

1 **TITLE:** The effects of 6 months of progressive high effort resistance training methods upon  
2 strength, body composition, function, and wellbeing of elderly adults

3

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23 **CONFLICT OF INTEREST STATEMENT:**

24 The authors declare that there are no conflicts of interest regarding the publication of this  
25 paper.

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1 **Abstract**

2 *Purpose:* The present study examined the progressive implementation of a high effort  
3 resistance training (RT) approach in older adults over 6 months and through a 6 month follow-  
4 up on strength, body composition, function and wellbeing of older adults.

5 *Methods:* Twenty three older adults (aged 61 to 80 years) completed a 6 month supervised  
6 RT intervention applying progressive introduction of higher effort set end points. After  
7 completion of the intervention participants could choose to continue performing RT  
8 unsupervised until 6 months follow-up.

9 *Results:* Strength, body composition, function, and wellbeing all significantly improved over  
10 the intervention. Over the follow-up, body composition changes reverted to baseline values,  
11 strength was reduced though remained significantly higher than baseline, and wellbeing  
12 outcomes were mostly maintained. Comparisons over the follow-up between those who did,  
13 and those who did not, continue with RT revealed no significant differences for changes in any  
14 outcome measure.

15 *Conclusions:* Supervised RT employing progressive application of high effort set end points is  
16 well tolerated and effective in improving strength, body composition, function and wellbeing in  
17 older adults. However, whether participants continued, or did not, with RT unsupervised at  
18 follow-up had no effect on outcomes perhaps due to reduced effort employed during  
19 unsupervised RT.

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1 **Introduction**

2 The age associated decline in physical function and condition is widely evidenced. For  
3 example, bone mineral density, muscle mass, strength, and cardiorespiratory fitness all  
4 decline with increasing age and affect health and wellbeing [1-6]. The World Health  
5 Organisation physical activity guidelines for older adults including a range of approaches  
6 designed to attenuate this age-related decline [7]. In particular, due to the loss of muscle mass  
7 and strength, inclusion of whole body ‘muscle strengthening activities’ (e.g. resistance training;  
8 RT) is encouraged 2 x / week.

9

10 Participation in RT is associated with reduced morbidity and mortality risk in the elderly [8, 9].  
11 Hurley and Roth [10] noted that “*~2 decades of age-associated strength loss can be regained*  
12 *in ~2 months of resistance exercise*” and RT can even enhance cardiorespiratory fitness in  
13 older adults [11, 12]. Higher levels of strength and cardiorespiratory fitness are also associated  
14 with greater cognitive function [13,14] as well as functional ability, improved walking speed,  
15 and a reduced risk of falling [15-19]. The outcomes of RT, such as increased muscle mass  
16 [20, 21], strength [22-26], and cardiorespiratory fitness [27, 28] may even contribute towards  
17 reduced mortality risk in the elderly. Further, though there is inter-individual variability in  
18 responsiveness in older adults [29], all seem to benefit in some way from RT [30].

19

20 In consideration of the benefits of RT in older adults, studies have examined the manipulation  
21 of RT variables (length of training intervention, load, repetition range, repetition duration, rest  
22 periods, training frequency, set volume) for optimal benefits [31]. Indeed, recent meta-  
23 analyses have attempted to characterise the literature in this regard [32, 33]. These generally  
24 highlight that a range of RT approaches seem similarly effective for older adults reporting large  
25 effect sizes (ES). However, one variable often not considered is the role of effort, and as such  
26 the set end points used during RT; a variable that in younger adults has been suggested to  
27 potentially impact upon adaptation [34, 35].

28

1 Clear definitions of set end points in RT, representing a progression of intensity of effort, have  
2 recently been suggested including: non-repetition maximum (nRM), self-determined repetition  
3 maximum (sdRM), momentary failure (MF), and momentary failure plus advanced techniques  
4 (MF+) [36]. In these the nRM represents completion of an arbitrary pre-determined number of  
5 repetitions despite a person being able to perform more, the sdRM represents the point where  
6 a person determines they could not complete the next repetition if it were attempted (i.e. they  
7 predict MF on the next repetition), MF represents the point where a person cannot complete  
8 the current repetition in the prescribed form despite attempting to do so, and MF+ is where  
9 after reaching MF a person continues using an advanced RT technique such as forced  
10 repetitions, or drop sets. Within these definitions MF represents the point of maximal effort as  
11 it is the point where, despite the greatest effort, a person is unable to meet and overcome the  
12 demands of the exercise.

13

14 Intensity of effort may be important in determining the efficacy of RT in older adults. Where  
15 nRM has previously been used as set end point (a target repetition number in combination  
16 with a submaximal rating of perceived exertion [RPE] using the OMNI-RES Scale) there were  
17 no significant improvements in any outcome measures compared to a non-training control  
18 group over 8 weeks of supervised elastic band based RT [37]. One recent study has employed  
19 the use of sdRM as a set end point in a supervised low volume (single set) and low frequency  
20 (twice a week) RT intervention [38] reporting significant increases in strength outcomes with  
21 large within participant ESs (1.59 to 3.31). Though not representing a maximal effort, the  
22 application of sdRM in older adults does induce a relatively high perceived effort [39].  
23 Considering that in younger adults there may be additional benefit of training to maximal effort  
24 (i.e. MF) it is of interest to examine higher effort approaches in older adults.

25

26 High effort RT interventions performed to MF in older adults are uncommon but have been  
27 employed previously examining the role of load [40]. Adaptations to heavier- or lighter-loads  
28 seem similar when repetitions are performed to MF in older adults [40] similarly to findings in

1 both adolescent [41] and young adult populations [42]. However, though supervised high effort  
2 RT is effective, Van Roie et al. [43] have reported that long term adherence after the initial  
3 supervised intervention, whether using heavier- or lighter-loads, is poor. Further, the training  
4 effort of participants may drop considerably over this period. Indeed participants were  
5 performing a lower number of repetitions with training loads lighter than during the initial 12  
6 week intervention [43]. However, measures of fitness or function were not made at follow-up.  
7 Though a relatively low dose of RT is needed to maintain strength and muscle mass after an  
8 initial 12 week RT intervention for older adults [44], it is possible that the reduced effort  
9 employed might mean that initial efforts are potentially wasted as adaptations may not be  
10 maintained.

11

12 It may be that a longer initial supervised RT intervention combined with the use of progressive  
13 introduction to high effort set end points could result in greater long term adherence and  
14 maintenance of initial adaptations. High effort RT can cause discomfort [39; 45] which could  
15 generate negative affect. Introduction to RT initially at lower efforts might permit expectations  
16 of positive outcome affect reinforcing behaviour and allowing gradual introduction to higher  
17 effort RT [46]. However, to the authors' knowledge no study has examined the application of  
18 RT in older adults using clearly defined set end points inducing progressively higher efforts.  
19 As such, the aim of the present study was to examine the progressive implementation of a  
20 high effort RT approach [47, 48] in older adults over 6 months and through a 6 month follow-  
21 up on strength, body composition, function and wellbeing of older adults.

22

## 23 **Materials & Methods**

### 24 **Study Design**

25 A single arm prospective trial was conducted examining the effects of a 25 week supervised  
26 RT intervention progressive implementation of high effort set end points in older adults. Upon  
27 completion of the 6 month intervention participants self-selected as to whether they continued  
28 participating in RT unsupervised or not. Participants were followed up 6 months post

1 intervention. The study design was ethically approved by the author's institution. All  
2 procedures were performed in accordance with the ethical standards of the Helsinki  
3 Declaration. Written informed consent was obtained from all participants.

