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When Matched for Relative Leg Strength at Baseline, Male and Female Older Adults Respond Similarly to Concurrent Aerobic and Resistance Exercise Training

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Abstract

Timmons, JF, Hone, M, Duffy, O, and Egan, B. When matched for relative leg strength at baseline, male and female older adults respond similarly to concurrent aerobic and resistance exercise training. *J Strength Cond Res* XX(X): 000–000, 2021—Comparisons between sexes of adaptive responses with concurrent aerobic and resistance exercise training are largely unexplored. A supervised 12 weeks intervention of concurrent exercise training was used to investigate sex-specific differences, if any, in the response to concurrent exercise training in older adults. Community-dwelling men ($n = 14$; 68.0 ± 1.8 years; 27.8 ± 3.8 $\text{kg}\cdot\text{m}^{-2}$) and women ($n = 14$; 68.9 ± 3.8 years; 25.1 ± 3.8 $\text{kg}\cdot\text{m}^{-2}$) were pair-matched for relative leg strength expressed as leg press 1 repetition maximum per kg of leg lean body mass (LBM; assessed by dual-energy X-ray absorptiometry). Subjects undertook 24 minutes of concurrent aerobic (12 minutes) and resistance (12 minutes) exercise training 3 times per week i.e., 72 minutes of active exercise time per week. Muscle strength, physical function, and body composition were assessed before (PRE) and after 12 weeks (POST) of exercise training. The increase in absolute leg press strength was larger in men (mean difference ± *SE*, 25.3 ± 11.8 kg; $p = 0.041$, $\eta_p^2 = 0.156$), but when expressed as leg press strength relative to leg LBM, training-induced increases were not different between the sexes (mean difference ± *SE*, 0.30 ± 0.46 $\text{kg}\cdot\text{kg}^{-1}$; $p = 0.526$, $\eta_p^2 = 0.016$). No other measure of muscle strength (hand-grip and chest press), physical function (gait speed, timed-up-and-go, sit-to-stand, and Chester step test), or body composition (LBM and fat mass) differed in response to exercise training for between-sex comparisons. When male and female older adults are pair matched for relative leg strength at baseline before commencing exercise training, sex-specific adaptive responses to concurrent aerobic and resistance exercise training are largely similar for muscle strength, physical function, and body composition.

Key Words: aerobic fitness, body composition, combined training, lean body mass, physical function

Introduction

Both aerobic and resistance exercise training have efficacy in the prevention and treatment of age-related declines in skeletal muscle mass, strength, and physical function (26,45) and are the basis of recommendations for maintaining skeletal muscle health in older adults (7). However, much of the focus of exercise interventions in older adults has been on resistance exercise training alone (3,43), despite the obvious therapeutic value of concurrent aerobic and resistance exercise training (5,13,26,45,48). Notably, this combination can simultaneously target improvements in muscle strength, aerobic fitness, and physical function in older adults in a time-efficient manner (5,45,48).

Because there are sex-specific differences in a variety of paradigms related to skeletal muscle physiology and function with advancing age (6,18), it is relevant to consider whether there are sex-specific differences in the response to exercise training. Such findings may in turn inform more specific exercise prescription for older men and women. To this end, sex-specific differences in the response to exercise training in older adults has been the subject of several studies of resistance exercise training (1,8,12,17,22,24,25,28,30,35,46). Overall, the results are equivocal for whether responses are different between the sexes, especially given that the interpretation depends on the parameter of interest (e.g., strength or hypertrophy), and whether considering the response to training in absolute or relative terms (8,17,22,24,28,30,35,46), which may also be a function of the duration of training intervention (1,8,12,28).

At the same body mass, men tend to have lower body fat, and greater lean body mass (LBM) and muscle strength (15). However, strength expressed relative to muscle mass or cross-sectional area is largely similar in men and women (15,33). Therefore, an appropriate strategy for comparing responses to exercise training may be to pair match male and female subjects for relative muscle strength at baseline, but to the best of our knowledge, this approach has not been used previously in older adults. Moreover,

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only 2 previous studies have formally compared responses with concurrent aerobic and resistance exercise training between older men and women (26,41). Neither study observed a difference between the sexes for increases in muscle strength in response to exercise training, but 1 study used a small sample size (n = 7 of each sex) (41), and the other study only measured strength as an isometric measure (26). In these 2 studies, and in many of the prior between-sex comparison studies of resistance training in older adults, commonly used tests of physical function, such as the Short Physical Performance Battery (20), have not been assessed alongside traditional strength measures. Therefore, the aim of this study was to investigate whether sex-specific differences exist in response to concurrent aerobic and resistance exercise training in older adults when male and female subjects are pair matched for relative leg strength at baseline before commencing the training intervention.

