ORIGINAL ARTICLE

Effects of combined resistance and aerobic training on body composition and functional capacity in middle-aged adults: A 12-week intervention study

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ABSTRACT

This 12-week intervention study investigated the effects of a combined resistance and aerobic training (CT) program on body composition and functional capacity in sedentary middle-aged adults (n = 64; 32 males, 32 females; mean age 51.3 ± 6.2 years). Participants underwent supervised CT sessions three times weekly. Outcomes were assessed at baseline, week 6, and week 12, including fat mass (FM), fat-free mass (FFM), phase angle (PhA), handgrip strength (HGS), and estimated $\dot{V}O_{2max}$. Significant reductions in FM (−3.6 ± 1.1 kg) and increases in FFM (+1.8 ± 0.7 kg) and PhA (+0.6 ± 0.2°) were observed. Functional capacity improved markedly, with HGS increasing by 4.2 ± 1.3 kg (males) and 3.1 ± 1.1 kg (females), and $\dot{V}O_{2max}$ by 4.6 ± 1.5 ml/kg/min. Correlational and regression analyses revealed PhA as a strong predictor of functional gains. No significant changes in diet or physical activity outside the intervention were noted. The findings support the utility of CT in enhancing health-related outcomes during middle age and suggest that PhA may serve as a practical biomarker of exercise responsiveness.

Keywords: Sport medicine, Bioelectrical impedance analysis, Phase angle, Handgrip strength, Estimated $\dot{V}O_{2max}$, Functional capacity, Resistance training, Aerobic training.

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INTRODUCTION

Middle age represents a critical life stage often characterized by insidious yet consequential alterations in physiological function and body composition. Progressive declines in skeletal muscle mass (sarcopenia) frequently occur concurrently with increases in adipose tissue, particularly visceral fat (Santanasto et al., 2017; Janssen et al., 2000). These shifts are not merely aesthetic concerns; they are intrinsically linked to diminished physical function, an elevated risk profile for metabolic diseases such as type 2 diabetes and cardiovascular disease, and an overall reduction in health-related quality of life (Cruz-Jentoft et al., 2019). While historically viewed as near-inevitable consequences of chronological ageing, a robust body of evidence now firmly establishes that these deleterious trajectories can be significantly mitigated, or even partially reversed, through targeted lifestyle interventions, with structured exercise playing a paramount role (Fragala et al., 2019).

Exercise interventions traditionally focus on either aerobic training (AT) or resistance training (RT). AT is well-recognized for its potent effects on improving cardiorespiratory fitness (CRF) and positively influencing cardiometabolic risk factors, including facilitating fat mass reduction (An, Su, & Meng, 2024) and increasing insulin sensitivity through several molecular mechanisms such as improved glucose transporter activity and reduced oxidative stress (Yaribeygi, 2019). Conversely, RT is unequivocally the most effective strategy for stimulating muscle protein synthesis, leading to increases in muscle mass, strength, and functional capacity, thereby directly counteracting sarcopenic processes (An, Su, & Meng, 2024; Marcos-Pardo, Vaquero-Cristóbal, & Huber, 2023). Given these distinct yet complementary benefits, combined or concurrent training (CT), integrating both AT and RT within the same program, emerges as a highly rational and potentially synergistic approach for comprehensively addressing the multifaceted physiological challenges of middle age (Schroeder et al., 2019). Recent meta-analytic evidence confirms that CT is as effective as AT alone for improving body composition markers, like fat mass and as effective as RT alone for enhancing lean body mass and muscle mass in middle-aged and older populations (Khalafi et al., 2025). Furthermore, concerns regarding an "*interference effect*," where concurrent modalities might blunt adaptations to one another, appear less significant for muscle hypertrophy and maximal strength development than previously thought, particularly with appropriate program design (Schumann et al., 2022), bolstering the feasibility and efficacy of CT.

Accurate assessment of intervention-induced changes necessitates appropriate measurement tools. Bioelectrical impedance analysis (BIA) offers a practical, non-invasive method for tracking changes in body composition. Beyond traditional estimates of fat mass (FM) and fat-free mass (FFM), BIA yields the phase angle (PhA), derived from the relationship between resistance and reactance. PhA is increasingly recognized not merely as an indicator of body cell mass but as a sensitive biomarker reflecting cellular membrane integrity, hydration status, and overall cellular health (Norman et al., 2012; Fernández-Jiménez et al., 2022, Rosa et al., 2025). Higher PhA values are consistently associated with better nutritional status, greater muscle quality, and favourable health outcomes (Lukaski et al., 2017; Costa Pereira et al., 2024). Moreover, recent studies suggest PhA is responsive to physical activity levels and exercise training (Yamada et al., 2022; Souza et al., 2017), potentially offering insights into the qualitative adaptations within muscle tissue beyond simple mass accretion.

Functional capacity, encompassing both muscular strength and aerobic fitness, remains a cornerstone of healthy ageing. Handgrip strength (HGS), easily measured via dynamometry, serves as a reliable surrogate for overall muscle strength and possesses significant prognostic value, predicting morbidity, mortality, and future health status (Leong et al., 2015). Similarly, aerobic capacity, often quantified as maximal oxygen consumption ($\dot{V}O_{2max}$), is a powerful independent predictor of cardiovascular health and all-cause mortality (Kodama et al., 2009). Improvements in both HGS and $\dot{V}O_{2max}$ are critical targets for interventions aiming to enhance functional independence and longevity through middle age and beyond.

Despite the established importance of maintaining healthy body composition and functional capacity, and the growing interest in CT, research specifically investigating the effects of a structured, supervised, and periodized 12-week CT program in previously sedentary middle-aged adults remains somewhat limited. Furthermore, while PhA shows promise, its responsiveness to CT and its relationship with concurrent changes in established functional measures (HGS and $\dot{V}O_{2max}$) within this specific demographic and intervention timeframe warrants further elucidation. Therefore, this study aimed to investigate the effects of a 12-week combined resistance and aerobic training programme on body composition (assessed via BIA, including PhA), muscle strength (measured by HGS), and aerobic capacity (estimated via submaximal testing) in sedentary adults aged 35-64 years. A secondary aim was to explore the relationships between changes in BIA-derived PhA and changes in functional parameters, evaluating its potential utility as a practical biomarker for monitoring exercise-induced adaptations in this population.

METHODS

Study design and participants

This prospective interventional study employed a single-group, pre-post design. Participants were recruited from the local community through advertisements and referrals from primary care practices. The study was carried out in accordance with the ethical requirements established by the Catholic University's research governance policies and adhered to the principles of the Declaration of Helsinki. All participants were informed about the nature, purpose, and procedures of the study and voluntarily provided written informed consent before participation. They were also informed of their right to withdraw from the study at any time without consequences. Personal data were collected and processed in compliance with the General Data Protection Regulation.

Inclusion criteria comprised: (1) age 35-64 years; (2) sedentary lifestyle (defined as <150 minutes of moderate-intensity physical activity per week); (3) body mass index (BMI) between 20-35 kg/m²; and (4) medical clearance for exercise participation. Exclusion criteria included: (1) presence of cardiovascular, pulmonary, or metabolic diseases; (2) musculoskeletal conditions that would preclude exercise participation; (3) use of medications known to significantly affect body composition; and (4) participation in a structured exercise programme within the previous six months.

