Clinical Study

The Effects of 6 Months of Progressive High Effort Resistance Training Methods upon Strength, Body Composition, Function, and Wellbeing of Elderly Adults

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Purpose. The present study examined the progressive implementation of a high effort resistance training (RT) approach in older adults over 6 months and through a 6-month follow-up on strength, body composition, function, and wellbeing of older adults. **Methods.** Twenty-three older adults (aged 61 to 80 years) completed a 6-month supervised RT intervention applying progressive introduction of higher effort set end points. After completion of the intervention participants could choose to continue performing RT unsupervised until 6-month follow-up. **Results.** Strength, body composition, function, and wellbeing all significantly improved over the intervention. Over the follow-up, body composition changes reverted to baseline values, strength was reduced though it remained significantly higher than baseline, and wellbeing outcomes were mostly maintained. Comparisons over the follow-up between those who did and those who did not continue with RT revealed no significant differences for changes in any outcome measure. **Conclusions.** Supervised RT employing progressive application of high effort set end points is well tolerated and effective in improving strength, body composition, function, and wellbeing in older adults. However, whether participants continued, or did not, with RT unsupervised at follow-up had no effect on outcomes perhaps due to reduced effort employed during unsupervised RT.

1. Introduction

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

Participation in RT is associated with reduced morbidity and mortality risk in the elderly [8, 9]. Hurley and Roth [10]

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

In consideration of the benefits of RT in older adults, studies have examined the manipulation of RT variables

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

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

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

High effort RT interventions performed to MF in older adults are uncommon but have been employed previously examining the role of load [40]. Adaptations to heavier- or lighter-loads seem similar when repetitions are performed to MF in older adults [40] similarly to findings in both adolescent [41] and young adult populations [42]. However, though supervised high effort RT is effective, Van Roie et al. [43] have reported that long term adherence after the initial supervised intervention, whether using heavier- or lighter-loads, is poor. Further, the training effort of participants may drop considerably over this period. Indeed participants were performing a lower number of repetitions with training loads lighter than during the initial 12-week intervention [43]. However, measures of fitness or function were not made at

follow-up. Though a relatively low dose of RT is needed to maintain strength and muscle mass after an initial 12-week RT intervention for older adults [44], it is possible that the reduced effort employed might mean that initial efforts are potentially wasted as adaptations may not be maintained.

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

2. Materials and Methods

2.1. Study Design. A single arm prospective trial was conducted examining the effects of a 6 month supervised RT intervention with progressive implementation of high effort set end points in older adults. Upon completion of the 6-month intervention participants self-selected whether they continued participating in RT unsupervised or not. Participants were followed up 6 months after intervention. The study design was ethically approved by the author's institution. All procedures were performed in accordance with the ethical standards of the Helsinki Declaration. Written informed consent was obtained from all participants. The trial was registered in the ISRCTN registry (ISRCTN15170767).

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

FIGURE 1: Twenty-five-metre course for carrying task.

$n = 4$, males $n = 1$) for unrelated health reasons. At follow-up 13 participants had continued engaging in the RT intervention unsupervised (females $n = 5$, males $n = 8$).

2.3. Materials and Equipment. Strength measurements and training were performed using leg press, chest press, seated row, knee extension, knee flexion, trunk extension, and trunk flexion resistance machines (Ergo-Fit, Germany). Body composition including body mass, whole body muscle, and fat mass and percentage was estimated using bioelectrical impedance (Tanita MC 180, Tanita Europe B. V., Amsterdam). This device is reported as valid compared with dual energy X-ray absorptiometry for estimating body composition in healthy adults [51]. Physical function in tasks of daily living was measured as isometric grip strength performed using a digital handgrip dynamometer (Trailite, Germany), a stair climb task involving 6 flights of 17 steps (102 steps in total) each at 17 cm height, a carrying task using a shopping basket weighing either 5 kg for females or 10 kg for males which was lifted from the ground, carried around a 25 m course involving various turns of both 90° and 180° (Figure 1), and then placed on the ground again at the end, and a chair rise task using a chair at 45 cm height. Resting heart rate was measured using an A300 Polar Monitor (Polar, Finland). Rating of perceived exertion (RPE) using Borg's CR-10 scale was taken during both the stair climb task and carrying task. Questionnaires were also used to examine perceived function and wellbeing. The WHO-5 Wellbeing Index was completed in addition to a questionnaire asking participants to rate their overall present state of health, comparison with other older adults of their age, present sporting condition, and ease with which they can perform household chores, stair climbing, shopping, gardening, and transport. For these participants were asked to provide ratings using a 5-point Likert scale ranging from 1 ("very bad") to 5 ("very well") for state of health, comparison with other older adults, and sporting condition and 0 ("this is very difficult for me") to 5 ("I can manage this easily") for ease with which they can perform household chores, stair climbing, shopping, gardening, and transport.

2.4. Testing. Testing was conducted before and after the intervention and at 6-month follow-up for all outcomes with the

exception of physical function tests which were conducted before and after intervention only. Muscular strength testing was performed in the following order with 2-3 minutes of rest between exercises: leg press, chest press, and seated row. Participants performed a ~5RM test following National Strength and Conditioning Association guidelines for RM testing [52]. From this, predicted 1RM was calculated using the Brzycki [53] formula. Body composition was measured on a separate day from muscular performance testing both before and after the intervention following the manufacturer's guidelines. Testing for the stair climb task, carrying task, and chair rise task was performed using a stopwatch. For each the participants were instructed to begin on the command "Go" and to complete the task as quickly as possible. For the stair climb task this involved climbing the 102 steps, for the carrying task this involved picking up the shopping basket, completing the 25 m course, and then placing the shopping basket on the ground at the end of the course, and for the chair rise task this involved the participants beginning seated on the chair with their arms folded across their chest and then standing from the chair until their legs were straight five times. Isometric grip strength was taken as the average of two maximal voluntary isometric efforts. Participants positioned their arms adducted at their sides with elbows at 90° as recommended by the American Society of Hand Therapists [54]. Participants were instructed to squeeze the handle of the dynamometer progressively harder culminating in a maximal voluntary effort after 3 seconds and lasting for a further 2 seconds.

