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Feasibility and effectiveness of a 6-month, home-based, resistance exercise delivered by a remote technological solution in healthy older adults

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HIGHLIGHTS

- The home-based device-supported resistance training is safe and feasible.
- The home-based device-supported resistance training positively affects walking parameters and lower limbs' maximal force.
- This approach should be incentivized when barriers to participation in traditional resistance exercise programs are present.

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ABSTRACT

Background: Aging is characterized by a physiological decline in physical function, muscle mass, strength, and power. Home-based resistance training interventions have gained increasing attention from scientists and healthcare system operators, but their efficacy is yet to be fully determined.
Aims: to verify the safety, feasibility, and efficacy of a home-based resistance training program delivered by innovative technological solution in healthy older adults.
Methods: 73 participants (36 females) were randomly allocated to either a control (C) or an intervention (I) group consisting of a 6-months home-based resistance training program delivered through an innovative technological solution, which included a wearable inertial sensor and a dedicated tablet. The safety and feasibility of the intervention were assessed by recording training-related adverse events and training adherence. Body composition, standing static balance, 10-meter walking, and loaded 5 sit-to-stand tests were monitored to quantify efficacy.
Results: No adverse events were recorded. Adherence to the training program was relatively high (61 % of participants performed the target 3 sessions) in the first trimester, significantly dropping during the second one. The intervention positively affected walking parameters ($p < 0.05$) and maximal force ($p = 0.009$) while no effect was recorded on body composition, balance, and muscle power.
Conclusions: The home-based device-supported intervention was safe and feasible, positively affecting walking parameters and lower limbs' maximal force. This approach should be incentivized when barriers to participation in traditional resistance exercise programs are present.

1. Introduction

Aging is characterized by a natural decline in overall fitness, including loss of muscle mass, strength, and power. This decline contributes to an increased risk of adverse health events, resulting in a progressively limited ability to carry out daily activities (Cruz-Jentoft & Sayer, 2019). For this reason, governments have been increasingly implementing interventions to fight physical inactivity among the elderly as part of health policies intended to maintain a high quality of life (de Oliveira et al., 2019; Ferreira et al., 2023).

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Resistance training is commonly considered an effective exercise intervention to promote increased skeletal muscle mass, muscle strength, and improvements in physical performance parameters (e.g., walking speed) while reducing relative adipose tissue (Geng et al., 2023; Maruya et al., 2016; Nascimento et al., 2019).

Traditional resistance training is typically performed in specialized facilities (e.g., commercial gym), under supervision, and utilizing special equipment (e.g., dynamic-constant external resistance machine). However, this setting may represent a disincentive to the older population due to accessibility and cost limitations, especially in low- and middle-income countries. Furthermore, older individuals experience intrinsic challenges such as reduced mobility, a high perception of difficulty, fear of injury, time constraints and lack of interest and/or knowledge. They also encounter environmental barriers including a lack of transportation or limited public transport options and distance from exercise facilities. These factors pose obstacles to maintaining an active lifestyle as well as to participating in exercise programs (Burton et al., 2017; Fyfe et al., 2022; Thiebaud et al., 2014).

Therefore, attention towards effective and accessible strategies (e.g., bodyweight exercise or small equipment) for resistance training administration for preserving strength and functional ability across the lifespan has been rising (Fyfe et al., 2022). In this context, home-based resistance training interventions have gained increasing attention from both scientists and operators of the health care system, but their actual efficacy is yet to be fully determined (Langeard et al., 2022). Recent systematic reviews (Chaabene et al., 2021; Mañas et al., 2021; Song et al., 2023) reported an overall modest to small effect of home-based exercise interventions on muscle strength and power (effect size 0.30–0.34; effect size 0.43–0.44 respectively), balance and walking speed (effect size 0.28–0.32; effect size, 0.34 respectively).

In a remote/offline setting, the lack of monitoring of exercise execution (i.e., safeness concern) and adherence to the training program with a proper progression of the overload could represent factors influencing efficacy (Chaabene et al., 2021; Lacroix et al., 2017). While most studies reported fair to good compliance (mean adherence: 67–70 %), this variable is typically based on participant-filled training diaries (Chaabene et al., 2021; Mañas et al., 2021) known to potentially overestimate adherence (Chaabene et al., 2021). Therefore, objective quantitative and qualitative indexes of compliance to the prescribed sessions and, within the session, to the single exercises, sets and repetitions, are needed to evaluate actual program efficacy.

Various technological solutions developed by the industry aim to fill the gap between exercise prescription and monitoring the execution of home-based training programs. Often, these devices combine wearable sensors and dedicated software that easily delivers the prescription of exercises from the trainer and monitors the correct and actual execution of the training session. While the above features appear extremely promising, the overall safety, feasibility, and efficacy of these devices in the specific context of sarcopenia prevention in older adults remain to be determined.

The aim of this study is to test the safety, feasibility, and effectiveness, on body composition, balance, gait and strength, of a 6-month home-based resistance training program administered through an innovative technological solution, in healthy older adults.

2. Methods

2.1. Procedure

This 6-month randomized control trial was conducted at the University of Verona (University of Verona, Verona, Italy) in accordance with the CONSORT statement (Schulz et al., 2011). All procedures used in the study were approved by the Ethics Committee for Human Research from the University of Verona (28/2023) and were conducted in conformity with the Declaration of Helsinki. All participants signed a written informed consent prior to participation. During the 6 months, assessments were conducted at the beginning (T0), midpoint (T3), and conclusion of the experimental protocol (T6). At each assessment window, the participants attended the laboratory twice, at the same time of the day, separated by at least a 72-hour recovery. Participants were instructed to refrain from strenuous activities during the 24 h preceding each visit. During the first visit, anthropometric measures and body composition markers were collected, while the second visit included balance, gait and strength test for each participant.

