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RESEARCH

The role of physical activity levels in retaining high-speed resistance training effects on body composition: a 1-year follow-up in older adults

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Abstract

Purpose This study evaluated the influence of physical activity (PA) on the retention of body composition effects achieved through a 16-week high-speed resistance training (HSRT) program over a 1-year follow-up period.

Methods Forty independent older adults participated in the supervised 16-week HSRT program. After the intervention ended, participants were encouraged to maintain high PA levels. At the 1-year follow-up, 36 participants completed the assessments and were divided into the light activity group (LAG, $N=20$, age 70.00 ± 3.66 years) and the moderate-to-vigorous activity group (MVAG, $N=16$, age 68.50 ± 2.09 years). Body composition (InBody® S10), PA levels (International Physical Activity Questionnaire), and anthropometric measurements were assessed at four time points.

Results Significant time effects were observed for several body composition parameters over the 1-year follow-up period, with large effect sizes. Specifically, MVAG revealed significant declines in weight ($p=0.002$, $d_{unb}=-0.22$), body mass index ($p=0.002$, $d_{unb}=-0.30$), and fat mass (%) ($p=0.028$, $d_{unb}=-0.30$) from post-intervention to the 1-year follow-up. Conversely, LAG demonstrated significant reductions in fat-free mass ($p=0.018$, $d_{unb}=-0.14$), muscle mass ($p=0.010$, $d_{unb}=-0.15$), and lean mass ($p=0.014$, $d_{unb}=-0.14$) from pre-intervention to the 6-month follow-up ($p<0.001$, $d_{unb}=-0.18$), with body cell mass also presenting significant declines from post-intervention to the 1-year follow-up ($p=0.035$, $d_{unb}=-0.13$). Despite an overall decline, PA remained relatively higher than pre-intervention, particularly for total weekly activity (minutes) and energy expenditure from moderate-to-vigorous PA.

Conclusions This study highlights the benefits of engaging in at least moderate PA activities for retaining the effects achieved on a previous exercise program, particularly reductions in fat mass.

Keywords Aging · Muscle · Adiposity · Healthy lifestyle · Exercise

Abbreviations

BMI	Body mass index
BIA	Bioelectrical impedance analysis
ESs	Effect sizes
ECW	Extracellular water
HSRT	High-speed resistance training
ICW	Intracellular water
Kg	Kilograms
LAG	Light activity group
L	Liters
MVAG	Moderate-to-vigorous activity group
MVPA	Moderate and vigorous physical activity

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IPAQ	International physical activity questionnaire
PA	Physical activity
RT	Resistance training
TBW	Total body water

Introduction

The aging process is characterized by natural and progressive cellular impairments across various tissues, which contribute to a gradual decline in overall physiological function [1]. These age-related impairments include loss of muscle mass and strength, an increase in fat mass, and reduced levels of physical activity (PA), all of which accelerate the decline in functional capacity and increase vulnerability to weakness and frailty [2–4].

To counteract these age-related changes, several studies have demonstrated the effectiveness of resistance training (RT) programs, including both traditional and high-speed resistance training (HSRT), in older populations [5–7]. Key findings from these RT studies include reductions in fat mass [5, 7–13], muscle mass increases [10, 12, 14], and protective effects on phase angle [5, 14], a parameter derived from bioelectrical impedance analysis (BIA) [15], which has been considered a functional mark of the cell's health and mass [16]. However, most studies indicate that these benefits gradually disappear once the program ends [5–7, 9–12]. For example, Krčmár et al. [12] conducted a 12-week RT program followed by a 12-week detraining period, whose participants experienced a 1.6% loss in muscle mass and a 2.8% increase in fat mass. For this reason, Dos Santos et al. [5] recommend continuous monitoring and follow-up to ensure the long-term effectiveness of RT interventions.

Despite this, the evidence regarding the effects of exercise cessation among older people is still limited. Few studies have examined the long-term effects of exercise programs using more than one assessment point over a 12-month follow-up period [11]. Importantly, to our knowledge, most studies on long-term effects have limited participants' usual PA levels or have advised against starting new exercise programs following the intervention ceased [8, 11, 17].

Previous research has shown that moderate PA levels and regular participation in exercise programs positively impact daily functioning in older adults [18, 19] and may prevent or delay muscle mass decline [20]. Unfortunately, the cessation/interruption of community-based programs is often inevitable [11]. Hence, researchers should adopt a proactive approach, encouraging participants to maintain active lifestyles post-intervention to prevent a return to sedentary behaviors, which respond to ethical concerns [21]. Therefore, this study aimed to examine how different levels of PA (light *vs.* moderate-to-vigorous) influence the body composition parameters' effects achieved through a 16-week HSRT program over a 1-year follow-up period. As a secondary aim, PA levels were also evaluated throughout the follow-up period.

Methods

Study design

This longitudinal study is a secondary analysis of the "Idade Activa" research project, registered on clinicaltrials.gov (ID: NCT05586087). The study adheres to the principles of the Declaration of Helsinki and has received ethical approval from the local university's Ethics Committee (no. 22030). All participants were thoroughly informed about the study's objectives, potential benefits, and risks and provided written informed consent.

Previously, this research employed a parallel two-group clinical trial design over 16 weeks of a HSRT program, with the results published elsewhere [14]. From that study, only participants from the intervention group were included. Participants from the control group were excluded, as they either began new exercise programs or participated in other research projects after the intervention, making them ineligible for the long-term follow-up analysis related to the original study.

The participants included in this study were assessed at four time points: pre- (M0), post-intervention (M1), and 6 months (M2) and 1 year (M3) following the HSRT program. The committee recommended encouraging intervention group participants to maintain PA levels and further analyzing how different levels of PA influenced the effects of the 16-week HSRT program. Consequently, these participants were encouraged to sustain high levels of PA and were allowed to start new exercise programs without restriction.

Participants

This study analyzed participants who successfully completed the 1-year follow-up assessment. The final sample consisted of 36 independent older adults (age, 69.33 ± 3.12 years) who had previously undergone a 16-week HSRT program and underwent all assessments at each time point. Based on their PA levels measured using the International Physical Activity Questionnaire–Short Form (IPAQ-SF) at the 1-year follow-up, participants were further divided into two groups: the light activity group (LAG, $N = 20$, age, 70.00 ± 3.66 years) and the moderate-to-vigorous activity group (MVAG, $N = 16$, age, 68.50 ± 2.09 years). To enhance methodology transparency, we have included a supplementary Excel spreadsheet from Cheng [22], which provides anonymized participant responses across the four assessment time points

(M0, M1, M2, and M3) along with the established criteria for defining PA levels.

Participants met the following inclusion criteria: (a) being at least 65 years old; (b) being able to walk independently; and (c) performing daily living tasks. Exclusion criteria included a diagnosis of diabetes or cardiac disease, recent surgery within the past 6 months, or an active oncological condition.

Measurements

Anthropometric and body composition assessments were carried out during the morning hours (8:30–10:30 a.m). Participants were instructed to fast for a minimum of eight hours prior to testing, to ensure they had emptied their bladders, and to refrain from engaging in PA or consuming alcohol and caffeine within the preceding 24 h. To maintain consistency and minimize variability, all measurements were administered by the same trained researcher, following a standardized protocol for every individual.