4

#### 5 Participants

6 Power analysis of effect sizes from recent meta-analysis of RT research with untrained older  
7 participants [33] was conducted to determine participant numbers (n) using ESs of 1.57 for  
8 improvements in strength. Participant numbers were calculated using G\*Power [49, 50].  
9 These calculations suggested only ~3 participants were required to meet the required power  
10 of 0.8 at an alpha value of  $p \leq 0.05$  for the statistical analyses proposed (see below). However,  
11 though this might be the minimum participant requirement for the studies primary outcome  
12 (strength) attempts were made to recruit a greater number of participants considering  
13 estimated attrition rates of potentially ~50%. A total of 28 participants were initially recruited  
14 (females  $n = 14$ , males  $n = 14$ ; age  $69.1 \pm 4.9$  years, range 61 to 80 years). Participants were  
15 required to be at least 60 years of age, present with a medical certificate verifying their  
16 otherwise good health, had not previously engaged in RT, and to not have any contraindication  
17 to participation in RT. Participants were excluded if they had a pacemaker (due to the use of  
18 bioelectrical impedance analysis), failed to attend  $\geq 4$  training sessions, or did not meet the  
19 above criteria. Twenty three participants completed the study with 5 drop-outs (females  $n = 4$ ,  
20 males  $n = 1$ ) for unrelated health reasons. At follow up 13 participants had continued engaging  
21 in the RT intervention unsupervised (females  $n = 5$ , males  $n = 8$ ).

22

#### 23 Materials & Equipment

24 Strength measurements and training were performed using leg press, chest press, seated  
25 row, knee extension, knee flexion, trunk extension, and trunk flexion resistance machines  
26 (Ergo-Fit, Germany). Body composition including body mass, whole body muscle and fat mass  
27 and percentage was estimated using bioelectrical impedance (Tanita MC 180, Tanita Europe  
28 B.V., Amsterdam). This device is reported as valid compared with dual energy X-ray

1 absorptiometry for estimating body composition in healthy adults [51]. Physical function in  
2 tasks of daily living was measured as isometric grip strength performed using a digital handgrip  
3 dynamometer (Trailite, Germany), a stair climb task involving 6 flights of 17 steps (102 steps  
4 in total) each at 17 cm height, a carrying task using a shopping basket weighing either 5 kg  
5 for females or 10 kg for males which was lifted from the ground, carried around a 25 m course  
6 involving various turns of both 90° and 180° (figure 1), and then placed on the ground again  
7 at the end, and a chair rise task using a chair at 45 cm height. Heart rate was measured using  
8 an A300 Polar Monitor (Polar, Finland) during performance of the stair climb task, and rating  
9 of perceived exertion (RPE) using Borg's CR-10 scale taken during both the stair climb task  
10 and carrying task. Questionnaires were also used to examine perceived function and  
11 wellbeing. The WHO-5 Wellbeing Index was completed in addition to a questionnaire asking  
12 participants to rate their overall present state of health, comparison with other older adults of  
13 their age, present sporting condition, and ease with which they can perform household chores,  
14 stair climbing, shopping, gardening, and transport. For these participants were asked to  
15 provide ratings using a 5 point likert scale ranging from 1 ("Very bad") to 5 ("Very well") for  
16 state of health, comparison with other older adults, and spotting condition, and 0 ("This is very  
17 difficult for me") to 5 ("I can manage this easily") for ease with which they can perform  
18 household chores, stair climbing, shopping, gardening, and transport.

19

## 20 Testing

21 Testing was conducted pre- and post-intervention, and at 6 months follow up for all outcomes  
22 with the exception of physical function tests which were conducted pre- and post-intervention  
23 only. Muscular strength testing was performed in the following order with 2-3 minutes rest  
24 between exercises; leg press, chest press, and seated row. Participants performed a ~5RM  
25 test following National Strength and Conditioning Association guidelines for RM testing [52].  
26 From this, predicted 1RM was calculated using the Bryzcki [53] formula. Body composition  
27 was measured on a separate day from muscular performance testing both before and after  
28 the intervention following the manufacturer's guidelines. Testing for the stair climb task,

1 carrying task, and chair rise task was performed using a stopwatch. For each the participants  
2 were instructed to begin on the command “Go” and to complete the task as quickly as possible.  
3 For the stair climb task this involved climbing the 102 steps, for the carrying task this involved  
4 picking up the shopping basket, completing the 25 m course, and then placing the shopping  
5 basket on the ground at the end of the course, and for the chair rise task this involved the  
6 participants beginning seated on the chair with their arms folded across their chest and then  
7 standing from the chair until their legs were straight five times. Isometric grip strength was  
8 taken as the average of two maximal voluntary isometric efforts. Participants positioned their  
9 arms adducted at their sides with elbows at 90° as recommended by the American Society of  
10 Hand Therapists [54]. Participants were instructed to squeeze the handle of the dynamometer  
11 progressively harder culminating in a maximal voluntary effort after 3 seconds and lasting for  
12 a further 2 seconds.

13

#### 14 Training

15 During the intervention period training was supervised and conducted 2x/week (at least 48  
16 hours between sessions) for 6 months (25 weeks). Participants all performed a general warm-  
17 up using either treadmill, cross-trainer, upright cycle ergometer, or recumbent cycle ergometer  
18 depending on preference for 10 minutes followed by a single set of moderate load leg press,  
19 chest press, and seated row for 15 repetitions prior to each training session. In each training  
20 session participants performed leg press, chest press, seated row, knee extension, knee  
21 flexion, trunk extension, and trunk flexion. Order of exercises was not fixed and dependent  
22 upon preference and availability of equipment in the gym where training was conducted. Rest  
23 between exercises lasted for 2-4 minutes. Participants were instructed to perform the  
24 exercises using relatively long repetition duration of at least 2 seconds concentric, 1 second  
25 pause at the top of the range of motion, and 2 seconds eccentric, and to not exceed 4 seconds  
26 concentric, 1 second pause at the top of the range of motion, and 4 seconds eccentric. The  
27 first 2 weeks of the intervention was a familiarisation phase whereby participants trained using  
28 a single set of each exercise using a moderate load and performing 15-18 repetitions i.e. nRM.



1 After this period participants progressed for a further 2 weeks to perform each exercise to a  
2 set end of point of sdRM defined as cessation at the point where participants predicted they  
3 would reach momentary failure if the next repetition was attempted [36]. After this period  
4 participants progressed to perform each exercise to a set end point of MF and continued  
5 training in this manner until week 18. For the final 6 weeks of the intervention participants  
6 progressed to perform each exercise to set end point of MF followed by a drop set whereby  
7 the load was reduced by ~5 kg and an additional set continued to the point of MF was  
8 performed immediately upon completion of the first. Load was progressed for each group by  
9 2-10% in the next session if participants could achieve greater than 12 repetitions before  
10 reaching the defined set end point for their current period of training (in the case of the final 6  
11 weeks this applied to the first set performed to momentary failure). After the 25-week  
12 intervention participants wishing to continue performing resistance training unsupervised  
13 where given access to the training facility and allowed to train without direct supervision.

14

### 15 Data Analysis

16 Independent variables for analyses in the present study were time (pre-, post-intervention, and  
17 follow-up), and also whether participants did, or did not, continue with unsupervised resistance  
18 training during the follow-up period. Dependent variables were strength, body composition,  
19 physical function, and perceived wellbeing and function. Assumptions of normality were  
20 examined using a Shapiro-Wilk test and assumptions of equality of variance examined using  
21 Mauchly's test for sphericity. Strength and body composition data met assumptions of  
22 normality of distribution and equality of variance so repeated measures analysis of variance  
23 (ANOVA) was used to examine effects by time (pre-, post-intervention, and follow-up). Post  
24 hoc pairwise comparisons using a Bonferonni adjustment were conducted comparing pre- to  
25 post-intervention (encompassing the intervention period), post-intervention to follow-up  
26 (encompassing the follow-up period), and pre-intervention to follow-up (encompassing the  
27 whole study). Physical function data met assumptions of normality of distribution and so paired  
28 samples *t*-tests were used to examine effects by time (pre- to post-intervention). Questionnaire

1 data did not meet assumptions of normality of distribution and so a non-parametric Friedman  
2 tests was used to examine effects by time (pre-, post-intervention, and follow-up). Post hoc  
3 pairwise comparisons using Wilcoxon signed ranks tests were conducted comparing pre- to  
4 post-intervention (encompassing the intervention period), post-intervention to follow-up  
5 (encompassing the follow-up period), and pre-intervention to follow-up (encompassing the  
6 whole study). Between groups comparisons were made for absolute changes in strength, body  
7 composition, and questionnaire data using independent samples *t*-tests and Mann Whitney-U  
8 tests (follow-up minus post-intervention) for the follow-up period comparing those who either  
9 did, or did not, continue with unsupervised RT. Further, 95% confidence intervals (CI) and  
10 within participant ESs ( $d = \mu_{\text{change}} / \sigma_{\text{change}}$ ; small = 0.20-0.49, moderate = 0.50-0.79, and large  
11 =  $\geq 0.80$ ) were calculated for changes in strength, body composition, and physical function  
12 across the intervention (post- minus pre-intervention) period. Statistical analysis was  
13 performed using SPSS statistics computer package (vs.23; IBM, Portsmouth, UK) and  $p \leq 0.05$   
14 set as the limit for statistical significance.