Methods

Experimental Approach to the Problem

A parallel group with matched pairs, pre-post design comprising a 12-week concurrent aerobic and resistance exercise training intervention in male and female older adults was used. An a priori sample size calculation (G*Power v3.1) required a sample size of 26 subjects based on a 2 group design (n = 13 per group) assuming to detect a "large" effect size (partial eta squared [η_p^2] = 0.25) for a given parameter at a type I error rate (α) of 0.05 and a power ($1-\beta$) of 0.8. The primary outcome was change from PRE to POST in 1 repetition maximum (1RM) leg press strength relative to leg LBM compared between groups. Lower limb strength was chosen as the primary outcome and basis for pair matching at baseline because of the observation of the age-related declines in muscle mass, muscle strength, and power being greater for the lower compared with upper limbs (16,33), and role of declining lower limb strength in the etiology of sarcopenia (10). Secondary outcomes included changes in other measures of muscle strength, physical function, body mass, and composition assessed both within-groups and between-groups. These assessments were performed before (PRE) and after 12 (POST) weeks of intervention.

Subjects

All experimental procedures were approved by the University College Dublin Research Ethics Committee in accordance with the *Declaration of Helsinki*. Subjects provided written informed consent before participation. Recruitment was primarily through the University College Dublin Alumni newsletter seeking men and women aged ≥65 years who were medically stable (19), free-living, fully mobile, and capable of completing the proposed intervention. Subjects were excluded if they reported a history of myocardial infarction, cardiac illness, vascular disease, uncontrolled metabolic disease, stroke, or major systemic disease or if already engaging in 2 or more structured exercise training sessions per week.

After assessment at PRE, a sample size of female subjects (n = 15) was finalized, after which pair matching with male subjects was performed from a cohort of n = 24 males assessed at PRE. Pair matching was based on <5% difference between male and female pairs for relative leg strength, with secondary matching based on <5% difference in age. After finalizing the respective n = 15 cohorts, the exercise training program commenced as fully supervised, small group (n = 4–6) training, and without a requirement for sexes or pairs to train exclusively together. One female subject withdrew from the study during the training intervention, and therefore, this male-female pair was removed from the analysis resulting in a final sample size of n = 14 per group (Table 1).

Procedures

Assessments. The assessment procedure was identical in content and sequence at PRE and POST, and performed over 2 consecutive days at each time point by the same personnel. On day 1, subjects arrived to the laboratory after an overnight fast (>8 hours) and minimal morning ambulation. Body mass (to the nearest 0.05 kg) using a calibrated digital scale (SECA, Germany), height (to the nearest 0.01 m) using a wall-mounted stadiometer (Holtain, United Kingdom), and body composition by dual-energy X-ray absorptiometry (DXA; Lunar iDXA, GE Healthcare, Chicago, IL) were measured. Regional measures of body composition including trunk fat and LBM of the upper and lower limbs (arms and legs, respectively) were obtained from the DXA scan analysis. Hand-grip strength of the dominant hand was then measured to the nearest 0.5 kg using a hydraulic hand dynamometer (JAMAR) (38). Lower-body physical function was assessed using the 8 foot (2.4 m) timed-up-and-go test (34), and the Short Physical Performance Battery (SPPB) consisting of habitual gait speed (3 m), standing balance (nontandem, semi-tandem, and tandem), and 5 repetition sit-to-stand (20). Aerobic fitness was assessed using the Chester Step Test (44). On day 2, subjects reported to the exercise training facility (Medfit Proactive Healthcare, Dublin) for the assessment of lower and upper limb strength by 1RM on leg press and chest press machines, respectively (Milon, Germany). One week before the assessment at PRE, a familiarization session was performed, wherein the correct lifting technique was demonstrated and practiced for each exercise, after which maximum strength was estimated using the multiple repetitions testing procedure. This, in turn, informed the subsequent assessment of 1RM performed at PRE. Relative strength for chest press and leg press were calculated as absolute strength (kg) measured from the 1RM tests expressed per kg of LBM of the arms for chest press and per kg of LBM of the legs for leg press.