Bioelectrical composition

The InBody® S10 (Model JMW140, Biospace Co., Ltd., Seoul, Korea), a multifrequency, tetrapolar bioelectrical impedance analyzer, was used to evaluate the body composition, in accordance with the manufacturer's instructions [23] and has been used in several previous studies [24–31].

Unlike traditional BIA devices that rely heavily on population-based prediction equations, the InBody S10 captures direct impedance values across five distinct body segments (arms, legs, and trunk) [32]. By evaluating electrical resistance across these segments at multiple frequencies, the device differentiates between fat mass, lean mass, water compartments, and other body compartments with improved accuracy. BIA assesses body composition by detecting differences in tissue conductivity, which vary according to water and electrolyte content, properties that are typically lower in fat tissue compared to muscle [25, 32].

Before the assessment, all metallic accessories were removed, and the electrode sites were cleaned using ethyl alcohol and cotton to ensure optimal conductivity. Participants were then instructed to lie in a supine position in a quiet environment for approximately 10 min to stabilize body fluids. Subsequently, eight electrodes were placed on standardized anatomical sites (thumbs, middle fingers, and ankles of both hands and feet), in order to enable multisegmental BIA. This procedure was conducted following the manufacturer's guidelines, which specify that segmental analysis using the InBody system minimizes cross-influence between body segments, thereby improving measurement precision.

Additionally, the device performed a total of 30 impedance readings at six distinct frequencies (1, 5, 50, 250, 500, and 1000 kHz) across five body segments: the right and left arms, trunk, and right and left legs. Additionally, 15 measurements of reactance and phase angle were obtained at three frequencies (5, 50, and 250 kHz) for the same segments. The following parameters were measured: (i) body fat (%); (ii) fat mass (kg); (iii) fat-free mass (kg); (iv) skeletal muscle mass (kg); (v) lean mass (kg); (vi) body cell mass (kg); (vii) phase angle (°); (viii) total body water (TBW) (L); (ix) intracellular water (ICW) (L); and (x) extracellular water (ECW) (L). Phase angle was measured, although only the data corresponding to the 50 kHz frequency were presented according to previous studies [24, 25, 32]. The manufacturer's guidelines for interpreting each parameter are available elsewhere [33].

Physical activity

Participants' PA levels were assessed using the IPAQ-SF [34, 35]. The IPAQ-SF collected data on total activity days and minutes per week and detailed PA indicators, including total PA (sum of walking, moderate, and vigorous MET-min/week), moderate and vigorous physical activity (MVPA) scores, walking, moderate and vigorous activity rates in MET/minute/week and sitting time during the week or weekend.

Based on their responses, which are presented in the supplementary Excel spreadsheet developed by Cheng [22], participants were categorized into light, moderate, or vigorous activity levels (Table A in the supplementary file). In addition, participants were asked to report the main activities they had carried out in the last six months (i.e., from 6- to 12-month follow-up) [Table B in the supplementary file].

Anthropometric

Anthropometric assessments included measuring weight and height by an electronic scale (Tanita®, MC 780MA, Amsterdam, Netherlands) and a stadiometer (SECA® 220, Hamburg, Germany), which are accurate to 0.01 kg and 0.1 cm, respectively. The participants were required to wear light clothing and no shoes. Body mass index (BMI) was subsequently calculated via the standard formula: BMI = body mass (kg)/height^2 (m^2).

High-speed resistance training protocol

The intervention is described in detail elsewhere [14]. In brief, the HSRT intervention was implemented three times per week over a 16-week period, with all sessions supervised. The exercise prescription was updated biweekly. Each session included a warm-up phase (10–15 min), a fundamental phase (45–55 min), and a cool-down phase (5–10 min). The main training segment incorporated both upper and lower body exercises, such as squats (using either a Smith machine or dumbbells based on individual capability), leg press, leg extension; calf raise; seated row; peck fly; lat pull down; and incline bench press (Technogym, SPA, Cesena, Italy).

Progressive loading was based on the average concentric velocity across sets, personalized for each participant and exercise [36, 37]. During the initial phase (weeks 1–4), training targeted *starting strength* with concentric velocities exceeding 1.3 m/s. From weeks 5 to 10, velocity was reduced to the 1.3–1.0 m/s range (speed/strength), and in the final phase (weeks 11–16), it ranged between 1.0 and 0.75 m/s (strength/speed). The mean concentric phase velocity for each set and exercise was tracked using a BEAST™ inertial sensor (Beast Technologies, Brescia, Italy) [38], which provided real-time feedback to both participants and supervisors, and displayed the average concentric velocity after each set.

Six accelerometers were used simultaneously, each connected to a separate smartphone via Bluetooth. Participants were also instructed to perform the concentric phase of each repetition as fast as possible, while controlling the eccentric phase over 2–3 s.

Statistical analysis

Data were analyzed using SPSS software (version 26, IBM Corp., Armonk, NY, USA), with a significance threshold of $p \leq 0.050$ (two-tailed). Alongside traditional null hypothesis significance testing, an estimation-focused approach was applied [39, 40]. Prior to data collection, a power analysis using G-power software (University of Dusseldorf, Germany) determined the required sample size based on the following parameters: repeated measures ANOVA for within–between interaction, effect size $f = 0.25$, $\alpha = 0.05$, power = 0.80, two groups, and four measurement points. The resulting power analysis indicated that a minimum of 24 participants was necessary to achieve approximately 82% power for rejecting the null hypothesis.

Repeated-measures ANOVA were used to assess changes over time for each outcome under study. Pairwise comparisons between time points and between groups were conducted using Bonferroni adjustments. Effect sizes (ESs) for pairwise comparisons were calculated using Cohen's d_{unbiased} (d_{unb}) through a specific spreadsheet [39], and classified as trivial (< 0.20), small (0.20–0.49), medium (0.50–0.80), or large (> 0.80) [41]. In addition, the ESs for the ANOVA were expressed as partial eta squared (η_p^2) and interpreted as small (0.010–0.059), medium (0.060–0.140), or large (> 0.140) [41].

Results

Participants

The participants' ages are shown in Table 1. Several significant differences were detected over the study period.

Body composition

Table 2 presents the changes in body composition parameters across the four measurement points. Overall, all parameters exhibited a significant time effect, with large ESs observed throughout the study period.

Table 2 also presents that there were no significant differences between groups. Additionally, several significant within-group differences were observed across multiple time points and measures.