Of the 78 individuals initially enrolled, 64 (32 males, 32 females) completed the 12-week intervention and all assessment timepoints, representing an 82% completion rate. Reasons for dropout included time constraints (n = 8), illness unrelated to the intervention (n = 3), and relocation (n = 3).

Exercise intervention

Participants engaged in a 12-week supervised exercise programme consisting of three sessions per week (Monday, Wednesday, Friday), each lasting approximately 60 minutes. All sessions were conducted in a fitness facility equipped with resistance training machines and aerobic exercise equipment. Each session was supervised by qualified exercise kinesiologists with a participant-to-instructor ratio not exceeding 8:1.

The training protocol was based on recommendations to improve muscular and aerobic fitness in a healthy adult population (American College of Sports Medicine, 2009; Garber et al., 2011; Liguori, Feito, Fountaine, & Roy, 2021).

Each training session comprised:

1. Warm-up (5-10 minutes): Light aerobic activity and dynamic stretching.
2. Resistance training (25-30 minutes): Exercises targeting major muscle groups included leg press, chest press, seated row, shoulder press, and lat pull down. Training followed a periodised protocol with progression from 2 sets of 12-15 repetitions in weeks 1-4, to 3 sets of 10-12 repetitions in weeks 5-8, and 3 sets of 8-10 repetitions in weeks 9-12. Intensity was controlled using the Repetitions in Reserve (RIR) method, with participants training at an RIR of 0-2 (i.e., 0-2 repetitions left before muscular failure). Weights were adjusted individually to ensure training to near-muscular failure while maintaining proper form. A progression criterion was adopted whereby the load was increased (2–5% for upper limb, 5–10% for lower limb) when a participant successfully completed 15 (weeks 1-4), 12 (weeks 5-8) or 10 (weeks 9-12) repetitions with an RIR ≤1 in two consecutive sessions (Souza et al., 2017). Rest intervals ranged from 60–90 seconds between sets and 2–3 minutes between exercises.
3. Aerobic training (20-25 minutes): Performed on treadmill, stationary bicycle, or elliptical trainer. Intensity progressed from 60-65% of heart rate reserve (HRR) in weeks 1-4, to 65-70% HRR in weeks 5-8, and 70-75% HRR in weeks 9-12.
4. Cool-down (5 minutes): Light aerobic activity and static stretching.

Participants were instructed to maintain their habitual dietary patterns throughout the intervention period but completed 3-day food diaries at baseline, week 6, and week 12 to monitor for significant changes in caloric intake or macronutrient distribution.

Outcome measurements

Assessments were conducted at baseline (week 0), mid-intervention (week 6), and post-intervention (week 12). All measurements were taken by the same experienced assessors to minimise inter-rater variability.

Anthropometry and body composition

Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer (Seca, Hamburg, Germany). Body mass was measured to the nearest 0.1 kg using a calibrated digital scale (Seca, Hamburg, Germany) with participants wearing light clothing and no footwear. BMI was calculated as body mass divided by height squared (kg/m²).

Bioelectrical impedance analysis was performed using a phase-sensitive bioimpedance analyser at 50 kHz (BIA 101, BIVA Pro, Akern, Florence, Italy) following the manufacturer's guidelines and standardized protocols (Lukaski et al., 2017). Measurements were conducted in the morning following an overnight fast, with participants in a supine position on a non-conductive surface, with a leg opening of 45° compared to the median line of the body and the upper limbs abducted 30° from the trunk (National Institutes of Health [NIH], 1994). After cleansing the skin with alcohol, four disposable electrodes (Biatrodes Akern Srl, Florence, Italy) were positioned in a tetrapolar configuration: two on the dorsal surface of the right hand (at the distal metacarpals and between the distal prominences of the radius and ulna) and two on the dorsal surface of the right foot (at the distal metatarsals and between the medial and lateral malleoli) (NIH, 1994).

Prior to each test session, the accuracy of the analyser was verified and calibrated using a reference circuit according to the manufacturer's instructions.

Handgrip strength
Handgrip strength was measured using a Jamar Plus+ digital hand dynamometer (JAMAR PLUS +, Sammors Preston, Rolyon, Bolingbrook, IL, USA) following the American Society of Hand Therapists protocol (American Society of Hand Therapists, 2015). Participants were seated with their elbow flexed at 90°, forearm in neutral position, and wrist in slight extension (0-30°). After a familiarization phase, participants performed three maximal voluntary contractions (MVCs) of the dominant hand, each lasting at least 3 seconds. A rest interval of 60 seconds was provided between attempts. The peak force output was recorded and expressed in kilograms (kg). The average measurement, as well as the highest value, was chosen for analysis (Lupton et al., 2022).

Aerobic capacity
Aerobic capacity was estimated using the Åstrand-Ryhming submaximal bicycle ergometer test (Åstrand & Ryhming, 1954; Gerber et al., 2025), administered on a calibrated cycle ergometer (Monark 828E, Monark Exercise AB, Vansbro, Sweden). Heart rate was continuously monitored throughout the test using a chest strap sensor (Polar H10) in conjunction with a Polar Vantage V2 multisport watch (Polar Electro Oy, Kempele, Finland), ensuring a high temporal resolution and validated reliability in submaximal testing contexts.

To minimize the risk of premature fatigue and to ensure participant safety, initial workloads were intentionally conservative: 60 Watts for men and 40 Watts for women. Following a 2–3 minute warm-up phase, workload was incrementally adjusted so that perceived exertion approached a level of 13 on the Borg Rating of Perceived Exertion scale (RPE), while heart rate progressively increased toward a predetermined target zone.

The target heart rate range was stratified by age group: 130–160 beats per minute (bpm) for participants aged ≤40 years, and 120–150 bpm for those above 40 years. Participants were instructed to maintain a cadence of 60–70 revolutions per minute (rpm) over a standard six-minute test duration. If heart rate stabilized—defined as a variation of no more than ±5 bpm over the final two minutes—the test was concluded. In cases where stabilization was not achieved, the protocol was extended by an additional one or two minutes, up to a maximum of eight minutes total.

Heart rate was recorded at the end of each minute, alongside subjective measures of effort (Borg RPE scale) and affective valence. Post-test, maximal oxygen uptake ($\dot{V}O_{2max}$) was estimated following the procedure described by Buono et al. (1989), using the mean heart rate of the final two minutes and the corresponding workload. This value was subsequently corrected for the age factor.

Physical activity and dietary monitoring
Physical activity outside the intervention was monitored using the International Physical Activity Questionnaire (IPAQ) (Mannocci et al., 2010) at baseline, week 6, and week 12. Participants also completed 3-day food diaries (two weekdays and one weekend day) at the same timepoints. Nutritional intake was analysed using dietary analysis software (Nutritics, Dublin, Ireland).