Exercise Training Intervention. The exercise training intervention was fully supervised and consisted of 3 exercise sessions per week (Monday, Wednesday, and Friday) of concurrent aerobic and resistance exercise training lasting ~40 minutes per session, which included a standardized warm-up and cool down. The warm-up used RAMP principles (R, raise heart rate and core/muscle temperature; A, activate musculature, M, mobilization of joints to create full range of motion; and P, potentiate/increase intensity in preparation for the exercise protocol) over the course of 5 minutes including 3 minutes of low-to-moderate intensity aerobic exercise and 2 minutes of low intensity body mass movements/calisthenics. The cool down was 5 minutes in duration consisting of low-intensity body mass movements/calisthenics and walking to gradually lower heart rate, and incorporated static stretching of the major muscle groups of the upper and lower limbs. All training sessions were supervised and performed on the Milon Circle (Milon). Each session consisted 3 × 4 min intervals of aerobic exercise (Cross Trainer and Stationary Cycle Ergometer) and 2 rounds of the 6 resistance exercise

Table 1

Subject characteristics at baseline (PRE).*†

	Male (*n* = 14)	Female (*n* = 14)	*p*
Age (y)	68.0 ± 1.8	68.9 ± 3.8	0.485
Anthropometry			
Height (m)	1.76 ± 0.05	1.63 ± 0.07	<0.001
Body mass (kg)	86.3 ± 12.2	66.2 ± 8.7	<0.001
BMI ($kg\cdot m^{-2}$)	27.8 ± 3.8	25.1 ± 3.8	0.070
Body composition			
Body fat (%)	29.6 ± 6.6	38.5 ± 5.9	<0.001
Fat mass (kg)	25.1 ± 9.7	25.2 ± 6.7	0.978
Trunk fat (kg)	20.9 ± 8.1	16.6 ± 3.5	0.076
LBM (kg)	57.3 ± 3.3	38.5 ± 2.4	<0.001
ALM (kg)	26.22 ± 2.06	16.77 ± 1.51	<0.001
Physical function and muscle strength			
Gait speed ($m\cdot s^{-1}$)	1.66 ± 0.29	1.54 ± 0.26	0.276
TUGT (s)	6.00 ± 1.12	6.03 ± 1.01	0.926
Sit-to-stand (s)	11.06 ± 2.71	11.50 ± 2.59	0.660
CST (bpm)	121 ± 15	129 ± 10	0.132
Hand-grip strength (kg)	40.4 ± 7.7	26.1 ± 4.6	<0.001
1RM leg press (kg)	134.3 ± 26.5	91.8 ± 18.1	<0.001
Relative leg press ($kg\cdot kg^{-1}$)	7.03 ± 1.42	7.21 ± 1.42	0.735
1RM chest press (kg)	52.4 ± 7.4	27.3 ± 5.5	<0.001
Relative chest press ($kg\cdot kg^{-1}$)	7.47 ± 1.13	6.87 ± 1.28	0.200

*1RM = 1 repetition maximum; ALM = appendicular lean mass; BMI = body mass index; CST = Chester step test; LBM = lean body mass; TUGT = timed-up-and-go-test.

†Relative strength is absolute strength expressed per kg of LBM of the arms for chest press, and per kg of LBM of the legs for leg press. *p* values are reported from independent samples *t*-tests.

circuit (leg press, seated row, chest press, lat pulldown, leg extension, and tricep dips). The aerobic and resistance exercises were interspersed by having subjects complete 3 resistance exercises, followed by one 4 minutes interval of aerobic exercise, and repeating this pattern twice before concluding with 3 resistance exercises. A rest period of 30 seconds was taken in between each set of resistance exercise or interval of aerobic exercise.

For the aerobic exercise modes, the power output was adjusted to elicit a target intensity of 80% of age-predicted maximum heart rate for each 4 minutes interval throughout the training intervention to ensure that a progressive overload was continuously provided. For the resistance exercises, subjects commenced training for weeks 1–4 with the prescription of 15 tempo-controlled repetitions of a given exercise in a 60 seconds period. The tempo for each 4 seconds repetition comprised of a 2 seconds eccentric movement, a 1 second pause, and a 1 second concentric movement and no pause between repetitions. For weeks 5–8, the prescription was adjusted to 12 tempo-controlled repetitions of a given exercise in a 60 seconds period. The tempo for each 5 seconds repetition comprised a 3 seconds eccentric movement, a 1 second pause, and a 1 second concentric movement and no pause between repetitions. For weeks 9–12, the prescription was adjusted to 10 tempo-controlled repetitions of a given exercise in a 60 seconds period. The tempo for each 6 seconds repetition comprised a 4 seconds eccentric movement, a 1 second pause, and a 1 second concentric movement and no pause between repetitions. Subjects began the training intervention at ~60% of 1RM, but once an exercise could be completed comfortably for the 60 seconds period, an ~5% increment in weight to be lifted was added for the next training session to provide a progressive overload. For the weeks 5–8, and weeks 9–12, the load lifted was not prescribed based on %1RM but was manually adjusted by the practitioner according to the ability of each subject at the new prescription for repetitions/tempo, after which progressive overload was applied as described. The compliance with set duration and tempo was facilitated by the presence of a metronome and timer visible to subjects on a digital display on each resistance training machine.