15

## 16 **Results**

### 17 **Strength**

18 Descriptive data for all strength outcomes and all time points, and 95% CIs and ESs for  
19 changes are reported in Table 1. Figure 2 also shows individual responses at each time point  
20 for strength measures. Repeated measures ANOVA revealed significant effects by time for  
21 leg press 1RM ( $F_{(2,26)} = 88.876, p < 0.001$ ), chest press 1RM ( $F_{(2,26)} = 63.577, p < 0.001$ ), and  
22 seated row 1RM ( $F_{(2,26)} = 88.876, p < 0.001$ ). Post hoc pairwise comparisons revealed  
23 significant differences between pre- and both post-intervention and follow-up time points for  
24 leg press 1RM ( $p < 0.001$ ), chest press 1RM ( $p < 0.001$ ), and seated row 1RM ( $p < 0.001$ ).  
25 Significant differences between post-intervention and follow-up time points were also found  
26 for leg press 1RM ( $p < 0.001$ ) and chest press 1RM ( $p = 0.017$ ).

27

1 Independent samples  $t$ -tests for changes over the follow-up period revealed no significant  
2 differences between those who chose to continue with unsupervised training compared with  
3 those who did not for change in leg press 1RM ( $t_{(21)} = -1.150$ ,  $p = 0.263$ ; -98.38 kg vs -154.74  
4 kg respectively), change in chest press 1RM ( $t_{(21)} = -0.522$ ,  $p = 0.607$ ; 30.48 kg vs -38.99 kg  
5 respectively), or change in seated row 1RM ( $t_{(21)} = -1.412$ ,  $p = 0.173$ ; -22.81 kg vs -46.64 kg  
6 respectively).

7

### 8 Body Composition

9 Descriptive data for all body composition outcomes and all time points, and 95% CIs and ESs  
10 for changes are reported in Table 1. Figure 3 shows individual responses at each time point  
11 for body composition measures. Repeated measures ANOVA revealed significant effects by  
12 time for BMI ( $F_{(2,26)} = 3.654$ ,  $p = 0.040$ ), fat mass ( $F_{(2,26)} = 9.752$ ,  $p = 0.001$ ), fat percentage  
13 ( $F_{(2,26)} = 10.120$ ,  $p = 0.001$ ), and muscle percentage ( $F_{(2,26)} = 10.543$ ,  $p < 0.001$ ), but not body  
14 mass ( $F_{(2,26)} = 3.175$ ,  $p = 0.058$ ), or muscle mass ( $F_{(2,26)} = 3.940$ ,  $p = 0.086$ ). Post hoc pairwise  
15 comparisons revealed significant differences between pre- and post-intervention for fat mass  
16 ( $p = 0.003$ ), fat percentage ( $p = 0.004$ ), and muscle percent ( $p = 0.007$ ). Significant differences  
17 between post-intervention and follow-up time points were also found for fat mass ( $p = 0.005$ ),  
18 fat percentage ( $p = 0.006$ ), and muscle percent ( $p = 0.004$ ).

19

20 Independent samples  $t$ -tests for changes over the follow-up period revealed no significant  
21 differences between those who chose to continue with unsupervised training compared with  
22 those who did not for change in body mass ( $t_{(21)} = 0.791$ ,  $p = 0.438$ ; 0.65 kg vs 1.22 kg  
23 respectively), change in BMI ( $t_{(21)} = 1.458$ ,  $p = 0.160$ ; 0.09 kg.m<sup>2</sup> vs 0.45 kg.m<sup>2</sup> respectively),  
24 change in fat mass ( $t_{(21)} = -0.931$ ,  $p = 0.363$ ; 2.13 kg vs 1.47 kg respectively), change in fat  
25 percentage ( $t_{(21)} = -0.671$ ,  $p = 0.510$ ; 2.04% vs 1.54% respectively), change in muscle mass  
26 ( $t_{(21)} = 1.161$ ,  $p = 0.259$ ; -1.02 kg vs -0.24 kg respectively), and change in muscle percentage  
27 ( $t_{(21)} = 0.786$ ,  $p = 0.440$ ; -2.03% vs -1.45% respectively).

28

1 Function

2 Descriptive data for all function outcomes and all time points, and 95% CIs and ESs for  
3 changes are reported in Table 2. Figure 4, 5, 6 and 7 show individual responses at each time  
4 point for function measures. Paired samples *t*-tests revealed significant differences from pre-  
5 to post-intervention for resting heart rate ( $t_{(21)} = 3.096, p = 0.005$ ), stair climb time ( $t_{(21)} = 2.858,$   
6  $p = 0.009$ ), stair climb rating RPE ( $t_{(21)} = 3.257, p = 0.004$ ), carrying task time ( $t_{(22)} = 10.350, p$   
7  $< 0.001$ ), carrying task RPE ( $t_{(22)} = 4.858, p < 0.001$ ), chair rise time ( $t_{(22)} = 5.249, p < 0.001$ ),  
8 and left hand grip strength ( $t_{(21)} = -4.006, p = 0.001$ ) but not right hand grip strength ( $t_{(21)} = -$   
9  $1.431, p = 0.167$ ).

10

11 Questionnaires

12 Descriptive data for all questionnaire outcomes and all time points, and Friedman and  
13 Wilcoxon test *p* values are reported in Table 1. Friedman tests revealed significant effects by  
14 time for state of health, comparison with other seniors, WHO-1, WHO-2, WHO-3, WHO-4,  
15 WHO-5, and perceived ability to accomplish household chores, stair climbing, shopping,  
16 gardening, transport, but not present sporting condition. Post hoc Wilcoxon signed ranks tests  
17 revealed significant differences between pre- and both post-intervention and follow-up time  
18 points for state of health, comparison with other seniors, WHO-1, WHO-2, WHO-3, WHO-4,  
19 WHO-5, and perceived ability to accomplish household chores, stair climbing, shopping,  
20 gardening, and transport, and only pre- and post-intervention for perceived ability to  
21 accomplish sports. Significant differences between post-intervention and follow-up time points  
22 were also found for WHO-1, WHO-2, WHO-3, WHO-4, and perceived ability to accomplish  
23 sports, gardening, and transport.

24

25 Mann Whitney-U test revealed no significant differences between those who chose to continue  
26 with unsupervised training compared with those who did not for change in perceived state of  
27 health ( $U = 53.000, p = 0.435; 0.00 \pm 1.50$  pts vs  $0.00 \pm 1.25$  pts respectively), comparison with  
28 other seniors ( $U = 57.000, p = 0.648; 0.00 \pm 0.50$  pts vs  $0.00 \pm 1.50$  pts respectively), WHO-1 ( $U$

1 = 63.500,  $p = 0.927$ ;  $0.00 \pm 1.00$  pts vs  $0.00 \pm 1.25$  pts respectively), WHO-2 ( $U = 61.000$ ,  $p =$   
2  $0.832$ ;  $0.00 \pm 1.00$  pts vs  $-0.50 \pm 1.25$  pts respectively), WHO-3 ( $U = 60.500$ ,  $p = 0.784$ ; -  
3  $1.00 \pm 2.00$  pts vs  $-0.50 \pm 2.00$  pts respectively), WHO-4 ( $U = 63.000$ ,  $p = 0.927$ ;  $0.00 \pm 1.00$  pts  
4 vs  $-0.50 \pm 1.25$  pts respectively), WHO-5 ( $U = 50.000$ ,  $p = 0.376$ ;  $-0.00 \pm 1.50$  pts vs  $-1.00 \pm 1.00$   
5 pts respectively), and perceived ability to accomplish household chores ( $U = 57.000$ ,  $p =$   
6  $0.648$ ;  $0.00 \pm 1.00$  pts vs  $-0.50 \pm 1.00$  pts respectively), stair climbing ( $U = 63.000$ ,  $p = 0.927$ ;  
7  $0.00 \pm 1.50$  pts vs  $0.50 \pm 0.75$  pts respectively), shopping ( $U = 61.000$ ,  $p = 0.832$ ;  $0.00 \pm 1.00$  pts  
8 vs  $0.00 \pm 1.25$  pts respectively), gardening ( $U = 49.000$ ,  $p = 0.343$ ), transport ( $U = 49.000$ ,  $p$   
9  $0.343$ ;  $0.00 \pm 1.00$  pts vs  $-0.50 \pm 1.50$  pts respectively), and sports ( $U = 61.000$ ,  $p = 0.832$ ; -  
10  $1.00 \pm 1.50$  pts vs  $-1.00 \pm 3.25$  pts respectively).

