The short-term training and detraining effects of supervised versus unsupervised resistance exercise in aging adults

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ABSTRACT

This study compared the effects of a 4-week supervised (SUP) and unsupervised (UNSUP) resistance training programme followed by 12 weeks of detraining (DET). Thirty-six healthy aging adults (age: 53.6 ± 3.6 years; body mass index: 28.3 ± 5.1 kg/m^2) were randomly allocated to a SUP group (n = 17) or an UNSUP group (n = 19). Participants completed three training sessions per week using resistance bands and body weight movements. Measures of physical performance were administered at baseline, at the end of the training programme, and after the DET period. Function was assessed with the six minute walk test (6MWT), timed up-and-go (TUG), 30 s chair sit-to-stand (STS), stair-climb test (SCT), 40 m fast-paced walk test (FPWT) and sit-and-reach test (SRT), whereas the isometric mid-thigh pull (IMTP) and hand grip test were used to measure muscle strength. Following training, improvements in performance were found in the 6MWT, TUG, 30 s chair STS, SCT, FPWT, SRT, and IMTP ($p < 0.05$), with no significant differences between groups ($p > 0.05$). In addition, the majority of training-induced improvements remained significantly above baseline values after the DET period ($p < 0.05$). No significant between-group differences were observed following training or DET ($p > 0.05$). Four weeks of either SUP or UNSUP resistance training is sufficient to substantially improve muscle strength and function in aging adults, and these gains are largely preserved following prescribed exercise cessation. Home-based resistance training appears to be a practical and effective alternative to traditional SUP programmes that may help circumvent many barriers to physical activity in aging adults.

Keywords: Resistance training, functional capacity, home-based exercise, aging.

INTRODUCTION

Regular exercise opposes the debilitating effects of aging by mitigating declines in muscle strength and function (42). In particular, progressive resistance training has consistently been shown to improve functional abilities in adults aged ≥50 years (18, 21, 38). However, the research area is currently dominated by gym-based interventions requiring specialised equipment and personnel, with little consideration for long-term sustainability (11). A lack of access to transportation and traditional resistance facilities limits the widespread application of resistance training to this discrete population. In fact, older individuals are more likely to engage in exercise interventions that are easily accessible, do not require transport, and involve no out-of-pocket costs (23).

Home-based exercise is a convenient alternative to supervised programmes and may promote greater long-term participation than exercising at a designated setting (3). Despite the clear economic and practical benefits of home-based exercise, a recent systematic review (37) has suggested that supervised (SUP) resistance training improves measures of muscle strength to a greater extent than unsupervised (UNSUP) programmes. It is pertinent to note, however, that the limited work systematically comparing these two intervention strategies have employed SUP group exercise sessions, whereas the UNSUP home exercise has been performed individually. Given that social interaction is a robust and well-established exercise motive for older adults (20), it is conceivable that these comparisons were confounded by the social element of group training. Delivering both interventions on an individual basis would better identify the impact that supervision alone has on exercise-derived functional benefits in aging adults. It is also important that UNSUP resistance training programmes still pay attention to the fundamental principles of exercise physiology in order to strike a balance between efficacious and sustainable training.

Perhaps the hallmark of an effective resistance training programme, the principle of specificity asserts that the training stimulus must be specific to the desired adaptation (41). That is, the exercise must replicate the biomechanical movement patterns and underpinning bioenergetics involved in the performance of the primary outcome measurement (27). In order to improve function, training movements should promote the transfer of force through lower-body triple extension to simulate activities of everyday life, such as rising from a chair and climbing the stairs. It is therefore surprising that the majority of training studies in older persons have primarily involved single-joint movements and/or resistance machines (18, 21, 25). Training with elastic bands enables the execution of functional movement patterns through a full range of motion (ROM). Moreover, multi-articular exercises can easily be performed in multiple planes of motion because the direction of the resistance depends on the positioning of the elastic device rather than gravity (32). Importantly, elastic bands and free weights have been shown to exert similar benefits on measures of functional capacity in older adults (17).

The extent to which training-induced adaptations can be maintained after the cessation of prescribed exercise is a necessary consideration for any training programme. Studies have shown periods of detraining to retain (31, 36, 48) or completely reverse (18) measures of musculoskeletal strength and function following systematised resistance training. It is currently unknown whether supervision mediates the effect that detraining has on physical performance in aging individuals. Therefore, the aims of this study were threefold: 1) to examine the effectiveness of a short-term functional resistance training programme on measures of muscle strength and function in adults aged 50 to 65 years; 2) to compare the efficacy of resistance training performed in a SUP versus UNSUP setting, and 3) to determine whether changes in muscle strength and function are maintained following a detraining period of 12 weeks. Based on the current literature, we hypothesised that 1) resistance training would result in significant improvements in all outcome measurements, 2) the SUP group would improve strength and functional performance to a greater extent than the UNSUP group, and 3) training-induced improvements would remain above baseline levels following the detraining period in both training groups.