2.2. Participants

Participants were recruited by local advertisement. The inclusion criterion was age above 60 years, while a preliminary telephone interview and a successive medical screening allowed excluding of individuals with any orthopedic, mental, or neurological diseases that could interfere with the ability to perform a resistance training protocol. Participants who met the inclusion criteria were divided into either the intervention group or the control group, randomized and counterbalanced for sex and age. The intervention group underwent a 6-month home-based resistance training program with an innovative technological solution (see further for the description), while the control group was instructed to maintain their regular lifestyle.

2.3. Exercise intervention

The home-based intervention group was asked to perform a minimum of 3 and a maximum of 5 training sessions per week, each lasting from 30 to 70 min each, for a total of 6 months. Each session contained 8 to 10 exercises targeting major muscle groups of the core, the upper and lower limbs (2 - 3 exercises for each body district) (Fragala et al., 2019). Minimal equipment (body weight, chair, ab mat, elastic bands, and bottles of water) was used. Training periodization followed the principles of overload and progression: the training load was modulated by progressively increasing the volume (set x reps) of the exercises, the number of exercises (from 8 to 12), the strength requirement (e.g., the resistance of the elastic bands, from bi-podalic to mono-podalic exercise), and the postural challenge connected with the exercises (e.g. standing vs sitting) (Ratamess, Alvar, Evetoch, Housh, Kibler, Kraemer, 2009). An example of the training progression is provided in Table 1.

The exercise program was designed and administered remotely through an innovative technological solution (Kari® system, Euleria, Trento) which included a web-based prescription interface for the trainer and a Tablet and a wearable inertial sensor (IMU-sensor) for each participant. The prescription interface allowed trainers to select from a menu of predefined exercises and, for each exercise, to customize the number of sets and repetitions. On the contrary, speed of movement (slow and controlled), time under tension (2 s for both concentric and eccentric phases) and rest periods (passive) were standardized for all exercises. The tablet displayed video-instructions for the execution of the exercises, while the IMU-sensor provided real-time feedback to the participant a on the quality of the execution (i.e.: range of motion and speed of movement) by visualizing a feedback signal (Fig. 1). In addition, the system calibrated the individual and exercise-specific maximal range of motion from the first 3 repetitions of the first set, and then used this reference for monitoring the quality of the execution of the remaining repetitions.

Finally, the technological solution allowed the recording of the duration of the training sessions, training frequency (number of training sessions per week), number of exercises, sets, and repetitions completed, and the overall quality of the movement (i.e., an index of the overlapping between the target and actual movement pattern, as determined by the IMU-sensor).

Each participant received a 30-minute, one-to-one tutorial on using the technological solution.

Table 1
Example of workload progression in a weekly training session.

Week 1				**Week 12**				**Week 24**			
Exercise	Sets	Reps	Int.	Exercise	Sets	Reps	Int.	Exercise	Sets	Reps	Int.
Wall push-ups	2	8–10	Body weight	Chair push-ups	4	10–12	Body weight	Kneeling push-ups	4	12–15	Body weight
Seated rower	2	8–10	Yellow e.b.	Standing rower	4	10–12	Red e.b.	Monolateral rower	4	12–15	Black e.b.
Wall body french press	2	8–10	Body weight	Chair body french press	4	10–12	Body weight	Kneeling body french press	4	12–15	Body weight
Bicep curls	2	8–10	Yellow e.b.	Monolateral bicep curls	4	10–12	Red e.b.	Monolateral bicep curls	4	12–15	Black e.b.
Sit to stand	2	8–10	Body weight	Squat	4	10–12	Body weight	Bulgarian squat	4	12–15	Body weight
Inverse lunges	2	8–10	Body weight	Lunges	4	10–12	Body weight	Chair single squat	4	12–15	Body weight
Glutes bridge	2	8–10	Yellow e.b.	Sliding glutes bridge	4	10–12	Red e.b.	Monolateral glutes bridge	4	12–15	Black e.b.
Kneeling plank	2	8–10	Body weight	Plank	4	10–12	Body weight	Side plank	4	12–15	Body weight
Bird dog	2	8–10	Body weight	Banded anti-rotation	4	10–12	Yellow e.b.	Banded anti-rotation	4	12–15	Red e.b.

The table outlines training variables (exercises, sets, repetitions, and intensity) for one of the three weekly target training sessions during the 1st, 12th, and 24th week. Reps: repetitions; Int.: intensity; bw: body weight; e.b.: elastic band.

Fig. 1. The figure illustrates the technological solution consisting of a tablet (the dedicated software displays video instructions and real-time visual feedback) and a wearable inertial sensor (magnetically attached to an elastic band).

2.4. Data collection and analysis

2.4.1. Dropouts, adverse events and incidents

Drop out was defined as cessation of participation in the study protocol before it was completed. If a participant requested to interrupt their involvement in the study, the reasons were investigated and recorded. Adverse events were closely monitored during both physical tests and the intervention phase. Participants were instructed to use the technological solution warning system to report any difficulty, pain and discomfort experienced during training sessions. In case of warning report, participants were contacted to determine its origin and aetiology. An adverse event was defined as an intervention-related incident (such as muscle or joint soreness/stiffness) requiring a modification of the exercise program for 1 or more sessions (Fyfe et al., 2022).