11

## 12 **Discussion**

13 The present study examined the implementation of a 25 week supervised RT intervention  
14 introducing increased effort through progressive application of defined set end points. Over  
15 the course of the intervention there were significant changes in strength, body composition,  
16 function, and wellbeing outcomes. Participants were also followed-up for 6 months post  
17 intervention. Over the follow-up period body composition changes reverted to baseline values,  
18 strength gains were significantly decreased compared to post intervention but remained  
19 significantly higher than baseline, and questionnaire outcomes were mostly maintained.  
20 During the follow-up period participants self-selected whether they wanted to continue  
21 participating in RT unsupervised (57% of participants continued). When comparing between  
22 the group that self-selected to continue with RT, and those who did not, there appeared to be  
23 no significant differences for changes in any outcome measures over the follow-up period.  
24 Despite the initial effectiveness of the RT intervention, these data suggest that continuation of  
25 RT unsupervised offered no additional benefit to maintaining intervention induced changes  
26 compared with cessation of training.

27

1 Improvements in strength across the intervention period were significant and large when  
2 considering the ESs. Further, individual responses (figure 2) revealed that all participants  
3 increased in strength though the magnitude of change showed considerable inter-individual  
4 variability. High effort RT has been shown to produce large improvements in strength in older  
5 adults even when employed at a low volume and frequency [38]. The results of the present  
6 study further support this whilst employing progressive applications of set end points  
7 culminating in use of MF and MF+[drop sets]. This is apparently the first study to employ such  
8 a RT approach in older adults. Fisher et al. [38] reported within participant ESs for males and  
9 females respectively of 2.19 and 2.36 for leg press, 1.59 and 1.59 for chest press, and 2.67  
10 and 2.84 for seated row when considering load progression from beginning to end of a ~12 or  
11 ~19 week RT intervention respectively using sdRM as a set end point. The ESs for change in  
12 1RM in the present study were similarly large (2.66, 2.51, and 2.38 for leg press, chest press  
13 and seated row respectively) though not larger than that reported by Fisher et al. [38]  
14 suggesting that employing higher effort set end points such as MF and MF+[drop sets] may  
15 not be necessary to maximise strength gains in older adults. However, strength gains are  
16 thought to be highly specific to the task being performed during training [55-57]. As such, for  
17 comparative purposes the within participants ESs for increases in training load across the  
18 intervention period for the present study were 3.41, 2.84, and 2.67 for leg press, chest press  
19 and seated row respectively suggesting benefits for training to MF and MF+[drop sets]  
20 compared with just sdRM for leg press and chest press. However, it should be noted that the  
21 present study did not directly compare different RT set end points and so further research  
22 should examine this in older populations.

23

24 Neither body mass, BMI, nor muscle mass changes across the intervention period were  
25 significant; however, there were significant decreases in fat mass and fat percentage as well  
26 as increased muscle percentage. Studies applying traditional RT approaches of multiple sets  
27 performed to an nRM have reported significant changes in body composition in older adults  
28 [58]. However, when higher effort set end points have been used (MF) low volume single set

1 RT is similarly effective [59]. This despite the fact that single set approaches have been  
2 suggested to likely require insufficient energy costs to produce improvements in body fat [60],  
3 although, the set end points applied in this study was unclear (described as volitional fatigue).  
4 Prior studies in young adults using low volume, high intensity of effort approaches have shown  
5 similar body composition changes to the present study and these have been ascribed to the  
6 higher effort set end points used (i.e. MF and MF+) [48, 61]. Indeed, body composition  
7 changes appear greater in older individuals with low volume higher effort interventions  
8 compared with higher volume lower effort approaches [62, 63]. Though body compositions  
9 changes are possible with participation in high effort RT it is difficult to ascribe the changes  
10 reported in the present study purely to the effects of the intervention. Recent work has shown  
11 that older adults tend to spontaneously make other lifestyle changes such as improvements  
12 in diet including energy intake and increases in non-RT physical activity when initiating and  
13 maintaining an RT intervention [64]. As such, RT could act as a first step in public health  
14 approaches in the elderly.

15

16 With the exception of right hand grip strength, all functional outcomes improved significantly  
17 over the intervention period. Questionnaire data further corroborate these improvements  
18 suggesting that participants perceived their general state of health, comparison to other older  
19 adults, wellbeing, and ability to accomplish many functional tasks was significantly improved  
20 after the intervention. As noted, functional ability and risk of falling is associated with strength  
21 [15, 16] and as such RT is recommended for improving falls risk, gait ability and balance in  
22 physically frail older adults [17]. The improved functional ability in the present study may  
23 therefore have been a result of the significant strength gains produced. Indeed, baseline  
24 strength levels are correlated with gait speed and improve with RT [18], and a recent study  
25 also reported that the improvements in gait speed as a result of RT are significantly related to  
26 gains in lower body strength ( $r = 0.45$ ;  $p = 0.04$ ) [19]. As such, out of curiosity a post hoc  
27 Pearson's correlation was examined between change in stair climb time and change in leg  
28 press 1RM over the intervention period for the present study finding a similar relationship ( $r =$

1 0.48; $p = 0.003$ ). Despite the apparent relationship between strength and functional ability in  
2 older adults the role of improved self-efficacy as a result of participation in the intervention  
3 might have impacted upon improved function [65]. Indeed, though functional outcomes were  
4 not examined at follow-up, the maintenance of most questionnaire outcomes despite the loss  
5 of strength suggested that improvements in perceived function may have been maintained.

6

7 During the follow-up period ~57% of participants opted to continue with unsupervised RT,  
8 considerably more than that reported by Van Roie et al. [44]. The greater maintenance of RT  
9 behaviours compared with that reported by Van Roie et al. [44] in the present study could be  
10 for a number of reasons. Further, though there was a significant loss of 1RM strength for leg  
11 press and chest press exercise (though not for seated row) over the follow-up period, strength  
12 was still significantly higher than baseline at 6 months follow-up. The same was not however  
13 the case for body composition changes, all of which returned to baseline levels. The loss of  
14 strength and body composition improvements across the follow-up period was not significantly  
15 different between those who opted to continue with RT and those who did not. However,  
16 though not significantly different, as can be seen from the individual response plots there was  
17 considerably greater variation in whether strength was maintained or lost compared with the  
18 changes across the intervention period and further, descriptive statistics suggested that loss  
19 of strength was less in the group that continued RT (-98.38 kg vs -154.74 kg, -30.48 kg vs -  
20 38.99 kg, and -22.81 kg vs -46.64 kg for leg press, chest press and seated row respectively).  
21 This did not appear to be the case for the body composition results though with no clear trend  
22 for more favourable outcomes in those who continued RT. The loss of strength despite  
23 continued RT is interesting considering that prior research has shown that strength gains can  
24 be maintained even with a very low RT dose. As noted Van Roie et al. [44] reported that the  
25 training effort of participants appeared to drop considerably as evidenced by the low number  
26 of repetitions being performed with training loads far lighter than during the initial 12-week  
27 intervention. Numerous studies have shown that strength and body composition changes are  
28 reduced when training unsupervised versus training with supervision [66, 67]. Indeed they



1 often train with lower loads and efforts [68, 69] and it has been suggested they likely avoid  
2 training to MF [70]. In the present study, at follow-up participants were training with loads  
3 lower, but not substantially so, having reduced them by ~2.4% to ~5.5%. As such it seems  
4 likely that effort was reduced during follow-up in the present study by avoidance of set end  
5 points resulting in higher effort (i.e. sdRM, MF, and MF+). Indeed, the majority of participants  
6 who continued training reported at follow-up to have switched to performing a multiple set (~3  
7 sets) program performed to nRM.