Statistical analysis
All statistical analyses were conducted using IBM SPSS Statistics for Windows, version 27.0 (IBM Corp., Armonk, NY, USA). Data were initially assessed for normality using the Shapiro–Wilk test. Descriptive

statistics are reported as mean ± standard deviation (SD) for normally distributed variables and as median with interquartile range (IQR) for non-normally distributed data.

Changes in outcome measures over the three timepoints (baseline, week 6, and week 12) were analysed using repeated-measures analysis of variance (RM-ANOVA) for normally distributed data. The assumption of sphericity was tested using Mauchly's test; when this assumption was violated, the Greenhouse–Geisser correction was applied to adjust the degrees of freedom. Post-hoc comparisons were performed using the Bonferroni adjustment for multiple testing.

For non-normally distributed variables, Friedman's test was employed, followed by Wilcoxon signed-rank tests for pairwise comparisons. A Bonferroni correction was also applied to the Wilcoxon tests to control for type I error inflation due to multiple comparisons.

Sex differences at baseline and in change scores were analysed using independent samples t-tests or Mann–Whitney U tests, depending on the data distribution and homogeneity of variances (verified with Levene's test).

Associations between changes in body composition (e.g., fat mass, fat-free mass, phase angle) and functional outcomes (handgrip strength and estimated $\dot{V}O_{2max}$) were assessed using Pearson's product-moment or Spearman's rank correlation coefficients, depending on the normality and linearity of the data.

Multiple linear regression analyses were conducted to identify independent predictors of changes in handgrip strength and estimated $\dot{V}O_{2max}$. Predictor variables included changes in fat-free mass, fat mass, and phase angle. Prior to model inclusion, multicollinearity was assessed via variance inflation factor (VIF), and residuals were examined for normality, linearity, and homoscedasticity. The Durbin–Watson statistic was used to assess independence of residuals. Statistical significance was set at $p < .05$ (two-tailed). Effect sizes were calculated as partial eta-squared (η^2) for ANOVA (with thresholds of small ≥0.01, medium ≥0.06, and large ≥0.14) and Cohen's d for t-tests (small ≥0.2, medium ≥0.5, large ≥0.8), providing a complementary perspective on the practical significance of findings.

RESULTS

All outcome variables met the assumptions for normal distribution as verified by the Shapiro–Wilk test; therefore, parametric analyses were applied throughout.

Participant characteristics

The baseline characteristics of the 64 participants who completed the study are presented in Table 1. The sample included equal numbers of males and females with a mean age of 51.3 ± 6.2 years. No significant differences were observed between males and females in age or BMI, though males had significantly higher baseline values for fat-free mass, phase angle, handgrip strength, and estimated $\dot{V}O_{2max}$ (all $p < .001$).

Adherence and adverse events

The mean attendance rate for exercise sessions was 89.3 ± 6.7% (32.1 ± 2.4 out of 36 sessions). No significant sex differences in attendance were observed (males: 88.7 ± 7.1%, females: 89.9 ± 6.3%, $p = .472$). No serious adverse events related to the intervention were reported. Minor adverse events included delayed-onset muscle soreness (n = 15), which resolved within the first two weeks, and non-specific knee discomfort (n = 3), which was addressed through exercise modification.

Table 1. Baseline characteristics of study participants.

Characteristic	All (n = 64)	Males (n = 32)	Females (n = 32)	*p*-value
Age (years)	51.3 ± 6.2	50.8 ± 6.5	51.8 ± 5.9	.528
Height (cm)	171.4 ± 9.1	178.2 ± 6.4	164.6 ± 5.3	<.001
Body mass (kg)	78.6 ± 12.3	84.5 ± 10.4	72.7 ± 11.2	<.001
BMI (kg/m²)	26.7 ± 3.2	26.6 ± 2.9	26.8 ± 3.5	.806
Fat mass (kg)	25.9 ± 7.4	21.8 ± 5.7	30.0 ± 6.4	<.001
Fat-free mass (kg)	52.7 ± 10.5	62.7 ± 5.4	42.7 ± 4.3	<.001
Phase angle (°)	5.6 ± 0.7	6.0 ± 0.6	5.2 ± 0.5	<.001
Handgrip strength (kg)	32.8 ± 10.1	41.3 ± 6.3	24.3 ± 4.5	<.001
Estimated VO_{2max} (ml/kg/min)	27.4 ± 5.8	30.6 ± 5.1	24.2 ± 4.7	<.001

Note. Data presented as mean ± standard deviation. p-values refer to independent t-tests comparing males and females.

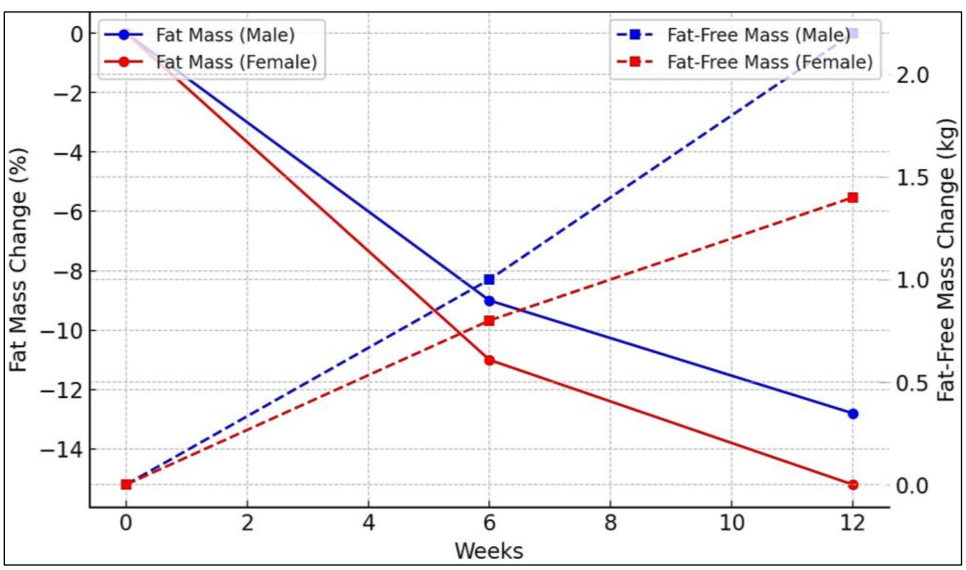
Changes in body composition

Table 2 presents the changes in body composition parameters across the intervention period. Significant improvements were observed in all measured parameters from baseline to week 12 (all $p < .001$). Notably, while significant reductions in body mass and fat mass were observed by week 6, significant increases in fat-free mass and phase angle were only detected at week 12.

Table 2. Changes in body composition parameters throughout the 12-week intervention.