2.4.2. Adherence to the training program

Adherence to the training program was evaluated based on the completion of the target training frequency (number of training sessions completed per week). To be considered “completed”, a training session required that more than half (>50 %) of the exercises and sets prescribed were actually performed. Subsequently, the weekly training frequency was averaged over the first and the second trimester of the intervention, for each participant and the group mean for each trimester was calculated. The percentage of participants who achieved the target and recommended number of training sessions (i.e. 3 and 2) every week was calculated, for each trimester.

2.4.3. Anthropometric and body composition measures

Participants were asked to be barefoot and wear only underwear during anthropometric and body composition assessments. Body mass was measured using an electronic scale (Tanita electronic scale BWB-800 MA, Tokyo, Japan) with an accuracy of 0.1 kg. Height was measured with precision to the nearest 0.005 m using a Harpenden stadiometer (Holtain Ltd., Crymych, Pembs, UK). A dual-energy X-ray absorptiometry (DXA) scan was employed to assess total body composition, performed on a QDR Explorer fan-beam densitometer (Hologic Inc, Horizon C DXA System, USA). It was administered and analyzed using Hologic Discovery version 12.6.1 (Holtain Ltd, UK) (Nana et al., 2015). The body composition variables of interest included the percentage of body fat mass (%FM) and the appendicular lean mass index (ALMI) as the ratio between appendicular lean mass and height squared for all the participants.

2.4.4. Physical test

During the second visit to the laboratory, participants performed the following battery of tests in random order: (i) 30 s of static balance, (ii) 10 m of straight walking, and (iii) a loaded 5 sit-to-stand test. Before initiating the testing battery, all participants engaged in a 5-minute warm-up on a cycle ergometer (Monark 814 E, Monark, Vargerb SE) set at 50 W (60 rpm) and completed four active lower-limb mobility exercises and 5–6 repetitions of the sit-to-stand movement (Bochicchio et al., 2023).

2.4.4.1. Static balance test. The body center of pressure was recorded by a force plate (1000 Hz, AMTI Inc., Watertown, MA, USA) positioned under the participant’s feet during 30″ of static balance in a semi-tandem position (with the toe of the rear foot in contact with the front midfoot) with open eyes. After showing the correct posture, a familiarization trial was performed. An operator stayed near to the participant to prevent any risk of fall. Time was stopped at 30 s or if the participants moved their feet or grasped the operator for support.

Raw data were collected and subsequently analyzed with a self-written MATLAB code. Briefly, the force signal was low pass filtered at 5 Hz using a fourth-order Butterworth filter. After that, ellipse area (cm^2), anterior-posterior mean distance (mean distance AP), and medio-lateral mean distance (mean distance ML) were extracted following the standard procedure (Prieto et al., 1996).

2.4.4.2. 10-meter walking test. Participants were instructed to walk along a 10 m straight path at self-selected speed. Following a countdown, participants started walking from a standing position at 0.30 m from the starting line. The start and finish time, velocity at 10 m, cadence (in Hz), step length (cm), and percentages of double support (%) were measured with a validated system consisting of photocells (Witty gate, Microgate, Bolzano, Italy) integrated with 10, 1 m photoelectric cells bars and dedicated software (Optogait, Microgate, Bolzano, Italy). Each trial was repeated twice. The system software automatically extracted the spatial-temporal parameters of gait, and the best trial (i.e., the lower time value) was recorded for further analysis.

2.4.4.3. Loaded 5 sit-to-stand. Participants began the test from a seated position on a 0.49 m height box and performed the test according to the following specific instructions: stand up and sit down from the chair 5 times, as fast as possible, with the arms crossed over the chest, making sure that the torso and shanks are perpendicular to the ground at the start of each repetition. Participants completed 2 sets of the 5STS test under 4 different weight conditions: body weight (BW), +12.5 % BW, +25 % BW, and +32.5 % BW (Bochicchio et al., 2023). Added weight was obtained with a 0–30 kg adjustable weighted vest (Weight Vest bv30, Lacertosus, Parma, IT). Weight conditions sequence was randomized and counterbalanced and repeated twice, with a 3-minute rest between trials and a 5-minute break between conditions.

Ground reaction forces were recorded with a force plate (1000 Hz, AMTI Inc., Watertown, MA, USA) placed under the participants' feet. In addition, a marker was fixed on the greater trochanter to assess the kinematic variables of the movement using a motion capture system comprising 8 infrared cameras (100 Hz, Vicon, Oxford, UK). The force plate and motion capture system were synchronized during the entire data collection process and key variables (i.e. vertical force and velocity) were directly computed from Vicon software. Then, a second-order low-pass Butterworth filter was applied to the vertical force (cut-off frequency: 7 Hz) and velocity (cut-off frequency: 20 Hz).

Mean concentric force and velocity were computed following the procedure described in Bochicchio et al. (2023) for each weight condition, in each participant. This allowed us to develop individual force-velocity (F-v, linear equation) and power-velocity (P-v, second-order equation) relationships and to calculate the muscle function indexes such as maximal force (F0, intercept between linear regression equation and y-axis), velocity (V0, intercept between linear regression equation and x-axis) and power (Pmax, apex of the second-order equation).

MatLab (Version R2021B, MathWorks Inc, Natick, Massachusetts, USA) scripts were employed for GRFs and kinematic signal analyses. Then, the variables of interest were exported in a Microsoft Excel spreadsheet (Microsoft 365, Version 16.0.16501.20228, Microsoft Corporation, Washington, USA) alongside anthropometric measures for further calculations.