8

9 Though reduced, it may be that strength gains remain elevated above baseline levels despite  
10 reduced effort in continued RT. However, whether given sufficient time participants strength  
11 would return to baseline values despite continued RT without application of sufficient effort by  
12 application of appropriate set end points is a question of importance. If this were the case,  
13 efforts to implement behaviour change including participation in RT unsupervised in addition  
14 to employment of initial supervised RT in older adults might be considered to represent a  
15 costly and ineffective public health approach. Previous studies suggested that older adults  
16 lose strength and power faster than young adults [71]. Fiatarone et al. [18] reported 32%  
17 strength loss after only 4 weeks of detraining. Moreover, Cadore et al. [72] showed that 1/3 of  
18 the participants (older adults with dementia and severe functional loss) died in the 6 months  
19 following interruption of a RT intervention. Therefore, it seems that unsupervised low volume  
20 resistance training might not be sufficient to overcome this tendency. However, there was also  
21 no significant differences between either groups for changes in wellbeing outcomes from the  
22 questionnaire data the improvements of which were maintained at follow-up. This suggests  
23 that the initial supervised intervention may have at least had some lasting effects upon  
24 perceived wellbeing which were maintained irrespective of whether unsupervised RT was  
25 continued, even if objective outcomes were not maintained. As such, longer term trials are  
26 needed to examine the long term effects of initial RT and efficacy of continued participation  
27 after initial supervised RT.

28

1 **Conclusions**

2 The present study shows that a 25 week supervised RT intervention employing progressive  
3 application of high effort set end points is well tolerated and is effective in improving strength,  
4 body composition, function and wellbeing in older adults. Compared with prior studies, a  
5 considerable proportion of participants (~57%) opted to continue with RT unsupervised after  
6 completion of the intervention. Strength and body composition outcomes were generally  
7 reduced at 6 months follow-up, though strength remained above baseline, and wellbeing  
8 outcomes were maintained. However, there appeared to be no significant effect upon the  
9 degree of loss of improvements whether participants continued, or did not, with RT  
10 unsupervised at follow-up. This may be due to the likely reduced effort employed during  
11 unsupervised RT. As such, future work should examine approaches to ensure maintenance  
12 of initial RT outcomes in older adults when transferring to unsupervised continuation of RT.

13

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1 Table 1. Strength and body composition pre, post, and follow-up descriptive data (mean±SD), and intervention and follow-up period change ( $\Delta$ )

Measure	Pre-Intervention (mean±SD)	Post-Intervention (mean±SD)	Follow-up (mean±SD)	Intervention Period Change ( $\Delta$ )		Follow-up Period Change ( $\Delta$ )		2
				95%CI	ES	95%CI	ES	
<i>Strength</i>								
Leg press 1RM (kg)	92.03±31.95	242.86±76.60 <sup>a</sup>	183.96±61.91 <sup>a,b</sup>	126.29 to 175.35	2.66	-173.64 to -72.13	-1.04	3
Chest press 1RM (kg)	33.85±12.83	70.60±25.23 <sup>a</sup>	59.831±21.83 <sup>a,b</sup>	30.42 to 43.09	2.51	-50.68 to -17.10	-0.90	
Seated row 1RM (kg)	40.76±14.33	81.99±24.74 <sup>a</sup>	74.86±22.46 <sup>a</sup>	33.75 to 48.72	2.38	-50.91 to -15.43	-0.81	4
<i>Body Composition</i>								
Body mass (kg)	79.19±16.84	77.54±16.44	78.43±16.41	-2.59 to -0.71	-0.76	0.16 to 1.63	0.52	
BMI (kg.m <sup>2</sup> )	27.04±3.80	26.49±3.72	26.73±3.71	-0.87 to -0.25	-0.79	-0.01 to 0.51	0.42	5
Fat mass (kg)	22.06±6.80	19.74±6.44 <sup>a</sup>	21.58±6.61 <sup>b</sup>	-3.16 to -1.47	-1.19	1.11 to 2.57	1.09	
Fat percent (%)	27.90±6.43	25.52±6.30 <sup>a</sup>	27.34±6.00 <sup>b</sup>	-3.30 to -1.47	-1.13	1.07 to 2.58	1.04	
Muscle mass (kg)	54.27±12.77	54.94±12.72	54.27±12.77	-0.14 to 1.48	0.36	1.37 to 0.02	-0.42	6
Muscle percent (%)	68.47±6.13	70.78±6.00 <sup>a</sup>	69.02±5.73 <sup>b</sup>	1.45 to 3.20	1.15	-2.53 to -1.02	-1.02	
Note: <sup>a</sup> indicates significant difference ( $p \leq 0.05$ ) with post hoc pairwise comparison pre- compared with post-intervention/follow-up; <sup>b</sup> indicates significant difference ( $p \leq 0.05$ ) with post hoc pairwise comparison post-intervention compared with follow-up								

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1 Table 2. Function pre and post descriptive data (mean±SD), and intervention and follow-up period change ( $\Delta$ )

Measure	Pre-Intervention (mean±SD)	Post-Intervention (mean±SD)	Intervention Period Change ( $\Delta$ )		2
			95%CIs	ES	
<i>Physical Function</i>					
Resting heart rate (beat.min <sup>-1</sup> )	94.59±17.82	85.68±10.33 <sup>a</sup>	-14.95 to -3.05	-0.64	3
Stair climb time (seconds)	72.25±9.00	64.27±17.74 <sup>a</sup>	-13.91 to -2.44	-0.59	
Stair climb rating of perceived exertion (0-10)	4.68±1.73	3.59±1.89 <sup>a</sup>	-1.70 to -0.30	-0.67	4
Carrying task time (seconds)	44.96±5.34	39.19±4.71 <sup>a</sup>	-6.70 to -4.49	-2.16	
Carrying task rating of perceived exertion (0-10)	3.35±1.50	1.74±1.00 <sup>a</sup>	-2.35 to -0.92	-1.01	
Chair rise time (seconds)	9.63±2.25	7.73±1.73 <sup>a</sup>	-2.66 to -1.09	-1.09	5
Right hand grip strength (kg)	35.34±10.52	36.70±10.91	1.17 to 3.63	0.87	
Left hand grip strength (kg)	34.01±10.95	36.41±10.81 <sup>a</sup>	-0.62 to 3.33	0.31	6
Note: <sup>a</sup> indicates significant difference ( $p \leq 0.05$ ) for paired samples <i>t</i> -test pre- compared with post-intervention/follow-up; <sup>b</sup> indicates significant difference ( $p \leq 0.05$ ) for paired samples <i>t</i> -test post-intervention compared with follow-up					

