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Citation: Orange, Sam, Marshall, Phil, Madden, Leigh A. and Vince, Rebecca V. (2019) Short-Term Training and Detraining Effects of Supervised Versus Unsupervised Resistance Exercise in Aging Adults. *Journal of Strength and Conditioning Research*, 33 (10). pp. 2733-2742. ISSN 1064-8011

Published by: Lippincott Williams & Wilkins

URL: <https://doi.org/10.1519/JSC.0000000000002536>
<<https://doi.org/10.1519/JSC.0000000000002536>>

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NEWCASTLE

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

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12

13 *Brief running head:* Supervised vs. unsupervised resistance training

14 *Disclosure statement:* This research did not receive any specific grant from funding agencies in the
15 public, commercial, or not-for-profit sectors.

16 All data were collected in the Sport, Health and Exercise Science laboratory at the University of Hull.

17 **ABSTRACT**

18 This study compared the effects of a 4-week supervised (SUP) and unsupervised (UNSUP) resistance
19 training programme followed by 12 weeks of detraining (DET). Thirty-six healthy aging adults (age:
20 53.6 ± 3.6 years; body mass index: 28.3 ± 5.1 kg/m²) were randomly allocated to a SUP group (n = 17)
21 or an UNSUP group (n = 19). Participants completed three training sessions per week using resistance
22 bands and body weight movements. Measures of physical performance were administered at baseline,
23 at the end of the training programme, and after the DET period. Function was assessed with the six
24 minute walk test (6MWT), timed up-and-go (TUG), 30 s chair sit-to-stand (STS), stair-climb test (SCT),
25 40 m fast-paced walk test (FPWT) and sit-and-reach test (SRT), whereas the isometric mid-thigh pull
26 (IMTP) and hand grip test were used to measure muscle strength. Following training, improvements in
27 performance were found in the 6MWT, TUG, 30 s chair STS, SCT, FPWT, SRT, and IMTP ($p < 0.05$),
28 with no significant differences between groups ($p > 0.05$). In addition, the majority of training-induced
29 improvements remained significantly above baseline values after the DET period ($p < 0.05$). No
30 significant between-group differences were observed following training or DET ($p > 0.05$). Four weeks
31 of either SUP or UNSUP resistance training is sufficient to substantially improve muscle strength and
32 function in aging adults, and these gains are largely preserved following prescribed exercise cessation.
33 Home-based resistance training appears to be a practical and effective alternative to traditional SUP
34 programmes that may help circumvent many barriers to physical activity in aging adults.

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

36

37 INTRODUCTION

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

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

59 Perhaps the hallmark of an effective resistance training programme, the principle of specificity asserts
60 that the training stimulus must be specific to the desired adaptation (41). That is, the exercise must
61 replicate the biomechanical movement patterns and underpinning bioenergetics involved in the
62 performance of the primary outcome measurement (27). In order to improve function, training

63 movements should promote the transfer of force through lower-body triple extension to simulate
64 activities of everyday life, such as rising from a chair and climbing the stairs. It is therefore surprising
65 that the majority of training studies in older persons have primarily involved single-joint movements
66 and/or resistance machines (18, 21, 25). Training with elastic bands enables the execution of functional
67 movement patterns through a full range of motion (ROM). Moreover, multi-articular exercises can
68 easily be performed in multiple planes of motion because the direction of the resistance depends on the
69 positioning of the elastic device rather than gravity (32). Importantly, elastic bands and free weights
70 have been shown to exert similar benefits on measures of functional capacity in older adults (17).

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

85 **METHODS**

86 **Experimental Approach to the Problem**

87 This study was a two-arm experimental trial whereby participants were randomly allocated to a SUP or
88 UNSUP group. Both groups completed four weeks of functional resistance training with all variables

89 controlled between conditions apart from the level of supervision. Outcomes measurements of
90 functional and physical performance were administered at baseline (prior to group allocation), at the
91 end of the 4-week intervention, and after a detraining (DET) period of 12 weeks. All participants agreed
92 to maintain their current diet and activity levels during the intervention period. There were no particular
93 instructions or guidance given during the 12-week DET phase.