METHODS

Experimental Approach to the Problem

This study was a two-arm experimental trial whereby participants were randomly allocated to a SUP or UNSUP group. Both groups completed four weeks of functional resistance training with all variables controlled between conditions apart from the level of supervision. Outcomes measurements of functional and physical performance were administered at baseline (prior to group allocation), at the end of the 4-week intervention, and after a detraining (DET) period of 12 weeks. All participants agreed to maintain their current diet and activity levels during the intervention period. There were no particular instructions or guidance given during the 12-week DET phase.

Subjects

All participants were required to be aged 50 to 65 years, have a body mass index (BMI) of less than 35 kg/m^2, have not engaged in more than 30 min of moderate-vigorous intensity exercise on three or more days of the week for the last three months, and have no resistance training experience in the last 12 months. In total, 36 participants completed the resistance training intervention, with 17 in the SUP group and 19 in the UNSUP group (see Figure, Supplemental Digital Content 1). Participants were informed of the experimental procedures to be undertaken prior to signing an institutionally approved informed consent document to participate in the study. Baseline characteristics of study participants are presented in Table 1. The study was approved by the Sport, Health and Exercise Science Ethics Committee at the University of Hull.

[INSERT TABLE 1 ABOUT HERE]

Procedures

Resistance training programme

The resistance training programme was designed and delivered by a Certified Strength and Conditioning Specialist (CSCS) and was based on guidelines by the National Strength and Conditioning Association (NSCA) (27). Participants in both groups completed three sessions per week on non-consecutive days for the 4-week intervention period. One set of 8 repetitions was performed in week one, two sets of 8 repetitions in week two, two sets of 10 repetitions in week three, and three sets of 10 repetitions in week four. The intensity of exercise was performed at 4 to 6 on the modified 10-point rating of perceived exertion (RPE) scale (13) associated with the target number of repetitions. This corresponded with qualitative descriptions of “somewhat hard” to “hard”. After a dynamic warm-up that included targeted mobility exercises designed to increase the ROM in the ankle, hip and thoracic spine, participants performed 11 resistance exercises using body weight and resistance bands (Iron Woody Fitness, Onley, MT). Each exercise was based on a primary resistance training movement pattern as described in Table 2. Three colour-coded bands were used offering three incremental levels of resistance (Yellow, Purple and Red for light, medium and heavy resistance, respectively). Each session finished with a cool-down of static stretching that included ankle, hip, gluteal, hamstring and pectoral stretches.

The exercises focused on multi-articular and multi-planar movements to provide a functional training stimulus and mimic activities of daily living. Exercises were sequenced so that upper and lower body movements were alternated, which has been suggested to be beneficial for untrained individuals who may find that completing several lower- or upper-body exercises in succession is too strenuous (27). Progression (and regression) of the training load and volume was based on the participant’s RPE rating. If RPE was below four or above six, the exercise was progressed or regressed for the next workout, respectively. The resistance band exercises were progressed by changing from the current band to the next colour in the scale (e.g. Yellow to Purple). If a participant reached the level of resistance Red, another band was added while following the progression scale (e.g. Red plus Yellow). Body weight exercises were progressed using exercises of similar movement patterns with a higher degree of technical difficulty (e.g. biped stance to split stance).

[INSERT TABLE 2 ABOUT HERE]

UNSUP training programme

Participants completed the UNSUP training programme individually in their home. After completion of the baseline assessments, participants returned to the laboratory to be familiarised with the exercises to be used in the study and the use of the modified RPE scale. A CSCS checked for correct form in all exercises and adjusted technique if necessary. Participants then received an exercise package that included three colour-coded resistance bands, a heart rate monitor (FT1, Polar Electro, Kempele, Finland), an exercise DVD, a training log, an exercise progression/regression sheet and the modified RPE Scale. An instructional booklet was also included, written in layman language with pictures and diagrams, clearly describing all components of the programme. The CSCS telephoned all participants once per week to answer any questions and to document their RPE rating for each exercise. If participants' RPE for a given exercise fell outside the pre-determined level of intensity (RPE of below 4 or above 6), they were prompted to use their exercise progression/regression sheet to modify the exercise accordingly.

SUP training programme

The SUP group followed the same exercise programme as the UNSUP group, apart from that they completed the sessions in our Biomechanics laboratory and received one-to-one supervision by the same CSCS who provided telephone support to the UNSUP group. Participants received real-time encouragement and feedback on exercise technique with form being adjusted by the CSCS if necessary. RPE data was collected after the cessation of each training session and exercises were modified for the next workout accordingly.

Outcome measurements

Six minute walk test (6MWT): Participants were instructed to walk at their own maximal pace back and forth along a flat 30 m surface, covering as much ground as they could in six minutes. All instructions, encouragement, and monitoring adhered to the guidelines provided by the American Thoracic Society (4). Participants completed one trial and the distance covered was recorded in meters. The 6MWT has recently demonstrated excellent reliability in our laboratory (intraclass correlation [ICC] = 0.98), with the standard error of measurement (SEM) and minimum detectable change at 95% confidence intervals ($MDC_{95\%}$) reported at 13.7 m and 37.8 m, respectively (40).

Timed up-and-go (TUG): Participants sat in a firm, armless chair (height, 40 cm; depth, 39 cm) and were instructed to stand up, walk three meters before turning 180° and returning to the chair to sit down. Participants were instructed to perform the test as quickly as possible but in a controlled manner, with time recorded in seconds during one trial. TUG is a basic measure of functional mobility (7) and has demonstrated high test-retest reliability in our laboratory (ICC = 0.97; SEM = 0.22 s; $MDC_{95\%}$ = 0.62 s) (40).