Table 1 General characteristics of the sample (mean ± SD)

Measures	Groups	Intervention		Follow-up		Time effect	Interaction effect within groups	Interaction effect between groups
		M0 Pre	M1 Post	M2 6 Months	M3 12 Months			
Age (years)	LAG^{a,b,c,d,e,f}	68.55 ± 3.52	69.15 ± 3.57	69.45 ± 3.52	70.00 ± 3.66	$F = 130.500$¥	$F = 3.855$¥	$F = 1.988$
	MVAG^{b,c,d,e}	67.31 ± 2.06	67.50 ± 2.09	68.19 ± 2.01	68.50 ± 2.09	$\boldsymbol{p < 0.001}$	$\boldsymbol{p = 0.026}$	$p = 0.168$
						$\eta_p^2 = 0.793$§	$\eta_p^2 = 0.102$*	$\eta_p^2 = 0.055$#

Significant differences between periods are highlighted in bold ($p \leq 0.05$)

LAG, light activity group; MVAG, moderate-to-vigorous activity group; Kg, kilograms; BMI, body mass index; m, meters

¥, Greenhouse–Geisser correction

^{a}pre-intervention *vs.* post-intervention, ^{b}pre-intervention *vs.* 6-month follow-up, ^{c}pre-intervention *vs.* 12-month follow-up, ^{d}post-intervention *vs.* 6-month follow-up, ^{e}post-intervention *vs.* 12-month follow-up, ^{f}6-month follow-up *vs.* 12-month follow-up

η_p^2 values thresholds

$^\#$small effect: 0.010 to 0.059, *medium effect: 0.060 to 0.140, §large effect large: > 0.140

Table 2 Changes in body composition parameters effects over the study period

Measures	Groups	Intervention		Follow-up		Time effect	Interaction effect within groups	Interaction effect between groups
		M0 Pre	M1 Post	M2 6-Month	M3 12-Month			
Weight (kg)	LAG	67.89 ± 10.48	67.93 ± 11.37	66.64 ± 11.51	66.59 ± 11.01	$F = 13.644$¥	$F = 2.756$¥	$F = 0.013$
	MVAG^{b,c,e}	68.68 ± 11.39	67.52 ± 11.90	66.32 ± 12.00	64.79 ± 11.89	**$p < 0.001$**	$p = 0.068$	$p = 0.908$
	TS^{b,c,d,e}	68.24 ± 10.74	67.75 ± 11.44	66.49 ± 11.57	65.79 ± 11.28	$\eta_p^2 = 0.286$§	$\eta_p^2 = 0.075$*	$\eta_p^2 = 0.001$
BMI (kg/m^2)	LAG	27.32 ± 4.32	27.31 ± 4.51	26.75 ± 4.47	26.68 ± 4.24	$F = 14.938$¥	$F = 2.522$¥	$F = 0.110$
	MVAG^{b,c,e}	28.26 ± 3.57	27.76 ± 3.78	27.26 ± 3.88	26.58 ± 3.68	**$p < 0.001$**	$p = 0.086$	$p = 0.742$
	TS^{b,c,d,e}	27.74 ± 3.98	27.51 ± 4.15	26.98 ± 4.17	26.64 ± 3.94	$\eta_p^2 = 0.305$§	$\eta_p^2 = 0.069$*	$\eta_p^2 = 0.003$
Fat mass (%)	LAG	38.11 ± 7.61	37.78 ± 6.66	38.16 ± 7.32	37.45 ± 6.86	$F = 6.872$¥	$F = 3.022$¥	$F = 0.118$
	MVAG^{c,e,f}	40.08 ± 5.89	38.82 ± 6.01	38.61 ± 5.78	36.94 ± 5.77	**$p = 0.001$**	**$p = 0.044$**	$p = 0.734$
	TS ^{c,f}	38.98 ± 6.88	38.24 ± 6.31	38.36 ± 6.59	37.22 ± 6.31	$\eta_p^2 = 0.168$§	$\eta_p^2 = 0.082$*	$\eta_p^2 = 0.003$
Fat mass (kg)	LAG	26.36 ± 8.37	26.07 ± 7.88	25.92 ± 8.42	25.35 ± 7.69	$F = 9.124$¥	F = 2.764¥	$F = 0.001$
	MVAG^{b,c,e}	27.63 ± 6.88	26.42 ± 6.74	25.87 ± 6.93	24.13 ± 6.29	**$p < 0.001$**	$p = 0.066$	$p = 0.972$
	TS^{b,c,e}	26.93 ± 7.66	26.22 ± 7.29	25.89 ± 7.68	24.81 ± 7.04	$\eta_p^2 = 0.212$§	$\mathrm{\eta_p}^2 = 0.075$*	$\eta_p^2 = 0.001$
Fat-free mass (kg)	LAG^{b,d}	41.54 ± 5.29	41.87 ± 6.02	40.73 ± 5.91	41.24 ± 6.03	$F = 6.920$	$F = 0.575$	$F = 0.071$
	MVAG	40.83 ± 7.39	41.10 ± 7.50	40.45 ± 7.00	40.66 ± 7.60	**$p < 0.001$**	$p = 0.633$	$p = 0.792$
	TS^{b,d}	41.22 ± 6.23	41.53 ± 6.63	40.60 ± 6.32	40.98 ± 6.68	$\eta_p^2 = 0.169$§	$\eta_p^2 = 0.017$#	$\eta_p^2 = 0.002$
Muscle mass (kg)	LAG^{b,d}	22.60 ± 3.24	22.75 ± 3.67	22.05 ± 3.58	22.37 ± 3.68	$F = 7.944$	$F = 0.447$	$F = 0.052$
	MVAG^{d}	22.20 ± 4.53	22.39 ± 4.54	21.92 ± 4.20	22.06 ± 4.57	**$p < 0.001$**	$p = 0.720$	$p = 0.821$
	TS^{b,d,e}	22.42 ± 3.81	22.59 ± 4.02	21.99 ± 3.81	22.23 ± 4.04	$\eta_p^2 = 0.189$§	$\eta_p^2 = 0.013$#	$\eta_p^2 = 0.002$
Lean mass (kg)	LAG^{b,d}	39.22 ± 5.02	39.52 ± 5.72	38.42 ± 5.59	38.90 ± 5.73	$F = 6.821$	$F = 0.645$	$F = 0.068$
	MVAG	38.56 ± 7.04	38.78 ± 7.15	38.19 ± 6.68	38.36 ± 7.24	**$p < 0.001$**	$p = 0.588$	$p = 0.796$
	TS^{b,d}	38.93 ± 5.92	39.19 ± 6.31	38.32 ± 6.01	38.66 ± 6.35	$\eta_p^2 = 0.167$§	$\eta_p^2 = 0.019$#	$\eta_p^2 = 0.002$
Body cell mass (kg)	LAG^{d,e}	26.83 ± 3.47	27.30 ± 3.89	26.40 ± 3.92	26.77 ± 4.05	$F = 11.179$	$F = 0.612$	$F = 0.033$
	MVAG^{d}	26.68 ± 4.83	26.87 ± 4.91	26.27 ± 4.61	26.43 ± 5.02	**$p < 0.001$**	$p = 0.609$	$p = 0.856$
	TS^{b,d,e}	26.76 ± 4.06	27.11 ± 4.62	26.34 ± 4.18	26.61 ± 4.44	$\eta_p^2 = 0.247$§	$\eta_p^2 = 0.018$#	$\eta_p^2 = 0.001$
Phase angle (°)	LAG	5.54 ± 0.72	5.52 ± 0.67	5.37 ± 0.70	5.39 ± 0.76	$F = 3.205$	$F = 0.136$	$F = 0.258$
	MVAG	5.60 ± 0.47	5.61 ± 0.48	5.48 ± 0.43	5.53 ± 0.49	**$p = 0.026$**	$p = 0.938$	$p = 0.615$
	TS	5.56 ± 0.62	5.56 ± 0.59	5.42 ± 0.59	5.46 ± 0.65	$\eta_p^2 = 0.086$*	$\eta_p^2 = 0.004$	$\eta_p^2 = 0.008$
TBW (L)	LAG^{b,d}	30.55 ± 3.89	30.81 ± 4.44	29.97 ± 4.34	30.35 ± 4.43	$F = 6.928$	$F = 0.499$	$F = 0.070$
	MVAG	30.04 ± 5.49	30.26 ± 5.55	29.76 ± 5.18	29.90 ± 5.62	**$p < 0.001$**	$p = 0.684$	$p = 0.793$
	TS^{b,d}	30.32 ± 4.61	30.56 ± 4.89	29.88 ± 4.66	30.15 ± 4.92	$\eta_p^2 = 0.169$§	$\eta_p^2 = 0.014$#	$\eta_p^2 = 0.002$
ICW (L)	LAG^{b,d}	18.84 ± 2.49	18.99 ± 2.81	18.43 ± 2.75	18.69 ± 2.83	$F = 8.744$	$F = 0.441$	$F = 0.044$
	MVAG^{d}	18.60 ± 3.42	18.71 ± 3.48	18.34 ± 3.22	18.44 ± 3.51	**$p < 0.001$**	$p = 0.724$	$p = 0.835$
	TS^{b,d,e}	18.73 ± 2.89	18.86 ± 3.08	18.39 ± 2.92	18.58 ± 3.10	$\eta_p^2 = 0.205$§	$\eta_p^2 = 0.013$#	$\eta_p^2 = 0.001$
ECW (L)	LAG^{d}	11.71 ± 1.45	11.82 ± 1.66	11.55 ± 1.62	11.66 ± 1.64	$F = 3.611$	$F = 0.396$	$F = 0.112$
	MVAG	11.48 ± 2.04	11.56 ± 2.08	11.42 ± 1.97	11.46 ± 2.12	**$p = 0.016$**	$p = 0.756$	$p = 0.740$
	TS^{d}	11.61 ± 1.72	11.70 ± 1.84	11.49 ± 1.76	11.57 ± 1.85	$\eta_p^2 = 0.096$*	$\eta_p^2 = 0.012$#	$\eta_p^2 = 0.003$

