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Comparative effectiveness of progressive moderate- to high-intensity peripheral and inspiratory muscle training combined with aerobic exercise in community-dwelling older adults

A randomized clinical trial

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Abstract

Background: This study aims to compare the effects of moderate- to high-intensity peripheral and inspiratory muscle training, when combined with aerobic training, on muscle strength, respiratory muscle strength, physical performance, functional capacity, sarcopenia, and quality of life in older adults.

Methods: Thirty-four community-dwelling older adults were randomly assigned to either the peripheral muscle training (PMT) group (n = 17) or the inspiratory muscle training (IMT) group (n = 17). Participants in the PMT group performed resistance training targeting both the upper and lower extremities at 60 to 80% of their one-repetition maximum (1RM). In contrast, the IMT group engaged in IMT at 60 to 80% of their baseline maximum inspiratory pressure (MIP), using a threshold IMT device. Both groups additionally participated in supervised step-aerobic sessions twice weekly for 10 weeks, aiming for 50 to 70% of their individual maximum heart rate. Outcome measures included hand grip strength, MIP, maximum expiratory pressure (MEP), the 6-minute walk test (6-MWT), the Short Physical Performance Battery (SPPB), the SARC-F questionnaire, and the World Health Organization Quality of Life Instrument-Older Adults Module (WHOQOL-OLD). All assessments were conducted at baseline and repeated after completion of the 10-week training program in both groups.

Results: Between-group comparisons of pre- to post-intervention changes revealed a significant difference in the WHOQOL-OLD death and dying subscale, with greater improvement observed in the IMT group ($P = .019$, d = 0.185). In the PMT group, significant post-intervention increases were observed in MEP ($P = .003$, d = 0.876), MEP% ($P = .002$, d = 0.932), 6-MWT ($P = .001$, d = 0.974), and the WHOQOL-OLD sensory abilities subscale ($P = .035$, d = 0.528). In the IMT group, significant improvements were noted in MIP ($P = .002$, d = 0.788), MIP% ($P = .001$, d = 1.032), 6-MWT ($P = .003$, d = 0.889), and the WHOQOL-OLD death and dying subscale ($P = .040$, d = 0.564).

Conclusion: This study demonstrates that moderate- to high-intensity PMT and IMT, when combined with aerobic training, significantly enhances respiratory muscle strength, functional capacity, and quality of life in community-dwelling older adults.

Abbreviations: 1RM = one-repetition maximum, 6-MWT = 6-minute walk test, ACSM = American College of Sports Medicine, AT = after training, BT = before training, HIRT = high-intensity resistance training, IMT = inspiratory muscle training, MEP = maximum expiratory pressure, MIP = maximum inspiratory pressure, PARQ = Physical Activity Readiness Questionnaire, PMT = peripheral muscle training, QoL = quality of life, RT = resistance training, SPPB = The Short Physical Performance Battery, TIMT = threshold inspiratory muscle trainer, WHOQOL-OLD = World Health Organization Quality of Life Instrument-Older Adults Module, Δ = After training-baseline.

Keywords: functional capacity, inspiratory muscle training, muscle strength, older adults, Peripheral muscle training, quality of life

The authors have no funding and conflicts of interest to disclose.

The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author on reasonable request.

The study was conducted in accordance with the Declaration of Helsinki and was approved by the İstanbul Biruni University Ethics Committee (Decision Number: 2023/85–03).

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1. Introduction

Aging is a universal and inevitable process characterized by a progressive decline that persists throughout the lifespan. Advancing age is accompanied by physiological alterations in the cardiovascular, respiratory, sensorimotor, and neuromuscular systems.[1] Motor performance is negatively affected by age-related loss of motor units in the neuromuscular system and changes in the morphology of existing motor units.[2] Sarcopenia, a prevalent age-related condition, is characterized by the progressive loss of skeletal muscle mass accompanied by declines in muscle strength and physical performance. It is a major contributor to disability, loss of independence, and increased mortality among older adults.[3] Changes in the respiratory system, such as lung elasticity and chest wall compliance, occur with aging.[4] Additionally, the diaphragm, a crucial respiratory muscle that plays a key role in inspiration, weakens with age. These changes make it harder to maintain the physical activity needed for a healthy life.[5] Studies in older adults suggest that respiratory muscle weakness may increase the incidence of morbidity and mortality.[4,6]

Resistance training (RT) is recommended for older adults to increase muscle mass, strength, and exercise capacity.[7,8] RT promotes muscle remodeling, thereby preserving muscle mass and contractile capacity.[9] RT can also reduce age-related changes in muscle function and has been confirmed to positively impact several factors, including improvements in activities of daily living, body composition, cognitive function, bone mineral density, quality of life (QoL), mobility, and balance in older adults.[7] Present guidelines recommend a comprehensive exercise program that includes aerobic, balance, flexibility, and resistance training to support and enhance the health of older adults.[10] A study on high-intensity resistance training (HIRT) in older women with sarcopenia showed improved respiratory muscle strength and health-related QoL.[11] Therefore, regular and adequate intensity resistance exercise training is recommended to achieve positive muscular and neural adaptations in healthy elderly individuals and those with chronic diseases.[10]