30 s chair sit-to-stand (STS): The 30 s chair STS is a reliable measure of lower extremity function and strength in older adults (ICC = 0.89) (33). The test was administered using the same chair as the TUG, which was supported against a wall. Participants began seated and were subsequently instructed to rise to a full standing position (legs straight) and then return to the seat (full weight on chair) with both arms crossed against the chest. A practice trial of two repetitions was given to check correct form, followed by one test trial. The total number of stands performed correctly in 30 s was recorded for analysis.

Stair-climb test (SCT): Participants ascended and descended a freestanding flight of five steps (step height, 20 cm) as quickly possible, but in a safe and controlled manner. The use of the handrails was permitted if required, and the test finished when both feet were flat on the ground level. One trial was permitted with the time recorded in seconds. Using our laboratory's custom-built staircase, the SCT has been shown to be highly reliable (ICC = 0.98; SEM = 0.08 s; $MDC_{95\%}$ = 0.22 s) (40).

40 m fast paced walk test (FPWT): Participants walked as quickly as possible along a 20 m flat surface, turned 180° around a cone, then walked 20 m back to the start line. The test finished when the participant had walked 40 m to cross back over the start line, with time recorded in seconds during one trial. The 40 m FPWT has previously demonstrated excellent reliability (ICC = 0.95, SEM = 1.0 m/s) (51).

Hand grip test: Using their dominant hand, participants squeezed the analogue dynamometer (TKK 5001 Grip-A, Tokyo, Japan) as hard as possible for 2-3 s. An upright biped position was maintained throughout the test with the arm in full extension. The grip position of the dynamometer was adjusted to each individual's hand size. The best score of two trials was recorded to the nearest 0.5 kg and used for analysis. The TKK dynamometer has recently recorded high reliability and criterion-related validity (12).

Isometric mid-thigh pull (IMTP): Using an analogue back dynamometer (TKK 5002 Back-A, Tokyo, Japan), participants maximally extended their knees and trunk for five seconds without bending their back. The height of the handle was individually adjusted so that the bar rested midway up the thigh and there was 145° of knee flexion (22). Two trials were performed with a two minute rest period in between. Each trial was recorded to the nearest 1 kg, with the mean value used for analysis. This test has previously demonstrated good to acceptable reliability (ICC = 0.81-0.85) (26).

Sit-and-reach test (SRT): SRT is a reliable (ICC = 0.94) (10) measure of hamstring and spinal flexibility. Participants sat on the floor with their legs fully extended and heels flat against a standardised box (height, 32.5 cm). One hand was placed on top of the other and participants gradually reached forward as far as possible along the measuring tape on top of the box. One trial was completed, and the furthest the participants reached and held for two seconds was recorded to the nearest 0.5 cm.

Heart rate: Average and maximum heart rate and session duration were recorded for each training session using the Polar heart rate monitor. Recording commenced before the start of the warm-up and stopped immediately after the last resistance exercise (before the cool-down).

Exercise compliance: Compliance in the training intervention was calculated as follows: ([sessions attended/total number of sessions] x 100). Participation in the SUP intervention was assessed via attendance at the supervised training sessions. Participation in the UNSUP intervention was evaluated using participants' training logs.

Sample size estimation

The sample size was calculated using G*Power software (version 3.1, Universität Düsseldorf, Düsseldorf, Germany). Given the type of study design (mixed ANOVA with repeated measures), the following input parameters were entered in order to obtain medium-sized group x time interaction effects: $\alpha = 0.05$, statistical power of 0.8, and an effect size of 0.25. Thus, a priori sample size for statistical significance was calculated as 28 participants (i.e. 14 in each group). A dropout rate of 20% was also considered. The medium effect size was based on a recent meta-analysis (37) comparing the effects of SUP versus UNSUP resistance training on measures of muscle strength in older adults (standardised mean difference [SMD] = 0.51).

Statistical analyses

All analyses were performed by intention to treat using SPSS for Windows (IBM SPSS, version 22.0, Chicago, IL). Shapiro-Wilk and Levene's tests were used to verify normality of data and homogeneity of variance, respectively, and all assumptions were met. To compare baseline characteristics between groups, an independent samples *t*-test was conducted for continuous variables, whereas the Mann-Whitney U test was used for ordinal data (gender). A 2 x 3 mixed-model ANOVA with repeated measures for group (between) and time (within) was used to examine the effects of the intervention on each outcome measurement. The alpha level indicating statistical significance for this test was set at $p < 0.05$. The data were then further explored with pair-wise comparisons using a Bonferroni-adjusted alpha level. The assumption of sphericity was assessed with Mauchly's test, and in the case of significant violations, the Greenhouse-Geisser epsilon correction was applied. The level for all confidence intervals (CI) was 95%.