2.5. Statistical analysis

Descriptive statistics were calculated and reported as mean ± standard deviation. Shapiro-Wilk test was run to test the normality of data distribution. For within participants' analysis of mean training frequency between the first and second trimester, a paired *t*-test was run for the intervention group. In addition, one-way repeated measures ANOVA was run to compare the training frequency between the first and all subsequent weeks of training.

Anthropometric, body composition, and physical performance measures at baseline (T0) between groups were compared by an unpaired *t*-test (for parametric data) or a Mann-Whitney test (for non-parametric data).

A one-way repeated measures ANOVA was used to determine changes within each group from the T0 timepoint for all the variables.

To test the effect of intervention, percentage differences from the baseline ($\frac{T3\ or\ T6-T0}{T0}\ \times 100$) were computed for each variable. Then, changes between groups and time were analysed by 2-way repeated measures ANOVA (Groups and Time), and Bonferroni correction was used for post-hoc analysis. Cohen effect size (d) was calculated as a measure of the magnitude (absolute values) of the within and between-groups differences. Effect sizes (ES) were rated as trivial (< 0.2), small (< 0.6), moderate ($0.6 < 1.2$), or large (> 1.2). The level of significance was set at 0.05. The SigmaPlot 12.0 software (SigmaStat, San Jose, CA, USA) was used to conduct all the statistical analyses. With a power of 0.80 and an α level of 0.05, 20 participants for each group were required to determine the between- and within-effect of the home-based training protocol based on a mean effect size of 0.30 (Chaabene et al., 2021; Mañas et al., 2021; Song et al., 2023) (G*power, Kiel, Germany). Given the long duration of the study, we recruited more participants than required for each group to overcome possible dropouts.

3. Results

75 older adults of both sexes met the inclusion criteria. During the study, 2 participants dropped out due to health-related issues unrelated to the intervention protocol. 73 older adults of both sexes (37 males and 36 females) were therefore included in the final analysis. Of these, 46 participants were allocated to the intervention group (means ± SD: age 67.1 ± 5.8 years; body mass 74.2 ± 15.5 kg; height 1.68 ± 0.09 m) while 27 participants were allocated to the control group (means ± SD: age 66.6 ± 6.2 years; body mass 72.1 ± 13.8 kg; height 1.67 ± 0.10 m). No intervention-related adverse events were recorded. In addition, during the physical tests, only 2 participants were unable to perform all 4 conditions of the loaded 5 sit-to-stand. Therefore, these data were discarded. Fig. 2 displays the flowchart of the participant's screening and participation.

The mean training frequency of the first and second trimesters and weekly adherence to the training program are displayed in Fig. 3. The mean training frequency during the second trimester was significantly lower than the first. In addition, 1-way RM ANOVA showed a significant drop in training frequency from the 16th to the last week of the intervention compared to the first week.

Personal data, anthropometric, and physical measures of participants are reported in Table 2. No differences were found between the intervention and control groups at baseline.

One-way repeated measure ANOVA showed an effect of time in the intervention group for 10-meter walking speed (T3: $p < 0.001$, ES = 0.53; and T6: $p < 0.001$, ES = 0.59), cadence (T3: $p < 0.001$, ES = 0.42; T6: $p < 0.001$, ES = 0.51), step length (T3: $p < 0.001$, ES = 0.43; T3: $p < 0.001$, ES = 0.45),% double support (T3: $p = 0.001$, ES = −0.23; T6: $p = 0.001$, ES = −0.28), and F0 (T6: $p = 0.009$, ES = 0.26) compared to baseline. An effect of time was detected also for the control group at T3 for 10 m walking speed (at T3: $p = 0.044$, ES = 0.28) and step length (T3: $p = 0.020$, ES = 0.25) compared to baseline.

Percentage changes in anthropometric and physical test parameters are displayed in Fig. 4. The 2-way RM ANOVA showed only a significant interaction (TIME x GROUP) for F0. In particular, the intervention group showed greater delta change at T6 compared to T3 (+9.35 % vs. +3.41 %, $p = 0.035$), which was also significantly different from the control group (+9.35 % vs. +4.13 %, $p = 0.014$).

4. Discussion

This study tested the feasibility and effectiveness of a 6-month, self-administered, home-based resistance training program with an innovative device in healthy older adults of both sexes. Our results indicate that the exercise intervention delivered through the home-based device-supported is feasible in terms of safety and adherence. In fact, no adverse outcomes were recorded throughout the study, while the compliance was very good for the first 3 months, yet decreased markedly thereafter. Moreover, the training program had a marginal or no effect on body composition, balance, and muscle function indexes, except for the walking parameters and the maximal force of the lower limbs during the