Inspiratory muscle training (IMT) is recommended to improve respiratory muscle strength and a more mechanically efficient breathing pattern.[3] In addition to enhancing inspiratory muscle strength, IMT fortifies diaphragmatic function, improves aerobic capacity and cardiac autonomic regulation, enhances physical performance and cough efficacy, and provides protection against respiratory infections.[3,4] IMT is performed by breathing against an external inspiratory load with different devices. This training is low-cost and can easily be implemented through a rehabilitation program.[3] High-resistance IMT is a low-volume and time-efficient form of intensive exercise that improves respiratory muscle strength and exercise tolerance in healthy middle-aged and older adults.[12] Reports show IMT improves balance performance, gait speed, and inspiratory muscle function in healthy older adults.[13] Seixas et al propose that, given the documented benefits of IMT, it represents a viable alternative or complementary training modality, particularly suitable for older adults in whom other forms of exercise may be impractical, and should be incorporated into therapeutic programs.[4]

Previous studies have demonstrated that increasing peripheral and inspiratory muscle strength may reduce the risk of mortality.[4,5] Moderate-intensity training of peripheral and inspiratory muscles has been evaluated in sarcopenic older adults, showing comparable effects on muscle strength but no significant improvements in muscle mass or physical performance.[14] However, to date, no studies have examined the combined effects of peripheral muscle training (PMT) and IMT alongside aerobic training in older adults. Furthermore, most prior research has focused on low- to moderate-intensity resistance training for either peripheral or inspiratory muscles. To address this gap in the literature, we aimed to compare the effects of moderate- to high-intensity PMT and IMT, when combined with aerobic training, on muscle strength, respiratory muscle strength, physical performance, functional capacity, sarcopenia, and quality of life (QoL) in community-dwelling older adults.

2. Materials and methods

2.1. Study design

A single-blinded and randomized clinical trial was designed in a local and public community-based healthy aging center from March 2024 to May 2025. This center serves a unique role by offering structured physical, cognitive, and social activities to older adults who live independently in their homes but wish to remain active and healthy in their later years. All members of the center were invited to attend an informational session. Participants were eligible for inclusion if they were aged 65 to 80 years, scored ≥ 20 on the Standardized Mini-Mental State Examination, were able to walk at least 10 meters with or without an assistive device, and responded "no" to all items on the Physical Activity Readiness Questionnaire (PAR-Q).[15] Exclusion criteria included participants who responded "yes" to at least one item on the PAR-Q and those with serious neurological or orthopedic conditions, severe visual or hearing impairments, diagnosed mental illness, severe cardiac or pulmonary disease, balance disorders, use of medications that could affect balance, or who are currently active smokers. A total of 71 older adults were assessed for eligibility, of whom 37 were excluded based on these criteria. Thirty-four volunteer participants were included in the study. Twenty-two older adults did not meet the inclusion criteria: 12 were over 80 years of age, and 10 did not meet the PAR-Q criteria. Fifteen additional individuals were excluded due to smoking. Participants who met all eligibility criteria and provided written informed consent were randomly allocated, in a 1:1 ratio, to either the PMT group (n = 17) or the IMT group (n = 17) using a computer-generated randomization sequence prepared by an independent researcher who was not involved in participant recruitment or assessment. Confidentiality of allocation was meticulously ensured through sealed, opaque, and sequentially numbered envelopes prepared by an independent researcher. Participants were given preprinted envelopes numbered 1 to 34, indicating their group assignment. These envelopes were opened only after participants' eligibility had been confirmed, before group assignment. Additionally, the experienced outcome assessor was unaware of participants' assigned training groups and was not involved in the intervention. To minimize detection bias, the physiotherapist responsible for conducting outcome assessments was not involved in the delivery of interventions and followed standardized testing protocols. Participants were instructed not to disclose their group assignment during assessments. The outcome assessor was not informed about participants' allocation, and most outcome measures were collected using validated objective instruments.[16]

The study was conducted in accordance with the Declaration of Helsinki and was approved by a local Ethics Committee (Decision Number: 2023/85–03). Written and signed informed consent was obtained from all individuals before their participation, in accordance with ethical standards. The trial was registered on the Clinical Trials.gov website (Registration number: NCT06321263).

Participants in the PMT group received resistance training for both upper and lower extremities while the IMT group performed threshold IMT. Both groups performed step aerobics training twice a week for 10 weeks under the supervision of a research physiotherapist.

2.2. Outcome measures

Sociodemographic information, including age, gender, body mass index, occupation, and educational level, was collected. The clinical information section also recorded details of medical conditions and medications.

2.2.1. Hand grip strength. Hand grip strength was measured with a Jamar (Hydraulic Hand Dynamometer SH5001 SAEHAN Corporation) dynamometer. Participants were seated with their dominant hand holding the dynamometer, their elbows flexed at a 90° angle, and their arms resting at their sides. Three consecutive measurements were taken, with a 1-minute interval between each. The highest value was recorded.[17] Handgrip strength is a core criterion for sarcopenia, as per the European Working Group on Sarcopenia in Older People 2 (EWGSOP2) guidelines.[18]