Parameter	Baseline	Week 6	Week 12	Effect size (η²)
Body mass (kg)	78.6 ± 12.3	77.1 ± 11.9*	76.3 ± 11.6*†	0.78
BMI (kg/m²)	26.7 ± 3.2	26.2 ± 3.1*	25.9 ± 3.0*†	0.76
Fat mass (kg)	25.9 ± 7.4	23.9 ± 7.1*	22.3 ± 6.8*†	0.84
Fat-free mass (kg)	52.7 ± 10.5	53.2 ± 10.4	54.5 ± 10.7*†	0.67
Phase angle (°)	5.6 ± 0.7	5.8 ± 0.7	6.2 ± 0.8*†	0.72

*Note. Data presented as mean ± standard deviation. p-values refer to repeated-measures ANOVA. *Significantly different from baseline (p < .05). †Significantly different from week 6 (p < .05).*



Note. It shows: A sharper decline in fat mass (%) during the first six weeks, more pronounced in females. A more substantial increase in fat-free mass (kg) in the latter half of the intervention, with males gaining more in absolute terms.

Figure 1. Changes in body composition over the intervention period.

Sex-specific analyses revealed that males exhibited greater absolute increases in fat-free mass than females (2.2 ± 0.8 kg vs. 1.4 ± 0.6 kg, $p < .001$), whereas females demonstrated greater relative reductions in fat mass (-15.2 ± 4.3% vs. -12.8 ± 3.9%, $p = .022$). However, improvements in phase angle were similar between sexes (males: +0.6 ± 0.2°, females: +0.6 ± 0.3°, $p = .842$).

Figure 1 illustrates the changes in body composition parameters throughout the intervention period. The most pronounced changes in fat mass occurred during the first six weeks, while fat-free mass increases were more substantial during the latter half of the intervention.

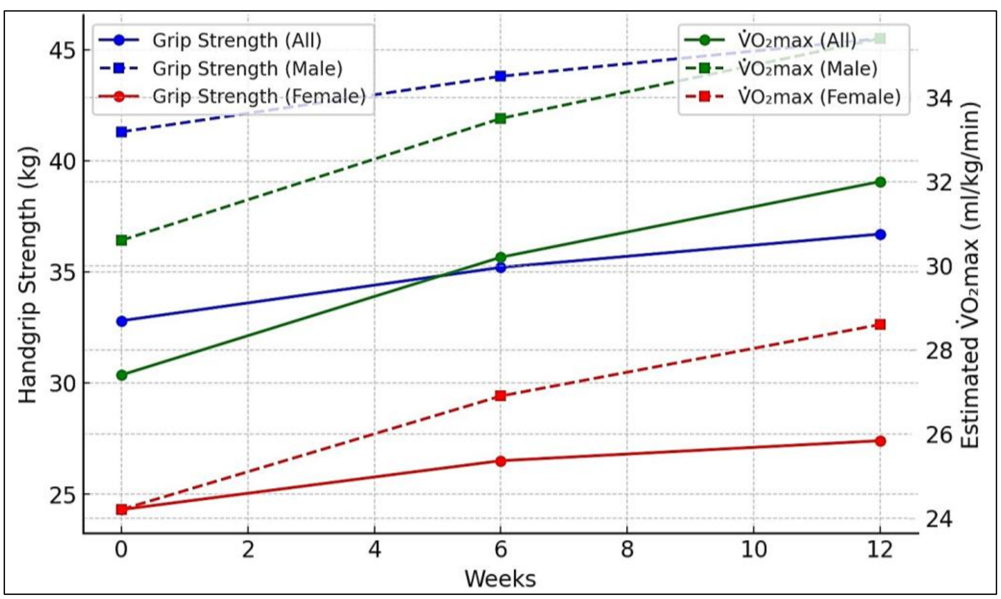
Changes in functional parameters

Significant improvements in handgrip strength and estimated $\dot{V}O_{2max}$ were observed over the 12-week intervention (Table 3). Unlike body composition parameters, significant improvements in functional measures were evident by week 6 and continued through week 12.

Table 3. Changes in functional parameters throughout the 12-week intervention.

Parameter	Baseline	Week 6	Week 12	Effect size (η²)
Handgrip strength (kg)				
All	32.8 ± 10.1	35.2 ± 10.3*	36.7 ± 10.5*†	0.74
Males	41.3 ± 6.3	43.8 ± 6.5*	45.5 ± 6.7*†	0.71
Females	24.3 ± 4.5	26.5 ± 4.7*	27.4 ± 4.8*†	0.68
Estimated $\dot{V}O_{2max}$ (ml/kg/min)				
All	27.4 ± 5.8	30.2 ± 6.0*	32.0 ± 6.3*†	0.81
Males	30.6 ± 5.1	33.5 ± 5.3*	35.4 ± 5.5*†	0.79
Females	24.2 ± 4.7	26.9 ± 4.9*	28.6 ± 5.1*†	0.75

*Note. Data presented as mean ± standard deviation. p-values refer to repeated-measures ANOVA. *Significantly different from baseline (p < .05). †Significantly different from week 6 (p < .05).*



Note. The trends indicate: A steady increase in handgrip strength for all groups, with males showing higher absolute values. A similar steady increase in VO_{2max}, with males having higher absolute values but relative improvements being comparable between sexes.

Figure 2. The progressive improvements in handgrip strength (kg) and estimated $\dot{V}O_{2max}$ (ml/kg/min) over the 12-week intervention.

Males demonstrated greater absolute improvements in handgrip strength compared to females (4.2 ± 1.3 kg vs. 3.1 ± 1.1 kg, *p* < .001), but relative improvements were similar (10.2 ± 3.2% vs. 12.8 ± 4.5%, *p* = .078). Similarly, while absolute increases in estimated $\dot{V}O_{2max}$ were greater in males (4.8 ± 1.6 ml/kg/min vs. 4.4 ± 1.4 ml/kg/min, *p* = .275), relative improvements were comparable (15.7 ± 5.2% vs. 18.2 ± 5.9%, *p* = .076).

Figure 2 illustrates the progressive improvements in handgrip strength and estimated $\dot{V}O_{2max}$ throughout the intervention period. The rate of improvement was relatively constant across the 12 weeks for both parameters.

Relationships between changes in body composition and functional parameters

Correlation analyses revealed significant associations between changes in body composition parameters and functional outcomes (Table 4). Notably, increases in phase angle demonstrated the strongest correlations with improvements in both handgrip strength and estimated $\dot{V}O_{2max}$.

Table 4. Correlations between changes in body composition and functional parameters over the 12-week intervention.