2.5. Training. During the intervention period training was supervised and conducted 2x/week (at least 48 hours between sessions) for 6 months (25 weeks). Participants all performed a general warm-up using either treadmill, cross-trainer, upright cycle ergometer, or recumbent cycle ergometer depending on preference for 10 minutes followed by a single set of moderate load leg press, chest press, and seated row exercises for 15 repetitions prior to each training session. In each training session participants performed leg press, chest press, seated row, knee extension, knee flexion, trunk extension, and trunk flexion. Order of exercises was not fixed and dependent upon preference and availability of equipment in the gym where training was conducted. Rest between exercises lasted for 2-4 minutes. Participants were instructed to perform the exercises using relatively long repetition duration of at least 2 seconds concentric, 1 second pause at the top of the range of motion, and 2 seconds eccentric and to not exceed 4 seconds concentric, 1 second pause at the top of the range of motion, and 4 seconds eccentric. The first 2 weeks of the intervention was a familiarisation phase whereby participants trained using a single set of each exercise using a moderate load and performing 15-18 repetitions, that is, nRM. After this period participants progressed for a further 2 weeks to perform each exercise to a set end of point of sdRM defined as cessation at the point where participants predicted they would reach momentary failure if the next repetition was attempted [36]. After this period participants progressed to perform each exercise to a set end point of MF and continued training

in this manner until week 18. For the final 6 weeks of the intervention participants progressed to perform each exercise to set end point of MF followed by a drop set whereby the load was reduced by ~5 kg and an additional set continued to the point of MF was performed immediately upon completion of the first. Load was progressed for each group by 2–10% in the next session if participants could achieve greater than 12 repetitions before reaching the defined set end point for their current period of training (in the case of the final 6 weeks this applied to the first set performed to momentary failure). After the 25-week intervention participants wishing to continue performing resistance training unsupervised were given access to the training facility and allowed to train without direct supervision.

2.6. Data Analysis. Independent variables for analyses in the present study were time (before intervention, after intervention, and at follow-up) and also whether participants did, or did not, continue with unsupervised resistance training during the follow-up period. Dependent variables were strength, body composition, physical function, and perceived well-being and function. Assumptions of normality were examined using a Shapiro-Wilk test and assumptions of equality of variance examined using Mauchly's test for sphericity. Strength and body composition data met assumptions of normality of distribution and equality of variance so repeated measures analysis of variance (ANOVA) was used to examine effects by time (before intervention, after intervention, and at follow-up). Post hoc pairwise comparisons using a Bonferroni adjustment were conducted comparing preintervention to postintervention period (encompassing the intervention period), postintervention to follow-up period (encompassing the follow-up period), and preintervention to follow-up period (encompassing the whole study). Physical function data met assumptions of normality of distribution and so paired samples *t*-tests were used to examine effects by time (before to after intervention). Questionnaire data did not meet assumptions of normality of distribution and so a non-parametric Friedman test was used to examine effects by time (before intervention, after intervention, and at follow-up). Post hoc pairwise comparisons using Wilcoxon signed ranks tests were conducted comparing pre- to postintervention period (encompassing the intervention period), postintervention to follow-up period (encompassing the follow-up period), and preintervention to follow-up period (encompassing the whole study). Between groups comparisons were made for absolute changes in strength, body composition, and questionnaire data using independent samples *t*-tests and Mann-Whitney *U* tests (follow-up minus postintervention period) for the follow-up period comparing those who either did or did not continue with unsupervised RT. Further, 95% confidence intervals (CI) and within-participant ESs ($d = \mu_{\text{change}}/\sigma_{\text{change}}$; small = 0.20–0.49, moderate = 0.50–0.79, and large = ≥ 0.80) were calculated for changes in strength, body composition, and physical function across the intervention (post- minus preintervention period) period. Statistical analysis was performed using SPSS statistics computer package (versus .23; IBM, Portsmouth, UK) and $p \leq 0.05$ set as the limit for statistical significance.

3. Results

3.1. Strength. Descriptive data for all strength outcomes and all time points and 95% CIs and ESs for changes are reported in Table 1. Figure 2 also shows individual responses at each time point for strength measures. Repeated measures ANOVA revealed significant effects by time for leg press 1RM ($F_{(2,26)} = 88.876, p < 0.001$), chest press 1RM ($F_{(2,26)} = 63.577, p < 0.001$), and seated row 1RM ($F_{(2,26)} = 48.750, p < 0.001$). Post hoc pairwise comparisons revealed significant differences between pre- and both postintervention and follow-up time points for leg press 1RM ($p < 0.001$), chest press 1RM ($p < 0.001$), and seated row 1RM ($p < 0.001$). Significant differences between postintervention and follow-up time points were also found for leg press 1RM ($p < 0.001$) and chest press 1RM ($p = 0.017$).

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

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

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

3.3. Function. Descriptive data for all function outcomes and all time points and 95% CIs and ESs for changes are reported in Table 2. Figures 4, 5, 6, and 7 show individual responses at each time point for function measures. Paired samples *t*-tests revealed significant differences from pre- to postintervention

TABLE 1: Strength and body composition preintervention, postintervention, and follow-up descriptive data (mean ± SD) and intervention and follow-up period change (Δ).