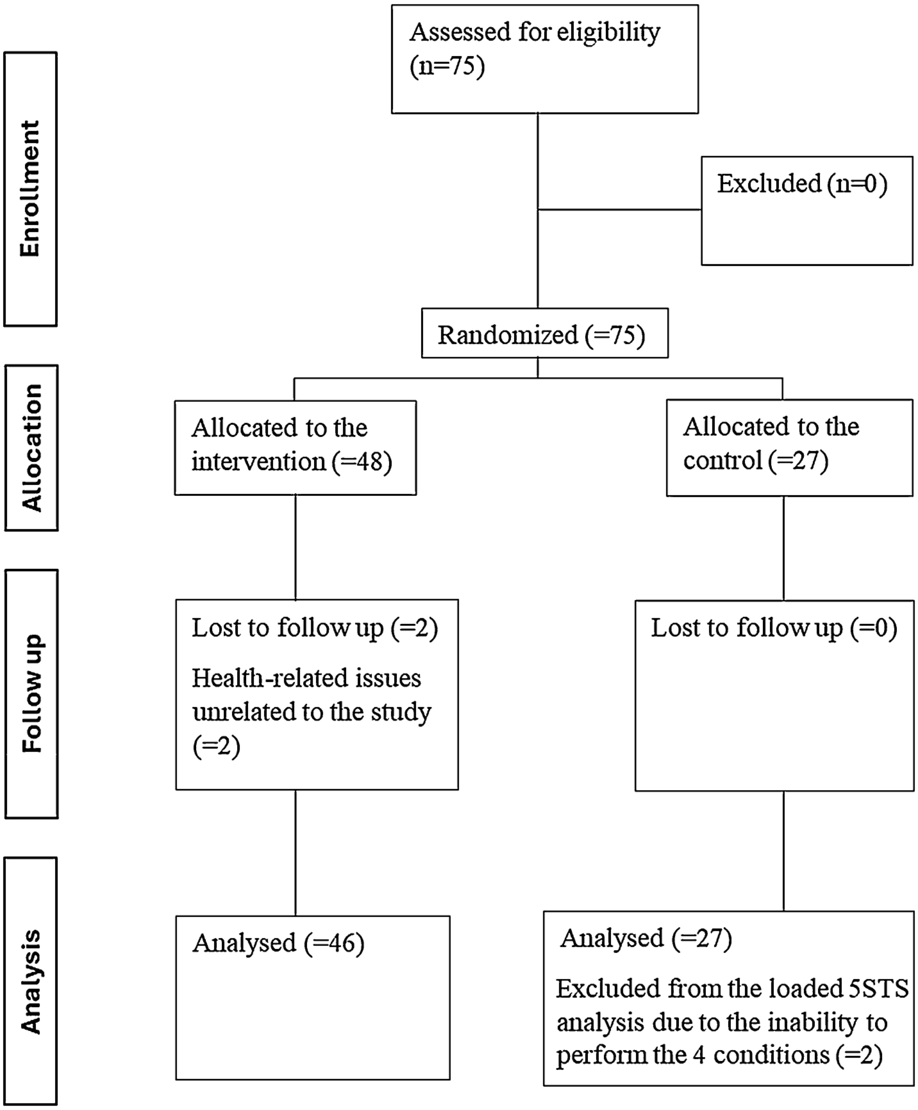

Fig. 2. Participants flow diagram.

sit-to-stand task that displayed a modest yet significant increase.

Safety is one of the most challenging aspects of home-based training programs. Therefore, very easy (low coordinative challenge), low intensity, double support, and low postural challenge exercises are typically prioritized at the expense of potentially more effective movement tasks. Recent systematic reviews (Chaabene et al., 2021; Mañas et al., 2021; Song et al., 2023) showed that remote exercise interventions seem to be overall safe. Even if the training program used in our study contained several complex, standing, single-leg exercises, our data confirm that no training-related adverse events were registered during the whole protocol. We speculate that the very slow, controlled movements imposed by the device, through visual feedback on the articular range and movement speed, could have contributed to this positive result.

During the first trimester, we recorded an adherence to the training program (MTF: 2.8 ± 1.1, 61 % of participants performed the recommended 3 sessions, 78 % of participants performed at least 2 sessions per week) comparable to that described in the literature for programs that proposed 2–3 sessions per week (from 47 % to 97 % with a weighted average of 67 %) (Mañas et al., 2021). However, a gradually decreasing adherence was observed (i.e., loss of 0.25 sessions per month) that brought the mean training frequency of the second trimester below the target value (3 sessions/week) and below the minimum recommended frequency for resistance training interventions (MTF: 1.9 ± 1.3 and 42 % of participants performed the recommended 3 sessions while 55 % of the participants performed 2 sessions per week). These observations suggest that long-term adherence to our program was possibly more difficult to maintain than in other studies (Chaabene et al., 2021). However, previous studies monitored adherence using training diaries filled out by the participants, an approach that is known to potentially overestimate this value (Chaabene et al., 2021). Moreover, many of the studies with the highest compliance included periodical direct contact with participants (i.e., via phone, internet, or personal visits) that may have contributed to maintaining a high adherence (Nilsson et al., 2020; Yamauchi et al., 2005). In our study, which was the first to measure objectively and automatically qualitative and quantitative adherence in real-time, this parameter should be free of overestimation.

4.1. *Effectiveness*

Our study was among the few (Lacroix et al., 2016; Maruya et al., 2016; Vitale et al., 2020) that measured anthropometric indexes of muscle mass and% body fat following home-based training programs. Resistance training is known to counteract the effect of aging on muscle mass (Chodzko-Zajko et al., 2009; Geng et al., 2023; Zeng et al., 2023). Muscle hypertrophy is mainly stimulated by metabolic stress and mechanical tension, activating intracellular pathways that induce muscle