Parameter	Change in handgrip strength	Change in estimated $\dot{V}O_{2max}$
Change in body mass	-0.31*	-0.38**
Change in fat mass	-0.42**	-0.49**
Change in fat-free mass	0.56**	0.48**
Change in phase angle	0.68**	0.57**

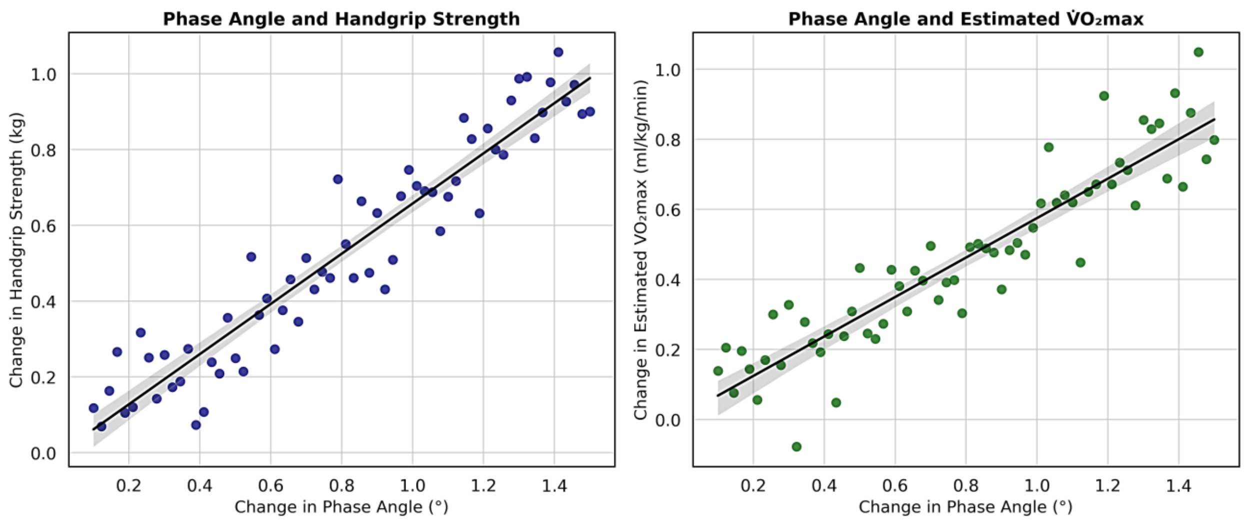
*Note. Values represent Pearson correlation coefficients (r). *p < .05, **p < .001.*

Multiple regression analysis (Table 5) identified changes in phase angle (β = 0.45, *p* < .001) and fat-free mass (β = 0.32, *p* = .003) as independent predictors of improvements in handgrip strength (R^2 = .53, *p* < .001). Similarly, changes in phase angle (β = 0.38, *p* < .001), fat mass (β = -0.29, *p* = .007), and fat-free mass (β = 0.26, *p* = .012) were identified as independent predictors of improvements in estimated $\dot{V}O_{2max}$ (R^2 = .48, *p* < .001).

Table 5. Multiple linear regression analyses predicting changes in functional parameters.

Dependent variable: Δ Handgrip strength				
Predictor	**β**	**SE**	**95% CI**	***p*-value**
Δ Phase angle	0.45	0.07	0.31 – 0.59	<.001
Δ Fat-free mass	0.32	0.09	0.13 – 0.51	.003
R^2 = .53, *p* < .001; VIF < 2.0				
Dependent variable: Δ $\dot{V}O_{2max}$				
Predictor	**β**	**SE**	**95% CI**	***p*-value**
Δ Phase angle	0.38	0.08	0.23 – 0.53	<.001
Δ Fat-free mass	0.26	0.10	0.06 – 0.45	.012
Δ Fat mass	-0.29	0.10	-0.48 – -0.10	.007
R^2 = .48, VIF < 2.0				

Figure 3 illustrates the relationship between changes in phase angle and improvements in functional parameters. The scatter plots demonstrate positive linear relationships, with greater increases in phase angle associated with more substantial improvements in both handgrip strength and estimated $\dot{V}O_{2max}$.



Note. Left plot: A positive linear correlation between phase angle changes and handgrip strength improvements (r = 0.68). Right plot: A positive linear correlation between phase angle changes and estimated $\dot{V}O_{2max}$ improvements (r = 0.57).

Figure 3. Relationships between changes in phase angle and improvements in functional parameters.

Physical Activity and dietary monitoring

Analysis of IPAQ data revealed no significant changes in physical activity outside the intervention (baseline: 95.3 ± 42.6 MET-min/week, week 12: 103.5 ± 46.2 MET-min/week, p = .326). Similarly, analysis of food diaries indicated no significant changes in total energy intake (baseline: 2187 ± 462 kcal/day, week 12: 2135 ± 445 kcal/day, p = .247) or macronutrient distribution (all p > .05) throughout the intervention period.

DISCUSSION

This study demonstrates that a 12-week combined resistance and aerobic training programme significantly improves body composition, muscle strength, and aerobic capacity in sedentary middle-aged adults. Our findings gain considerable support from recent meta-analyses confirming the efficacy of such concurrent approaches. Furthermore, our results highlight the potential utility of BIA-derived phase angle (PhA) as a practical biomarker for monitoring exercise-induced adaptations, a notion bolstered by emerging research linking PhA to muscle quality.

Body composition changes

The observed reductions in body mass (-2.3 kg on average) and particularly fat mass (-3.6 kg) align with the established benefits of exercise for improving body composition in middle-aged adults. A comprehensive 2025 meta-analysis by Khalafi and colleagues involving over 2800 middle-aged and older adults confirms that concurrent training (CT) is as effective as aerobic training (AT) alone for reducing various measures of adiposity, including fat mass and body fat percentage. Importantly, their analysis suggests CT may even yield superior reductions in body fat percentage compared to AT alone in middle-aged individuals and those with obesity, particularly over longer durations (>24 weeks) (Khalafi et al., 2025). While our 12-week intervention achieved comparable fat mass reductions (-3.6 kg) to the 8-month combined training study by Willis et al. (2012) (-3.7 kg), potentially attributable to our structured, supervised, and progressive design, the findings from Khalafi et al. (2025) provide robust, contemporary backing for the effectiveness of the combined modality itself.

The increases in fat-free mass (FFM, +1.8 kg) are particularly noteworthy given the relatively short intervention duration and the typical age-related decline in muscle mass (Cruz-Jentoft et al., 2019). This magnitude of gain is consistent with the ~1.1 kg increase reported by Peterson et al. (2011) following resistance training (RT) in adults over 50, and again, finds strong support in recent meta-analytic data. Khalafi et al. (2025) confirmed that CT is as effective as RT alone for increasing lean body mass (LBM) and muscle mass. Furthermore, a direct comparison meta-analysis by An et al. (2024) found that while AT surpasses RT for improving cardiorespiratory fitness and reducing body mass, RT is superior for enhancing LBM. This underscores the strategic advantage of our combined approach, effectively leveraging the distinct benefits of both modalities to achieve simultaneous improvements in fat loss and muscle gain within a single program.
Notably, the temporal patterns observed – predominant fat mass reductions in the first six weeks, with more substantial FFM increases in the latter half – may reflect an initial emphasis on lipolytic processes followed by the more delayed onset of significant muscle hypertrophy (Boutcher, 2011; Schoenfeld, 2010), a common pattern in response to initiating structured exercise

Functional improvements
The significant improvements in handgrip strength (HGS; males: +4.2 kg; females: +3.1 kg) demonstrate the effective transferability of whole-body resistance training to this clinically relevant measure of overall muscle function. These gains likely reflect both neuromuscular adaptations, such as enhanced neural drive and motor unit recruitment, and the underlying muscle hypertrophy suggested by the FFM increase (Schoenfeld, 2010). The importance of combined training for strength parameters is further supported by recent large-scale observational data. Sung et al. (2022), using nationwide Korean data, found that participation in combined aerobic and resistance exercise was most consistently associated with preserved HGS in middle-aged adults compared to single-modality or no exercise.