2.2.2. Maximum inspiratory and expiratory pressures. Respiratory muscle strength was assessed by mouth pressure measurement using the MicroRPM (Respiratory Pressure Meter) (CareFusion Corporation, Lewiston). Maximum inspiratory pressure (MIP) assessed inspiratory muscle strength, while maximum expiratory pressure (MEP) evaluated expiratory muscle strength following American Thoracic Society (ATS)/ European Respiratory Society (ERS) recommendations.[19] During the MIP measurement, the participant was instructed to perform a maximum forceful inspiration against a closed valve for at least 1.5 seconds following expiration. For MEP measurement, after maximum inspiration, the system was sealed with a valve, and the participant was instructed to execute a maximum forceful expiration against the closed valve for at least 1.5 seconds. At least 3 measurements were taken for both assessments, and the best value with <10% variability was recorded. Predicted values (in %) for MIP and MEP were also documented using the reference values reported by Black and Hyatt.[19]

2.2.3. 6-Minute walk test. A functional capacity assessment was performed using the 6-minute walk test (6-MWT) in accordance with the ATS guidelines.[20] Participants walked indoors on a flat and 30-meter-long surface for 6 minutes. The total distance in meters was recorded after this period.[20]

2.2.4. The Short Physical Performance Battery. The physical performance assessment of older adults was conducted using the Short Physical Performance Battery (SPPB). SPPB evaluates the physical and functional health status of older adults living in the community. Participants were tested for gait speed, sit-to-stand, and balance performance. Each test was scored from 0 (incomplete) to 4 (maximum performance), and the total score ranged from 0 to 12.[21] Based on the guidelines of the EWGSOP2, the SPPB was chosen because it is a comprehensive, validated, and reliable tool that assesses key physical performance components characteristic of sarcopenia, including gait speed, balance, and lower extremity muscle strength through the chair stand test. Its use allows for a holistic evaluation of functional status related to sarcopenia, aiding in early detection and appropriate intervention.[18]

2.2.5. SARC-F questionnaire. The SARC-F questionnaire was used to assess the risk of sarcopenia. Participants answered questions about their strength, mobility assistance, ability to stand up from a chair, stair climbing, and components related to fall incidents. Each component was scored on a scale of 0 to 2, with total scores ranging from 0 to 10.[22–24] Based on the recommendations of the EWGSOP2 guidelines, the SARC-F questionnaire was selected as a screening tool because it is a validated, simple, and reliable self-report instrument specifically designed to identify signs characteristic of sarcopenia. Its ease of use enables the rapid assessment of patients' perceived functional decline related to muscle strength and physical performance, facilitating early detection and intervention in both clinical and research settings.[18]

2.2.6. World Health Organization quality of life instrument-older adults module. The World Health Organization Quality of Life Instrument-Older Adults Module (WHOQOL-OLD) questionnaire was used to assess QoL for older adults. The questionnaire asked participants about 6 dimensions: autonomy, past, present, and future activities, sensory abilities, death and dying, intimacy, and social participation. Answers were rated on a 5-point Likert scale. The higher points are interpreted as better QoL.[25,26] This tool was selected over more generic QoL instruments due to its greater sensitivity in detecting psychosocial and functional changes in older populations.[25]

2.3. Interventions

2.3.1. The peripheral muscle training group. Participants performed progressive resistance exercises in groups of 5. Warm-up: 5 minutes of 8 to 10 repetitions of calisthenic exercises, including arm circles, bilateral shoulder flexion and extension, trunk rotation, elbow flexion and extension, mini squat, marching in place, stepping to the right and left side, hip extension (with the knee in extension), tiptoe raising up and down, and sit-to-stand on a chair. Main Training: 20 to 30 minutes of moderate- to high-intensity progressive resistance exercises on lower and upper extremity muscles were performed. Lower extremity exercises were ankle flexion, ankle extension, knee extension, hip flexion, hip extension, and hip abduction. Upper extremity exercises were grip (ball squeeze), wrist flexion, wrist extension, forearm pronation, forearm supination, elbow flexion, elbow extension, shoulder flexion, shoulder extension, shoulder abduction, and shoulder adduction.[14] The intensity of resistance exercises was determined by estimating the one-repetition maximum (1RM) for each muscle group using the indirect method. For each exercise, participants performed progressive trials to identify the maximum load they could lift through the full range of motion only once. Based on this determination, a training load corresponding to 60 to 80% of the calculated 1RM was prescribed. The program initially began at 60% of each participant's 1RM, with 8 to 10 repetitions and 1 to 3 sets, and the intensity was progressively increased over time according to the participant's perceived exertion (Borg scale 4 to 6). Progressive overload was applied using a session-by-session approach. When participants completed the maximum prescribed volume (10 repetitions × 3 sets) with correct technique and reported a Borg scale score of 4 to 6, training load was increased by approximately 5 to 10%. Progression followed a stepwise approach: first increasing repetitions and sets within the prescribed range, and subsequently increasing dumbbell weight or resistance band tension. To reduce participant burden and prevent fatigue, 1RM was assessed only at baseline and not retested during the intervention.[27] Increasing repetitions, adjusting resistance, and sets first, followed by incremental increases in dumbbell weight or resistance band tension, ensures both safety and progressive overload. The intensity determined using the 1RM for resistance band exercises was subsequently translated into the corresponding recommended band color.[28] Cool-down: The exercise protocol included 5 minutes of static stretching, comprising 15 seconds of stretch followed by 15 seconds of relaxation, for the pectoral muscles, posterior shoulder capsule, standing trunk rotation, trunk lateral flexion, and hamstring–gastrocnemius muscles. Each session consisted of a 5-minute warm-up (calisthenics), 20 to 30 minutes of resistance exercises, 15 to 20 minutes of step-aerobic training, and a 5-minute cool-down with stretching. The protocol was implemented for 60 minutes per session, twice weekly, over a period of 10 weeks. A research physiotherapist supervised it.