Significant differences between periods are highlighted in bold ($p \leq 0.050$)

LAG, light activity group; MVAG, moderate-to-vigorous activity group; TS, total sample; kg, kilograms; m, meter; %, percent; °, degrees; L, liters; TBW, total body water; ICW, intracellular water; ECW, extracellular water

¥, Greenhouse−Geisser correction

[a]pre-intervention *vs.* post-intervention, [b]pre-intervention *vs.* 6-month follow-up, [c]pre-intervention *vs.* 12-month follow-up, [d]post-intervention *vs.* 6-month follow-up, [e]post-intervention *vs.* 12-month follow-up, [f]6-month follow-up *vs.* 12-month follow-up

η_p^2 values thresholds

[#]small effect: 0.010 to 0.059, *medium effect: 0.060 to 0.140, §large effect large: > 0.140

For weight, only the MVAG demonstrated significantly lower values at the 6-month ($p = 0.007$, $d_{\text{unb}} = -0.19$ [−0.34 to −0.06]) and at the 12-month follow-ups ($p = 0.001$, $d_{\text{unb}} = -0.32$ [−0.54 to −0.12]) compared to pre-intervention. Moreover, weight at the 12-month follow-up was significantly lower than post-intervention ($p = 0.002$, $d_{\text{unb}} = -0.22$ [−0.38 to −0.07]). Similarly, BMI showed significant reductions only in the MVAG, with significantly lower values at the 6-month ($p = 0.007$, $d_{\text{unb}} = -0.25$ [−0.45 to −0.08]) and at the 12-month follow-ups ($p = 0.001$, $d_{\text{unb}} = -0.44$ [−0.75 to −0.17]) compared to pre-intervention. BMI at the 12-month follow-up was also significantly lower than post-intervention ($p = 0.002$, $d_{\text{unb}} = -0.30$ [−0.52 to −0.11]).

For fat mass (%), the MVAG demonstrated significantly lower values at the 12-month follow-up compared to pre- ($p = 0.002$, $d_{\text{unb}} = -0.51$ [−0.92 to −0.14]) and post-intervention ($p = 0.028$, $d_{\text{unb}} = -0.30$ [−0.61 to −0.02]). The MVAG also presented significantly lower values at the 12-month follow-up compared to the 6-month follow-up ($p = 0.048$, $d_{\text{unb}} = -0.27$ [−0.54 to −0.03]). Furthermore, fat mass (kg) for the MVAG demonstrated significantly lower values at the 6-month ($p = 0.030$, $d_{\text{unb}} = -0.24$ [−0.47 to −0.03]) and at the 12-month follow-ups ($p = 0.002$, $d_{\text{unb}} = -0.51$ [−0.91 to −0.15]) than pre-intervention. Additionally, fat mass (kg) showed significantly lower values at the 12-month follow-up compared to post-intervention ($p = 0.008$, $d_{\text{unb}} = -0.33$ [−0.63 to −0.07]).

In contrast, for fat-free mass, only LAG showed significantly lower values at the 6-month follow-up compared to pre- ($p = 0.018$, $d_{\text{unb}} = -0.14$ [−0.25 to −0.03]) and post-intervention ($p < 0.001$, $d_{\text{unb}} = -0.18$ [−0.29 to −0.09]). For muscle mass, both groups exhibited significantly lower values at the 6-month follow-up compared to post-intervention (LAG: $p < 0.001$, $d_{\text{unb}} = -0.19$ [−0.29 to −0.09]; MVAG: $p = 0.029$, $d_{\text{unb}} = -0.10$ [−0.18 to −0.03]). LAG values were also significantly lower at the 6-month follow-up compared to pre-intervention ($p = 0.010$, $d_{\text{unb}} = -0.15$ [−0.27 to −0.05]). For lean mass, only LAG exhibited significantly lower values at the 6-month follow-up than pre- ($p = 0.014$, $d_{\text{unb}} = -0.14$ [−0.26 to −0.04]) and post-intervention ($p < 0.001$, $d_{\text{unb}} = -0.19$ [−0.29 to −0.09]).

For body cell mass, both groups displayed significantly lower values at the 6-month follow-up compared to post-intervention (LAG: $p < 0.001$, $d_{\text{unb}} = -0.22$ [−0.34 to −0.12]; MVAG: $p = 0.006$, $d_{\text{unb}} = -0.12$ [−0.20 to −0.05]). The LAG values were also significantly lower at the 12-month follow-up than post-intervention ($p = 0.035$, $d_{\text{unb}} = -0.13$ [−0.24 to −0.03]). For TBW, LAG presented significantly lower values at the 6-month follow-up compared to pre- ($p = 0.023$, $d_{\text{unb}} = -0.13$ [−0.25 to −0.03]) and post-intervention ($p < 0.001$, $d_{\text{unb}} = -0.18$ [−0.29 to −0.09]). For ICW, both groups demonstrated significantly lower values at the 6-month follow-up compared to post-intervention (LAG: $p < 0.001$, $d_{\text{unb}} = -0.19$ [−0.30 to −0.10]; MVAG: $p = 0.029$, $d_{\text{unb}} = -0.10$ [−0.19 to −0.03]). In addition, the LAG showed significantly lower values at the 6-month follow-up compared to pre-intervention ($p = 0.009$, $d_{\text{unb}} = -0.15$ [−0.27 to −0.05]). Finally, for ECW, LAG showed significantly lower values at the 6-month follow-up than post-intervention ($p = 0.006$, $d_{\text{unb}} = -0.16$ [−0.27 to −0.06]).