RESULTS

Exercise responses

Exercise compliance was 94.6% in the SUP group and 98.7% in the UNSUP group, with no significant difference between conditions (4.1 ± 2.1%, $p = 0.066$, 95% CI: -8.4 to 0.3%). Session duration was 27.6 ± 2.9 min in the SUP group and 23.1 ± 3.4 min in the UNSUP group, with this difference reaching statistical significance (5 ± 1 min, $p < 0.05$, 95% CI: 2 to 7 min). There was a significant interaction between group and time on average heart rate ($p < 0.05$). Specifically, average heart rate was 14 ± 3 beats per minute (bpm) higher in the SUP group compared with the UNSUP group ($p < 0.05$, 95% CI: 7 to 22 bpm) (Figure 1). For maximum heart rate, there was no significant group by time interaction ($p = 0.770$). However, there were significant main effects of time ($p < 0.05$) and group ($p < 0.05$), showing that peak heart rate was 23 ± 4 bpm ($p < 0.05$; 95% CI: 14 to 33 bpm) higher in the SUP group compared with the UNSUP group.

[INSERT FIGURE 1 ABOUT HERE]

Physical performance outcomes

There were no significant main effects of group nor any significant interaction effects between group and time for any physical performance outcome ($p > 0.05$; Table 3). However, the main effect of time showed a statistically significant difference in all variables at the different time points ($p < 0.05$). With the exception of hand grip strength, Bonferroni-corrected pairwise comparisons revealed significant training-induced improvements in all performance tasks ($p < 0.05$; Table 3). DET resulted in significant reductions in 30 s chair STS, SCT, and IMTP performance in both the SUP and UNSUP conditions ($p < 0.05$; Table 3). TUG and SRT performance also significantly decreased in the UNSUP group but not in the SUP group following DET, although these reductions were not significantly different between conditions (TUG: 0.13 s, $p = 0.454$, 95% CI: -0.21 to 0.46 s; SRT: 1.31 cm, $p = 0.924$, 95% CI: -0.56 to 3.19 cm). Despite these performance decrements, the 6MWT, TUG, 30 s chair STS, SCT, FPWT, and IMTP remained significantly above baseline in both groups following DET ($p < 0.05$). No significant between-group differences emerged between conditions following training or DET ($p > 0.05$) (Table 4).

[INSERT TABLE 3 ABOUT HERE]

[INSERT TABLE 4 ABOUT HERE]

DISCUSSION

This study examined the short-term training and detraining effects of SUP versus UNSUP resistance training on muscle strength and function in adults aged 53.6 ± 3.6 years. Our data demonstrate a comparative increase in functional ability and muscle strength following both training interventions. These improvements were attained using low-cost elastic bands and a small weekly time commitment (83 and 69 min in SUP and UNSUP, respectively). In addition, the majority of training-induced adaptations remained above baseline values following the period of DET.

The training programme resulted in a significant increase in functional performance and IMPT strength, independent of the level of supervision. The magnitude of change, considered in relation to the error of measurement, suggests that the training-induced improvements are likely to be meaningful for aging adults. For example, the improved TUG performance observed in both groups (-0.84 and -0.93 s in SUP and UNSUP, respectively) exceeds the SEM (0.22 s) and $MDC_{95\%}$ (0.62 s) previously recorded in our laboratory (40). This improvement in functional performance is also greater than the magnitude reported in a previous meta-analysis of resistance training in older adults (-0.69 s, 95% CI: -1.11 to -0.27 s) (38) and is larger than the change observed in a number of recent studies in this area (16, 47). This difference may be attributed to the average age of participants. In this study, subjects had a mean age of 53.6 ± 3.6 years, whereas the mean age of trials included in the meta-analytic review (38) ranged from 65.8 ± 7.6 to 84.9 ± 4.8 years. Alternatively, the difference in magnitude may be related to the specificity of the exercise stimulus. The majority of resistance training studies in older adults involve single-joint exercises and/or the use of resistance machines, which limits the training movement to a fixed pattern in a single plane of motion. While this regimen is effective at enhancing maximal muscular strength, it appears to elicit a more modest effect on functional performance (39, 43). Our training intervention involved resistance training exercises that mimic the biomechanical movement patterns of everyday life activities, such as rising from a chair (e.g. squat), climbing the stairs (e.g. split squat) and twisting to pick an item up off the floor (e.g. core rotation).

Furthermore, many movement deficits develop during later adulthood such as a lack of ankle ROM and reduced hip extension, which result in adverse gait kinematics and a decline in functionality (34). Training programmes specifically targeting these age-related movement deficits have been shown to enhance gait velocity and centre of mass kinematics in the sit-to-stand transition (15, 44). Favourable changes in walking speed and sit-to-stand kinematics may aid in the performance of tasks such as the TUG. Therefore, the inclusion of specific mobility exercises in our intervention (designed primarily to increase ankle, hip and thoracic spine ROM) might have contributed to the large improvements in functional performance. Further research is required to confirm the mechanistic changes that underpin improvements in functional tasks following training.