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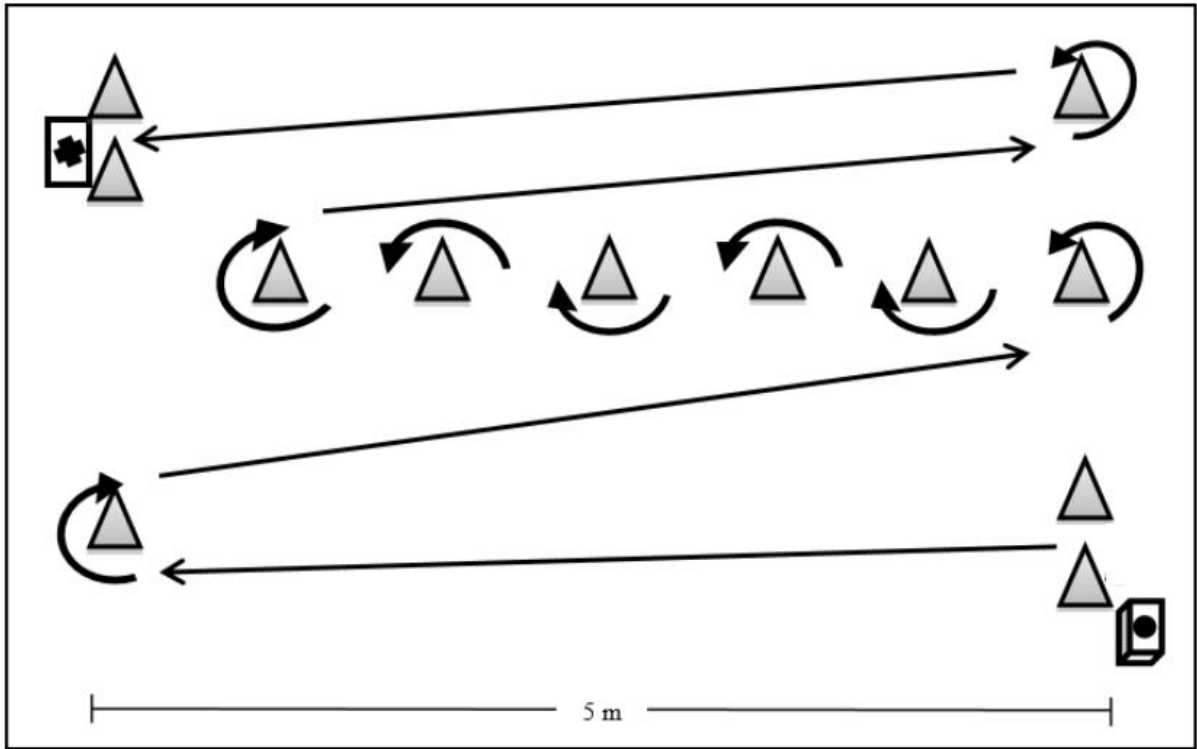
1 Table 3. Questionnaire pre, post, and follow-up descriptive data (median±IQR), and Friedman and Wilcoxon Signed Ranks test results ( $p$ )

Measure	Pre-Intervention (median±IQR)	Post-Intervention (median±IQR)	Follow-up (median±IQR)	Friedman Test ( $p$ )	Wilcoxon Signed Ranks Test ( $p$ )		
					Pre- to Post Comparison	Pre- to Follow-up Comparison	Post to Follow-up Comparison
<i>Questionnaire data</i>							
State of health	3.00±0.00	4.00±2.00 <sup>a</sup>	4.00±1.00 <sup>a</sup>	<0.001	<0.001	0.001	0.499
Comparison with other older adults	3.00±2.00	4.50±1.00 <sup>a</sup>	4.00±1.00 <sup>a</sup>	<0.001	<0.001	0.005	0.084
Sporting condition	3.00±2.00	4.00±1.00 <sup>a</sup>	3.50±2.00 <sup>b</sup>	0.113	0.006	0.744	0.020
WHO-1	3.00±2.00	4.00±1.00 <sup>a</sup>	4.00±0.00 <sup>a,b</sup>	<0.001	<0.001	0.007	0.010
WHO-2	3.00±1.00	4.00±1.25 <sup>a</sup>	4.00±1.00 <sup>a,b</sup>	<0.001	<0.001	<0.001	0.019
WHO-3	3.00±1.25	4.00±1.00 <sup>a</sup>	4.00±1.00 <sup>a,b</sup>	<0.001	<0.001	0.003	0.003
WHO-4	3.00±2.00	5.00±1.25 <sup>a</sup>	4.00±2.00 <sup>a,b</sup>	<0.001	<0.001	<0.001	0.017
WHO-5	3.00±1.25	4.00±1.00 <sup>a</sup>	4.00±0.25 <sup>a</sup>	<0.001	<0.001	<0.001	0.090
Perceived ability to accomplish:							
Household chores	3.00±1.25	4.00±1.00 <sup>a</sup>	4.00±1.00 <sup>a</sup>	<0.001	<0.001	0.002	0.071
Stair climbing	3.00±2.00	4.00±1.00 <sup>a</sup>	4.00±2.00 <sup>a</sup>	<0.001	<0.001	<0.001	0.589
Shopping	3.00±2.00	4.00±1.00 <sup>a</sup>	4.50±2.00 <sup>a</sup>	<0.001	<0.001	<0.001	0.327
Gardening	3.00±2.00	5.00±1.00 <sup>a</sup>	4.00±2.00 <sup>a,b</sup>	<0.001	<0.001	0.001	0.021
Transport	3.00±1.25	4.00±1.00 <sup>a</sup>	3.50±1.00 <sup>a,b</sup>	<0.001	<0.001	0.001	0.003

Note: <sup>a</sup>indicates significant difference ( $p \leq 0.05$ ) for Wilcoxon signed ranks test pre- compared with post-intervention/follow-up; <sup>b</sup>indicates significant difference ( $p \leq 0.05$ ) for Wilcoxon signed ranks test post-intervention compared with follow-up

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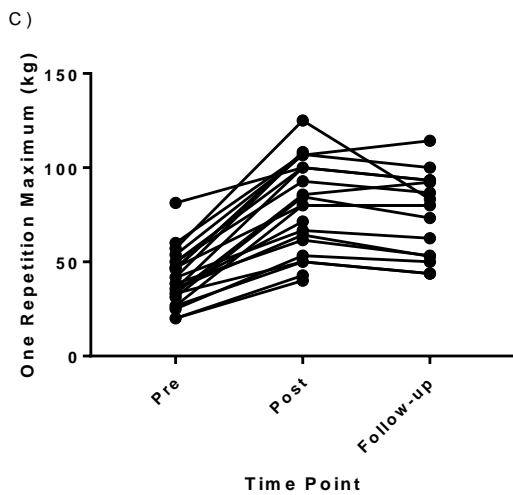
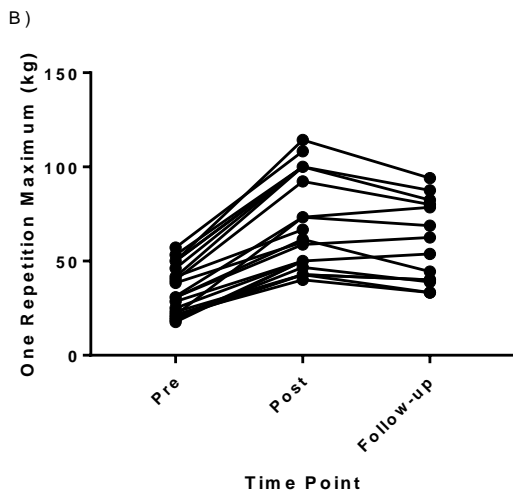
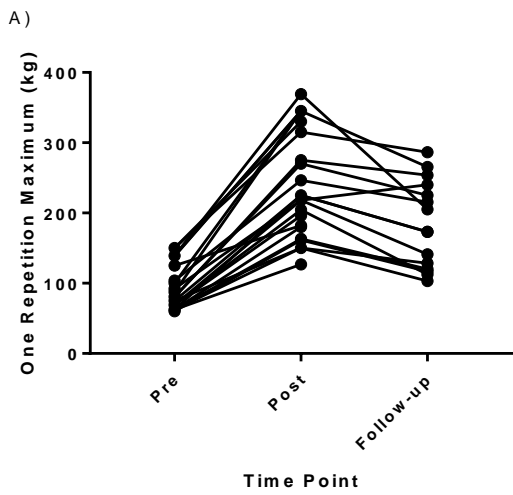
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2 Figure 1. Twenty five metre course for carrying task.