Pulse rate and oxygen levels were measured with a fingertip pulse oximeter, and systolic and diastolic blood pressure were measured with a sphygmomanometer before and after each session.

2.3.2. The inspiratory muscle training group. Participants were divided into 5 groups and trained for 10 weeks using a Threshold Inspiratory Muscle Trainer (TIMT) device (Threshold IMT®, Philips Respironics, Chichester, UK), which has a working range of 9 to 41 cmH_2O. Warm-up: 5 minutes of 8 to 10 repetitions of calisthenic exercises, including arm circles, bilateral shoulder flexion and extension, trunk rotation, elbow flexion and extension, mini squat, marching in place, stepping to the right and left side, hip extension (with the knee in extension), tiptoe raising up and down, and sit-to-stand on a chair. Main training: Participants in the IMT group performed IMT at an intensity of 60 to 80% of their baseline MIP using the TIMT device. Participants were trained to position themselves in a chair, sitting, and to apply the provided nose clip to prevent airflow through the nose. They then exhaled completely, placed the device's mouthpiece into their mouth, and inhaled with maximal force to open the valve. Participants performed 30 breathing cycles daily, 6 days per week (two days under the supervision of a research physiotherapist and 4 days at home) for 10 weeks. The workload was set at 60 to 80% of their MIP (in cmH_2O) and was gradually increased by 5 to 10% to maintain a modified Borg scale rating of 4 to 6.[5,14] Cool-down: Five minutes of static stretching exercises, 15 seconds of stretching, and 15 seconds of relaxation, including a pectoral stretch, posterior shoulder capsule stretch, standing trunk rotation, trunk lateral flexion, and hamstring-gastrocnemius stretch, were performed. Before and after each session, participants' pulse rate and oxygen saturation were measured using a fingertip pulse oximeter, while systolic and diastolic blood pressure were assessed with a sphygmomanometer. This monitoring allowed participants to maintain a comfortable breathing pattern, thereby preventing undesirable desaturation, elevations in heart rate, or symptoms of hyperventilation. The protocol included an initial 5-minute warm-up (calisthenics), 30 breathing cycles, 15 to 20 minutes of step aerobic exercise, and a final 5-minute cool-down (stretching).

2.3.3. Step aerobics training. A protocol was established for participants in both groups, where they performed basic step movements with one foot always in contact with the ground or step platform, while jumping or hopping movements were prohibited after strength exercises. This training program included the V step, the L step, side A steps for both left and right, knee lifts, leg raises, and kicking motions, accompanied by arm movements involving elbow flexion and shoulder abduction at both 90° and 180°, synchronized with the steps.[29] The training protocol followed the American College of Sports Medicine (ACSM) guidelines.[7] The step aerobics training was performed over 10 weeks, with 2 sessions per week, and each session lasted for 15 to 20 minutes. The intensity of the step aerobic exercises was initially set at 50 to 70% of the maximum heart rate (HR_{max}), which was calculated by multiplying the age-predicted maximum heart rate (HR_{max} = 220 – age) by a given percentage of exercise intensity. Heart rate was monitored during the step aerobics training by a fingertip pulse oximeter (Beijing Choice Electronic Tech. Co., Ltd., Beijing, China). The intensity of the step aerobic exercise was progressively increased by adjusting the number of steps per minute (step cadence) in 5 to 10% increments to maintain a perceived exertion level of 4 to 6 on the modified Borg scale. The step height was maintained at a constant level throughout the program, while the cadence was progressively increased according to individual tolerance and cardiovascular response, which facilitated a safe and gradual escalation of exercise intensity.

2.4. Statistical analysis and sample size

All statistical analyses were performed using IBM SPSS Statistics version 27.0 (IBM Corp., USA), with a significant value of $P < .05$. Descriptive data are presented as mean, standard deviation, and percentage (n%). Data distribution was assessed using the Shapiro–Wilk test. Variables with normal distribution, including MEP, MIP%, MEP%, 6-MWT, the WHOQOL-OLD total score, as well as the social participation and death and dying subscales of the WHOQOL-OLD, were analyzed using parametric tests (paired t-tests and independent samples t-tests). In contrast, nonparametric tests (Wilcoxon signed-rank test and Mann–Whitney *U* test) were used for variables that did not conform to a normal distribution, including handgrip strength, MIP, the total SPPB score, the SARC-F score, and the sensory abilities, autonomy, past, present and future activities, and intimacy subscales of the WHOQOL-OLD. Pearson chi-square or Fisher Exact chi-square test was used to determine the homogeneity of categorical variables between groups. Cohen d effect sizes were computed to quantify the magnitude of differences between groups, with values of 0.2, 0.5, and 0.8 indicating small, medium, and large effects, respectively.[30]

The sample size for this study was calculated based on a clinically significant difference reflecting functional capacity in the geriatric population. The G*Power Sample Size Calculator (University of Düsseldorf, Germany) was used, based on the minimum clinically significant difference value (50 meters) for a 6-MWT in older adults, as reported by Perrera et al.[31] A Type I error probability of 5% and statistical power of 80% were used; the effect size based on the literature was accepted as 0.531. Based on this power analysis, it was calculated that at least 30 participants would be sufficient for the primary analyses of the study. To account for potential participant dropouts, the sample size was increased by 10%, resulting in a total of 34 participants.