Measure	Preintervention (mean ± SD)	Postintervention (mean ± SD)	Follow-up (mean ± SD)	Intervention period change (Δ)			Follow-up period change (Δ)		
				95% CIs	ES		95% CIs	ES	
<i>Strength</i>									
Leg press 1RM (kg)	92.03 ± 31.95	242.86 ± 76.60 ^a	183.96 ± 61.91 ^{a,b}	126.29 to 175.35	2.66		-173.64 to -72.13		-1.04
Chest press 1RM (kg)	33.85 ± 12.83	70.60 ± 25.23 ^a	59.831 ± 21.83 ^{a,b}	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 ^a	74.86 ± 22.46 ^a	33.75 to 48.72	2.38		-50.91 to -15.43		-0.81
<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 ⁻²)	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
Fat mass (kg)	22.06 ± 6.80	19.74 ± 6.44 ^a	21.58 ± 6.61 ^b	-3.16 to -1.47	-1.19		1.11 to 2.57		1.09
Fat percent (%)	27.90 ± 6.43	25.52 ± 6.30 ^a	27.34 ± 6.00 ^b	-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
Muscle percent (%)	68.47 ± 6.13	70.78 ± 6.00 ^a	69.02 ± 5.73 ^b	1.45 to 3.20	1.15		-2.53 to -1.02		-1.02

Note: a indicates significant difference ($p \leq 0.05$) with post hoc pairwise comparison of pre- compared with postintervention/follow-up period; b indicates significant difference ($p \leq 0.05$) with post hoc pairwise comparison of postintervention compared with follow-up period.

FIGURE 2: One repetition maximum at preintervention, postintervention, and follow-up period: (a) leg press, (b) chest press, and (c) row.

TABLE 2: Function pre- and postintervention descriptive data (mean $\pm$ SD) and intervention and follow-up period change (Δ).

Measure	Preintervention (mean $\pm$ SD)	Postintervention (mean $\pm$ SD)	Intervention period change (Δ)	
			95% CIs	ES
<i>Physical function</i>				
Resting heart rate (beat·min ⁻¹)	94.59 $\pm$ 17.82	85.68 $\pm$ 10.33 ^a	-14.95 to -3.05	-0.64
Stair climb time (seconds)	72.25 $\pm$ 9.00	64.27 $\pm$ 17.74 ^a	-13.91 to -2.44	-0.59
Stair climb rating of perceived exertion (0–10)	4.68 $\pm$ 1.73	3.59 $\pm$ 1.89 ^a	-1.70 to -0.30	-0.67
Carrying task time (seconds)	44.96 $\pm$ 5.34	39.19 $\pm$ 4.71 ^a	-6.70 to -4.49	-2.16
Carrying task rating of perceived exertion (0–10)	3.35 $\pm$ 1.50	1.74 $\pm$ 1.00 ^a	-2.35 to -0.92	-1.01
Char rise time (seconds)	9.63 $\pm$ 2.25	7.73 $\pm$ 1.73 ^a	-2.66 to -1.09	-1.09
Right hand grip strength (kg)	35.34 $\pm$ 10.52	36.70 $\pm$ 10.91	1.17 to 3.63	0.87
Left hand grip strength (kg)	34.01 $\pm$ 10.95	36.41 $\pm$ 10.81 ^a	-0.62 to 3.33	0.31

Note: a indicates significant difference ($p \leq 0.05$) for paired samples t -test of pre- compared with postintervention/follow-up period; b indicates significant difference ($p \leq 0.05$) for paired samples t -test of postintervention compared with follow-up period.

FIGURE 3: Body composition at preintervention, postintervention, and follow-up: (a) body mass, (b) body mass index, (c) fat mass, (d) fat percentage, (e) muscle mass, and (f) muscle percentage.

period for resting heart rate ($t_{(21)} = 3.096$, $p = 0.005$), stair climb time ($t_{(21)} = 2.858$, $p = 0.009$), stair climb RPE ($t_{(21)} = 3.257$, $p = 0.004$), carrying task time ($t_{(22)} = 10.350$, $p < 0.001$), carrying task RPE ($t_{(22)} = 4.858$, $p < 0.001$), chair rise time ($t_{(22)} = 5.249$, $p < 0.001$), and left hand grip strength ($t_{(21)} = -4.006$, $p = 0.001$) but not right hand grip strength ($t_{(21)} = -1.431$, $p = 0.167$).

3.4. Questionnaires. Descriptive data for all questionnaire outcomes and all time points and Friedman and Wilcoxon test p values are reported in Table 3. Friedman tests revealed significant effects by time for state of health, comparison with other seniors, WHO-1, WHO-2, WHO-3, WHO-4, WHO-5, and perceived ability to accomplish household chores, stair climbing, shopping, gardening, and transport, but not

TABLE 3: Questionnaire preintervention, postintervention, and follow-up descriptive data (median $\pm$ IQR), and Friedman and Wilcoxon signed ranks test results (p).

Measure	Wilcoxon signed ranks test			
	Preintervention (median ± IQR)	Postintervention (median ± IQR)	Follow-up (median ± IQR)	Friedman test (<i>p</i>)
Questionnaire data				
State of health	3.00 ± 0.00	4.00 ± 2.00 ^a	4.00 ± 1.00 ^a	<0.001
Comparison with other older adults	3.00 ± 2.00	4.50 ± 1.00 ^a	4.00 ± 1.00 ^a	<0.001
Sporting condition	3.00 ± 2.00	4.00 ± 1.00 ^a	3.50 ± 2.00 ^b	0.113
WHO-1	3.00 ± 2.00	4.00 ± 1.00 ^a	4.00 ± 0.00 ^{a,b}	<0.001
WHO-2	3.00 ± 1.00	4.00 ± 1.25 ^a	4.00 ± 1.00 ^{a,b}	<0.001
WHO-3	3.00 ± 1.25	4.00 ± 1.00 ^a	4.00 ± 1.00 ^{a,b}	<0.001
WHO-4	3.00 ± 2.00	5.00 ± 1.25 ^a	4.00 ± 2.00 ^{a,b}	<0.001
WHO-5	3.00 ± 1.25	4.00 ± 1.00 ^a	4.00 ± 0.25 ^a	<0.001
Perceived ability to accomplish				
Household chores	3.00 ± 1.25	4.00 ± 1.00 ^a	4.00 ± 1.00 ^a	<0.001
Stair climbing	3.00 ± 2.00	4.00 ± 1.00 ^a	4.00 ± 2.00 ^a	<0.001
Shopping	3.00 ± 2.00	4.00 ± 1.00 ^a	4.50 ± 2.00 ^a	<0.001
Gardening	3.00 ± 2.00	5.00 ± 1.00 ^a	4.00 ± 2.00 ^{a,b}	<0.001
Transport	3.00 ± 1.25	4.00 ± 1.00 ^a	3.50 ± 1.00 ^{a,b}	<0.001