Physical activity

Table 3 presents the differences in IPAQ-SF scores across the four measurement points. Overall, most parameters declined over the follow-up period but remained higher at the 6-month and 12-month follow-ups compared to pre-intervention. Additionally, several significant between-group differences were observed at the 12-month follow-up: total activity (days) ($p < 0.001$, $d_{\text{unb}} = 3.02$ [2.09 to 4.06]), total activity in minutes per week ($p < 0.001$, $d_{\text{unb}} = 1.30$ [0.59 to 2.05]), MVPA ($p < 0.001$, $d_{\text{unb}} = 2.18$ [1.37 to 3.06]), walking activity ($p = 0.033$, $d_{\text{unb}} = 0.73$ [0.06 to 1.42]), and sitting time ($p = 0.009$, $d_{\text{unb}} = -0.90$ [−1.61 to −0.22]).

Regarding within-group differences, for total activity in days, only LAG showed significantly higher values at post- than pre-intervention ($p = 0.002$, $d_{\text{unb}} = 1.08$ [0.42 to 1.79]), significantly lower values at the 12-month follow-up compared to pre-intervention ($p < 0.001$, $d_{\text{unb}} = -1.33$ [−2.08 to −0.67]), significantly lower values at the 6-month ($p = 0.050$, $d_{\text{unb}} = -0.83$ [−1.54 to −0.18]) and 12-month follow-ups than post-intervention ($p < 0.001$, $d_{\text{unb}} = -3.67$ [−5.16 to −2.45]), and significantly lower values at the 12-month than 6-month follow-up ($p < 0.001$, $d_{\text{unb}} = -1.51$ [−2.36 to −0.76]). Additionally, for total activity in minutes per week, both groups demonstrated significantly higher values at post- than pre-intervention (LAG: $p < 0.001$, $d_{\text{unb}} = 1.58$ [0.89 to 2.37]; MVAG: $p < 0.001$, $d_{\text{unb}} = 2.02$ [1.10 to 3.12]), and significantly lower values at the 6-month (LAG: $p < 0.001$, $d_{\text{unb}} = -1.84$ [−2.78 to −1.03]; MVAG: $p = 0.003$, $d_{\text{unb}} = -1.29$ [−2.24 to −0.46]) and 12-month follow-ups than post-intervention (LAG: $p < 0.001$, $d_{\text{unb}} = -2.36$ [−3.39 to −1.50]; MVAG: $p = 0.004$, $d_{\text{unb}} = -1.14$ [−1.98 to −0.39]).

For MVPA, both groups presented significantly higher values at post- than pre-intervention (LAG: $p < 0.001$, $d_{\text{unb}} = 3.44$ [2.32 to 4.82]; MVAG: $p < 0.001$, $d_{\text{unb}} = 3.29$ [2.14 to 4.79]), and significantly lower values at the 6-month (LAG: $p < 0.001$, $d_{\text{unb}} = -2.54$ [−3.67 to −1.60]; MVAG: $p < 0.001$, $d_{\text{unb}} = -2.87$ [−4.24 to −1.77]) and 12-month follow-ups (LAG: $p < 0.001$, $d_{\text{unb}} = -4.45$ [−6.19 to −3.05]; MVAG: $p < 0.001$, $d_{\text{unb}} = -1.74$ [−2.83 to −0.78]) than post-intervention. In addition, MVAG also exhibited significantly higher values at the 12-month follow-up than pre-intervention ($p = 0.001$, $d_{\text{unb}} = 1.18$ [0.31 to 2.15]) and the 6-month follow-up ($p = 0.023$, $d_{\text{unb}} = 0.92$ [0.17 to −1.73]). Lastly, for

Table 3 Changes in physical activity over the study period

Measures	Groups	Intervention		Follow-up		Time effect	Interaction effect within groups	Interaction effect between groups
		M0 Pre	M1 Post	M2 6-Month	M3 12-Month			
Total activity (days)	LAG^{a,c,d,e,f}	5.35 ± 2.01	6.95 ± 0.22	5.70 ± 2.03	2.90 ± 1.48 †	$F = 14.403$¥	$F = 15.512$¥	$F = 10.654$
	MVAG	5.75 ± 1.88	6.88 ± 0.50	5.56 ± 1.75	6.62 ± 0.72	**$p < 0.001$**	**$p < 0.001$**	**$p = 0.003$**
	TS^{a,d,e}	5.53 ± 1.93	6.92 ± 0.37	5.64 ± 1.89	4.56 ± 2.22	$\eta_p^2 = 0.298$§	$\eta_p^2 = 0.313$§	$\eta_p^2 = 0.239$§
Total activity (minute/ week)	LAG^{a,d,e}	71.25 ± 42.36	131.25 ± 29.46	65.75 ± 38.33	54.25 ± 33.02 †	$F = 29.331$	$F = 3.009$	$F = 6.602$
	MVAG^{a,d,e}	74.38 ± 29.71	137.50 ± 29.72	86.25 ± 44.10	99.06 ± 34.36	**$p < 0.001$**	**$p = 0.034$**	**$p = 0.015$**
	TS^{a,d,e,}	72.64 ± 36.81	134.03 ± 29.32	74.86 ± 41.69	74.17 ± 40.09	$\eta_p^2 = 0.463$§	$\eta_p^2 = 0.081$*	$\eta_p^2 = 0.163$§
MVPA (MET/ minute/ week)	LAG^{a,d,e}	470.00 ± 404.32	1991.00 ± 444.21	591.00 ± 602.08	231.00 ± 302.03†	$F = 91.126$	$F = 7.368$	$F = 18.252$
	MVAG^{a,c,d,e,f}	596.25 ± 420.17	2226.25 ± 513.33	706.25 ± 493.41	1225.00 ± 579.68	**$p < 0.001$**	**$p < 0.001$**	**$p < 0.001$**
	TS^{a,d,e}	526.11 ± 410.43	2095.56 ± 483.84	642.22 ± 551.81	672.78 ± 666.68	$\eta_p^2 = 0.728$§	$\eta_p^2 = 0.178$§	$\eta_p^2 = 0.349$§
Walking (MET/ minute/ week)	LAG	603.90 ± 585.56	501.60 ± 529.69	1110.45 ± 1899.67	222.75 ± 219.39†	$F = 2.001$¥	$F = 1.565$¥	$F = 1.007$
	MVAG	1027.13 ± 1766.53	1103.44 ± 1397.32	662.06 ± 730.83	419.72 ± 310.68	$p = 0.137$	$p = 0.213$	$p = 0.323$
	TS	792.00 ± 1252.61	769.08 ± 1039.75	911.17 ± 1496.33	310.29 ± 278.11	$\eta_p^2 = 0.056$#	$\eta_p^2 = 0.044$*	$\eta_p^2 = 0.029$
Sitting time (hours)	LAG^{a,d,e,f}	4.95 ± 1.82	3.80 ± 1.06 †	4.85 ± 1.89	5.80 ± 1.61†	$F = 19.010$	$F = 1.331$	$F = 3.360$
	MVAG^{a,d,e}	4.63 ± 1.03	3.13 ± 0.81	4.31 ± 1.58	4.56 ± 0.89	**$p < 0.001$**	$p = 0.268$	$p = 0.076$
	TS^{a,d,e}	4.81 ± 1.51	3.50 ± 1.00	4.61 ± 1.76	5.25 ± 1.46	$\eta_p^2 = 0.359$§	$\eta_p^2 = 0.038$#	$\eta_p^2 = 0.090$*