With 12 minutes of aerobic exercise and 12 minutes of resistance exercise, each training session, therefore, consisted of 24 minutes of active exercise, for a total of 72 minutes of active exercise each week (36 minutes aerobic exercise and 36 minutes resistance exercise). This exercise training program has been previously shown to elicit improvements in a range of measures of muscle strength, physical function, and body composition in older adults (45). Subjects were encouraged to continue their habitual diet throughout the intervention period, but dietary intake was not monitored, and should therefore be considered as ad libitum intake.

Statistical Analyses

Data were analyzed using Jamovi v1.2 (The Jamovi Project, Australia) and illustrated using GraphPad Prism v8.4 (GraphPad Software, Inc.). Subject characteristics were compared between groups at PRE using an independent samples t-test, and data are reported as mean ± *SD*. Univariate analysis of covariance (ANCOVA), with values at PRE for a respective outcome parameter as a covariate, was used to investigate differences between groups at POST for all primary and secondary outcome parameters. For change from PRE within groups, differences were assessed by paired t-tests, and data are reported as mean difference (lower, upper 95% confidence limit of the mean difference), whereas for change from PRE between groups, estimated marginal means at POST from the ANCOVA analysis are reported as mean ± *SE*. Although ANCOVA is the most appropriate statistical approach for this study design (40,47), because of the practical value of interindividual and %change data, these data are included as Supplemental Digital Content 1 (see Figure 1 and Table 1, http://links.lww.com/JSCR/A254). For all null hypothesis statistical testing, statistical significance was accepted at $p \leq 0.05$. Standardized differences in the mean were used to assess magnitudes of effects for within-group changes from PRE to POST. These effect sizes were calculated using Cohen's *d*, and interpreted as trivial for <0.2, small for ≥0.2 to <0.5, moderate for ≥0.5 to <0.8, and large for ≥0.8. Estimates of the effect size from the ANCOVA analysis were determined using partial eta squared (η_p^2) with thresholds of ≥0.0099, ≥0.0588, and ≥0.1379 interpreted as small, moderate, and large effects, respectively, as recommended by Cohen and discussed elsewhere (37).

Results

At PRE, men were taller and heavier, had more LBM and lower percentage body fat, and stronger hand-grip strength (Table 1). Absolute strength in the upper and lower limbs was greater in men, but as per the pair-matched design, there was no difference between groups for relative leg press strength, nor was there a difference between groups in relative chest press strength (Table 1). Similarly, other measures of lower limb physical function were not significantly different at PRE, namely gait speed, sit-to-stand, and timed-up-and-go (Table 1).

Attendance at training sessions was 87.4 ± 5.8% (range 80–97%) in men (range 80–97%) and 88.8 ± 5.0% (range 80–97%) in women ($p = 0.488$). All measures of muscle strength and physical function were increased by the training intervention in both groups (Table 2). After adjustment for the value of the

Table 2

Changes from PRE to POST in body composition, physical function, and muscle strength in response to the 12 weeks of concurrent aerobic and resistance exercise training in male and female older adults.*†