Note: a indicates significant difference ($p \leq 0.05$) for Wilcoxon signed ranks test for pre- compared with postintervention/follow-up period; b indicates significant difference ($p \leq 0.05$) for Wilcoxon signed ranks test for postintervention compared with follow-up period.

FIGURE 4: Functional test times at preintervention and postintervention period: (a) stair climb time, (b) parkour time, and (c) chair rise time.

FIGURE 5: Resting heart rate at preintervention and postintervention period.

present sporting condition. Post hoc Wilcoxon signed ranks tests revealed significant differences between pre- and both postintervention and follow-up time points for state of health, comparison with other seniors, WHO-1, WHO-2, WHO-3, WHO-4, WHO-5, and perceived ability to accomplish

household chores, stair climbing, shopping, gardening, and transport and only pre- and postintervention periods for perceived ability to accomplish sports. Significant differences between postintervention and follow-up time points were also found for WHO-1, WHO-2, WHO-3, WHO-4, and perceived ability to accomplish sports, gardening, and transport.

Mann-Whitney U test revealed no significant differences between those who chose to continue with unsupervised training compared with those who did not for change in perceived state of health ($U = 53.000$, $p = 0.435$; 0.00 ± 1.50 pts versus 0.00 ± 1.25 pts, resp.), comparison with other seniors ($U = 57.000$, $p = 0.648$; 0.00 ± 0.50 pts versus 0.00 ± 1.50 pts, resp.), WHO-1 ($U = 63.500$, $p = 0.927$; 0.00 ± 1.00 pt versus 0.00 ± 1.25 pts, resp.), WHO-2 ($U = 61.000$, $p = 0.832$; 0.00 ± 1.00 pt versus -0.50 ± 1.25 pts, resp.), WHO-3 ($U = 60.500$, $p = 0.784$; -1.00 ± 2.00 pts versus -0.50 ± 2.00 pts, resp.), WHO-4 ($U = 63.000$, $p = 0.927$; 0.00 ± 1.00 pt versus -0.50 ± 1.25 pts, resp.), WHO-5 ($U = 50.000$, $p = 0.376$; -0.00 ± 1.50 pts versus -1.00 ± 1.00 pt, resp.), and perceived ability to accomplish household chores ($U = 57.000$, $p = 0.648$; 0.00 ± 1.00 pt versus -0.50 ± 1.00 pt, resp.), stair climbing ($U = 63.000$, $p = 0.927$; 0.00 ± 1.50 pts versus 0.50 ± 0.75 pts, resp.), shopping ($U = 61.000$, $p = 0.832$; 0.00 ± 1.00 pt versus 0.00 ± 1.25 pts, resp.), gardening ($U = 49.000$, $p = 0.343$), transport ($U = 49.000$,

FIGURE 6: Rating of perceived exertion during functional tests at preintervention and postintervention period: (a) stair climb, and (b) carrying task.

FIGURE 7: Hand grip strength at preintervention and postintervention period: (a) right and (b) left.

$p = 0.343$; 0.00 ± 1.00 pt versus -0.50 ± 1.50 pts, resp.), and sports ($U = 61.000$, $p = 0.832$; -1.00 ± 1.50 pts versus -1.00 ± 3.25 pts, resp.).

4. Discussion

The present study examined the implementation of a 6-month supervised RT intervention introducing increased effort through progressive application of defined set end points. Over the course of the intervention there were significant changes in strength, body composition, function, and wellbeing outcomes. Participants were also followed up for 6 months after intervention. Over the follow-up period body composition changes reverted to baseline values, strength gains were significantly decreased compared to postintervention period but remained significantly higher than baseline, and questionnaire outcomes were mostly maintained. During the follow-up period participants self-selected whether they wanted to continue participating in RT unsupervised (57% of participants continued). When comparing between the

group that self-selected continuing with RT and those who did not, there appeared to be no significant differences for changes in any outcome measures over the follow-up period. Despite the initial effectiveness of the RT intervention, these data suggest that continuation of RT unsupervised offered no additional benefit to maintaining intervention induced changes compared with cessation of training.

Improvements in strength across the intervention period were significant and large when considering the ESs. Further, individual responses (Figure 2) revealed that all participants increased in strength though the magnitude of change showed considerable interindividual variability. High effort RT has been shown to produce large improvements in strength in older adults even when employed at a low volume and frequency [38]. The results of the present study further support this whilst employing progressive applications of set end points culminating in use of MF and MF + [drop sets]. This is apparently the first study to employ such RT approach in older adults. Fisher et al. [38] reported within-participant ESs for males and females, respectively, of 2.19

and 2.36 for leg press, 1.59 and 1.59 for chest press, and 2.67 and 2.84 for seated row when considering load progression from beginning to end of ~12- or ~19-week RT intervention, respectively, using sDRM as a set end point. The ESs for change in 1RM in the present study were similarly large (2.66, 2.51, and 2.38 for leg press, chest press, and seated row, resp.) though not larger than that reported by Fisher et al. [38] suggesting that employing higher effort set end points such as MF and MF + [drop sets] may not be necessary to maximise strength gains in older adults. However, strength gains are thought to be highly specific to the task being performed during training [55–57]. As such, for comparative purposes the within-participants ESs for increases in training load across the intervention period for the present study were 3.41, 2.84, and 2.67 for leg press, chest press, and seated row, respectively, suggesting benefits for training to MF and MF + [drop sets] compared with just sDRM for leg press and chest press. However, it should be noted that the present study did not directly compare different RT set end points and so further research should examine this in older populations.