Significant differences between periods are highlighted in bold ($p \leq 0.050$)

LAG, light activity group; MVAG, moderate-to-vigorous activity group; TS, total sample; MET, metabolic equivalent task; PA, physical activity; MVPA, sum of minutes spent in moderate and vigorous activity

¥, Greenhouse−Geisser correction

^{a}pre-intervention *vs.* post-intervention, ^{b}pre-intervention *vs.* 6-month follow-up, ^{c}pre-intervention *vs.* 12-month follow-up, ^{d}post-intervention *vs.* 6-month follow-up, ^{e}post-intervention *vs.* 12-month follow-up, ^{f}6-month follow-up *vs.* 12-month follow-up

†, between groups at that assessment point

η_p^2 values thresholds

$^\#$small effect: 0.010 to 0.059, *medium effect: 0.060 to 0.140, §large effect large: > 0.140

sitting time, both groups displayed significantly lower values at post- than pre-intervention (LAG: $p = 0.004$, $d_{unb} = -0.74$ [−1.27 to −0.26]; MVAG: $p = 0.001$, $d_{unb} = -1.54$ [−2.48 to −0.75]), and significantly higher values at the 6-month (LAG: $p = 0.028$, $d_{unb} = 0.66$ [0.25 to 1.10]; MVAG: $p = 0.025$, $d_{unb} = 0.89$ [0.14 to 1.73]) and 12-month follow-ups (LAG: $p < 0.001$, $d_{unb} = 1.41$ [0.87 to 2.05]; MVAG: $p < 0.001$, $d_{unb} = 1.60$ [0.76 to 2.59]) than post-intervention. The LAG also displayed significantly higher values at the 12-month than the 6-month follow-up ($p = 0.033$, $d_{unb} = 0.52$ [0.12 to 0.95]).

Discussion

The aim of this study was to examine how different levels of PA influenced the retention of body composition effects achieved through a 16-week HSRT program over a 1-year follow-up period in older adults. Additionally, PA levels were also evaluated throughout the follow-up period. Hence, the main findings were threefold: (a) fat mass remained significantly lower at the 1-year follow-up compared to both pre- and post-intervention values, especially in the MVAG; (b) body cell mass values decreased over the follow-up period, with a significant decline observed in the LAG; and (c) with the exception of walking activity, all PA measures in the MVAG remained higher at the 1-year follow-up compared to pre-intervention, whereas the LAG showed a decline in these measures over the study period. These findings have important clinical implications, as increased fat mass and reduced PA are associated with poor health outcomes [42]. Additionally, the phase angle results highlight the protective role of RT on cellular function, reinforcing the effectiveness of the HSRT intervention [14] and by previous studies [5, 17].

The study showed that PA declined across both general categories (Table A, supplementary file) and specific parameters (Table 3) following the intervention. However, it is noteworthy that, when comparing pre-intervention values to the 12-month follow-up, some participants maintained their PA habits despite the overall reduction, especially the weekly activity (min) for MVAG. In contrast, the significant reduction observed in the LAG may reflect a decrease in motivation to engage in any form of PA. Although the IPAQ-SF is a validated instrument for assessing PA and sedentary behavior in older adults [43], it has inherent limitations, including susceptibility to desirability bias [44]. Nevertheless, it remains a cost-effective, practical, and accessible tool that minimizes the burden on both participants and researchers [45]. Therefore, these findings may have clinical relevance for exercise professionals, offering insights into how older adults sustain moderate levels of PA and how these behaviors influence body composition, factors that are essential for preventing cardiovascular disease, frailty and early mortality [46, 47].

Few studies have examined exercise cessation effects in older adults. Martínez-Aldao et al. [48] reported similar reductions in PA following a 24-week detraining period after an 8-month multi-component training program, while Esain et al. [49] observed a shift toward a less active lifestyle during 12 weeks of detraining after a 9-month intervention. Consistent with these findings, the present study suggests that when older adults are not engaged in supervised and structured programs, they tend to reduce their PA and, consequently, adopt a more sedentary lifestyle. This may be attributed to the fact that, beyond physical benefits, participation in formal programs promotes social interactions [48, 50], which can encourage individuals to organize additional activities (e.g., charity walks) and potentially mitigate isolation and inactivity [51].

Although RT programs are widely recognized as effective in counteracting age-related changes in body composition among older adults [5, 7, 8, 11–14, 52], studies have reported that these improvements are often lost during detraining periods, with declines observed as early as 2 weeks [17] and up to 12 months [7, 10].

In the present study, fat mass significantly decreased from pre- and post-intervention to the 12-month follow-up in the MVAG, demonstrating a protective role of their sustained PA habits. As the present research used a distinct methodology, most previous research did not align with these results [5, 7–13]. Furthermore, the MVAG exhibited significant reductions in weight (5.66% and 4.04%) and BMI (5.94% and 4.25%) at the 12-month follow-up compared to pre- and post-intervention values, respectively. Interestingly, BMI reductions were also observed in the LAG, a finding not reported in previous studies [5, 7, 8, 11, 12, 17, 52]. These findings may emphasize the benefits of maintaining an active lifestyle, possibly facilitated by increased health literacy and encouragement to sustain high PA levels or begin new exercise programs during the follow-up period. Unlike prior studies, which restricted participants to their usual activity levels or discouraged structured exercise [5, 7, 8, 11–13, 52], this study promoted continued engagement, reflecting an ethical commitment to public health [21].

In the present study, both groups demonstrated a decrease in muscle mass, particularly LAG, which also showed significant reductions in lean mass and fat-free mass from pre- and post-intervention to the 6-month follow-up. Previous studies have reported similar results after detraining periods [5, 7–13, 17]. As shown in Table B (supplementary file), most participants did not continue RT exercises, which likely contributed to the observed declines. This shift in exercise patterns during the follow-up period, with participants engaging more in cardiovascular activities than in RT exercises, is consistent with the findings of Snijders et al. [7]. Since RT provides a potent hypertrophic stimulus, particularly for type II muscle fibers often compromised by aging [53], these findings underscore the difficulty in maintaining muscle mass gains once RT ceases, further highlighting the impact of aging.

Body cell mass, which refers to the total weight of all living, metabolically active, and functionally vital cells in the body [54], declined significantly in both groups from the post-intervention to the 6-month follow-up. However, only the LAG exhibited a significant decrease from post-intervention to the 12-month follow-up. These results, along with the slight reductions in phase angle values, suggest that the physical activities performed during the follow-up period may have been insufficient to prevent declines in these parameters.

Although no prior studies have specifically examined body cell mass, similar decreases in phase angle after RT cessation have been reported [5, 17]. These findings suggest that RT cessation has detrimental effects on cellular health, such as mitochondrial function, level of inflammation and cell membrane integrity [16, 55], regardless of detraining duration. As Sardinha and Rosa [16] noted, the loss of hydration-mediated cell swelling (loss of ICW) is a key mechanism explaining these declines [56], which is supported by the ICW results (Table 3). This highlights the negative impact of stopping RT on cellular health.