Similarly, the substantial improvements in estimated $\dot{V}O_{2max}$ (+4.6 ml/kg/min, a ~17% increase) underscore the potent cardiorespiratory benefits of the combined training protocol. This aligns well with the meta-analysis by An et al. (2024), which confirmed the superiority of AT over RT for improving $\dot{V}O_{2max}$, highlighting the crucial contribution of the aerobic component of our intervention. Our observed $\dot{V}O_{2max}$ increase is comparable to the 15.9% gain reported by Huang et al. (2016) following 12 weeks of aerobic interval training in a similar population. The use of the Astrand-Rhyming submaximal test, while an estimation, has demonstrated reasonable validity in comparable populations (Hartung et al., 1995; Gerber et al., 2025), lending confidence to these findings.

Phase angle as a biomarker
Perhaps the most novel finding of this study is the strong positive correlation between increases in BIA-derived phase angle and improvements in both HGS ($r = 0.68$) and estimated $\dot{V}O_{2max}$ ($r = 0.57$). Phase angle, reflecting cellular membrane integrity and function, is increasingly recognized as a marker of cellular health and nutritional status (Norman et al., 2012; Rosa et al., 2025). The results strongly suggest it may also serve as a sensitive, non-invasive indicator of positive functional adaptations to exercise training. The mean PhA increase (0.6°) observed is consistent with, and indeed slightly larger than, the 0.34° increase reported by Souza et al. (2017) after 12 weeks of resistance training in older women.

Crucially, recent research provides a potential mechanistic link for our findings. A 2024 systematic review and meta-analysis by Costa Pereira and colleagues specifically investigated PhA as a marker of muscle quality. They found moderate positive correlations between PhA and skeletal muscle radiodensity (indicating less fat infiltration) and inverse correlations with muscle echogenicity, alongside weaker correlations with strength per unit mass (MQI) (Costa Pereira et al., 2024). This emerging evidence suggests that the exercise-induced increase in PhA we observed may reflect not only greater muscle mass (FFM) but also improvements in the quality and composition of the muscle tissue itself, which likely underpins the enhanced functional capacity (HGS and $\dot{V}O_{2max}$). Our finding that PhA increased similarly between sexes despite significantly different absolute FFM gains further supports the idea that PhA captures qualitative adaptations beyond simple mass accretion. The independent predictive value of PhA changes for functional improvements in our regression analyses strengthens its potential utility. Given BIA's accessibility and non-invasiveness, PhA could represent a practical biomarker for monitoring the efficacy of exercise interventions in diverse settings.

Sex differences

The analyses revealed expected baseline differences and subsequent sex-specific responses in absolute terms. Males exhibited greater absolute increases in FFM and HGS, consistent with higher baseline values and greater muscle mass (Janssen et al., 2000). However, the relative improvements in HGS (~10% vs ~13%), estimated $\dot{V}O_{2max}$ (~16% vs ~18%), and the absolute increase in phase angle were remarkably similar between males and females, suggesting comparable underlying adaptive responsiveness to the combined training stimulus.

This aligns with a growing body of evidence. While absolute adaptations often differ, relative changes are frequently similar when programmes are appropriately designed (Roberts et al., 2020). Specifically, regarding muscle growth, a very recent Bayesian meta-analysis by Refalo et al. (2025) confirmed that while absolute muscle size increases slightly favour males post-RT, relative increases are similar between sexes. However, some nuance regarding concurrent training specifically is emerging. A 2024 meta-analysis by Huiberts et al. found a small interference effect (blunted gains) for lower-body strength in males undertaking CT, but not in females, while upper-body strength and $\dot{V}O_{2max}$ adaptations showed no sex difference. While we measured HGS (upper body), these finding warrants consideration in future studies examining whole-body responses. The greater relative reduction in fat mass observed in females in this study (-15.2% vs -12.8%) may reflect known sex differences in adipose tissue metabolism, such as greater lipolytic sensitivity during exercise in females (Lundsgaard & Kiens, 2014). Overall, our findings support the notion that both middle-aged men and women benefit substantially and comparably in relative terms from combined training.

Clinical and practical implications

The improvements observed carry significant clinical and practical weight. The average increases in HGS (3.1-4.2 kg) exceed the minimal clinically important difference of 2.5 kg proposed by Bohannon (2019), suggesting meaningful functional gains. Likewise, the average $\dot{V}O_{2max}$ improvement (+4.6 ml/kg/min) surpasses the 3.5 ml/kg/min threshold associated with reduced mortality risk (Blair et al., 1995).

From a practical standpoint, these findings strongly endorse current physical activity guidelines advocating combined resistance and aerobic training for middle-aged adults (World Health Organization, 2020). The effectiveness of this approach is further cemented by recent meta-analyses (An et al., 2024; Khalafi et al., 2025) and supported by population-level data linking combined exercise to better strength outcomes (Sung et al., 2022). Our progressive overload, structured, and supervised intervention serves as a potential template for effective exercise prescription in this population. Furthermore, the identification of PhA as a responsive biomarker, potentially reflecting improvements in muscle quality (Costa Pereira et al., 2024), offers a practical, non-invasive tool for healthcare practitioners to monitor intervention efficacy and provide feedback, complementing traditional functional assessments.

Limitations and future directions

Several limitations warrant consideration. The single-group pre-post design precludes definitive causal conclusions, although the stability of external physical activity and diet mitigates confounding factors. The use of BIA, while validated (Malavolti et al., 2003) and practical, lacks the precision of DXA for body composition. Similarly, estimating $\dot{V}O_{2max}$ via a submaximal protocol, though validated (Hartung et al., 1995) and appropriate for this initially sedentary cohort, is less precise than direct measurement.

Future research should employ randomised controlled designs comparing combined training against single modalities or different CT configurations (intensities, volumes, sequencing). Longitudinal studies are needed to assess the durability of these adaptations and the long-term predictive value of PhA changes. Further investigation into the cellular and molecular mechanisms underpinning the relationship between PhA improvements and functional gains, potentially exploring the sex-specific nuances highlighted by Huiberts et al. (2024), would significantly enhance our understanding of exercise-induced adaptations.

CONCLUSIONS

A 12-week combined resistance and aerobic training programme significantly improves body composition, muscle strength, and aerobic capacity in sedentary middle-aged adults. The strong correlations between increases in BIA-derived phase angle and improvements in functional parameters suggest its potential utility as a biomarker for monitoring exercise-induced adaptations. These findings support current physical activity guidelines advocating combined training approaches for middle-aged adults and highlight the importance of structured, progressive exercise programming for optimising health outcomes in this population.

AUTHOR CONTRIBUTIONS

Ferdinando Cereda: conceptualization, methodology, formal analysis, data curation, investigation, writing – original draft, visualization, supervision, project administration. Luigi Marano: formal analysis, data curation, investigation, writing – review & editing.

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REFERENCES

American College of Sports Medicine (2009). American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. Medicine and science in sports and exercise, 41(3), 687-708. https://doi.org/10.1249/MSS.0b013e3181915670

American Society of Hand Therapists. (2015). ASHT clinical assessment recommendations: Impairment-based conditions (3rd ed.). American Society of Hand Therapists.