It is important that resistance training evokes changes that are clinically meaningful for the intended population. Changes in laboratory-based measurements following a resistance training intervention are designed to reflect changes in clinically meaningful endpoints (28). Because laboratory measurements are not clinically meaningful endpoints, they must be correlated with those that are in order to be considered valid (28). For example, performance in the SCT is associated with self-reported functional abilities in older adults (5) and the test involves the same movement patterns as climbing the stairs in a real-life setting. Though correlations cannot establish cause and effect, it is likely that the ~13% improvement in SCT performance would have a direct influence on an aging person's ability to climb a flight of stairs in day-to-day life. This magnitude of change is also consistent with other resistance training studies (~9 to 14%) (29, 30, 35) and exceeds the $MDC_{95\%}$ recorded previously (7.7%) (40), confirming that the change was not due to measurement error or variation within individual performance. Further work is warranted to delineate a causal relationship between improvements in laboratory-based measurements and changes in day-to-day function.

The resistance training programme followed the principle of progressive overload by systematically increasing resistance (grade of elastic band) and volume (number of sets and/or repetitions) over time. Additionally, in accordance with NSCA guidelines (27), the difficulty of exercise selection was individually tailored according to the participant's ability and perception of effort. That is, exercises were modified using exercises of similar movement patterns but with different technical difficulties. For example, the body weight squat was progressed to a body weight lunge when the participant rated the squat exercise as "easy" (≤3 on the modified RPE Scale). Both movements are multi-jointed motor actions involving large muscle groups, but the lunge is unilateral in nature, reduces the base of support from a biped stance to a split stance, and requires greater hip flexor ROM. The lunge also necessitates a larger amount of muscle force to decelerate the body's inertia and then accelerate the body back to the starting position. Advancing from low-skill to high-skill exercises may improve movement quality to a greater extent than increasing resistance load or volume alone. Indeed, a ceiling effect exists whereby further increases in strength will not lead to additional functional improvements in older adults (6). While modifying exercise selection based on individual ability is common practice in athlete populations, it is a strategy seldom included within training interventions for older adults. Researchers and practitioners should consider focusing on the primary movement pattern rather than the exercise itself, and move away from prescribing homogenous training programmes for a largely heterogeneous population.

The increases in functional ability and IMPT strength were similar between SUP and UNSUP groups. Between-group comparisons did not reach statistical significance for any variable, which is further supported by the 95% CIs spanning zero. While these nonsignificant results do not establish equivalence, the data implies that equivalency cannot be ruled out. This finding is in contrast to a recent meta-analytic review suggesting that, in a pooled analysis of five studies, SUP resistance training improves proxies of muscle strength to a greater extent than UNSUP programmes (SMD = 0.51) (37). However, when considering the primary data, three out of the five studies included in the review reported no differences between SUP and UNSUP interventions (1, 19, 46). Another included study compared SUP high-intensity training versus an UNSUP low-intensity programme (50); consequently the difference between groups may be attributed to different loading strategies rather than the level of supervision. The remaining study reported larger improvements in function following 12 weeks of SUP strength and balance training compared with a parallel home-based programme (36). Therefore, despite the recent publication of a well-designed meta-analysis (37), existing research comparing SUP versus UNSUP resistance training programmes in aging adults remains equivocal. Our data suggest that home-based resistance training with telephone support is an effective alternative to SUP programmes, although this finding requires replication in interventions lasting several months rather than weeks.

The present study is the first to demonstrate greater elevations in heart rate when untrained aging adults receive supervision during a resistance training intervention. Weekly telephone calls to the UNSUP group revealed lower mean stages of exercise progression compared with the SUP group, which implies that the greater heart rates may have been related to the completion of more advanced exercises. Direct supervision may have also fostered a higher quality in the execution of exercises due to continual technical feedback. Alternatively, the greater heart rates may be related to psychological factors such as competitiveness (i.e. presence of an audience) or external motivation (i.e. real-time encouragement). Interestingly, the average heart rate elicited in the SUP group (117 ± 8 bpm) was equivalent to ~70% of age-predicted HR_{max} (220-age), which meets the American College of Sports Medicine (ACSM) guidelines for moderate-intensity aerobic exercise (24). The capacity of resistance training to contribute to the aerobic component of International physical activity guidelines has been reported recently (9) and suggests that this resistance training, when programmed appropriately, can provide stimuli for both cardiovascular and musculoskeletal adaptation. In light of an increasingly sedentary population, promoting resistance training as a single method to achieve discernible health benefits should be considered. Future research should evaluate whether the higher heart rates elicited in the SUP versus UNSUP group translate into greater improvements in cardiovascular fitness.

Following exercise cessation, training-derived improvements were robust and remained above baseline values in both intervention groups. For example, performance in the 30 s chair STS test after DET was still ~14% greater than baseline. Previous studies have also reported that, after DET phases of 6 to 12 weeks, STS performance remains ~10% to 22% greater than pre-training values (2, 14, 36). Less retention of 30 s chair STS performance (~8%) has been observed following longer DET periods of 24 weeks (48) and one year (18). It is likely that the residual effect of resistance training diminishes with longer periods of DET. Age may also mediate the effects of DET; Seco and colleagues (45) have previously reported better maintenance of balance performance among 65-74 year olds compared to those aged 75 years or older. Given that we included younger participants (53.6 years) than the aforementioned studies (~65 years) (18, 48), it might be expected that our subjects would retain a greater proportion of their training improvements. In contrast, the initial training regimen does not appear to influence DETs effect on functional performance. We found the residual benefit of resistance training was similar between SUP and UNSUP interventions, which is consistent with data obtained recently by Lacroix and colleagues (36). Others have also demonstrated that DET is not affected by training load, training duration or repetition velocity among older adults (31, 48). However, comparing post-training to post-DET, the significant decreases in some parameters of physical performance highlight the negative effects of discontinuing a resistance training programme. This reinforces the notion that aging individuals should be engaged in a regimen of resistance training across the lifespan in order to mitigate age-related declines in function.