94 **Subjects**

95 All participants were required to be aged 50 to 65 years, have a body mass index (BMI) of less than 35
96 kg/m², have not engaged in more than 30 min of moderate-vigorous intensity exercise on three or more
97 days of the week for the last three months, and have no resistance training experience in the last 12
98 months. In total, 36 participants completed the resistance training intervention, with 17 in the SUP
99 group and 19 in the UNSUP group (see Figure, Supplemental Digital Content 1). Participants were
100 informed of the experimental procedures to be undertaken prior to signing an institutionally approved
101 informed consent document to participate in the study. Baseline characteristics of study participants are
102 presented in Table 1. The study was approved by the Sport, Health and Exercise Science Ethics
103 Committee at the University of Hull.

104 **[INSERT TABLE 1 ABOUT HERE]**

105 **Procedures**

106 **Resistance training programme**

107 The resistance training programme was designed and delivered by a Certified Strength and
108 Conditioning Specialist (CSCS) and was based on guidelines by the National Strength and Conditioning
109 Association (NSCA) (27). Participants in both groups completed three sessions per week on non-
110 consecutive days for the 4-week intervention period. One set of 8 repetitions was performed in week
111 one, two sets of 8 repetitions in week two, two sets of 10 repetitions in week three, and three sets of 10
112 repetitions in week four. The intensity of exercise was performed at 4 to 6 on the modified 10-point
113 rating of perceived exertion (RPE) scale (13) associated with the target number of repetitions. This

114 corresponded with qualitative descriptions of “somewhat hard” to “hard”. After a dynamic warm-up
115 that included targeted mobility exercises designed to increase the ROM in the ankle, hip and thoracic
116 spine, participants performed 11 resistance exercises using body weight and resistance bands (Iron
117 Woody Fitness, Onley, MT). Each exercise was based on a primary resistance training movement
118 pattern as described in Table 2. Three colour-coded bands were used offering three incremental levels
119 of resistance (Yellow, Purple and Red for light, medium and heavy resistance, respectively). Each
120 session finished with a cool-down of static stretching that included ankle, hip, gluteal, hamstring and
121 pectoral stretches.

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

133 **[INSERT TABLE 2 ABOUT HERE]**

134 **UNSUP training programme**

135 Participants completed the UNSUP training programme individually in their home. After completion
136 of the baseline assessments, participants returned to the laboratory to be familiarised with the exercises
137 to be used in the study and the use of the modified RPE scale. A CSCS checked for correct form in all
138 exercises and adjusted technique if necessary. Participants then received an exercise package that
139 included three colour-coded resistance bands, a heart rate monitor (FT1, Polar Electro, Kempele,

140 Finland), an exercise DVD, a training log, an exercise progression/regression sheet and the modified
141 RPE Scale. An instructional booklet was also included, written in layman language with pictures and
142 diagrams, clearly describing all components of the programme. The CSCS telephoned all participants
143 once per week to answer any questions and to document their RPE rating for each exercise. If
144 participants' RPE for a given exercise fell outside the pre-determined level of intensity (RPE of below
145 4 or above 6), they were prompted to use their exercise progression/regression sheet to modify the
146 exercise accordingly.

147 **SUP training programme**

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

154 **Outcome measurements**

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

162 *Timed up-and-go (TUG)*: Participants sat in a firm, armless chair (height, 40 cm; depth, 39 cm) and
163 were instructed to stand up, walk three meters before turning 180° and returning to the chair to sit down.
164 Participants were instructed to perform the test as quickly as possible but in a controlled manner, with
165 time recorded in seconds during one trial. TUG is a basic measure of functional mobility (7) and has

166 demonstrated high test-retest reliability in our laboratory (ICC = 0.97; SEM = 0.22 s; MDC_{95%} = 0.62
167 s) (40).