An, J., Su, Z., & Meng, S. (2024). Effect of aerobic training versus resistance training for improving cardiorespiratory fitness and body composition in middle-aged to older adults: A systematic review and meta-analysis of randomized controlled trials. Archives of gerontology and geriatrics, 126, 105530. https://doi.org/10.1016/j.archger.2024.105530

Åstrand, P. O., & Ryhming, I. (1954). A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during sub-maximal work. Journal of applied physiology, 7(2), 218-221. https://doi.org/10.1152/jappl.1954.7.2.218

Blair, S. N., Kohl, H. W., Barlow, C. E., Paffenbarger, R. S., Gibbons, L. W., & Macera, C. A. (1995). Changes in physical fitness and all-cause mortality: A prospective study of healthy and unhealthy men. JAMA, 273(14), 1093-1098. https://doi.org/10.1001/jama.1995.03520380029031

Bohannon, R. W. (2019). Minimal clinically important difference for grip strength: A systematic review. Journal of Physical Therapy Science, 31(1), 75-78. https://doi.org/10.1589/jpts.31.75

Boutcher, S. H. (2011). High-intensity intermittent exercise and fat loss. Journal of Obesity, 2011, 868305. https://doi.org/10.1155/2011/868305

Buono, M. J., Roby, J. J., Micale, F. G., & Sallis, J. F. (1989). Predicting Maximal Oxygen Uptake in Children: Modification of the Astrand-Ryhming Test. Pediatric exercise science, 1(3), 278-283. https://doi.org/10.1123/pes.1.3.278

Costa Pereira, J. P. D., Rebouças, A. S., Prado, C. M., Gonzalez, M. C., Cabral, P. C., Diniz, A. D. S., Trussardi Fayh, A. P., & Silva, F. M. (2024). Phase angle as a marker of muscle quality: A systematic review and meta-analysis. Clinical nutrition (Edinburgh, Scotland), 43(12), 308-326. https://doi.org/10.1016/j.clnu.2024.11.008

Cruz-Jentoft, A. J., Bahat, G., Bauer, J., Boirie, Y., Bruyère, O., Cederholm, T., Cooper, C., Landi, F., Rolland, Y., Sayer, A. A., Schneider, S. M., Sieber, C. C., Topinkova, E., Vandewoude, M., Visser, M., Zamboni, M., & Writing Group for the European Working Group on Sarcopenia in Older People 2 (EWGSOP2). (2019). Sarcopenia: Revised European consensus on definition and diagnosis. Age and Ageing, 48(1), 16-31. https://doi.org/10.1093/ageing/afy169

Fernández-Jiménez, R., Dalla-Rovere, L., García-Olivares, M., Abuín-Fernández, J., Sánchez-Torralvo, F. J., Doulatram-Gamgaram, V. K., Hernández-Sanchez, A. M., & García-Almeida, J. M. (2022). Phase Angle and Handgrip Strength as a Predictor of Disease-Related Malnutrition in Admitted Patients: 12-Month Mortality. Nutrients, 14(9), 1851. https://doi.org/10.3390/nu14091851

Fragala, M. S., Cadore, E. L., Dorgo, S., Izquierdo, M., Kraemer, W. J., Peterson, M. D., & Ryan, E. D. (2019). Resistance training for older adults: Position statement from the National Strength and Conditioning Association. Journal of Strength and Conditioning Research, 33(8), 2019-2052. https://doi.org/10.1519/JSC.0000000000003230

Garber, C. E., Blissmer, B., Deschenes, M. R., Franklin, B. A., Lamonte, M. J., Lee, I. M., Nieman, D. C., Swain, D. P., & American College of Sports Medicine (2011). American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. Medicine and science in sports and exercise, 43(7), 1334-1359. https://doi.org/10.1249/MSS.0b013e318213fefb

Gerber, M., Schilling, T., Ludyga, S., Faude, O., Schmidt-Trucksäss, A., Cody, R., Straus, D., Schneiders, A., & Brupbacher, G. (2025). Validity and feasibility of four standardized aerobic fitness tests in patients with depression: A cross-sectional study. Journal of psychiatric research, 181, 116-125. https://doi.org/10.1016/j.jpsychires.2024.11.019

Hartung, G. H., Blancq, R. J., Lally, D. A., & Krock, L. P. (1995). Estimation of aerobic capacity from submaximal cycle ergometry in women. Medicine and science in sports and exercise, 27(3), 452-457. https://doi.org/10.1249/00005768-199503000-00024

Huang, G., Wang, R., Chen, P., Huang, S. C., Donnelly, J. E., & Mehlferber, J. P. (2016). Dose-response relationship of cardiorespiratory fitness adaptation to controlled endurance training in sedentary older adults. European journal of preventive cardiology, 23(5), 518-529. https://doi.org/10.1177/2047487315582322

Huiberts, R. O., Wüst, R. C. I., & van der Zwaard, S. (2024). Concurrent Strength and Endurance Training: A Systematic Review and Meta-Analysis on the Impact of Sex and Training Status. Sports medicine (Auckland, N.Z.), 54(2), 485-503. https://doi.org/10.1007/s40279-023-01943-9

Janssen, I., Heymsfield, S. B., Wang, Z. M., & Ross, R. (2000). Skeletal muscle mass and distribution in 468 men and women aged 18-88 yr. Journal of Applied Physiology, 89(1), 81-88. https://doi.org/10.1152/jappl.2000.89.1.81

Khalafi, M., Kheradmand, S., Habibi Maleki, A., Symonds, M. E., Rosenkranz, S. K., & Batrakoulis, A. (2025). The Effects of Concurrent Training Versus Aerobic or Resistance Training Alone on Body Composition in Middle-Aged and Older Adults: A Systematic Review and Meta-Analysis. Healthcare, 13(7), 776. https://doi.org/10.3390/healthcare13070776

Kodama, S., Saito, K., Tanaka, S., Maki, M., Yachi, Y., Asumi, M., Sugawara, A., Totsuka, K., Shimano, H., Ohashi, Y., Yamada, N., & Sone, H. (2009). Cardiorespiratory fitness as a quantitative predictor of all-cause mortality and cardiovascular events in healthy men and women: A meta-analysis. JAMA, 301(19), 2024-2035. https://doi.org/10.1001/jama.2009.681

Leong, D. P., Teo, K. K., Rangarajan, S., Lopez-Jaramillo, P., Avezum, A., Orlandini, A., Seron, P., Ahmed, S. H., Rosengren, A., Kelishadi, R., Rahman, O., Swaminathan, S., Iqbal, R., Gupta, R., Lear, S. A., Oguz, A., Yusoff, K., Zatonska, K., Chifamba, J., ... Yusuf, S. (2015). Prognostic value of grip strength: Findings from the Prospective Urban Rural Epidemiology (PURE) study. The Lancet, 386(9990), 266-273. https://doi.org/10.1016/S0140-6736(14)62000-6

Liguori, G., Feito, Y., Fountaine, C., & Roy, B. A. (Eds.). (2021). ACSM's guidelines for exercise testing and prescription (11th ed.). Lippincott Williams & Wilkins.