A limitation of this study is that the investigator was not blinded to group allocation, although all participants received the same instructions and strictly adhered to a predetermined testing protocol. Additionally, training intensity was controlled indirectly by selecting a target number of repetitions associated with a subjective perception of effort. While resistance training load is usually quantified using a percentage of one repetition maximum (1RM), the use of RPE has been shown to be a valid indicator of elastic resistance training intensity in older adults (17). The weekly telephone support provided to the UNSUP group may also have encouraged exercise adherence (8). Therefore, it is unknown whether the same results would have occurred if there was no contact with participants during the intervention period. Furthermore, we did not include an inactive control group, although we have interpreted the magnitude of effects in relation to the error of measurements that were matched for time in our laboratory (four weeks separating trials) (40). Finally, participants in this study were healthy adults aged 53.6 ± 3.6 years (range: 50 to 62 years) and may not be representative of all elderly persons. Most previous studies have included adults aged above 65 years, so comparisons made between our results and the current body of literature should take this age difference into consideration. The hypertrophic response to resistance training may be diminished with advancing age, but aging doesn't seem to impair one's ability to increase muscle strength (49). Future studies should assess whether a functional resistance training programme with minimal supervision is well-tolerated by older and mobility-limited individuals.

To conclude, this study demonstrated that a 4-week functional resistance training programme, performed using body weight movements and elastic bands, elicited meaningful improvements in physical performance. The increases in functional ability and muscle strength were similar between SUP and UNSUP groups, suggesting that home-based resistance training is a practical and effective alternative to SUP programmes for aging adults. Importantly, the training-induced improvements were largely preserved following exercise cessation.

PRACTICAL APPLICATIONS

A functional resistance training programme may be implemented into clinical practise in order to mitigate age-related declines in muscle strength and function. Owing to the comparative effectiveness of SUP and UNSUP groups, our data also suggest that practitioners may prescribe home-based resistance training as a cost-effective and practical alternative to SUP programmes that may help circumvent many barriers to physical activity in the aging population, such as lack of time, money, and transportation. This finding, however, requires replication in interventions lasting several months rather than weeks. The adaptations to a resistance training programme are well maintained beyond the cessation of training, although lifelong participation in resistance training should be encouraged in order to attenuate the inevitable decline in functional capacity during later adulthood. Taken together, these findings suggest that aging adults should choose a preferable environment for exercise (i.e. UNSUP at home or SUP in a facility) that will foster consistent adherence to resistance training in the longer-term.

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Figure and Table Captions

Figure 1. Average (A) and maximum (B) heart rate during the resistance training intervention. SUP = supervised; UNSUP = unsupervised; bpm = beats per minute. * indicates significantly different from session one ($p < 0.05$). † indicates significantly different from UNSUP ($p < 0.05$). Data are presented as means ± SE.

Table 1. Baseline characteristics of study participants.

Table 2. Primary resistance training movement patterns.

Table 3. Within-group changes between the different time points.

Table 4. Between-group changes between the different time points.

Table 1. Baseline characteristics of study participants

	Total (n = 36)	SUP (n = 17)	UNSUP (n = 19)	*p*-value
Age (years)	53.6 ± 3.6	52.9 ± 3.8	54.2 ± 3.3	0.295
Males/females	11/25	4/13	7/12	0.510
Body mass (kg)	78.0 ± 16.5	76.1 ± 17.4	79.7 ± 15.9	0.526
Height (cm)	165.9 ± 9.5	164.1 ± 9.5	167.5 ± 9.4	0.283
BMI (kg/m^2)	28.3 ± 5.1	28.1 ± 4.9	28.4 ± 5.5	0.832
Blood pressure				
Systolic (mmHg)	132.3 ± 11.4	131.4 ± 12.6	133.1 ± 10.6	0.653
Diastolic (mmHg)	84.7 ± 8.5	83.8 ± 9.6	85.5 ± 7.6	0.557
Resting HR (bpm)	72.7 ± 7.3	72.4 ± 8.3	73.0 ± 6.5	0.813
6MWT (m)	614.79 ± 53.33	614.23 ± 59.79	615.28 ± 48.50	0.954
TUG (s)	6.39 ± 0.65	6.33 ± 0.62	6.44 ± 0.68	0.592
30 s chair STS (reps)	12.8 ± 2.2	13.1 ± 2.2	12.6 ± 2.2	0.517
SCT (s)	5.86 ± 0.78	5.80 ± 0.83	5.91 ± 0.76	0.676
FPWT (s)	20.46 ± 1.76	20.51 ± 2.06	20.41 ± 1.50	0.871
Hand grip (kg)	34.8 ± 10.0	33.0 ± 8.3	36.5 ± 11.3	0.302
IMPT (kg)	79.4 ± 39.6	78.4 ± 35.7	80.4 ± 43.7	0.881
SRT (cm)	15.8 ± 9.7	17.4 ± 9.6	14.3 ± 9.7	0.332

SUP = supervised; UNSUP = unsupervised; BMI = body mass index; HR = heart rate; bpm = beats per minute; 6MWT = six minute walk test; TUG = timed up-and-go; STS = sit-to-stand; SCT = stair-climb test; FPWT = fast-paced walk test; IMTP = isometric mid-thigh pull; SRT = sit-and-reach test. Data are presented as means ± SD.