	Within-group differences: change from PRE		Between-group differences: ANCOVA-adjusted means at POST		
	Male ($n = 14$)	Female ($n = 14$)	Male ($n = 14$)	Female ($n = 14$)	ANCOVA
Body composition					
Body mass (kg)	−1.04 (−0.06 to −2.02)‡ $d = 0.61$	−0.09 (−0.76 to 0.58) $d = 0.08$	76.0 ± 0.4	75.5 ± 0.4	$p = 0.460$ $\eta_p^2 = 0.022$
Body fat (%)	−0.67 (−0.07 to −1.27)‡ $d = 0.64$	−0.72 (−0.22 to −1.23)§ $d = 0.83$	33.2 ± 0.3	33.5 ± 0.3	$p = 0.582$ $\eta_p^2 = 0.012$
Fat mass (kg)	−0.83 (−0.16 to −1.50)‡ $d = 0.71$	−0.54 (−0.01 to −1.06)‡ $d = 0.59$	24.3 ± 0.2	24.6 ± 0.2	$p = 0.353$ $\eta_p^2 = 0.035$
Trunk fat (kg)	−0.56 (−0.06 to −1.06)‡ $d = 0.64$	−0.18 (-0.59 to 0.24) $d = 0.31$	18.2 ± 0.2	18.6 ± 0.2	$p = 0.174$ $\eta_p^2 = 0.073$
LBM (kg)	0.19 (−0.45 to 0.84) $d = 0.17$	0.46 (0.09 to 0.83)‡ $d = 0.72$	47.9 ± 0.6	48.5 ± 0.6	$p = 0.645$ $\eta_p^2 = 0.009$
ALM (kg)	0.02 (−0.46 to 0.50) $d = 0.03$	0.20 (−0.08 to 0.47) $d = 0.42$	22.2 ± 0.4	21.0 ± 0.4	$p = 0.103$ $\eta_p^2 = 0.103$
Physical function and muscle strength					
Gait speed ($m \cdot s^{-1}$)	0.31 (0.15 to 0.47)‖ $d = 1.13$	0.32 (0.17 to 0.48)‖ $d = 1.21$	1.92 ± 0.07	1.91 ± 0.07	$p = 0.921$ $\eta_p^2 = 0.000$
TUGT (s)	−0.86 (−0.36 to −1.35)§ $d = 1.00$	−0.92 (−0.39 to −1.44)§ $d = 1.01$	5.15 ± 0.18	5.11 ± 0.18	$p = 0.885$ $\eta_p^2 = 0.001$
Sit-to-stand (s)	−2.11 (−0.86 to −3.36)§ $d = 0.97$	−2.49 (−1.31 to −3.67)§ $d = 1.22$	9.05 ± 0.41	8.92 ± 0.41	$p = 0.822$ $\eta_p^2 = 0.003$
CST (bpm)	−7.8 (−3.5 to −12.0)§ $d = 1.07$	−6.6 (−0.1 to −13.0)‡ $d = 0.59$	115.7 ± 2.4	119.2 ± 2.4	$p = 0.315$ $\eta_p^2 = 0.040$
Hand-grip strength (kg)	2.8 (0.2 to 5.4)‡ $d = 0.62$	3.6 (1.8 to 5.4)‖ $d = 1.17$	36.2 ± 1.4	36.8 ± 1.4	$p = 0.800$ $\eta_p^2 = 0.003$
1RM leg press (kg)	37.0 (21.7 to 52.3)‖ $d = 1.40$	21.1 (10.9 to 31.2)‖ $d = 1.20$	154.6 ± 7.2	129.3 ± 7.2	$p = 0.041$¶ $\eta_p^2 = 0.156$
Relative leg press ($kg \cdot kg^{-1}$)	1.95 (1.16 to 2.73)‖ $d = 1.43$	1.57 (0.78 to 2.35)‖ $d = 1.16$	9.02 ± 0.33	8.73 ± 0.33	$p = 0.526$ $\eta_p^2 = 0.016$
1RM chest press (kg)	7.9 (4.7 to 11.1)‖ $d = 1.42$	7.1 (4.9 to 9.4)‖ $d = 1.83$	48.3 ± 2.3	46.3 ± 2.3	$p = 0.641$ $\eta_p^2 = 0.009$
Relative chest press ($kg \cdot kg^{-1}$)	0.92 (0.46 to 1.38)‖ $d = 1.15$	1.47 (1.06 to 1.87)‖ $d = 2.10$	8.09 ± 0.21	8.63 ± 0.21	$p = 0.083$ $\eta_p^2 = 0.115$

*1RM = 1 repetition maximum; ALM = appendicular lean mass; BMI = body mass index; CST = Chester step test; LBM = lean body mass; TUGT = timed-up-and-go-test; ANCOVA = analysis of covariance; CL = confidence limit.

†Data are reported as mean difference (95% CL) for within-group changes from PRE, or as adjusted means ± *SE* representing estimated marginal means from ANCOVA analysis for between-group differences. Relative strength is absolute strength expressed per kg of LBM of the arms for chest press, and per kg of LBM of the legs for leg press.

‡Within-group differences were assessed by paired sample *t*-tests with significance indicated by $p < 0.05$ for the annotated parameter.

§Within-group differences were assessed by paired sample *t*-tests with significance indicated by $p < 0.01$ for the annotated parameter.