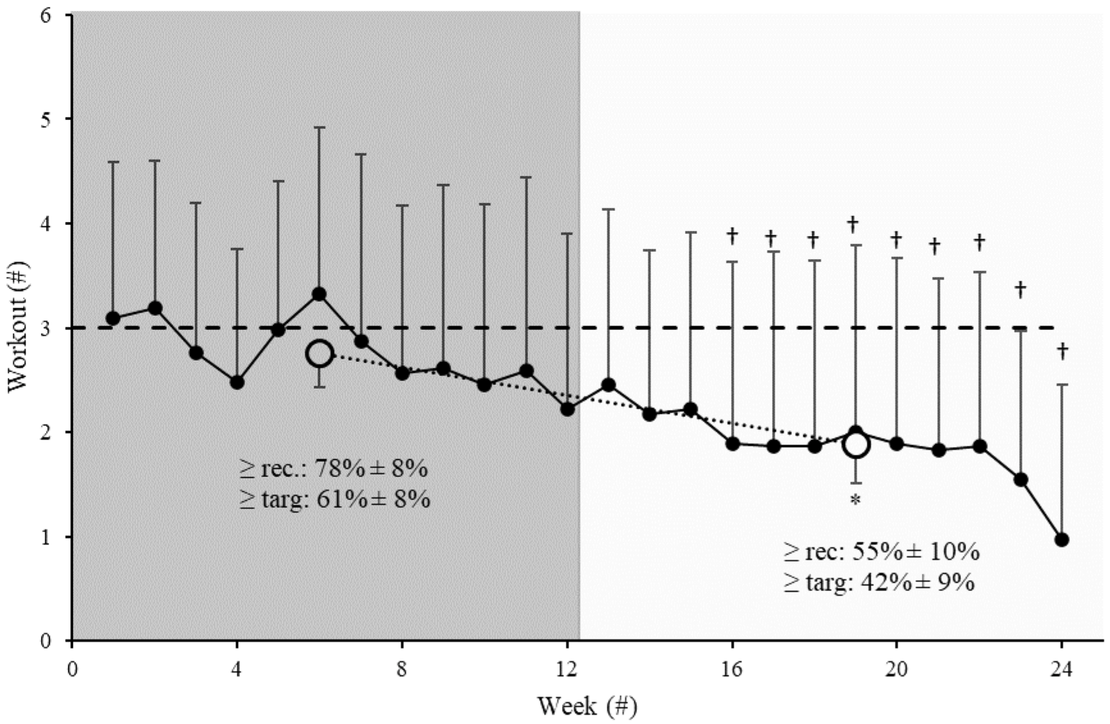

Fig. 3. The graph displays the weekly adherence trend (●) to the training program along with the average number of weekly sessions performed (○) in the first (dark grey) and the second (light grey) trimester. In addition, the mean percentage of participants that completed the target (at least 3) and recommended (at least 2) training sessions per week are reported for each trimester. The bold dashed line represents the target workout frequency prescribed for the intervention program. * indicates significant differences between trimesters in mean training frequency (paired *t*-test on means). † indicates a significant difference from the training frequency of the first week (1way RM ANOVA). A significance level was set at $p < 0.05$.

Table 2
Individual characteristic and physical measures of participants at baseline (T0).

Assessment	Variables	n	Intervention			n	Control			n	Total			*p-value*
Personal data	# (% females)	46	50 %			27	48 %			73	49 %			
	Age (yrs)	46	67.07	±	5.81	27	66.59	±	6.25	73	66.89	±	5.93	0.539
Anthropometry and body composition	Height (m)	46	1.68	±	0.09	27	1.67	±	0.10	73	1.68	±	0.09	0.706
	Body mass (kg)	46	74.16	±	15.55	27	72.11	±	13.76	73	73.40	±	14.85	0.558
	ALMI (kg m^{-2})	44	7.22	±	2.00	27	7.18	±	1.24	71	7.21	±	1.31	0.957
	Body fat (%)	44	31.70	±	7.45	27	30.97	±	8.03	71	30.97	±	8.03	0.694
Balance (Semi-tandem)	Ellipse area (mm^2)	44	1499.08	±	920.52	25	1380.30	±	822.77	69	1456.04	±	882.08	0.750
	Mean distance AP (mm)	44	8.56	±	3.14	25	8.23	±	2.89	69	8.44	±	3.03	0.760
	Mean distance ML (mm)	44	6.31	±	3.18	25	5.83	±	2.65	69	6.13	±	2.99	0.722
Gait (10-meter walking)	Velocity (m s^{-1})	45	1.31	±	0.28	27	1.38	±	0.24	72	1.34	±	0.22	0.183
	Cadence (step•min^{-1})	45	111.59	±	19.22	27	115.09	±	11.14	72	112.90	±	10.53	0.174
	Double support (%)	45	27.09	±	6.19	27	26.06	±	3.59	72	26.70	±	4.38	0.340
	Step length (cm)	45	70.11	±	12.60	27	71.71	±	9.08	72	70.71	±	7.98	0.412
Strength (Loaded 5 Sit-to-Stand)	F0 (N)	44	1492.95	±	499.25	25	1506.06	±	671.36	69	1497.70	±	461.35	0.616
	V0 (m s^{-1})	44	0.86	±	0.24	25	0.94	±	0.34	69	0.89	±	0.20	0.218
	Pmax (W)	44	320.57	±	118.09	25	339.05	±	138.23	69	327.27	±	102.92	0.162

Mean ± SD of personal data, anthropometric, body composition, and physical measures are reported for intervention, control, and total group. ALMI, appendicular lean mass index; Mean distance AP, Antero-Posterior mean distance; Mean distance ML = Medio-Lateral mean distance; F0, maximum force; V0, maximum velocity; Pmax, maximum power. The p-values of the unpaired *t*-test (parametric data) or Mann-Whitney (non-parametric data) are displayed on the right side. The tests used for balance, gait and strength assessment are indicated in brackets.

growth (Schoenfeld, 2010). Accordingly, our intervention was designed to progressively increase the volume (i.e., total amount of work) and the strength demands on a given muscle group (i.e., from dual to single limb) over time. However, in agreement with studies of similar duration and frequency (Lacroix et al., 2016; Maruya et al., 2016; Vitale et al., 2020), anthropometric indexes of muscle mass were unaffected by the training intervention (weight: $p = 0.169$; ALMI: $p = 0.404$).