Despite offering valuable insights, certain limitations should be acknowledged. First, both the assessor and participants were aware of the study's objectives, which could have introduced bias through expectancy effects. Second, PA was assessed using a self-reported questionnaire, which may lack precision. Older adults often overestimate their PA, potentially affecting group classification accuracy. While IPAQ-SF is a widely used and validated tool [35, 43], future studies should incorporate objective measures (e.g., accelerometers) alongside self-reported data to improve accuracy. Finally, caloric intake was not controlled during the follow-up period, which could have influenced the outcomes.

Conclusions

This study highlights the positive role of PA in retaining the effects achieved during the HSRT program. Participants who engaged in MVPA successfully maintained reductions in fat mass, BMI, and weight. However, significant declines in muscle mass, lean mass, fat-free mass and body cell mass were observed in both groups after the cessation of the HSRT program. The reduced motivation among LAG participants may have contributed to the significant declines in PA parameters observed at the 1-year follow-up compared to pre-intervention.

These findings underscore the critical importance of maintaining PA habits to preserve the benefits of structured training. They also emphasize the vulnerability of muscle mass and cellular health to the cessation of RT programs. Therefore, the information suggests that researchers and practitioners should actively encourage older adults to sustain at least moderate PA after completing exercise programs, whether these are part of scientific interventions or routine practices, to mitigate the negative effects associated with stopping structured training.

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Data availability The data that support the findings of this study are available from the corresponding author, A.D.M., upon reasonable request.

Declarations

Conflict of interest The authors declare no competing interests.

Ethical approval This study was conducted in accordance with the requirements of the Declaration of Helsinki and was approved by the Ethics Committee of Evora University with clearance number 22030. This clinical trial was registered on clinicaltrial.gov (ID: NCT05586087).

Informed consent All participants provided informed consent to participate in the study and authorized the publication of their data.

References

1. Harman D (1981) The aging process. Proc Natl Acad Sci U S A 78:7124–7128. https://doi.org/10.1073/pnas.78.11.7124
2. Faulkner JA, Larkin LM, Claflin DR, Brooks SV (2007) Age-related changes in the structure and function of skeletal muscles. Clin Exp Pharmacol Physiol 34:1091–1096. https://doi.org/10.1111/j.1440-1681.2007.04752.x
3. Lang T, Streeper T, Cawthon P et al (2010) Sarcopenia: etiology, clinical consequences, intervention, and assessment. Osteoporos Int 21:543–559. https://doi.org/10.1007/s00198-009-1059-y
4. Izquierdo M, De Souto Barreto P, Arai H et al (2025) Global consensus on optimal exercise recommendations for enhancing healthy longevity in older adults (ICFSR). J Nutr Health Aging 29:100401. https://doi.org/10.1016/j.jnha.2024.100401
5. Dos Santos L, Cyrino ES, Antunes M et al (2016) Changes in phase angle and body composition induced by resistance training in older women. Eur J Clin Nutr 70:1408–1413. https://doi.org/10.1038/ejcn.2016.124
6. Mertz KH, Reitelseder S, Rasmussen MA et al (2023) Changes in muscle mass and strength during follow-up after one-year resistance training interventions in older adults. J Strength Cond Res 37:2064–2070. https://doi.org/10.1519/JSC.0000000000004517
7. Snijders T, Leenders M, de Groot LCPGM et al (2019) Muscle mass and strength gains following 6 months of resistance type exercise training are only partly preserved within one year with autonomous exercise continuation in older adults. Exp Gerontol 121:71–78. https://doi.org/10.1016/j.exger.2019.04.002
8. Amarante Do Nascimento M, Nunes JP, Pina FLC et al (2022) Comparison of 2 weekly frequencies of resistance training on muscular strength, body composition, and metabolic biomarkers in resistance-trained older women: effects of detraining and

retraining. J Strength Cond Res 36:1437–1444. https://doi.org/10.1519/JSC.0000000000003799