Table 2. Primary resistance training movement patterns

Movement	Key exercise
Hip extension[a]	Shoulder-raised bilateral glute bridge
Lower-body triple extension[a]	Squat
Horizontal push[a]	Modified press-up
Lower-body triple extension[a]	Split squat
Scapula retraction[b]	Standing scapula retraction w/ Yellow band
Lateral rotatory[b]	Lateral walk w/ Yellow band
Vertical push[b]	Incline chest press w/ Yellow band
Hip hinge[b]	Deadlift w/ Yellow band
Horizontal pull[b]	Seated row w/ Yellow band
Full-body extension[b]	Push press w/ Yellow band
Anti-rotation[b]	Core rotation w/ Yellow band

The resistance exercises were based on primary resistance training movement patterns. Key exercises used in the intervention are shown here. These key exercises were regressed or progressed according to the participants' rating of perceived exertion.

[a]body weight exercise; [b]resistance band exercise; w/ = with.

559 **Table 3**. Within-group changes between the different time points

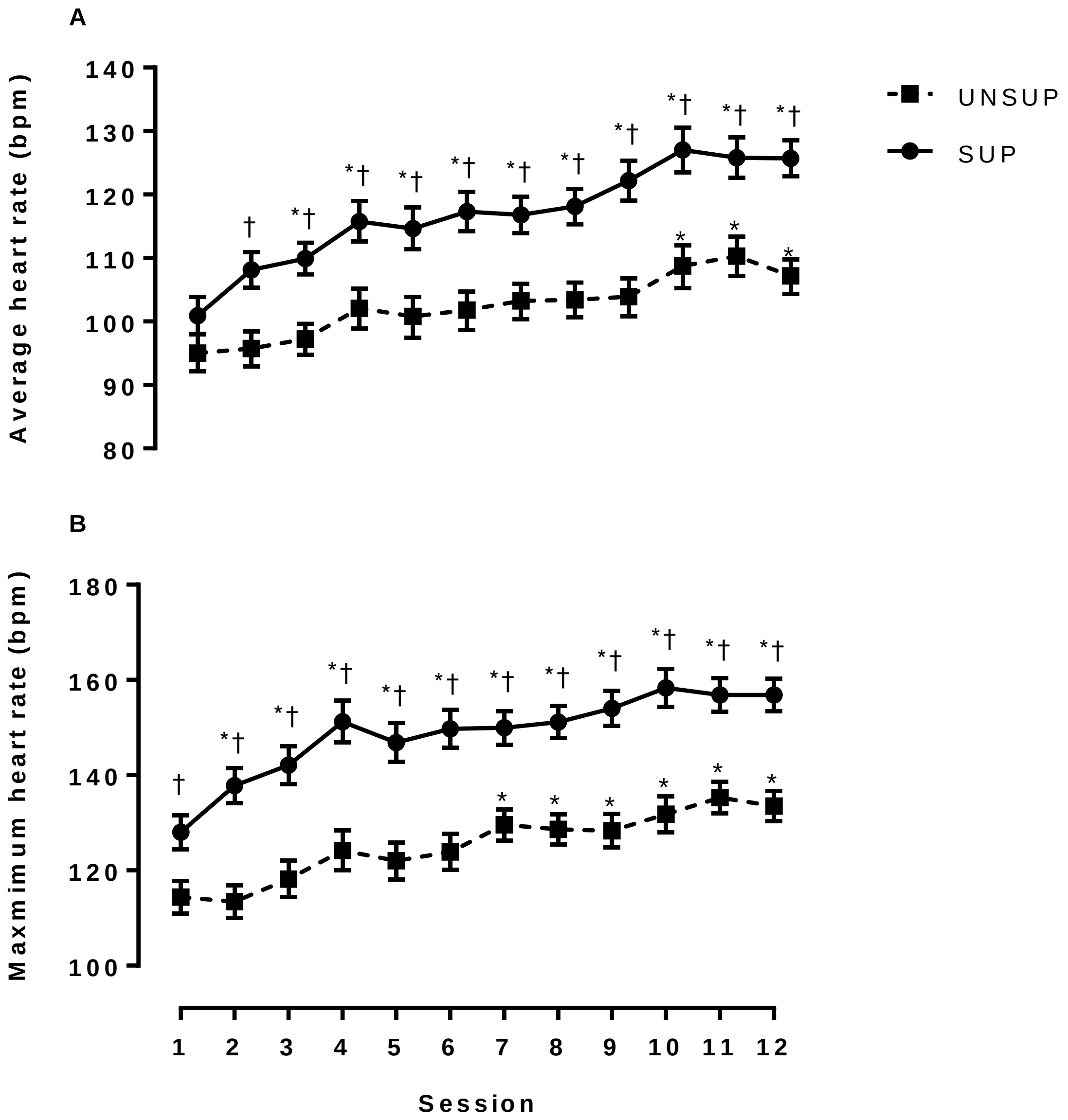
Outcome	PRE-POST	PRE-DET	POST-DET	Time x group interaction *p*-value
6MWT (m)				
SUP	48.6 (28.4 to 68.8)*	30.6 (6.2 to 55.0)*	-18.0 (-38.3 to 2.2)	0.849
UNSUP	42.7 (17.8 to 67.7)*	24.7 (1.6 to 47.8)*	-18.1 (-37.8 to 1.7)	
TUG (s)				
SUP	-0.84 (-1.16 to -0.53)*	-0.61 (-0.88 to -0.34)*	0.23 (-0.16 to 0.62)	0.746
UNSUP	-0.93 (-1.28 to -0.58)*	-0.57 (-0.88 to -0.27)*	0.36 (0.13 to 0.58)*	
30s Chair STS (s)				
SUP	3.4 (2.8 to 3.9)*	1.8 (1.0 to 2.6)*	-1.6 (-2.6 to -0.6)*	0.784
UNSUP	3.1 (2.0 to 4.1)*	1.8 (0.8 to 2.9)*	-1.3 (-2.4 to -0.1)*	
SCT (s)				
SUP	-0.74 (-1.12 to -0.36)*	-0.42 (-0.78 to -0.05)*	0.32 (0.07 to 0.57)*	0.923
UNSUP	-0.79 (-1.17 to -0.41)*	-0.44 (-0.78 to -0.11)*	0.34 (0.14 to 0.55)*	
FWPT (s)				
SUP	-1.74 (-2.87 to -0.62)*	-0.93 (-1.42 to -0.44)*	0.81 (-0.48 to 2.10)	0.299
UNSUP	-1.37 (-1.98 to -0.76)*	-1.22 (-1.85 to -0.60)*	0.15 (-0.28 to 0.57)	
Hand grip test (kg)				
SUP	0.9 (-1.0 to 2.7)	1.6 (-0.3 to 3.5)	0.7 (-0.7 to 2.2)	0.140
UNSUP	0.8 (-0.2 to 1.8)	0.3 (-0.7 to 1.2)	-0.6 (-1.8 to 0.7)	
IMPT (kg)				
SUP	25.0 (16.4 to 33.6)*	14.4 (7.2 to 21.6)*	-10.6 (-18.3 to -3.0)*	0.829
UNSUP	26.6 (14.3 to 38.8)*	17.6 (4.8 to 30.5)*	-8.9 (-17.6 to -0.3)*	
SRT (cm)				
SUP	3.2 (-0.2 to 6.6)*	2.1 (-1.7 to 6.0)	-1.0 (-3.2 to 1.1)	0.495
UNSUP	3.2 (1.3 to 5.1)*	0.9 (-0.8 to 2.6)	-2.3 (-3.7 to -1.0)*	