168 *30 s chair sit-to-stand (STS)*: The 30 s chair STS is a reliable measure of lower extremity function and
169 strength in older adults (ICC = 0.89) (33). The test was administered using the same chair as the TUG,
170 which was supported against a wall. Participants began seated and were subsequently instructed to rise
171 to a full standing position (legs straight) and then return to the seat (full weight on chair) with both arms
172 crossed against the chest. A practice trial of two repetitions was given to check correct form, followed
173 by one test trial. The total number of stands performed correctly in 30 s was recorded for analysis.

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

179 *40 m fast paced walk test (FPWT)*: Participants walked as quickly as possible along a 20 m flat surface,
180 turned 180° around a cone, then walked 20 m back to the start line. The test finished when the participant
181 had walked 40 m to cross back over the start line, with time recorded in seconds during one trial. The
182 40 m FPWT has previously demonstrated excellent reliability (ICC = 0.95, SEM = 1.0 m/s) (51).

183 *Hand grip test*: Using their dominant hand, participants squeezed the analogue dynamometer (TKK
184 5001 Grip-A, Tokyo, Japan) as hard as possible for 2-3 s. An upright biped position was maintained
185 throughout the test with the arm in full extension. The grip position of the dynamometer was adjusted
186 to each individual's hand size. The best score of two trials was recorded to the nearest 0.5 kg and used
187 for analysis. The TKK dynamometer has recently recorded high reliability and criterion-related validity
188 (12).

189 *Isometric mid-thigh pull (IMTP)*: Using an analogue back dynamometer (TKK 5002 Back-A, Tokyo,
190 Japan), participants maximally extended their knees and trunk for five seconds without bending their
191 back. The height of the handle was individually adjusted so that the bar rested midway up the thigh and

192 there was 145° of knee flexion (22). Two trials were performed with a two minute rest period in
193 between. Each trial was recorded to the nearest 1 kg, with the mean value used for analysis. This test
194 has previously demonstrated good to acceptable reliability (ICC = 0.81-0.85) (26).

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

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

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

207 **Sample size estimation**

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

216 **Statistical analyses**

217 All analyses were performed by intention to treat using SPSS for Windows (IBM SPSS, version 22.0,
218 Chicago, IL). Shapiro-Wilk and Levene's tests were used to verify normality of data and homogeneity
219 of variance, respectively, and all assumptions were met. To compare baseline characteristics between
220 groups, an independent samples *t*-test was conducted for continuous variables, whereas the Mann-
221 Whitney U test was used for ordinal data (gender). A 2 x 3 mixed-model ANOVA with repeated
222 measures for group (between) and time (within) was used to examine the effects of the intervention on
223 each outcome measurement. The alpha level indicating statistical significance for this test was set at *p*
224 < 0.05. The data were then further explored with pair-wise comparisons using a Bonferroni-adjusted
225 alpha level. The assumption of sphericity was assessed with Mauchly's test, and in the case of
226 significant violations, the Greenhouse-Geisser epsilon correction was applied. The level for all
227 confidence intervals (CI) was 95%.

228 **RESULTS**

229 **Exercise responses**

230 Exercise compliance was 94.6% in the SUP group and 98.7% in the UNSUP group, with no significant
231 difference between conditions ($4.1 \pm 2.1\%$, $p = 0.066$, 95% CI: -8.4 to 0.3%). Session duration was 27.6
232 ± 2.9 min in the SUP group and 23.1 ± 3.4 min in the UNSUP group, with this difference reaching
233 statistical significance (5 ± 1 min, $p < 0.05$, 95% CI: 2 to 7 min). There was a significant interaction
234 between group and time on average heart rate ($p < 0.05$). Specifically, average heart rate was 14 ± 3
235 beats per minute (bpm) higher in the SUP group compared with the UNSUP group ($p < 0.05$, 95% CI:
236 7 to 22 bpm) (Figure 1). For maximum heart rate, there was no significant group by time interaction (p
237 = 0.770). However, there were significant main effects of time ($p < 0.05$) and group ($p < 0.05$), showing
238 that peak heart rate was 23 ± 4 bpm ($p < 0.05$; 95% CI: 14 to 33 bpm) higher in the SUP group compared
239 with the UNSUP group.