‖Within-group differences were assessed by paired sample *t*-tests with significance indicated by $p < 0.001$ for the annotated parameter.

¶Significant between-group differences are indicated by $p < 0.05$ for the annotated parameter.

respective parameter at PRE, ANCOVA analyses revealed that the increase in absolute leg press strength was larger in men (mean difference ± *SE*, 25.3 ± 11.8 kg; $p = 0.041$, $\eta_p^2 = 0.156$) (Figure 1A), but when expressed as leg press strength relative to leg LBM, increases were similar between the sexes (mean difference ± *SE*, 0.30 ± 0.46 $kg \cdot kg^{-1}$; $p = 0.526$, $\eta_p^2 = 0.016$) (Figure 1B). Increases in chest press strength were not significantly different between groups in terms of either absolute values (Figure 1C) or relative to arm LBM (Figure 1D). After adjustment for the value of the respective parameter at PRE, ANCOVA analyses revealed that no measure of body composition differed in response to exercise training between the sexes (Table 2). Independent of the absence of between-group differences, within-group PRE-POST comparisons revealed that ALM did not change in either sex, whereas whole-body LBM did increase in women, but not men (Table 2). Conversely, although fat mass decreased in both groups, trunk fat and body mass decreased in men only, but not women (Table 2).

Discussion

Using parallel group design with men and women pair matched for relative leg strength at baseline, this study demonstrates that sex-specific adaptive responses to concurrent aerobic and resistance exercise training are largely similar in male and female older adults with respect to muscle strength, physical function, and body composition.

Although broad guidelines for exercise prescription in older adults are well-established (7), meta-analyses (3,23,32) and original investigations (4,42,45) continue to explore the "optimal" prescription for exercise training in older adults. To the best of our knowledge, sex-specific differences in older adults in response to exercise training have not been the subject of systematic review and meta-analysis, but several studies have directly compared the response with resistance exercise training in older men and women (1,8,12,17,22,24,25,28,30,35,46). Broadly speaking, the results are equivocal because for any given parameter of strength or body composition, reports of larger change in men,

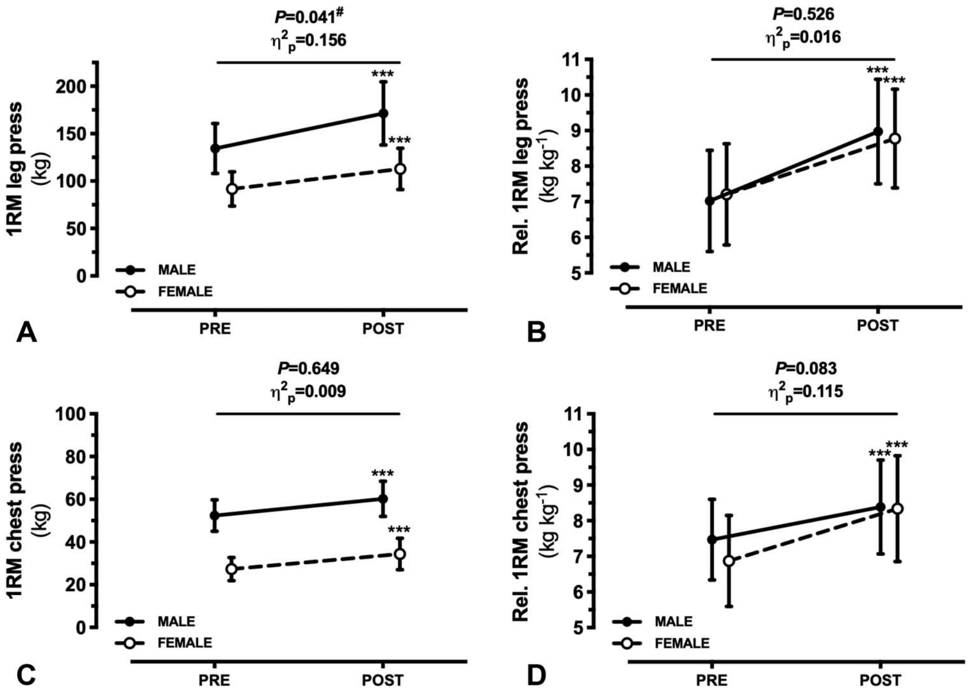

Figure 1. Changes in lower and upper limb muscle strength assessed in response to 12 weeks of concurrent aerobic and resistance exercise training in male and female older adults. A) Group mean ± *SD* for 1RM leg press; (B) group mean ± *SD* for 1RM leg press relative to leg LBM; (C) group mean ± *SD* for chest press; and (D) group mean ± *SD* for 1RM chest press relative to arm LBM. Between-group differences are reported from ANCOVA analysis; $^{\#}p < 0.05$ denoting a significance difference between groups. Within-group differences are reported from paired *t*-tests; $^{***}p < 0.001$ denotes significant difference from PRE to POST within group. 1RM = 1 repetition maximum; LBM = lean body mass; ANCOVA = analysis of covariance.