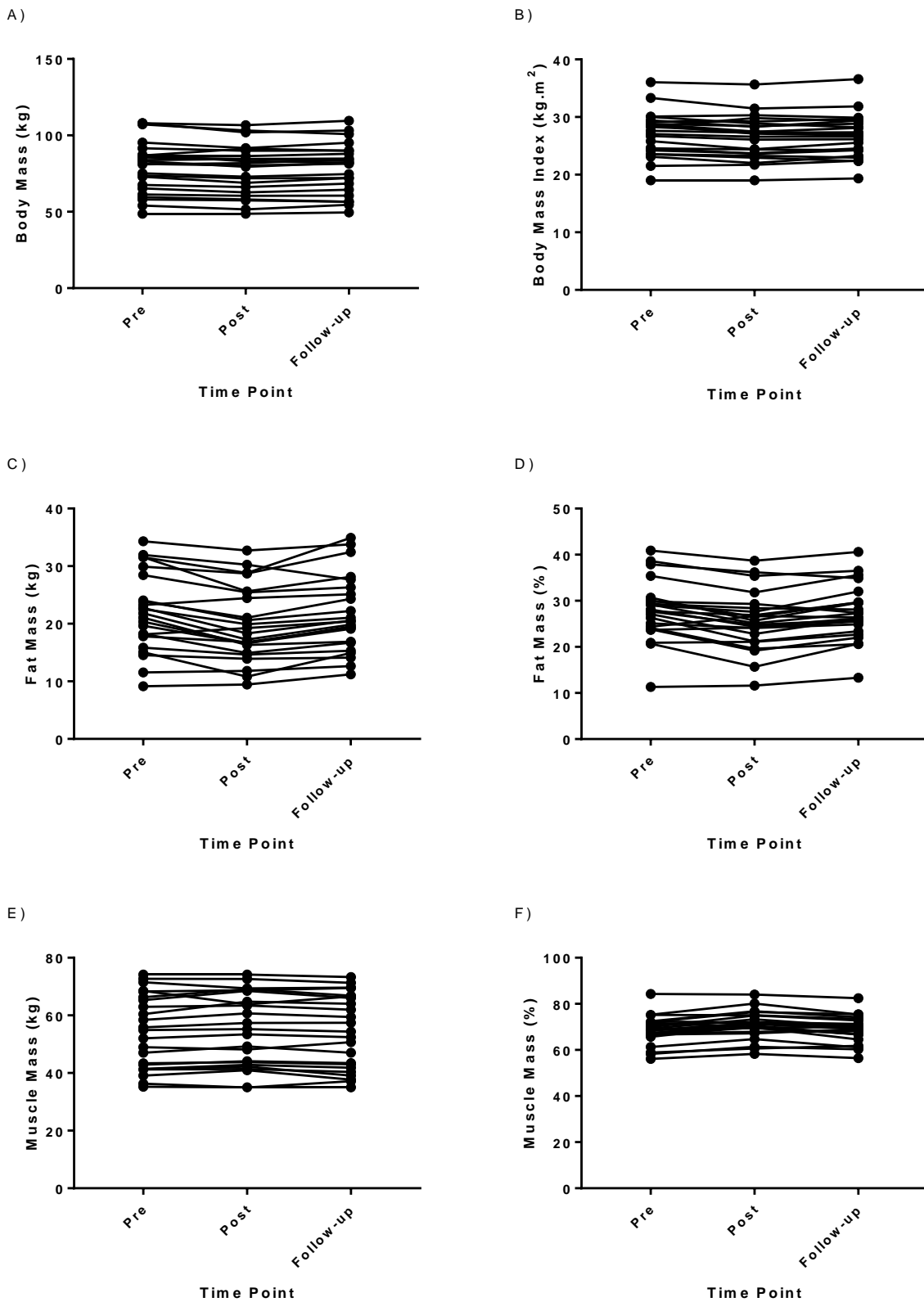




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2 Figure 2. One repetition maximum at pre, post, and follow-up: A) Leg press, B) chest press,

3 and C) row.

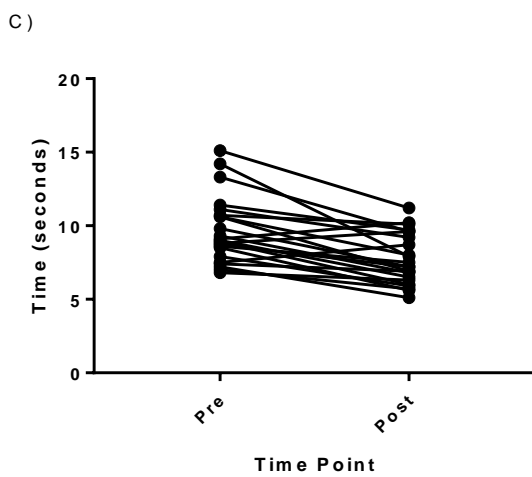
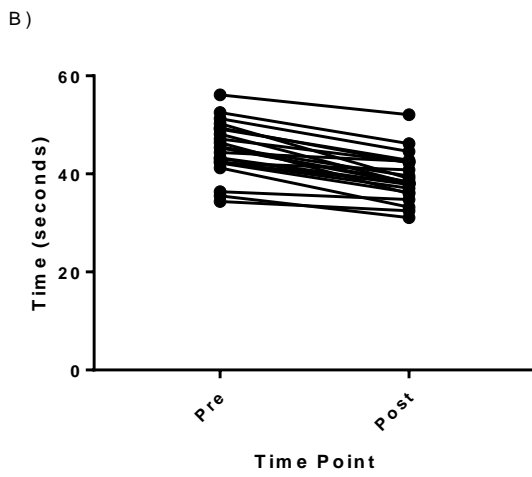
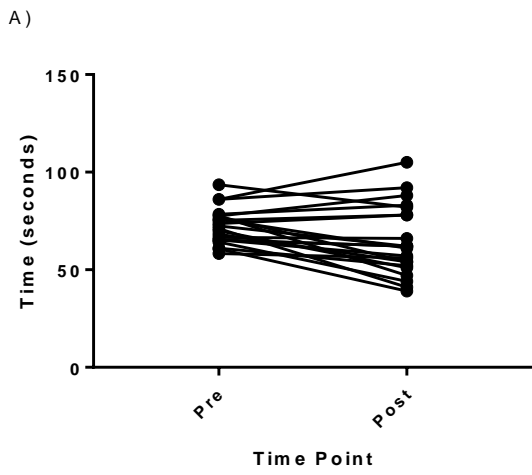


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2 Figure 3. Body composition at pre, post, and follow-up: A) Body mass, B) body mass index,

3 C) fat mass, D) fat percentage, E) muscle mass, and F) muscle percentage.

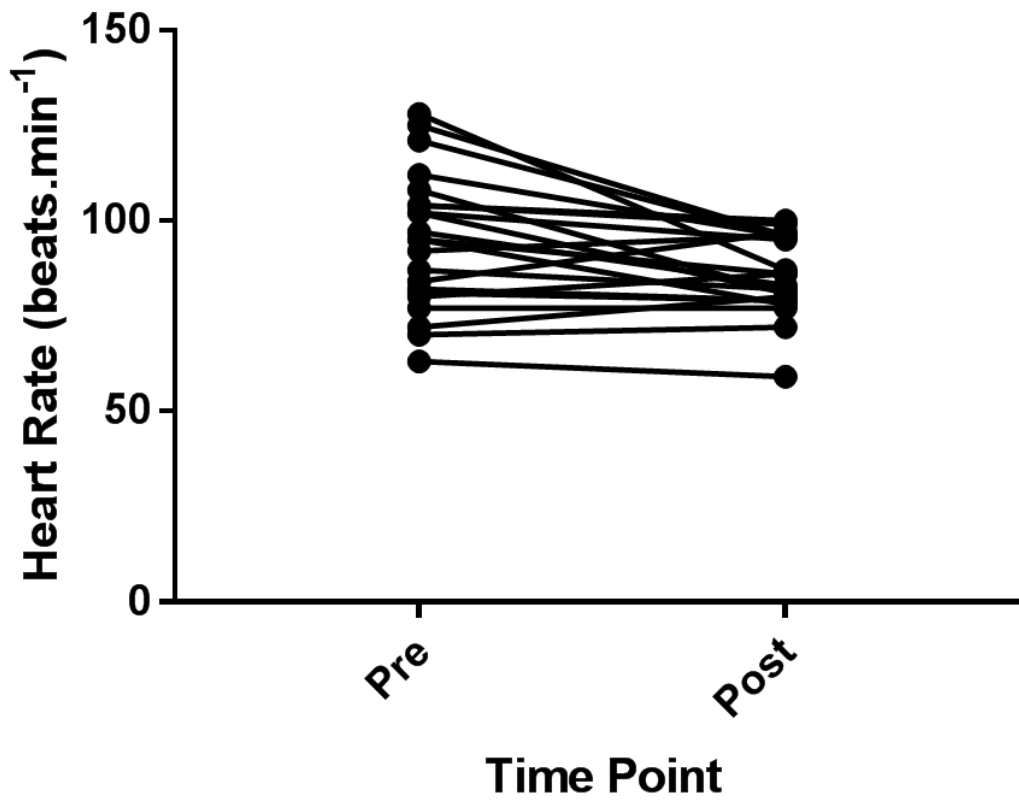
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3 Figure 4. Functional test times at pre and post: A) Stair climb time, B) parcour time, and C)