240 **[INSERT FIGURE 1 ABOUT HERE]**

241 **Physical performance outcomes**

242 There were no significant main effects of group nor any significant interaction effects between group
243 and time for any physical performance outcome ($p > 0.05$; Table 3). However, the main effect of time
244 showed a statistically significant difference in all variables at the different time points ($p < 0.05$). With
245 the exception of hand grip strength, Bonferroni-corrected pairwise comparisons revealed significant
246 training-induced improvements in all performance tasks ($p < 0.05$; Table 3). DET resulted in significant
247 reductions in 30 s chair STS, SCT, and IMTP performance in both the SUP and UNSUP conditions (p
248 < 0.05 ; Table 3). TUG and SRT performance also significantly decreased in the UNSUP group but not
249 in the SUP group following DET, although these reductions were not significantly different between
250 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
251 to 3.19 cm). Despite these performance decrements, the 6MWT, TUG, 30 s chair STS, SCT, FPWT,
252 and IMTP remained significantly above baseline in both groups following DET ($p < 0.05$). No
253 significant between-group differences emerged between conditions following training or DET ($p >$
254 0.05) (Table 4).

255 [INSERT TABLE 3 ABOUT HERE]

256 [INSERT TABLE 4 ABOUT HERE]

257 DISCUSSION

258 This study examined the short-term training and detraining effects of SUP versus UNSUP resistance
259 training on muscle strength and function in adults aged 53.6 ± 3.6 years. Our data demonstrate a
260 comparative increase in functional ability and muscle strength following both training interventions.
261 These improvements were attained using low-cost elastic bands and a small weekly time commitment
262 (83 and 69 min in SUP and UNSUP, respectively). In addition, the majority of training-induced
263 adaptations remained above baseline values following the period of DET.

264 The training programme resulted in a significant increase in functional performance and IMPT strength,
265 independent of the level of supervision. The magnitude of change, considered in relation to the error of
266 measurement, suggests that the training-induced improvements are likely to be meaningful for aging
267 adults. For example, the improved TUG performance observed in both groups (-0.84 and -0.93 s in SUP

268 and UNSUP, respectively) exceeds the SEM (0.22 s) and $MDC_{95\%}$ (0.62 s) previously recorded in our
269 laboratory (40). This improvement in functional performance is also greater than the magnitude reported
270 in a previous meta-analysis of resistance training in older adults (-0.69 s, 95% CI: -1.11 to -0.27 s) (38)
271 and is larger than the change observed in a number of recent studies in this area (16, 47). This difference
272 may be attributed to the average age of participants. In this study, subjects had a mean age of 53.6 ± 3.6
273 years, whereas the mean age of trials included in the meta-analytic review (38) ranged from 65.8 ± 7.6
274 to 84.9 ± 4.8 years. Alternatively, the difference in magnitude may be related to the specificity of the
275 exercise stimulus. The majority of resistance training studies in older adults involve single-joint
276 exercises and/or the use of resistance machines, which limits the training movement to a fixed pattern
277 in a single plane of motion. While this regimen is effective at enhancing maximal muscular strength, it
278 appears to elicit a more modest effect on functional performance (39, 43). Our training intervention
279 involved resistance training exercises that mimic the biomechanical movement patterns of everyday life
280 activities, such as rising from a chair (e.g. squat), climbing the stairs (e.g. split squat) and twisting to
281 pick an item up off the floor (e.g. core rotation).

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

291 It is important that resistance training evokes changes that are clinically meaningful for the intended
292 population. Changes in laboratory-based measurements following a resistance training intervention are
293 designed to reflect changes in clinically meaningful endpoints (28). Because laboratory measurements
294 are not clinically meaningful endpoints, they must be correlated with those that are in order to be

295 considered valid (28). For example, performance in the SCT is associated with self-reported functional
296 abilities in older adults (5) and the test involves the same movement patterns as climbing the stairs in a
297 real-life setting. Though correlations cannot establish cause and effect, it is likely that the ~13%
298 improvement in SCT performance would have a direct influence on an aging person's ability to climb
299 a flight of stairs in day-to-day life. This magnitude of change is also consistent with other resistance
300 training studies (~9 to 14%) (29, 30, 35) and exceeds the $MDC_{95\%}$ recorded previously (7.7%) (40),
301 confirming that the change was not due to measurement error or variation within individual
302 performance. Further work is warranted to delineate a causal relationship between improvements in
303 laboratory-based measurements and changes in day-to-day function.