Neither body mass, BMI, nor muscle mass changes across the intervention period were significant; however, there were significant decreases in fat mass and fat percentage as well as increased muscle percentage. Studies applying traditional RT approaches of multiple sets performed to an nRM have reported significant changes in body composition in older adults [58]. However, when higher effort set end points have been used (MF) low volume single set RT is similarly effective [59]. Despite the fact that research by Phillips and Ziuraitis [60] has suggested single set approaches require insufficient energy costs to reduce body fat, the set end points applied in their study were unclear (described as volitional fatigue). Prior studies in young adults using low volume and high intensity of effort approaches have shown similar body composition changes to the present study and these have been ascribed to the higher effort set end points used (i.e., MF and MF+) [48, 61]. Indeed, body composition changes appear greater in older individuals with low volume higher effort interventions compared with higher volume lower effort approaches [62, 63]. Though body composition changes are possible with participation in high effort RT it is difficult to ascribe the changes reported in the present study purely to the effects of the intervention. Recent work has shown that older adults tend to spontaneously make other lifestyle changes such as improvements in diet including energy intake and increases in non-RT physical activity when initiating and maintaining an RT intervention [64]. As such, RT could act as a first step in public health approaches in the elderly.

With the exception of right hand grip strength, all functional outcomes improved significantly over the intervention period. Questionnaire data further corroborate these improvements suggesting that participants perceived their general state of health, comparison to other older adults, well-being, and ability to accomplish many functional tasks were significantly improved after the intervention. As noted, functional ability and risk of falling are associated with strength [15, 16] and as such RT is recommended for improving falls

risk, gait ability, and balance in physically frail older adults [17]. The improved functional ability in the present study may therefore have been a result of the significant strength gains produced. Indeed, baseline strength levels are correlated with gait speed and improve with RT [18], and a recent study also reported that the improvements in gait speed as a result of RT are significantly related to gains in lower body strength ($r = 0.45$; $p = 0.04$) [19]. As such, out of curiosity post hoc Pearson's correlation was examined between change in stair climb time and change in leg press 1RM over the intervention period for the present study finding a similar relationship ($r = 0.48$; $p = 0.003$). Despite the apparent relationship between strength and functional ability in older adults the role of improved self-efficacy as a result of participation in the intervention might have impacted upon improved function [65]. Indeed, though functional outcomes were not examined at follow-up, the maintenance of most questionnaire outcomes despite the loss of strength suggested that improvements in perceived function may have been maintained.

During the follow-up period ~57% of participants opted to continue with unsupervised RT, considerably more than those reported by Trappe et al. [44]. The greater maintenance of RT behaviours compared with that reported by Trappe et al. [44] in the present study could be for a number of reasons. Further, though there was a significant loss of 1RM strength for leg press and chest press exercise (though not for seated row) over the follow-up period, strength was still significantly higher than baseline at 6-month follow-up. The same was not the case for body composition changes, all of which returned to baseline levels. The loss of strength and body composition improvements across the follow-up period were not significantly different between those who opted to continue with RT and those who did not. However, though not significantly different, as can be seen from the individual response plots there was considerably greater variation in whether strength was maintained or lost compared with the changes across the intervention period and, further, descriptive statistics suggested that loss of strength was less in the group that continued RT (–98.38 kg versus –154.74 kg, –30.48 kg versus –38.99 kg, and –22.81 kg versus –46.64 kg for leg press, chest press, and seated row, resp.). This did not appear to be the case for the body composition results though with no clear trend for more favourable outcomes in those who continued RT. The loss of strength despite continued RT is interesting considering that prior research has shown that strength gains can be maintained even with a very low RT dose. As noted Trappe et al. [44] reported that the training effort of participants appeared to drop considerably as evidenced by the low number of repetitions being performed with training loads far lighter than during the initial 12-week intervention. Numerous studies have shown that strength and body composition changes are reduced when training without supervision versus training with supervision [66, 67]. Indeed they often train with lower loads and efforts [68, 69] and it has been suggested they likely avoid training to MF [70]. In the present study, at follow-up participants were training with loads lower, but not substantially so, having reduced them by ~2.4% to ~5.5%. As such it seems likely that effort was reduced during follow-up

in the present study by avoidance of set end points resulting in higher effort (i.e., sdRM, MF, and MF+). Indeed, the majority of participants who continued training reported at follow-up to have switched to performing a multiple set (~3 sets) program performed to nRM.