Lukaski, H. C., Kyle, U. G., & Kondrup, J. (2017). Assessment of adult malnutrition and prognosis with bioelectrical impedance analysis: Phase angle and impedance ratio. Current Opinion in Clinical Nutrition and Metabolic Care, 20(5), 330-339. https://doi.org/10.1097/MCO.0000000000000387

Lundsgaard, A. M., & Kiens, B. (2014). Gender differences in skeletal muscle substrate metabolism - molecular mechanisms and insulin sensitivity. Frontiers in Endocrinology, 5, 195. https://doi.org/10.3389/fendo.2014.00195

Lupton-Smith, A., Fourie, K., Mazinyo, A., Mokone, M., Nxaba, S., & Morrow, B. (2022). Measurement of hand grip strength: A cross-sectional study of two dynamometry devices. The South African journal of physiotherapy, 78(1), 1768. https://doi.org/10.4102/sajp.v78i1.1768

Malavolti, M., Mussi, C., Poli, M., Fantuzzi, A. L., Salvioli, G., Battistini, N., & Bedogni, G. (2003). Cross-calibration of eight-polar bioelectrical impedance analysis versus dual-energy X-ray absorptiometry for the assessment of total and appendicular body composition in healthy subjects aged 21-82 years. Annals of human biology, 30(4), 380-391. https://doi.org/10.1080/0301446031000095211

Mannocci, A., Di Thiene, D., Del Cimmuto, A., Masala, D., Boccia, A., & De Vito, E. (2010). International Physical Activity Questionnaire: validation and assessment in an Italian sample. Italian Journal of Public Health, 7(4). https://doi.org/10.2427/5694

Marcos-Pardo, P. J., Vaquero-Cristóbal, R., & Huber, G. (2023). The Power of Resistance Training: Evidence-based Recommendations for Middle-aged and Older Women's Health. Retos: Nuevas

Tendencias en Educación Física, Deporte y Recreación, 50, 1097-1108. https://doi.org/10.47197/retos.v51.99638
National Institutes of Health (US), Office of Medical Applications of Research. (1994). Bioelectrical impedance analysis in body composition measurement: National Institutes of Health technology assessment conference statement, December 12-14, 1994. NIH Office of Medical Applications of Research.
Norman, K., Stobäus, N., Pirlich, M., & Bosy-Westphal, A. (2012). Bioelectrical phase angle and impedance vector analysis - clinical relevance and applicability of impedance parameters. Clinical Nutrition, 31(6), 854-861. https://doi.org/10.1016/j.clnu.2012.05.008
Peterson, M. D., Sen, A., & Gordon, P. M. (2011). Influence of resistance exercise on lean body mass in aging adults: A meta-analysis. Medicine and Science in Sports and Exercise, 43(2), 249-258. https://doi.org/10.1249/MSS.0b013e3181eb6265
Refalo, M. C., Nuckols, G., Galpin, A. J., Gallagher, I. J., Hamilton, D. L., & Fyfe, J. J. (2025). Sex differences in absolute and relative changes in muscle size following resistance training in healthy adults: a systematic review with Bayesian meta-analysis. PeerJ, 13, e19042. https://doi.org/10.7717/peerj.19042
Roberts, B. M., Nuckols, G., & Krieger, J. W. (2020). Sex Differences in Resistance Training: A Systematic Review and Meta-Analysis. Journal of strength and conditioning research, 34(5), 1448-1460. https://doi.org/10.1519/JSC.0000000000003521
Rosa, G. B., Lukaski, H. C., & Sardinha, L. B. (2025). The science of bioelectrical impedance-derived phase angle: Insights from body composition in youth. Reviews in Endocrine and Metabolic Disorders. https://doi.org/10.1007/s11154-025-09964-7
Santanasto, A. J., Goodpaster, B. H., Kritchevsky, S. B., Miljkovic, I., Satterfield, S., Schwartz, A. V., Cummings, S. R., Boudreau, R. M., Harris, T. B., & Newman, A. B. (2017). Body Composition Remodeling and Mortality: The Health Aging and Body Composition Study. The journals of gerontology. Series A, Biological sciences and medical sciences, 72(4), 513-519. https://doi.org/10.1093/gerona/glw163
Schoenfeld, B. J. (2010). The mechanisms of muscle hypertrophy and their application to resistance training. Journal of Strength and Conditioning Research, 24(10), 2857-2872. https://doi.org/10.1519/JSC.0b013e3181e840f3
Schroeder, E. C., Franke, W. D., Sharp, R. L., & Lee, D. C. (2019). Comparative effectiveness of aerobic, resistance, and combined training on cardiovascular disease risk factors: A randomized controlled trial. PLoS One, 14(1), e0210292. https://doi.org/10.1371/journal.pone.0210292
Schumann, M., Feuerbacher, J. F., Sünkeler, M., Freitag, N., Rønnestad, B. R., Doma, K., & Lundberg, T. R. (2022). Compatibility of Concurrent Aerobic and Strength Training for Skeletal Muscle Size and Function: An Updated Systematic Review and Meta-Analysis. Sports medicine (Auckland, N.Z.), 52(3), 601-612. https://doi.org/10.1007/s40279-021-01587-7
Souza, M. F., Tomeleri, C. M., Ribeiro, A. S., Schoenfeld, B. J., Silva, A. M., Sardinha, L. B., & Cyrino, E. S. (2017). Effect of resistance training on phase angle in older women: A randomized controlled trial. Scandinavian journal of medicine & science in sports, 27(11), 1308-1316. https://doi.org/10.1111/sms.12745
Sung, J. H., Son, S. R., Baek, S. H., & Kim, B. J. (2022). The association of aerobic, resistance, and combined exercises with the handgrip strength of middle-aged and elderly Korean adults: a nationwide cross-sectional study. BMC geriatrics, 22(1), 676. https://doi.org/10.1186/s12877-022-03293-z
Willis, L. H., Slentz, C. A., Bateman, L. A., Shields, A. T., Piner, L. W., Bales, C. W., Houmard, J. A., & Kraus, W. E. (2012). Effects of aerobic and/or resistance training on body mass and fat mass in overweight

or obese adults. Journal of Applied Physiology, 113(12), 1831-1837. https://doi.org/10.1152/japplphysiol.01370.2011

World Health Organization. (2020). WHO guidelines on physical activity and sedentary behaviour. World Health Organization. Retrieved from [Accessed 2025, 22 September]: https://www.who.int/publications/i/item/9789240015128

Yamada, Y., Yoshida, T., Murakami, H., Kawakami, R., Gando, Y., Ohno, H., Tanisawa, K., Konishi, K., Julien, T., Kondo, E., Nakagata, T., Nanri, H., & Miyachi, M. (2022). Phase angle obtained via bioelectrical impedance analysis and objectively measured physical activity or exercise habits. Scientific reports, 12(1), 17274. https://doi.org/10.1038/s41598-022-21095-6