3. Results

Seventy-one older individuals were assessed for eligibility, and twenty-two older people did not meet the inclusion criteria. Twelve of them were over 80 years of age, and ten of them did not meet the physical activity readiness questionnaire criteria. Fifteen smokers met the exclusion criteria. Thirty-four volunteer participants were included in the study. The participants reported no intervention-related adverse effects during the study. Adaptation to the training program was excellent overall. Two participants withdrew from the training program due to personal reasons. While one participant in the PMT group needed to provide care for a grandchild, whereas one participant in the IMT group traveled to another city. Thirty-two participants completed the study and were included in the statistical analysis.

The demographic and clinical characteristics of the participants in the groups at baseline are presented in Table 1. There was no statistically significant difference between the 2 groups ($P > .05$). The pre-intervention characteristics of the participants are presented in Table 2. Both groups were found to be statistically similar ($P > .05$) in terms of hand grip strength, inspiratory and expiratory muscle strength, functional capacity, physical performance, sarcopenia risk, and quality of life at baseline (Table 2). Changes within each group and between-group differences in the outcome measures are presented in Table 3. Significant improvements were observed in specific measurements in both groups; however, differences were noted between the groups in particular areas (Table 3). In both groups, adherence to the training program was high, with rates above 80%.

In the between-group comparison of pre- and post-interventionchanges, a statistically significant small effect size improvement was observed in the death and dying subscale of the WHOQOL-OLD in favor of the IMT group ($P = .019$, $d = .185$). After training, the PMT group showed significant improvements in MEP ($P = .003$, $d = .876$), MEP% ($P = .002$, $d = .932$), 6-MWT ($P = .001$, $d = .974$), and the sensory abilities subscale of the WHOQOL-OLD ($P = .035$, $d = .528$),

Table 1

Baseline demographic characteristics of the participants inter-groups.

Demographic data	PMT group (n = 16) mean (SD)		IMT group (n = 16) mean (SD)		*P* value
Age (years)	68.56 (4.13)		69.69 (4.07)		.270
BMI (kg/m^2)	27.20 (2.99)		26.43 (2.63)		.446
SMMSE	29.25 (0.85)		29.00 (0.81)		.423
Gender	N	%	n	%	1.000
Female	13	81.3	13	81.3	
Male	3	18.8	3	18.8	
Education status	N	%	n	%	.506
Primary school graduate	2	12.5	1	6.3	
High school graduate	3	18.8	6	37.5	
Bachelor's degree	8	50.0	8	50.0	
Postgraduate	3	18.8	1	6.3	
Working status	n	%	n	%	.831
Retired, not working	13	81.3	14	87.5	
Retired, working	2	12.5	1	6.3	
Other	1	6.3	1	6.3	
Comorbidity	n	%	n	%	.842
No comorbidity	4	25	4	25.0	
Diabetes mellitus	6	37.5	7	43.8	
Dyslipidemia	3	18.8	1	6.3	
Thyroid diseases	1	6.3	2	12.5	
Gastrointestinal diseases	2	12.5	2	12.5	

BMI = body mass index, IMT = inspiratory muscle training, PMT = peripheral muscle training, SD = standard deviation, SMMSE = Standardized Mini-Mental State Examination.

Table 2

Baseline outcome measurements of the participants' inter-groups.

Baseline values	PMT group (n = 16) mean (SD)	IMT group (n = 16) mean (SD)	*P* value
Handgrip Strength (kg)	23.38 (6.76)	23.75 (7.22)	1.000
MIP (cm H_2O)	70.00 (18.32)	63.31 (17.45)	.270
MEP (cm H_2O)	88.88 (19.91)	87.25 (26.25)	.845
MIP% (cm H_2O)	93.40 (23.28)	86.62 (28.10)	.463
MEP% (cm H_2O)	61.80 (13.15)	60.10 (14.34)	.729
6-MWT (meter)	479.96 (54.32)	507.31 (52.43)	.158
SPPB total score	11.69 (0.60)	11.88 (0.34)	.539
SARC-F score	1.31 (0.94)	1.06 (1.06)	.445
WHOQOL-OLD total score	82.44 (7.03)	79.13 (7.07)	.194
Sensory Abilities subscale	8.00 (0.89)	7.94 (1.61)	.196
Autonomy subscale	16.00 (2.63)	14.69 (2.15)	.184
Past, Present, and Future Activities subscale	16.69 (2.05)	16.13 (1.99)	.341
Social Participation subscale	15.81 (2.58)	16.00 (2.10)	.940
Death and Dying subscale	9.06 (3.45)	8.56 (3.82)	.701
İntimacy subscale	15.81 (2.37)	15.50 (1.63)	.867

6-MWT = 6-minute walk test, IMT = inspiratory muscle training, MEP = maximum expiratory pressure, MIP = maximum inspiratory pressure, PMT = peripheral muscle training, SD = standard deviation, SPPB = Short Physical Performance Battery, WHOQOL-OLD = World Health Organization Quality of Life Instrument-Older Adults Module.

with medium to large effect sizes. In the IMT group, significant improvements were observed in MIP (P = .002, d = .788), MIP% (P = .001, d = 1.032), 6-MWT (P = .003, d = .889), and the death and dying subscale of the WHOQOL-OLD (P = .040, d = .564), also with medium to large effect sizes.