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

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

338 The present study is the first to demonstrate greater elevations in heart rate when untrained aging adults
339 receive supervision during a resistance training intervention. Weekly telephone calls to the UNSUP
340 group revealed lower mean stages of exercise progression compared with the SUP group, which implies
341 that the greater heart rates may have been related to the completion of more advanced exercises. Direct
342 supervision may have also fostered a higher quality in the execution of exercises due to continual
343 technical feedback. Alternatively, the greater heart rates may be related to psychological factors such
344 as competitiveness (i.e. presence of an audience) or external motivation (i.e. real-time encouragement).
345 Interestingly, the average heart rate elicited in the SUP group (117 ± 8 bpm) was equivalent to $\sim 70\%$
346 of age-predicted HR_{max} ($220 - \text{age}$), which meets the American College of Sports Medicine (ACSM)
347 guidelines for moderate-intensity aerobic exercise (24). The capacity of resistance training to contribute
348 to the aerobic component of International physical activity guidelines has been reported recently (9)

349 and suggests that this resistance training, when programmed appropriately, can provide stimuli for both
350 cardiovascular and musculoskeletal adaptation. In light of an increasingly sedentary population,
351 promoting resistance training as a single method to achieve discernible health benefits should be
352 considered. Future research should evaluate whether the higher heart rates elicited in the SUP versus
353 UNSUP group translate into greater improvements in cardiovascular fitness.

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

373 A limitation of this study is that the investigator was not blinded to group allocation, although all
374 participants received the same instructions and strictly adhered to a predetermined testing protocol.
375 Additionally, training intensity was controlled indirectly by selecting a target number of repetitions

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

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

397 **PRACTICAL APPLICATIONS**

398 A functional resistance training programme may be implemented into clinical practise in order to
399 mitigate age-related declines in muscle strength and function. Owing to the comparative effectiveness
400 of SUP and UNSUP groups, our data also suggest that practitioners may prescribe home-based
401 resistance training as a cost-effective and practical alternative to SUP programmes that may help

402 circumvent many barriers to physical activity in the aging population, such as lack of time, money, and
403 transportation. This finding, however, requires replication in interventions lasting several months rather
404 than weeks. The adaptations to a resistance training programme are well maintained beyond the
405 cessation of training, although lifelong participation in resistance training should be encouraged in order
406 to attenuate the inevitable decline in functional capacity during later adulthood. Taken together, these
407 findings suggest that aging adults should choose a preferable environment for exercise (i.e. UNSUP at
408 home or SUP in a facility) that will foster consistent adherence to resistance training in the longer-term.

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545

ACCEPTED

546 **Figure and Table Captions**

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

551 **Table 1.** Baseline characteristics of study participants.

552 **Table 2.** Primary resistance training movement patterns.

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

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

555

556 **Table 1.** Baseline characteristics of study participants

	Total (n = 36)	SUP (n = 17)	UNSUP (n = 19)	<i>p</i> -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.

558 **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.

^abody weight exercise; ^bresistance band exercise; w/ = with.