Percent body fat is another health-related index that is threatened by aging and is potentially sensitivity to resistance training (Chodzko-Zajko et al., 2009; Fragala et al., 2019). While traditional resistance training has been shown to positively affect the%BF in healthy older individuals (ES = −0.53, $p < 0.001$) (Chen et al., 2021), our intervention group not displayed a significant reduction in%BF ($p = 0.255$). Therefore, we can state that our intervention had no effect on body fat. These results appear more similar to those of other home-based studies that found small, non-significant effects on the fat mass (Maruya et al., 2016;

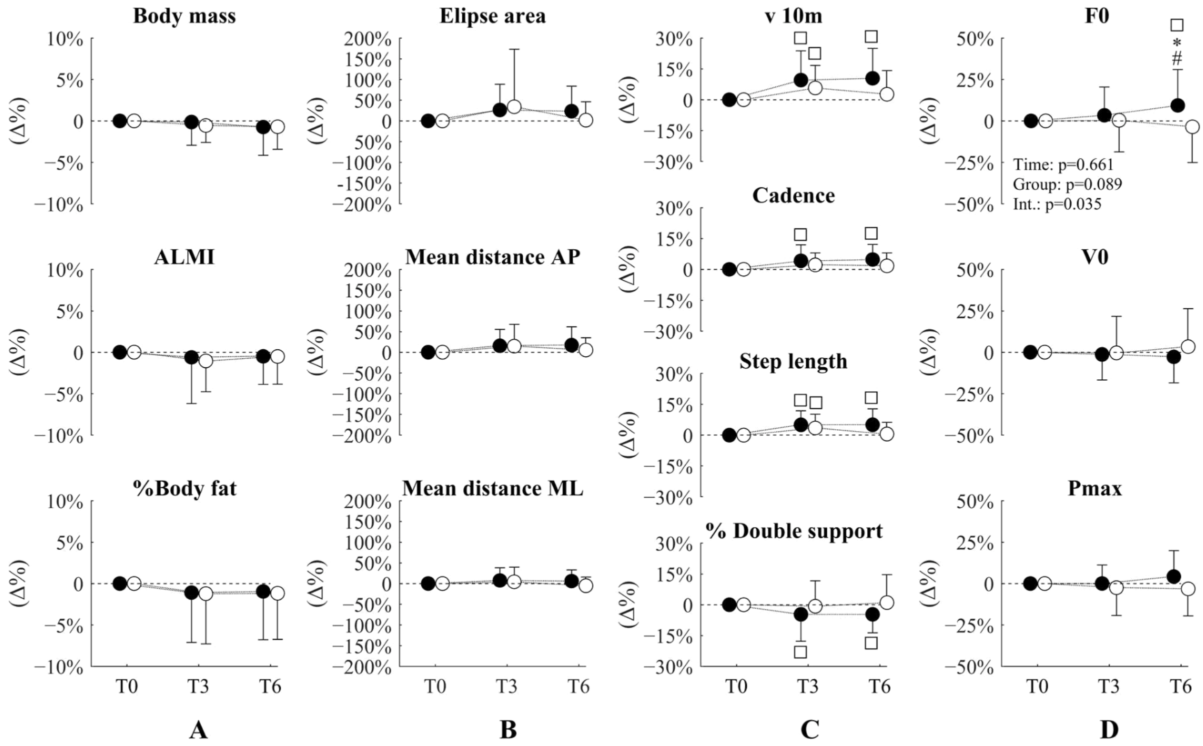

Fig. 4. Black dots represent the Intervention group, while the white dots represent the control group. Comparison of mean percentage delta changes between trimesters are displayed for anthropometric characteristics (left side panel A), Walking (in the left-middle Panel B), Static sway (in the right-middle Panel C) and Loaded 5 STS test (right side Panel D) variables. ☐ indicates time-effect on the absolute values. The graphs displayed the main effects of Group, Time, and Interaction in a text box when significant differences were found ($p < 0.05$). For the post-hoc analysis, * indicates significant difference from T3-T0 ($p < 0.05$); while # indicates significant difference from control group ($p < 0.05$).

Tsekoura et al., 2018).

In summary, the modest changes that were observed suggest that the overall training load delivered in our intervention may not have been sufficient to stimulate a gain in muscle mass and/or a reduction in body fat in our healthy older individuals.

The ability to control the body's center of pressure within the limits of the base of support is defined as balance (Yang et al., 2012). This ability decreases with aging and is one of the most critical factors associated with the augmented risk of falls in older individuals (Cyarto et al., 2008; Yang et al., 2012). Different forms of exercise training seem to positively affect balance (Cyarto et al., 2008) yet with somewhat inconsistent results. In fact, a recent systematic-review (Labata-lezaun et al., 2023) that included in the analysis only studies whit interventions lasting 12 weeks, showed that traditional resistance training has no effect on the static balance ability in older individuals (ES = 1.99, $p = 0.19$). On the other hand, previously described home-based resistance training protocols of comparable durations showed an overall small to modest yet significant effect (ES = 0.28–0.32) on balance (Chaabene et al., 2021; Lacroix et al., 2017; Mañas et al., 2021). In our study we did not find any improvement in all sway parameters (from $p < 0.052$ to $p = 0.504$). Since the benefits of resistance training on balance are thought to be mediated by improved neuromuscular control (i.e., improved coordination between agonist and antagonist muscles, decreased variability of force, and more effective recruitment and synchronization of motor units) (Sousa et al., 2013), we speculate that our program may have not been sufficiently intense or specific to effectively impact on this aspect. Therefore, whenever balance improvement is a desired outcome, either heavier intensity or else balance-specific exercise tasks should be incorporated in the training routine, the latter being easier and safer to administer in a home-based, unsupervised context.