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

5. Conclusions

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

Conflicts of Interest

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

References

- [1] L. Warming, C. Hassager, and C. Christiansen, "Changes in bone mineral density with age in men and women: a longitudinal study," *Osteoporosis International*, vol. 13, no. 2, pp. 105–112, 2002.
- [2] D. B. Burr, "Muscle strength, bone mass, and age-related bone loss," *Journal of Bone and Mineral Research*, vol. 12, no. 10, pp. 1547–1551, 1997.
- [3] I. Janssen, S. B. Heymsfield, Z. Wang, and R. Ross, "Skeletal muscle mass and distribution in 468 men and women aged 18–88 yr," *Journal of Applied Physiology*, vol. 89, no. 1, pp. 81–88, 2000.
- [4] I. Janssen, S. B. Heymsfield, and R. Ross, "Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability," *Journal of the American Geriatrics Society*, vol. 50, no. 5, pp. 889–896, 2002.
- [5] M. D. Fitzgerald, H. Tanaka, Z. V. Tran, and D. R. Seals, "Age-related declines in maximal aerobic capacity in regularly exercising vs. sedentary women: A meta-analysis," *Journal of Applied Physiology*, vol. 83, no. 1, pp. 160–165, 1997.
- [6] T. M. Wilson and H. Tanaka, "Meta-analysis of the age-associated decline in maximal aerobic capacity in men: relation to training status," *The American Journal of Physiology—Heart and Circulatory Physiology*, vol. 278, no. 3, pp. H829–H834, 2000.
- [7] World Health Organisation, "Global Recommendations on Physical Activity for Health: 65 years and above, 2011," <http://www.who.int/dietphysicalactivity/physical-activity-recommendations-65years.pdf?ua=1>.
- [8] C. Drenowatz, X. Sui, S. Fritz et al., "The association between resistance exercise and cardiovascular disease risk in women," *Journal of Science and Medicine in Sport*, vol. 18, no. 6, pp. 632–636, 2015.
- [9] J. L. Kraschnewski, C. N. Sciamanna, J. M. Poger et al., "Is strength training associated with mortality benefits? A 15 year cohort study of US older adults," *Preventive Medicine*, vol. 87, pp. 121–127, 2016.
- [10] B. F. Hurley and S. M. Roth, "Strength training in the elderly: effects on risk factors for age-related diseases," *Sports Medicine*, vol. 30, no. 4, pp. 249–268, 2000.
- [11] D. I. Lovell, R. Cuneo, and G. C. Gass, "Strength training improves submaximum cardiovascular performance in older men," *Journal of Geriatric Physical Therapy*, vol. 32, no. 3, pp. 117–124, 2009.
- [12] P. Frank, E. Andersson, M. Pontén, B. Ekblom, M. Ekblom, and K. Sahlin, "Strength training improves muscle aerobic capacity and glucose tolerance in elderly," *Scandinavian Journal of Medicine and Science in Sports*, vol. 26, no. 7, pp. 764–773, 2016.
- [13] W.-L. Chen, T.-C. Peng, Y.-S. Sun et al., "Examining the association between quadriceps strength and cognitive performance in the elderly," *Medicine (United States)*, vol. 94, no. 32, Article ID e1335, 2015.
- [14] P. Freudenberger, K. Petrovic, A. Sen et al., "Fitness and cognition in the elderly: The Austrian Stroke Prevention Study," *Neurology*, vol. 86, no. 5, pp. 418–424, 2016.
- [15] L. Z. Rubenstein, "Falls in older people: epidemiology, risk factors and strategies for prevention," *Age and Ageing*, vol. 35, supplement 2, pp. ii37–ii41, 2006.
- [16] N. D. M. Jenkins, S. L. Buckner, H. C. Bergstrom et al., "Reliability and relationships among handgrip strength, leg extensor strength and power, and balance in older men," *Experimental Gerontology*, vol. 58, pp. 47–50, 2014.