larger change in women, or no difference in response have been observed (1,8,12,17,22,24,25,28,30,35,46). Coherent conclusions from the data and explanation of divergent findings are confounded by general experimental variation and differences in the resistance training programs used in each investigation in terms of duration of intervention, frequency of training, training volume (i.e., sets, repetitions, and number of exercises), unilateral versus bilateral training, anatomical location and method of measurement of strength or body composition, and whether data are reported as absolute or %change from baseline. Of the studies with sample sizes of ≥12 per sex, and reporting both absolute and relative changes in response to training (8,22,24,28), the general effects are that larger absolute increases in muscle strength are observed in men, but no differences in relative increases in muscle strength are observed between the sexes.

In this study, our approach was novel as an attempt to negate strength differences between the sexes at baseline by pair-matching subjects based on the primary outcome of relative leg strength. This is an important methodological consideration because even when data are expressed as %change, or baseline differences are corrected by statistical methods, neither approach accounts for individual differences in relative strength before commencing training. Using this experimental approach, no difference was observed between older men and women in terms of increases in relative leg strength in response to exercise training. The often reported increase in absolute leg strength being larger in men (1,8,24,25,28,46) was also observed in this study despite the groups being matched for relative leg strength at PRE. However, when expressed as %change from PRE, neither absolute nor relative leg strength differed between sexes in response to exercise training.

Although there was also no difference between the sexes for the increase in chest press strength in response to training based on ANCOVA analysis, it is a cautionary note that when these data are examined as %change from PRE, there was a statistically significant difference between men and women, with that difference being a larger increase observed in women (see Table 1, Supplemental Digital Content 1, http://links.lww.com/JSCR/A254). This discrepancy between analyses of absolute and %change for leg and chest press is an illustration of Lord's Paradox, which describes the phenomenon of different conclusions being reached depending on the method of accounting for baseline differences between groups (36,40). Resolving this paradox relies on a careful explication of the specific research question being asked (36), which in this study centers a priori on the "direct" rather than "total" differences between sexes in response to exercise training. Although %change from PRE data is of practical and clinical relevance (47), this question of sex-specific differences is therefore best addressed using ANCOVA analysis with adjustment baseline differences between groups as a covariate (36,40,47). Nevertheless, if considering the % change from PRE data, the observation of larger increases in upper limb strength in women compared with men has been reported in a recent meta-analysis of sex differences in response to resistance exercise training in adults aged 18–50 years (39). Untrained women may therefore display a higher capacity to increase upper limb strength, but mechanisms remain speculative as to whether the differences are due to neural, muscular, or motor learning adaptations.

The exercise training in this study was in the form of concurrent aerobic and resistance exercise, as opposed to the aforementioned studies exploring sex differences that were resistance exercise training. However, concurrent training is well established as a means to increase muscle strength in older adults (23). Importantly, the resistance exercise stimulus in our intervention comprised of 6 strength exercises perfumed as 2 sets of 15 repetitions at ~60% 1RM undertaken 3 times weekly for 12 weeks, which is broadly similar to the training stimulus of typical resistance training studies (3,43).

Specifically in relation to concurrent exercise training, only 2 previous studies have formally compared responses between older men and women (26,41). Neither study observed a difference between the sexes for increases in muscle strength in response to concurrent exercise training (26,41), but a larger increase (9 vs. 17%) in aerobic fitness ($\dot{V}O_2$peak) in the female cohort was observed in one study (26). Our data do not support this latter finding, but the increases in aerobic fitness in this study were only ~5% and were assessed indirectly based on submaximal heart rate methods (44). Moreover, in contrast to our 36 minutes of aerobic exercise training per week for 12 weeks, in that study subjects trained for 21 weeks and were undertaking ~150 minutes per week of aerobic exercise training for the final 7 weeks (26). Therefore, we cannot exclude the possibility that a longer intervention and greater training stimulus would result in divergent responses in aerobic fitness between the sexes.