4. Discussion

The findings of this randomized clinical trial demonstrate that both moderate to high-intensity PMT and IMT, when combined with aerobic training, significantly enhance respiratory muscle strength, functional capacity, and QoL in community-dwelling older adults. Specifically, the resistance training component of the intervention was delivered at a moderate-to-high intensity, which is slightly higher than the intensities typically reported in previous training protocols involving older adults.[32,33]

Although both training methods were effective in improving functional capacity and respiratory outcomes, intergroup comparisons revealed domain-specific advantages. IMT led to significantly greater improvement in the death and dying subscale of the WHOQOL-OLD questionnaire compared to PMT, suggesting a potential psychological or existential benefit associated with improved respiratory function. The PMT group showed significant gains in MEP, MEP%, 6-MWT distance, and sensory abilities, while the IMT group exhibited notable improvements in MEP, MIP%, 6-MWT, and the death and dying subscale. Although the between-group effect size in the death and dying subscale was small (d = .185), the observed statistical significance suggests that even subtle improvements in this domain may have clinical importance. Prior research has emphasized that perceptions of death and dying are strongly associated with psychological well-being, life satisfaction, and overall quality of life in

Table 3

Intra-group and inter-group changes in outcome measurements.

Outcome measures		PMT group (n = 16) mean (SD)	Within-group change, 95% CI	Intra-group *P*	IMT group (n = 16) mean (SD)	Within-group change 95% CI	Intra-group *P*	Inter-group *P*
Handgrip Strength (kg)	BT	23.38 (6.76)		.156	23.75 (7.22)		.564	.254
	AT	24.13 (7.67)			23.50 (6.38)			
	Δ	0.75 (2.29)	(–0.47, 1.97)		-0.25 (1.77)	(–1.19, 0.69)		
MIP	BT	70.00 (18.32)		.092	63.31 (17.45)		**.002***	.056
(cm H_2O)	AT	76.56 (19.34)			80.18 (21.52)			
	Δ	6.56 (12.54)	(–0.12, 13.24)		16.87 (15.78)	(8.46, 25.28)		
MEP	BT	88.88 (19.91)		**.003***	87.25 (26.25)		.080	.299
(cm H_2O)	AT	102.31 (26.85)			94.81 (32.81)			
	Δ	-13.43 (15.33)	(–21.61, –5.26)		-7.56 (16.08)	(–16.13, 1.00)		
MIP%	BT	93.40 (23.28)		.057	86.62 (28.10)		**.001***	.057
(cmH_2O)	AT	101.92 (24.40)			108.38 (31.54)			
	Δ	-8.51 (16.51)	(–17.31, 0.28)		-21.75 (21.08)	(–32.99, –10.51)		
MEP%	BT	61.80 (13.15)		**.002***	60.10 (14.34)		.075	.256
(cmH_2O)	AT	70.74 (16.55)			64.98 (16.29)			
	Δ	-8.94 (9.59)	(–14.05, –3.82)		-4.88 (10.20)	(–10.32,0.55)		
6-MWT	BT	479.96 (54.32)		**.001***	507.31 (52.43)		**.003***	.742
(meter)	AT	519.25 (44.21)			541.93 (63.81)			
	Δ	-39.28 (40.30)	(–60.75, –17.80)		-34.62 (38.90)	(–55.35, –13.89)		
SPPB	BT	11.69 (0.60)		.102	11.88 (0.34)		.564	.564
total score	AT	11.94 (0.25)			11.94 (0.25)			
	Δ	0.25 (0.57)	(–0.05, 0.55)		0.06 (0.44)	(–0.17, 0.29)		
SARC-F	BT	1.31 (0.94)		.518	1.06 (1.06)		.109	.468
Score	AT	1.13 (1.02)			0.69 (0.94)			
	Δ	-0.18 (1.04)	(–0.74, 0.37)		-0.37 (0.88)	(–0.84, 0.09)		
WHOQOL-OLD total score	BT	82.44 (7.03)		.259	79.12 (7.07)		.298	.122
	AT	80.56 (5.85)			80.75 (5.45)			
	Δ	1.87 (6.39)	(–1.53, 5.28)		-1.62 (6.03)	(–4.83, 1.58)		
Sensory Abilities subscale	BT	8.00 (0.89)		**.035***	7.94 (1.61)		.369	.341
	AT	9.06 (1.69)			8.38 (1.74)			
	Δ	-1.06 (1.80)	(–2.02, –0.10)		-0.43 (1.82)	(–1.40, 0.53)		
Autonomy	BT	16.00 (2.63)		.153	14.69 (2.15)		.750	.590
subscale	AT	16.81 (1.79)			14.69 (3.07)			
	Δ	0.81 (2.34)	(–0.43, 2.06)		-0.00 (2.75)	(–1.46, 1.46)		
Past, Present, and Future Activities subscale	BT	16.69 (2.05)		.135	16.13 (1.99)		.752	.361
	AT	15.69 (2.33)			16.00 (1.67)			
	Δ	-1.00 (2.28)	(–2.21, 0.21)		-0.12 (1.66)	(–1.01, 0.76)		
Social Participation	BT	15.81 (2.58)		.799	15.87 (1.99)		.353	.641
subscale	AT	15.94 (3.04)			16.00 (1.67)			
	Δ	-0.12 (1.92)	(–1.15, 0.90)		-0.43 (1.82)	(–1.41, 0.53)		
Death and Dying subscale	BT	9.06 (3.45)		.206	8.56 (3.82)		**.040***	**.019***
	AT	8.13 (4.06)			10.00 (4.25)			
	Δ	0.93 (2.83)	(–0.57, 2.45)		-1.43 (2.55)	(–2.79, –0.07)		
Intimacy	BT	15.81 (2.37)		.698	15.50 (1.63)		.435	.696
subscale	AT	16.00 (2.25)			15.81 (1.60)			
	Δ	0.18 (2.13)	(–0.95, 1.32)		0.31 (1.53)	(–0.50, 1.13)		

