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1 **The short-term training and detraining effects of supervised versus**

2 **unsupervised resistance exercise in aging adults**

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

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

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/m^2, 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%.

RESULTS

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]**

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 ~70%

346   of age-predicted HR_{max} (220-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 DETs 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

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 ± 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)	*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.

557

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.

[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).

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).

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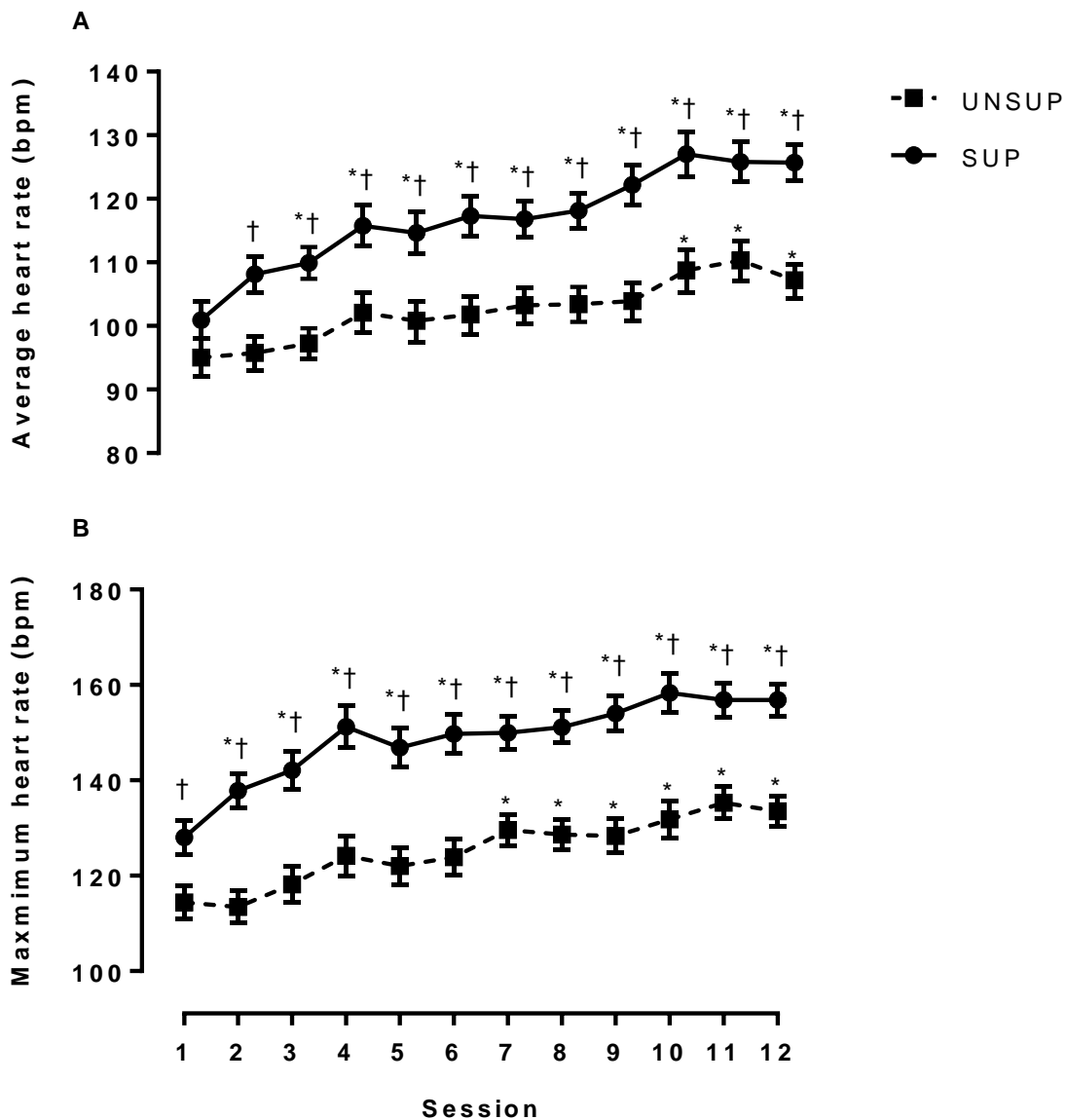
562   **Supplemental Digital Content 1**. Participant flowchart