current results, Fatouros et al. demonstrated that 80% 1RM whole-body HRT yielded greater SUT (12.6%) and SDT (13.7%) improvements in older men than 40% 1RM LRT (6.5% and 6.9%, respectively) [21]. Moreover, other researchers found that short-term (6-12 weeks) low-load, slow-movement, bodyweight-based RT achieved a 28.79% gain in 30s-CST [1], while whole-body and lower-limb elastic band RT resulted in 102.82% [16] and 31.31% [4] increases, respectively, in 30s-CST. Other short-term regimens, such as progressive whole-body RT (moderate to vigorous: 10.52% in 30s-ACT and 21.43% in 30s-CST) [7], machine/dumbbell RT (moderate-intensity: 58% in 30s-ACT and 68% in 30s-CST) [32], and instability training (21.35% in 30s-CST) [20], also confirm significant endurance gains in sedentary older adults. Concurrently, long-term (24-28 weeks) isolated RT (8.46% in 30s-ACT and 21.11% in 30s-CST) and combined resistance + balance training (6.50% in 30s-ACT and 41.93% in 30s-CST) [8], as well as intense elastic-band RT (32.97% in 30s-ACT and 79% in 30s-CST) [15] validate sustained muscular endurance capacity improvements in community-dwelling older adults. Conversely, 12 weeks of RT at moderate (3 × 15 at 60% 1RM) or heavy (3 × 8 at 80% 1RM) intensities induced similar functional improvements (walking performance, endurance, stair climbing) in inactive older adults, despite the heavy RT achieving superior 1RM strength gains [9]. Furthermore, one-set protocols at 80% vs. 50% 1RM also showed comparable strength/functional benefits [20]. Functional variability stems from differences in training variables, exercises selected and training status of the subjects [27]; however, the present study suggests that functional gains are substantially linked to increased muscle strength and power.

While this study provides valuable insights into the differential effects of LRT and HRT in older adults, several limitations should be acknowledged. First, the relatively small sample size – comprising only elderly women – limits the generalizability of the findings to broader populations [22]. Second, the absence of detailed physiological assessments and surrogate biomarkers restricted our ability to elucidate the underlying mechanisms driving the observed training adaptations in both HRT and LRT groups. Third, the use of a per-protocol analysis, which excluded participants with low adherence or those missing more than three sessions, may have inflated the observed effect sizes and introduced a potential selection bias. Fourth, the monitoring of the SC group relied solely on weekly self-reported check-ins, without objective verification methods such as accelerometers or activity logs, making it impossible to fully exclude unrecorded increases in daily physical activity. Finally, the relatively long rest intervals between sets – implemented to ensure safety and adherence among inactive elderly participants – may have attenuated the magnitude of physiological adaptation, thus representing an additional methodological limitation of the present study.

Conclusions

This study indicates that eight-week progressive LRT and HRT programs can successfully improve body composition, strength, gait time, and functional capacity in community-dwelling older adults. Contrary to long-term prior research [5, 8, 15], these results suggest an eight-week duration may be sufficient to elicit positive functional fitness changes, which is promising for motivating participation due to rapid observable results. Furthermore, the benefits of RT on strength and walking time in elderly women are strongly intensity-dependent. Consequently, HRT interventions should be considered a vital strategy by coaches and healthcare providers to maximize improvements in the physical and functional capacity of older women.

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