- [17] E. L. Cadore, L. Rodríguez-Mañas, A. Sinclair, and M. Izquierdo, "Effects of different exercise interventions on risk of falls, gait ability, and balance in physically frail older adults: a systematic review," *Rejuvenation Research*, vol. 16, no. 2, pp. 105–114, 2013.
- [18] M. A. Fiatarone, E. C. Marks, N. D. Ryan, C. N. Meredith, L. A. Lipsitz, and W. J. Evans, "High-intensity strength training in nonagenarians. Effects on skeletal muscle," *Journal of the American Medical Association*, vol. 263, no. 22, pp. 3029–3034, 1990.
- [19] L. Santos, A. S. Ribeiro, B. J. Schoenfeld et al., "The improvement in walking speed induced by resistance training is associated with increased muscular strength but not skeletal muscle mass in older women," *European Journal of Sport Science*, 2017.
- [20] P. Srikanthan and A. S. Karlamangla, "Muscle mass index as a predictor of longevity in older adults," *American Journal of Medicine*, vol. 127, no. 6, pp. 547–553, 2014.
- [21] P. Srikanthan, T. B. Horwich, and C. H. Tseng, "Relation of Muscle Mass and Fat Mass to Cardiovascular Disease Mortality," *American Journal of Cardiology*, vol. 117, no. 8, pp. 1355–1360, 2016.
- [22] K. A. Volaklis, M. Halle, B. Thorand et al., "Handgrip strength is inversely and independently associated with multimorbidity among older women: Results from the KORA-Age study," *European Journal of Internal Medicine*, vol. 31, pp. 35–40, 2016.
- [23] A. B. Newman, V. Kupelian, M. Visser et al., "Strength, but not muscle mass, is associated with mortality in the health, aging and body composition study cohort," *Journals of Gerontology A: Biological Sciences and Medical Sciences*, vol. 61, no. 1, pp. 72–77, 2006.
- [24] P. D. Loprinzi, "Lower extremity muscular strength, sedentary behavior, and mortality," *Age*, vol. 38, no. 2, article no. 32, 2016.
- [25] A. Guadalupe-Grau, J. A. Carnicero, A. Gómez-Cabello et al., "Association of regional muscle strength with mortality and hospitalisation in older people," *Age and Ageing*, vol. 44, no. 5, Article ID afv080, pp. 790–795, 2015.
- [26] B. H. Strand, R. Cooper, A. Bergland et al., "The association of grip strength from midlife onwards with all-cause and cause-specific mortality over 17 years of follow-up in the Tromsø Study," *Journal of Epidemiology and Community Health*, vol. 70, no. 12, pp. 1214–1221, 2016.
- [27] P. Kokkinos, Jonathan Myers, John Peter Kokkinos et al., "Exercise capacity and mortality in black and white men," *Circulation*, vol. 117, no. 5, pp. 614–622, 2008.
- [28] P. Kokkinos, J. Myers, C. Faselis et al., "Exercise capacity and mortality in older men: a 20-year follow-up study," *Circulation*, vol. 122, no. 8, pp. 790–797, 2010.
- [29] J. Prestes, D. da Cunha Nascimento, R. A. Tibana et al., "Understanding the individual responsiveness to resistance training periodization," *Age*, vol. 37, no. 3, article no. 55, 2015.
- [30] T. A. Churchward-Venne, M. Tieland, L. B. Verdijk et al., "There are no nonresponders to resistance-type exercise training in older men and women," *Journal of the American Medical Directors Association*, vol. 16, no. 5, pp. 400–411, 2015.
- [31] A. Paoli, "Resistance training: The multifaceted side of exercise," *American Journal of Physiology - Endocrinology and Metabolism*, vol. 302, no. 3, p. 387, 2012.
- [32] N. L. Silva, R. B. Oliveira, S. J. Fleck, A. C. Leon, and P. Farinatti, "Influence of strength training variables on strength gains in adults over 55 years-old: a meta-analysis of dose-response relationships," *Journal of Science and Medicine in Sport*, vol. 17, no. 3, pp. 337–344, 2014.
- [33] R. Borde, T. Hortobágyi, and U. Granacher, "Dose-Response Relationships of Resistance Training in Healthy Old Adults: A Systematic Review and Meta-Analysis," *Sports Medicine*, vol. 45, no. 12, pp. 1693–1720, 2015.
- [34] J. Fisher, J. Steele, S. Bruce-Low, and D. Smith, "Evidence-based resistance training recommendations," *Medicina Sportiva*, vol. 15, no. 3, pp. 147–162, 2011.
- [35] J. Fisher, J. Steele, and D. Smith, "Evidence-based resistance training recommendations for muscular hypertrophy," *Medicina Sportiva*, vol. 17, no. 4, pp. 217–235, 2013.
- [36] J. Steele, J. Fisher, J. Giessing, and P. Gentil, "Clarity in reporting terminology and definitions of set endpoints in resistance training," *Muscle & Nerve*, 2017.
- [37] W. R. Martins, M. P. Safons, M. Bottaro et al., "Effects of short term elastic resistance training on muscle mass and strength in untrained older adults: a randomized clinical trial," *BMC Geriatrics*, vol. 15, no. 1, article no. 101, pp. 1–10, 2015.
- [38] J. Fisher, J. Steele, P. McKinnon, and S. McKinnon, "Strength gains as a result of brief, infrequent resistance exercise in older adults," *Journal of Sports Medicine*, vol. 2014, Article ID 731890, 2014.
- [39] J. Steele, J. Fisher, S. McKinnon, and P. McKinnon, "Differentiation between perceived effort and discomfort during resistance training in older adults: Reliability of trainee ratings of effort and discomfort, and reliability and validity of trainer ratings of trainee effort," *Journal of Trainology*, vol. 6, no. 1, pp. 1–8, 2016.
- [40] E. Van Roie, C. Delecluse, W. Coudyzer, S. Boonen, and I. Bautmans, "Strength training at high versus low external resistance in older adults: effects on muscle volume, muscle strength, and force-velocity characteristics," *Experimental Gerontology*, vol. 48, no. 11, pp. 1351–1361, 2013.
- [41] A. R. Assunção, M. Bottaro, J. B. Ferreira-Junior, M. Izquierdo, E. L. Cadore, and P. Gentil, "The chronic effects of low- and high-intensity resistance training on muscular fitness in adolescents," *PLoS ONE*, vol. 11, no. 8, Article ID e0160650, 2016.
- [42] R. W. Morton, S. Y. Oikawa, C. G. Wavell et al., "Neither load nor systemic hormones determine resistance training-mediated hypertrophy or strength gains in resistance-trained young men," *Journal of Applied Physiology*, vol. 121, no. 1, pp. 129–138, 2016.
- [43] E. Van Roie, I. Bautmans, W. Coudyzer, F. Boen, and C. Delecluse, "Low- and high-resistance exercise: Long-term adherence and motivation among older adults," *Gerontology*, vol. 61, no. 6, pp. 551–560, 2015.
- [44] S. Trappe, D. Williamson, and M. Godard, "Maintenance of whole muscle strength and size following resistance training in older men," *Journals of Gerontology - Series A Biological Sciences and Medical Sciences*, vol. 57, no. 4, pp. B138–B143, 2002.
- [45] J. P. Fisher, M. Ironside, and J. Steele, "Heavier and lighter load resistance training to momentary failure produce similar increases in strength with differing degrees of discomfort," *Muscle & Nerve*, 2017.
- [46] R. A. Winett, D. M. Williams, and B. M. Davy, "Initiating and maintaining resistance training in older adults: a social cognitive theory-based approach," *The British Journal of Sports Medicine*, vol. 43, no. 2, pp. 114–119, 2009.
- [47] J. Giessing, *High Intensity Training (HIT): How to Build Muscles in Minutes - Fast Efficient And Healthy*, Herstellung & Verlag, Norderstedt, Germany, 2016.
- [48] J. Giessing, B. Eichmann, J. Steele, and J. Fisher, "A comparison of low volume 'high-intensity-training' and high volume traditional resistance training methods on muscular performance,