6-MWT = 6-minute walk test, AT = after training, BT = before training, CI = confidence interval, IMT = inspiratory muscle training, MEP = maximum expiratory pressure, MIP = maximum inspiratory pressure, PMT = peripheral muscle training, SD = standard deviation, SPPB = Short Physical Performance Battery, WHOQOL-OLD = World Health Organization Quality of Life Instrument-Older Adults Module, Δ = after training-baseline.

P* **< .05.

older adults.[25,26,34] Given the existential and emotional nature of this construct, small yet measurable changes may translate into meaningful benefits for individuals, particularly in community-dwelling populations where maintaining psychological resilience is crucial. Thus, while the magnitude of change was modest, the finding underscores the potential of IMT to influence domains of quality of life beyond physical health positively. These findings suggest that while both training methods significantly contribute to the physical health and perceived quality of life of older adults, IMT may offer additional benefits in areas related to emotional well-being and existential concerns. Therefore, tailoring interventions to individual priorities and needs may optimize the effectiveness of geriatric rehabilitation programs.

These results suggest that both exercise approaches significantly improve functional capacity and QoL in community-dwelling older adults, and that each method may however provide domain-specific benefits. IMT appears to provide greater improvements in inspiratory muscle strength and psychological aspects related to the perception of death and dying, suggesting potential benefits for emotional and existential well-being. In other words, PMT appears to be more effective in increasing expiratory muscle strength and sensory abilities related to QoL. These results underscore the importance of individualized intervention planning to optimize outcomes in geriatric rehabilitation.

This study's results on respiratory muscle strength are consistent with those of Kim et al (2022) and Seixas et al (2020), who

reported significant increases in MIP after IMT. However, Seixas et al (2020) did not observe significant improvements in MEP, whereas our study demonstrated a considerable increase in MEP in the PMT group. This discrepancy may be attributed to the progressive intensity adjustments and the activation of core muscles during peripheral resistance exercises, which may have indirectly contributed to strengthening the expiratory muscles. The training load for both inspiratory and peripheral muscle exercises was gradually increased and prescribed as a percentage of the load deemed sufficient to elicit training adaptations. Our results are also consistent with those of Flor-Rufino et al (2023), which found that HIRT significantly improved MEP in older women with sarcopenia. The improvement in MEP in the PMT group suggests that PMT may improve respiratory muscle function, possibly through core stabilization and postural muscle activation. Given the high prevalence of respiratory muscle weakness in the elderly, PMT may provide a protective benefit by contributing to better respiratory muscle values in older adults.[4,5,11]

These results are consistent with previous research by Iranzo et al (2018), who showed that resistance training of peripheral and inspiratory muscles increased muscle strength and functional capacity in elderly individuals with sarcopenia.[14] However, similar to their findings, we did not observe significant changes in hand grip strength. This finding may be explained by the relatively healthy and functionally independent profile of our participants, who exhibited preserved baseline handgrip strength values. A recent study in the Turkish population reported gender-specific cutoff points for handgrip strength, 35 kg for men and 20 kg for women[35], which are substantially higher than the thresholds recommended by the EWGSOP2. Given these elevated values, it is plausible that a ceiling effect constrained the potential for measurable improvements following the intervention. In contrast, previous trials involving frail or sarcopenic older adults demonstrated significant gains in handgrip strength after resistance training, likely due to their lower baseline levels and, consequently, greater capacity for observable improvements.[36]

Functional capacity, evaluated by the 6-MWT, showed significant increases in both groups, similar to the findings of Kalapotharakos et al (2010), who reported enhanced functional capacity after resistance training in older adults. In our study, incorporating aerobic training likely improved endurance and overall mobility, as suggested by the ACSM guidelines.[7,37]

The SPPB is a valuable tool for assessing mobility and physical performance in older adults; low scores have been associated with an increased risk of disability and hospitalization.[21] In our study, both groups had high baseline SPPB scores, indicating relatively good physical performance. Although minor improvements were noted, these changes were not statistically significant. These findings are consistent with those of Iranzo et al (2018), who suggested that PMT and IMT may help maintain better functional performance in individuals with high baseline scores. The strong baseline performance of our participants contributed to this finding, highlighting the importance of targeted interventions for individuals with lower physical performance.[14]