PRE = pre-intervention; POST = post-intervention; DET = detraining; SUP = supervised; UNSUP = unsupervised; 6MWT = six minute walk test; TUG = timed up-and-go; STS = sit-to-stand; SCT = stair-climb test; FPWT = fast-paced walk test; IMTP = isometric mid-thigh pull; SRT = sit-and-reach test. * indicates significant difference within-groups ($p < 0.05$). Data are presented as means (95% confidence intervals).

Table 4. Between-group changes between the different time points

	PRE-POST	PRE-DET	POST-DET
6MWT (m)	5.89 (-19.08 to 30.86)	5.93 (-19.78 to 31.65)	0.41 (-21.65 to 21.73)
TUG (s)	0.09 (-0.28 to 0.45)	0.04 (-0.28 to 0.36)	0.13 (-0.21 to 0.46)
30 s Chair STS (reps)	0.30 (-0.64 to 1.24)	0.03 (-1.03 to 1.08)	0.33 (-0.83 to 1.48)
SCT (s)	0.05 (-0.36 to 0.47)	0.28 (-0.35 to 0.40)	0.24 (-0.22 to 0.27)
FPWT (s)	0.37 (-0.58 to 1.32)	0.29 (-0.33 to 0.91)	0.66 (-0.33 to 1.7)
Hand grip test (kg)	0.04 (-1.52 to 1.59)	1.33 (-0.23 to 2.88)	1.29 (-0.18 to 2.75)
IMTP (kg)	1.58 (-10.17 to 13.32)	3.3 (-8.41 to 14.97)	1.7 (-7.2 to 10.61)
SRT (cm)	0.03 (-2.88 to 2.95)	1.28 (-1.84 to 4.39)	1.31 (-0.56 to 3.19)

PRE = pre-intervention; POST = post-intervention; DET = detraining; 6MWT = six minute walk test; TUG = timed up-and-go; STS = sit-to-stand; SCT = stair-climb test; FPWT = fast-paced walk test; IMTP = isometric mid-thigh pull; SRT = sit-and-reach test. Data are presented as means (95% confidence interval).


A
UNSUP
SUP
Average heart rate (bpm)
140
130
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B
Maxmimum heart rate (bpm)
180
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Session

561

Supplemental Digital Content 1. Participant flowchart