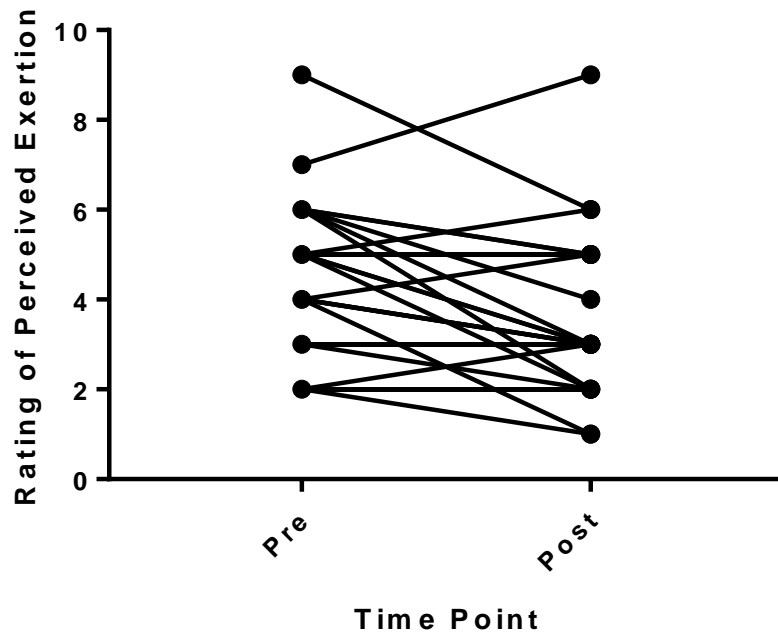
4 chair rise time.



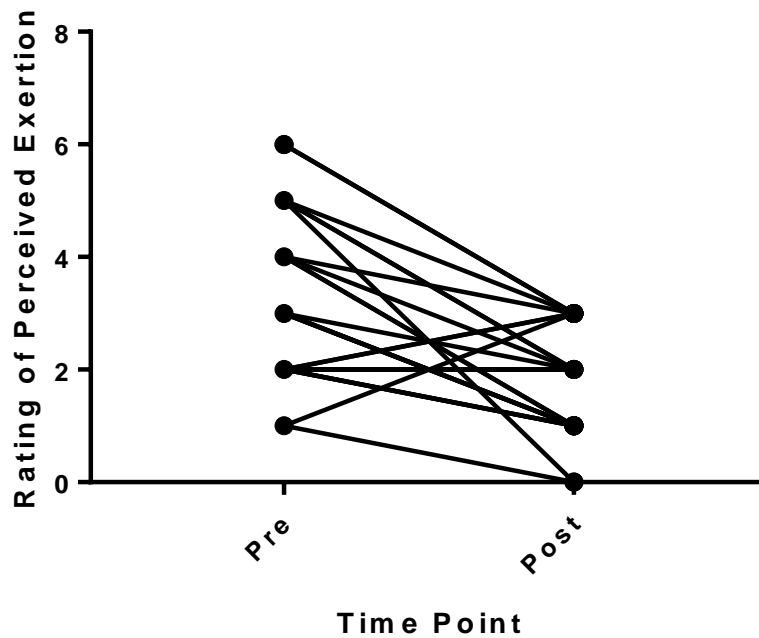
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2 Figure 5. Heart rates for stair climb test at pre and post resting heart rate.

A)



B)

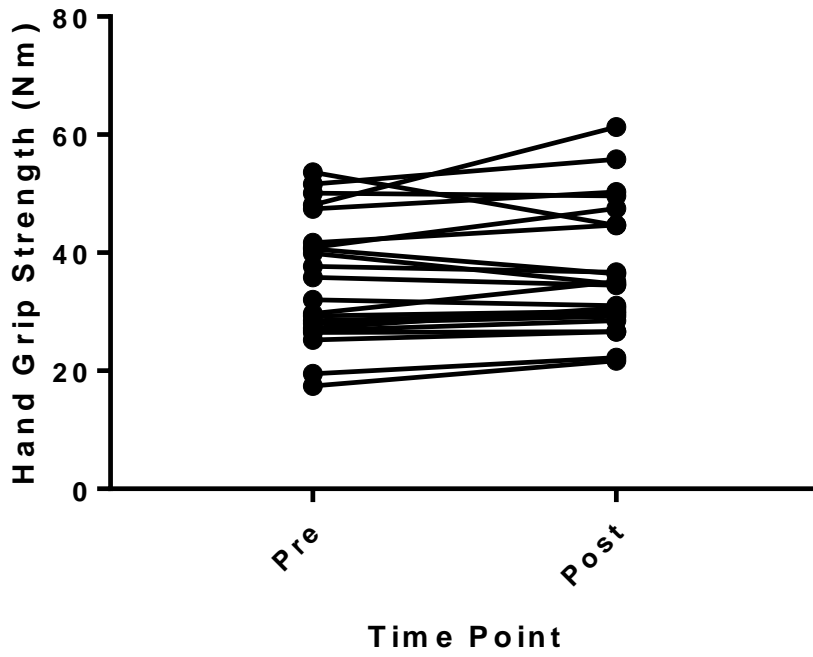


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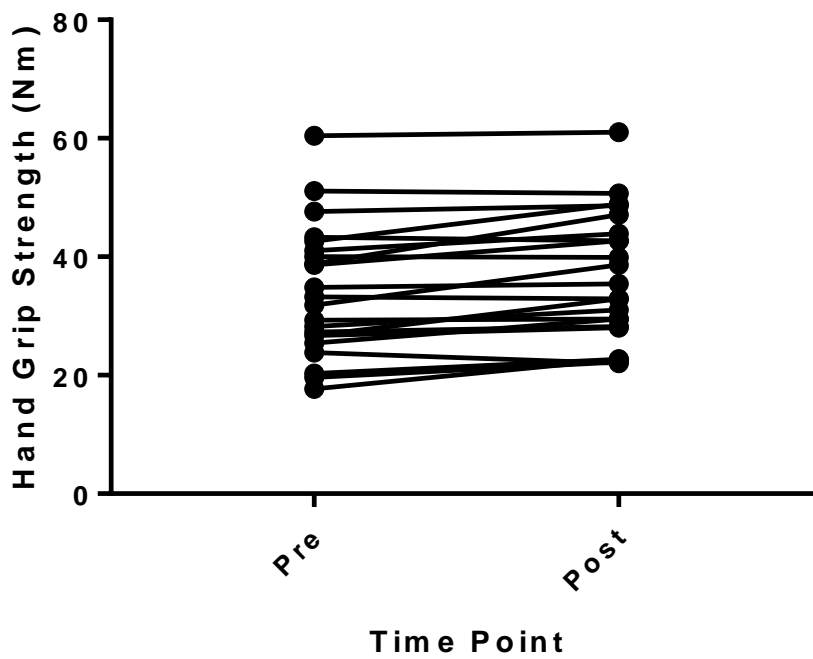
2 Figure 6. Rating of perceived exertion during functional tests at pre and post: A) Stair climb,

3 and B) carrying task.

A)



B)



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2 Figure 7. Hand grip strength at pre and post: A) Right, and B) left.