9. Bavaresco Gambassi B, Dos Santos Júnior CR, Dos Santos AO et al (2024) Resistance training maintains physical function but does not prevent changes in body composition and biochemical markers after detraining in aging adults. J Bodyw Mov Ther 37:146–150. https://doi.org/10.1016/j.jbmt.2023.11.026
10. Bezerra EDS, Orssatto LBR, Oliveira SN et al (2021) One-year cessation following resistance training differently affects neuromuscular, body composition, and functional capacity in older adults. Sport Sci Health 17:347–355. https://doi.org/10.1007/s11332-020-00695-7
11. Douda HT, Kosmidou KV, Smilios I et al (2015) Community-based training–detraining intervention in older women: a five-year follow-up study. J Aging Phys Act 23:496–512. https://doi.org/10.1123/japa.2013-0241
12. Krčmár M, Halmová N, Krajčovič J, Krčmárová B (2021) Muscular strength, functional fitness, body composition, and quality of life after 12 weeks of detraining in older females. Phys Occup Ther Geriatr 39:129–143. https://doi.org/10.1080/02703181.2020.1809602
13. Taaffe DR, Henwood TR, Nalls MA et al (2009) Alterations in muscle attenuation following detraining and retrainingin resistance trained older adults. Gerontology 55:217–223. https://doi.org/10.1159/000182084
14. Duarte Martins A, Paulo Brito J, Fernandes O et al (2024) Effects of a 16-week high-speed resistance training program on body composition in community-dwelling independent older adults: a clinical trial. Clin Nutr ESPEN 63:84–91. https://doi.org/10.1016/j.clnesp.2024.06.010
15. Foster KR, Lukaski HC (1996) Whole-body impedance–what does it measure? Am J Clin Nutr. https://doi.org/10.1093/ajcn/64.3.388s
16. Sardinha LB, Rosa GB (2023) Phase angle, muscle tissue, and resistance training. Rev Endocr Metab Disord. https://doi.org/10.1007/s11154-023-09791-8
17. Freitas SP, Júdice PB, Hetherington-Rauth M et al (2021) The impact of 2 weeks of detraining on phase angle, BIVA patterns, and muscle strength in trained older adults. Exp Gerontol 144:111175. https://doi.org/10.1016/j.exger.2020.111175
18. Toto PE, Raina KD, Holm MB et al (2012) Outcomes of a multicomponent physical activity program for sedentary, community-dwelling older adults. J Aging Phys Act 20:363–378. https://doi.org/10.1123/japa.20.3.363
19. Manning KM, Hall KS, Sloane R et al (2024) Longitudinal analysis of physical function in older adults: the effects of physical inactivity and exercise training. Aging Cell 23:e13987. https://doi.org/10.1111/acel.13987
20. Manini TM, Everhart JE, Anton SD et al (2009) Activity energy expenditure and change in body composition in late life. Am J Clin Nutr 90:1336–1342. https://doi.org/10.3945/ajcn.2009.27659
21. Esmonde K (2023) Exercising caution: a case for ethics analysis in physical activity promotion. Public Health Ethics 16:77–85. https://doi.org/10.1093/phe/phad004
22. Cheng HL (2016) A simple, easy-to-use spreadsheet for automatic scoring of the international physical activity questionnaire (IPAQ) short form (updated November 2016). https://doi.org/10.13140/RG.2.2.21067.80165
23. InBody (2024) InBodyS10 user’s manual.
24. Yang EM, Park E, Ahn YH et al (2017) Measurement of fluid status using bioimpedance methods in Korean pediatric patients on hemodialysis. J Korean Med Sci 32:1828–1834. https://doi.org/10.3346/jkms.2017.32.11.1828
25. Buckinx F, Reginster J-Y, Dardenne N et al (2015) Concordance between muscle mass assessed by bioelectrical impedance analysis and by dual energy X-ray absorptiometry: a cross-sectional study. BMC Musculoskelet Disord 16:60. https://doi.org/10.1186/s12891-015-0510-9
26. Ng BK, Liu YE, Wang W et al (2018) Validation of rapid 4-component body composition assessment with the use of dual-energy X-ray absorptiometry and bioelectrical impedance analysis. Am J Clin Nutr 108:708–715. https://doi.org/10.1093/ajcn/nqy158
27. Jayanama K, Putadechakun S, Srisuwarn P et al (2018) Evaluation of body composition in hemodialysis Thai patients: comparison between two models of bioelectrical impedance analyzer and dual-energy X-ray absorptiometry. J Nutr Metab 2018:4537623. https://doi.org/10.1155/2018/4537623
28. Chung YJ, Kim EY (2021) Usefulness of bioelectrical impedance analysis and ECW ratio as a guidance for fluid management in critically ill patients after operation. Sci Rep 11:12168. https://doi.org/10.1038/s41598-021-91819-7
29. Kim W-J, Jo G-Y, Park J-H, Do H-K (2021) Feasibility of segmental bioelectrical impedance analysis for mild- to moderate-degree breast cancer-related lymphedema. Medicine (Baltimore) 100:e23722. https://doi.org/10.1097/MD.0000000000023722
30. Koch B, Miller A, Glass NA et al (2022) Reliability of multifrequency bioelectrical impedance analysis to quantify body composition in patients after musculoskeletal trauma. Iowa Orthop J 42:75–82
31. Kim M, Shinkai S, Murayama H, Mori S (2015) Comparison of segmental multifrequency bioelectrical impedance analysis with dual-energy X-ray absorptiometry for the assessment of body composition in a community-dwelling older population. Geriatr Gerontol Int 15:1013–1022. https://doi.org/10.1111/ggi.12384
32. Kyle U (2004) Bioelectrical impedance analysis? Part I: review of principles and methods. Clin Nutr 23:1226–1243. https://doi.org/10.1016/j.clnu.2004.06.004
33. InBody (2018) The professional’s guide to the InBody result sheet
34. IPAQ (2005) Guidelines for data processing and analysis of the international physical activity questionnaire (IPAQ)—short and long forms, revised on November 2005
35. Craig CL, Marshall AL, Sjöström M et al (2003) International physical activity questionnaire: 12-country reliability and validity. Med Sci Sports Exerc 35:1381–1395. https://doi.org/10.1249/01.MSS.0000078924.61453.FB
36. Mann B (2016) Developing explosive athletes: use of velocity based training in athletes. Ultimate Athlete Concepts, Muskegon Heights, MI, USA
37. Mann B, Ivey PA, Sayers SP (2015) Velocity-based training in football. Strength Cond J 37:52–57. https://doi.org/10.1519/SSC.0000000000000177
38. Vallejo FT, Chien LT, Hébert-Losier K, Beaven M (2020) Validity and reliability of the BeastTM sensor to measure movement velocity during the back squat exercise. J Sport Exerc Sci 4:100–105. https://doi.org/10.36905/jses.2020.02.05
39. Cumming G, Calin-Jageman R (2017) Introduction to the new statistics: estimation, open science, and beyond, 1st edn. Routledge
40. Ho J, Tumkaya T, Aryal S et al (2019) Moving beyond *P* values: data analysis with estimation graphics. Nat Methods 16:565–566. https://doi.org/10.1038/s41592-019-0470-3
41. Cohen J (1988) Statistical power analysis for the behavioral sciences, 2nd Edition. Lawrence Erlbaum Associates, Hillsdale
42. Mozaffarian D, Hao T, Rimm EB et al (2011) Changes in diet and lifestyle and long-term weight gain in women and men. N Engl J Med 364:2392–2404. https://doi.org/10.1056/NEJMoa1014296
43. Grimm EK, Swartz AM, Hart T et al (2012) Comparison of the IPAQ-short form and accelerometry predictions of physical activity in older adults. J Aging Phys Act 20:64–79. https://doi.org/10.1123/japa.20.1.64

44. Adams SA, Matthews CE, Ebbeling CB (2005) The effect of social desirability and social approval on self-reports of physical activity. Am J Epidemiol 161:389–398. https://doi.org/10.1093/aje/kwi054
45. Kowalski K, Rhodes R, Naylor P-J et al (2012) Direct and indirect measurement of physical activity in older adults: a systematic review of the literature. Int J Behav Nutr Phys Act 9:148. https://doi.org/10.1186/1479-5868-9-148
46. Cruz-Jentoft AJ, Bahat G, Bauer J et al (2019) Sarcopenia: revised European consensus on definition and diagnosis. Age Ageing 48:16–31. https://doi.org/10.1093/ageing/afy169
47. Landi F, Cruz-Jentoft AJ, Liperoti R et al (2013) Sarcopenia and mortality risk in frail older persons aged 80 years and older: results from ilSIRENTE study. Age Ageing 42:203–209. https://doi.org/10.1093/ageing/afs194
48. Martínez-Aldao D, Diz JC, Varela S et al (2020) Impact of a five-month detraining period on the functional fitness and physical activity levels on active older people. Arch Gerontol Geriatr 91:104191. https://doi.org/10.1016/j.archger.2020.104191
49. Esain I, Gil SM, Bidaurrazaga-Letona I, Rodriguez-Larrad A (2019) Effects of 3 months of detraining on functional fitness and quality of life in older adults who regularly exercise. Aging Clin Exp Res 31:503–510. https://doi.org/10.1007/s40520-018-0990-1
50. Franco MR, Tong A, Howard K et al (2015) Older people's perspectives on participation in physical activity: a systematic review and thematic synthesis of qualitative literature. Br J Sports Med 49:1268–1276. https://doi.org/10.1136/bjsports-2014-094015
51. Mays AM, Kim S, Rosales K et al (2021) The leveraging exercise to age in place (LEAP) study: engaging older adults in community-based exercise classes to impact loneliness and social isolation. Am J Geriatr Psychiatry 29:777–788. https://doi.org/10.1016/j.jagp.2020.10.006
52. Zech A, Drey M, Freiberger E et al (2012) Residual effects of muscle strength and muscle power training and detraining on physical function in community-dwelling prefrail older adults: a randomized controlled trial. BMC Geriatr 12:68. https://doi.org/10.1186/1471-2318-12-68
53. Lavin KM, Roberts BM, Fry CS et al (2019) The importance of resistance exercise training to combat neuromuscular aging. Physiology 34:112–122. https://doi.org/10.1152/physiol.00044.2018
54. Haverkort EB, Reijven PLM, Binnekade JM et al (2015) Bioelectrical impedance analysis to estimate body composition in surgical and oncological patients: a systematic review. Eur J Clin Nutr 69:3–13. https://doi.org/10.1038/ejcn.2014.203
55. da Silva BR, Orsso CE, Gonzalez MC et al (2022) Phase angle and cellular health: inflammation and oxidative damage. Rev Endocr Metab Disord. https://doi.org/10.1007/s11154-022-09775-0
56. Häussinger D (1996) The role of cellular hydration in the regulation of cell function. Biochem J 313:697–710. https://doi.org/10.1042/bj3130697