Ji et al (2024) aimed to investigate the effectiveness of exercise and dietary interventions in older people with probable sarcopenia. The results suggest that exercise and nutritional interventions may help combat sarcopenia and may improve the quality of life of older adults by increasing muscle mass and strength. However, more research is needed on the ideal exercise intensity and timing of interventions. Our findings are consistent with previous research showing that exercise and dietary interventions can have a significant impact on reducing the risk of sarcopenia in older people. Studies have shown that combining exercise and nutrition programs improves muscle mass, strength, and physical performance, thereby preventing secondary conditions such as increased fall risk and osteoporosis. In this context, our study results suggest that exercise and nutrition strategies help prevent adverse health outcomes associated with sarcopenia by strengthening muscle function in older people. The observed improvement in the SARC-F score supports the feasibility and effectiveness of exercise interventions, especially in community-based health services. However, further studies are needed to optimize exercise intensity and frequency.[38]

QoL scores in both groups remained relatively stable, aligning with previous evidence suggesting that meaningful improvements in quality of life are more commonly observed in long-term interventions.[39] In this study, improvements were evident in specific subdomains, particularly in the sensory abilities subscale in the PMT group and the death and dying subscale in the IMT group; however, these changes were insufficient to yield a significant improvement in the overall WHOQOL-OLD score. In addition, our participants were community-dwelling older adults with relatively preserved baseline functional and psychosocial status, which may have contributed to a ceiling effect, restricting the capacity for detectable improvements in the total score. Despite these considerations, the observed improvements in the sensory abilities subscale likely reflect the positive effect of strengthening exercises on somatosensory function and neuromuscular coordination, whereas the significant within- and between-group improvements in the death and dying subscale in the IMT group suggest a potential role for IMT in alleviating death-related anxiety and fostering a sense of control. Mechanistically, enhanced respiratory efficiency may promote psychological resilience, reduce existential fears, and increase empowerment, thereby contributing to favorable changes in this sensitive domain of QoL.[40]

Older adults should be as physically active as possible. Physiologically, aerobic activity can support physical health by lowering resting blood pressure, reducing several inflammatory markers, and increasing the cortisol wake-up response. Similarly, the mental benefits of muscle-strengthening activities are enhanced by resistance training, which promotes both sympathetic and parasympathetic nervous system responses.[41] This moderate to high-intensity approach aligns with current exercise recommendations for enhancing muscular strength and improving functional independence in the aging population.[27] The uniqueness of this study lies in the application of these moderate to high resistance thresholds in a structured, supervised setting, demonstrating that community-dwelling older adults can safely tolerate and benefit from more intense training methods than typically assumed. These findings underscore the importance of individualized, progressive, and evidence-based exercise prescriptions in supporting healthy aging.

Some limitations should be considered when interpreting the results of this study. First, the relatively small sample size and single-center recruitment may limit the generalizability of our findings to the broader geriatric population. In addition, the participants were relatively healthy and community-dwelling older adults, which limits the generalizability of the findings to frailer individuals, those with significant comorbidities, or institutionalized populations. Furthermore, the relatively small sample size may have reduced the statistical power to detect small-to-moderate effects in certain outcome measures. Second, the absence of a non-intervention control group in the study makes it difficult to determine the absolute net effect of each training method and limits internal validity. Furthermore, due to the nature of the PMT and IMT protocols, session durations were not isochronous. Although the relative exercise intensity was standardized, differences in total application time should be considered a potential factor in comparing the effects of the interventions. Particularly in the IMT protocol, the shorter time required to complete the specified repetitions than the total exercise time in the PMT group suggests that the observed effects may be related to intervention-specific mechanisms rather than time-dependent stimuli. Third, while the 6-MWT, used to assess functional capacity, offers advantages in terms of clinical

applicability and safety, it may be influenced by factors such as motivation and self-regulation because it is a submaximal test performed at one's own pace. The relatively high functional capacity of the individuals included in the study suggests that speed-controlled, maximal tests (e.g., Incremental Shuttle Walk Test) may be more sensitive in revealing physiological limits and intervention-related changes. Finally, although the intervention program was structured and adapted, the lack of long-term follow-up evaluations limits the ability to conclude the sustainability of the observed effects. Additionally, while the WHOQOL-OLD covers relevant areas of quality of life, the lack of additional, specific measures targeting psychological or emotional well-being should also be considered. Future research should include larger, more heterogeneous samples, incorporate isochronous intervention designs and long-term follow-up, and provide a more comprehensive assessment of functional and psychosocial outcome measures to enhance both internal and external validity, thus better reflecting the complexity of real-world clinical settings.

5. Conclusions

Moderate to high-intensity PMT and IMT significantly improves respiratory muscle strength, functional capacity, and QoL in community-dwelling older adults when combined with aerobic exercises. A statistically significant between-group difference in the death and dying subscale favored the IMT group. Nevertheless, these findings support the overall effectiveness of structured physical activity interventions in enhancing respiratory function, physical performance, and quality of life in community-dwelling older adults. Notably, both interventions were designed to be time-efficient, cost-effective, and feasible for real-world implementation, requiring minimal equipment and infrastructure. These characteristics position them as promising strategies for integration into community health programs, rehabilitation services, and preventive care initiatives. Future studies with larger sample sizes, longer follow-up periods, and more diverse older populations are warranted to further investigate the multidimensional benefits, long-term efficacy, adherence, and scalability of these interventions for improving QoL in geriatric populations.

Author contributions

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