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

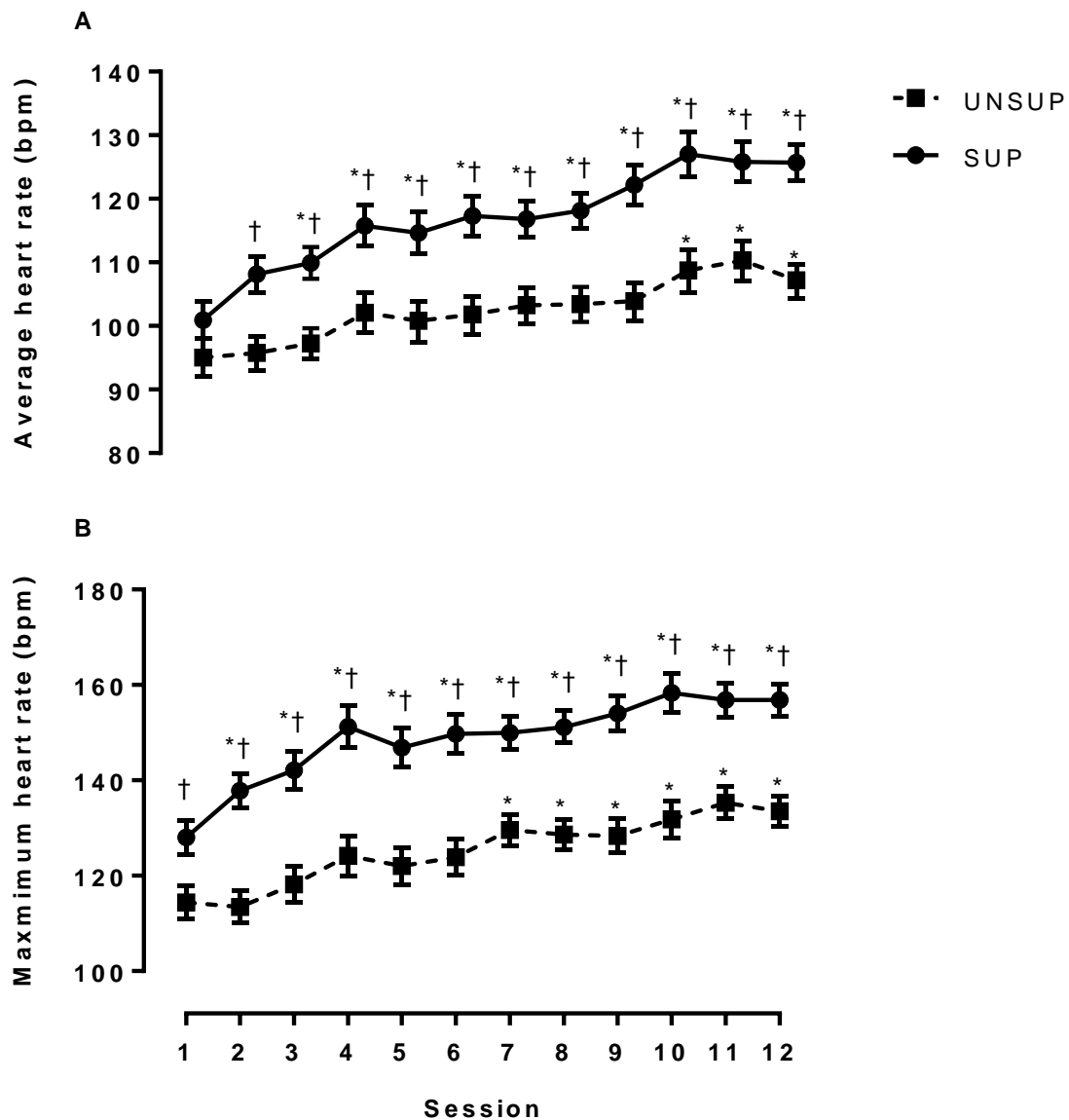
Outcome	PRE-POST	PRE-DET	POST-DET	Time x group interaction <i>p</i> -value
6MWT (m)				
SUP	48.6 (28.4 to 68.8)*	30.6 (6.2 to 55.0)*	-18.0 (-38.3 to 2.2)	0.849
UNSUP	42.7 (17.8 to 67.7)*	24.7 (1.6 to 47.8)*	-18.1 (-37.8 to 1.7)	
TUG (s)				
SUP	-0.84 (-1.16 to -0.53)*	-0.61 (-0.88 to -0.34)*	0.23 (-0.16 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).

560 **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).



562 **Supplemental Digital Content 1.** Participant flowchart