Despite interest in sex-specific effects on training-induced changes in muscle strength and body composition, few studies have included measures of physical function in older adults. Large differences in absolute strength between older men and women do not manifest as differences in physical function inasmuch as performance in tests such as the SPPB and TUG tend to be similar between the sexes (12,28). These similarities were also the case in this study, and all measures of physical function improved in response to exercise training, with no differences observed between the sexes. These findings support previous studies that demonstrated absence of difference between the sexes for improvements in the sit-to-stand test even when absolute increases in leg strength were larger in men (12,28).

Although there were some within-group changes in parameters of body composition i.e., LBM increased in women but not in men, and trunk fat decreased in men but not in women, when adjusted for between-group differences at baseline, no differences in change in the various measures of the body composition were observed between the sexes. This study used an ad libitum approach to dietary control whereby subjects were encouraged to continue their habitual diet because the aim was to evaluate the effect of concurrent aerobic and resistance exercise training itself, rather than a cointervention with dietary change. However, the lack of dietary monitoring can be considered a limitation. Exercise results in greater total daily energy expenditure, and in turn can result in compensatory behaviors that modulate the progression of change in body mass (27). In addition, dietary intervention can augment exercise training-mediated increases in LBM and strength in older adults (31). Therefore, future work on concurrent exercise training should investigate whether changes in LBM or ALM, or reductions in fat mass can be augmented by dietary interventions suggested for older adults at risk of decline in skeletal muscle mass and function (11).

Finally, an important methodological consideration is the measure of relative strength used in this study. The method of normalizing a measure of muscle strength relative to LBM is analogous to "muscle quality" i.e., strength per unit of muscle mass (2,14). However, an operational definition of muscle quality is lacking, nor is there a consensus on universal assessment method. Numerous approaches have been used including measuring muscle strength by isometric, isokinetic, or dynamic strength testing, and expressing that strength relative to muscle cross-sectional area, muscle volume, or muscle mass (2,14). Indeed, "relative strength" has been proposed to be just one of several domains of muscle quality (14). Expressing strength relative to LBM measured by DXA has been widely used (9,21,29,33), but most often either as hand-grip strength per kg arm LBM and knee extension per kg of leg LBM (9,21,29). The measures termed relative chest press strength and relative leg press strength in this study should include the caveat that not all of the musculature active in the respective movements is captured in the region-specific LBM measurement. Specifically, arm LBM does not include the pectoralis major muscle involved in the chest press, and leg LBM does not include the gluteal muscles involved in the leg press. Therefore, these relative strength measures are not suitable for comparison with existing data for muscle quality or relative strength for hand-grip or knee extension. Establishing operational definitions of muscle quality and relative strength, accompanied by specific protocols and cutpoint thresholds for functional impairment would be worthy avenues for future research (2,14).

Because some studies have observed differences between sexes in response to exercise training, there have been suggestions that this may result in older women requiring sex-specific training interventions (1,12). A contrasting opinion is that in relative terms, older men and women respond similarly to resistance exercise training and therefore generic training prescriptions will suffice for both sexes (8,28). Nevertheless, there is increasing interest in the area of "optimal" prescription of exercise training in older adults in terms of modes, frequency, and intensity (3,4,23,32,42,43,45), yet little of this work has considered whether there is a need for sex-specific exercise prescription. This study demonstrates that when relative leg strength is matched before commencing training, older men and women respond similarly to concurrent aerobic and resistance training in terms of muscle strength, physical function, and body composition. In generic contexts such as public health guidelines, generic exercise prescription may suffice, but future work should explore whether there is efficacy in sex-specific exercise prescription in scenarios such as rehabilitation from disuse atrophy i.e., wherein a defined deficit may need to be targeted.

Practical Applications

Central to recommendations for maintaining skeletal muscle health in older adults is the inclusion of both aerobic and resistance exercise as part of the overall training stimulus. This study demonstrates that delivering a concurrent exercise training program with aerobic and resistance exercise performed within the same session produces notable increases in muscle strength, aerobic fitness, and physical function in older adults, arguably in a time-efficient manner. Although the fitness profiles of men and women often differ (e.g., absolute strength and body composition), the responses across a range of fitness outcomes to a standardized exercise training program are largely similar between the sexes. At present, there is little evidence to suggest that male and female older adults require different training stimuli under the broad terms of current exercise prescription guidelines.

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J. F. Timmons and B. Egan conceived the study; J. F. Timmons, M. Hone, and O. Duffy performed the exercise training intervention; J. F. Timmons, M. Hone, and B. Egan performed the data collection and analysis; J. F. Timmons and B. Egan wrote the article; all authors approved the final version and submission of the article.

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