- body composition, and subjective assessments of training," *Biology of Sport*, vol. 33, no. 3, pp. 241–249, 2016.
- [49] F. Faul, E. Erdfelder, A. Lang, and A. Buchner, "G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences," *Behavior Research Methods*, vol. 39, no. 2, pp. 175–191, 2007.
- [50] F. Faul, E. Erdfelder, A. Buchner, and A.-G. Lang, "Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses," *Behavior Research Methods*, vol. 41, no. 4, pp. 1149–1160, 2009.
- [51] S. Leahy, C. O'Neill, R. Sohun, and P. Jakeman, "A comparison of dual energy X-ray absorptiometry and bioelectrical impedance analysis to measure total and segmental body composition in healthy young adults," *European Journal of Applied Physiology*, vol. 112, no. 2, pp. 589–595, 2012.
- [52] T. R. Baechle and R. W. Earle, *Essentials of Strength and Conditioning*, Human Kinetics, Champaign, IL, 2008.
- [53] M. Brzycki, "Strength testing predicting a one-rep max from reps-to-fatigue," *Recreation & Dance*, vol. 64, pp. 88–90, 1993.
- [54] E. E. Fess and C. Moran, *Clinical Assessment Recommendations*, American Society of Hand Therapists, Indianapolis, 1981.
- [55] J. Fisher, J. Steele, and D. Smith, "High- and low-load resistance training: Interpretation and practical application of current research findings," *Sports Medicine*, vol. 47, no. 3, pp. 393–400, 2017.
- [56] S. L. Buckner, M. B. Jessee, K. T. Mattocks et al., "Determining Strength: A Case for Multiple Methods of Measurement," *Sports Medicine*, vol. 47, no. 3, pp. 193–195, 2017.
- [57] P. Gentil, F. B. Del Vecchio, A. Paoli, B. J. Schoenfeld, and M. Bottaro, "Isokinetic dynamometry and 1RM tests produce conflicting results for assessing alterations in muscle strength," *Journal of Human Kinetics*, vol. 56, no. 1, pp. 19–27, 2017.
- [58] E. F. Binder, K. E. Yarasheski, K. Steger-May et al., "Effects of progressive resistance training on body composition in frail older adults: Results of a randomized, controlled trial," *Journal of Gerontology Series A: Biological Sciences and Medical Sciences*, vol. 60, no. 11, pp. 1425–1431, 2005.
- [59] D. A. Galvão and D. R. Taaffe, "Resistance exercise dosage in older adults: Single-versus multiset effects on physical performance and body composition," *Journal of the American Geriatrics Society*, vol. 53, no. 12, pp. 2090–2097, 2005.
- [60] W. T. Phillips and J. R. Zouraitis, "Energy cost of single-set resistance training in older adults," *Journal of Strength and Conditioning Research*, vol. 18, no. 3, pp. 606–609, 2004.
- [61] J. Giessing, J. Fisher, J. Steele, F. Rothe, K. Raubold, and B. Eichmann, "The effects of low-volume resistance training with and without advanced techniques in trained subjects," *Journal of Sports Medicine and Physical Fitness*, vol. 56, no. 3, pp. 249–258, 2016.
- [62] A. Paoli, F. Pacelli, A. M. Bargossi et al., "Effects of three distinct protocols of fitness training on body composition, strength and blood lactate," *Journal of Sports Medicine and Physical Fitness*, vol. 50, no. 1, pp. 43–51, 2010.
- [63] A. Paoli, Q. F. Pacelli, T. Moro et al., "Effects of high-intensity circuit training, low-intensity circuit training and endurance training on blood pressure and lipoproteins in middle-aged overweight men," *Lipids in Health and Disease*, vol. 12, no. 1, article 131, 2013.
- [64] T. M. Halliday, J. Tina Savla, E. L. Marinik et al., "Influence of resistance training initiation and maintenance on spontaneous dietary intake changes among prediabetes adult: 2131 Board #283 Jun 2, 3:30 PM – 5:00PM," *Medicine & Science in Sports & Exercise*, vol. 48, p. 601, 2016.
- [65] W. J. Rejeski, A. C. King, J. A. Katula et al., "Physical activity in prefrail older adults: confidence and satisfaction related to physical function," *Journal of Gerontology Series B: Psychological Sciences and Social Sciences*, vol. 63, no. 1, pp. P19–P26, 2008.
- [66] A. J. Coutts, A. J. Murphy, and B. J. Dascombe, "Effect of direct supervision of a strength coach on measures of muscular strength and power in young rugby league players," *Journal of Strength and Conditioning Research*, vol. 18, no. 2, pp. 316–323, 2004.
- [67] S. A. Mazzetti, W. J. Kraemer, J. S. Volek et al., "The influence of direct supervision of resistance training on strength performance," *Medicine and Science in Sports and Exercise*, vol. 32, no. 6, pp. 1175–1184, 2000.
- [68] S. C. Glass and D. R. Stanton, "Self-selected resistance training intensity in novice weightlifters," *Journal of Strength and Conditioning Research*, vol. 18, no. 2, pp. 324–327, 2004.
- [69] H. M. Elsangedy, M. P. Krause, K. Krinski, R. C. Alves, C. H. N. Chao, and S. G. Da Silva, "Is the self-selected resistance exercise intensity by older women consistent with the American college of sports medicine guidelines to improve muscular fitness?" *Journal of Strength and Conditioning Research*, vol. 27, no. 7, pp. 1877–1884, 2013.
- [70] P. Gentil and M. Bottaro, "Influence of supervision ratio on muscle adaptations to resistance training in nontrained subjects," *Journal of Strength and Conditioning Research*, vol. 24, no. 3, pp. 639–643, 2010.
- [71] L. Bosquet, N. Berryman, O. Dupuy et al., "Effect of training cessation on muscular performance: A meta-analysis," *Scandinavian Journal of Medicine and Science in Sports*, vol. 23, no. 3, pp. e140–e149, 2013.
- [72] E. L. Cadore, A. B. B. Moneo, M. M. Mensat et al., "Positive effects of resistance training in frail elderly patients with dementia after long-term physical restraint," *Age*, vol. 36, no. 2, pp. 801–811, 2014.