Mobility can be broadly defined as the ability to move indoors and outdoors, with or without the use of some type of transportation (Webber, Porter, & Menec, 2010). In this context, mobility is a comprehensive term that includes different physical abilities and mental capacities. Among them, locomotion or walking ability is one of the most important. Indeed, during aging, a decrease in the mobility of older individuals occurs (Webber, Porter, & Menec, 2010), and the reduced locomotion significantly impacts an individual's ability to engage in daily activities, making it a crucial factor influencing the lifestyles of older individuals (Song et al., 2023). A systematic review on home-based resistance training programs described no changes in gait parameters following training interventions (Mañas et al., 2021). In contrast to this, we found an improvement in all walking parameters (ES = −0.28–0.59; $p \leq 0.001$) that are comparable to the improvements described following traditional resistance training (i.e. gait speed ES = 0.42, $p = 0.008$) (Lopez et al., 2018; Song et al., 2023). The larger increase observed in our study compared to other home-based resistance training studies could result from the concomitant lifting of COVID-19 restriction policies, allowing participants to be spontaneously more active. In fact, small improvements in 10 m walking speed at T3 were observed even in the control group (ES = 0.28, $p = 0.043$). Interestingly, the improvements in walking parameters were maintained for the entire 6 months only in the intervention group, indirectly confirming the long-term positive effect of our training intervention *per se*.

Muscle strength and power decrease with aging at a rate of 1.5 % and 3–4 % per year after 50, respectively (Skelton et al., 1994). Muscle power (i.e., the capacity to apply force quickly) seems to be more strongly associated with functional performance (i.e., ability to perform activities of daily living) than maximal strength (Gray & Paulson, 2014). Previous studies (Chaabene et al., 2021; Mañas et al., 2021; Song et al., 2023) showed an overall modest to small effect of home-based exercise interventions on muscle strength and power (ES = 0.30–0.34; ES = 0.43–0.44, respectively). Our results are partially in accordance with this evidence since we found an improvement for F0 (+9.35 %, ES =

0.26) but not for maximal power (+4.25 %, ES = 0.08) after 6 months of training in the intervention group. Although an increase in muscle power was not observed, a decrease was not observed either, highlighting that the training intervention may have mitigated the natural decline of muscle power that can be expected with aging. This view is corroborated by the observed significant decline in our control group (−4.88 %, ES = −0.18). Slow muscle contractions have been shown to improve muscle strength in healthy older adults (Watanabe, Madarame, Ogasawara, Nakazato, & Ishii, 2014). In contrast, high-velocity muscle contractions are necessary and essential for improving peak muscle power (Fragala et al., 2019; Ratamess, Alvar, Evetoch, Housh, Kibler, Kraemer, 2009). The slow and controlled execution imposed by the device could have provided an adequate stimulus to improve muscle strength, but it could have underexposed our participants to muscle power adaptations. Therefore, implementing a comprehensive resistance training intervention that includes power training may be a better approach to improving overall muscle function in healthy older adults, with the challenge of ensuring safety in performing high-velocity movement tasks in a home-based self-managed remote context.

In summary, our home resistance training delivered with a technological device achieved a negligible overall effect on body composition, balance, and muscle power, which are lower than previous studies conducted in a home environment, except for walking parameters and maximal strength, which were similarly and positively improved. Perhaps, in our fit and healthy population, the sole execution of bodyweight exercises or with the use of small equipment (i.e., an overall light relative exercise intensity) in conjunction with the slow speed of movement delivered by the device may have produced an overall suboptimal intensity and limited the effectiveness of our home-based resistance training.

5. Conclusion

In conclusion, our results indicate that the exercise protocol delivered with the technological solution is safe, associated relatively good adherence for the first 3 months of intervention that decreased markedly thereafter. In addition, the 6-month of home-based resistance training positively affected walking parameters and the expression of the maximal force of the lower limbs during the sit-to-stand task while providing marginal or no effect on body composition, balance, and muscle power. While, the extent of the long-term benefits of our home-based resistance training on muscle mass and function appear limited, exercise therapists and practitioners should consider this low-cost and accessible approach whenever barriers to an active lifestyle and participation in traditional resistance exercise programs are present.

Declarations

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Funding and competing interests

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Ethics approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the Ethics Committee for Human Research from the University of Verona (28/2023).

Consent to participate

Informed consent was obtained from all individual participants included in the study.

CRediT authorship contribution statement

Luca Ferrari: Writing – review & editing, Writing – original draft, Investigation, Data curation, Conceptualization. **Gianluca Bochicchio:** Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Alberto Bottari:** Data curation. **Alessandra Scarton:** Methodology. **Valentina Cavedon:** Data curation. **Chiara Milanese:** Conceptualization. **Francesco Lucertini:** Writing – review & editing, Conceptualization. **Silvia Pogliaghi:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

On behalf of all authors, I confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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