Efficacy and Feasibility of a Novel Tri-Modal Robust Exercise Prescription in a Retirement Community: A Randomized, Controlled Trial

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OBJECTIVES: To test the feasibility and efficacy of current guidelines for multimodal exercise programs in older adults.

DESIGN: Randomized, controlled trial.

SETTING: Retirement village.

PARTICIPANTS: Thirty-eight subjects (14 men and 24 women) aged 76.6 ± 6.1.

INTERVENTION: A wait list control or 10 weeks of supervised exercise consisting of high-intensity (80% of one-repetition maximum (1RM)) progressive resistance training (PRT) 3 days per week, moderate-intensity (rating of perceived exertion 11 to 14/20) aerobic training 2 days per week, and progressive balance training 1 day per week.

MEASUREMENTS: Blinded assessments of dynamic muscle strength (1RM), balance, 6-minute walk, gait velocity, chair stand, stair climb, depressive symptoms, self-efficacy, and habitual physical activity level.

RESULTS: Higher baseline strength and psychological well-being were associated with better functional performance. Strength gains over 10 weeks averaged 39 ± 31% in exercise, versus 21 ± 24% in controls ($P = .10$), with greater improvements in hip flexion ($P = .01$), hip abduction ($P = .02$), and chest press ($P = .04$) in the exercise group. Strength adaptations were greatest in exercises in which the intended continuous progressive overload was achieved. Stair climb power (12.3 ± 15%, $P = .002$) and chair stand time ($-7.1 \pm 15\%$, $P = .006$) improved significantly and similarly in both groups. Reduction in depressive symptoms was significantly related to compliance (attendance rate $r = -0.568$, $P = .009$, PRT progression in loading $r = -0.587$, $P = .02$, and total volume of aerobic training $r = -0.541$, $P = .01$), as well as improvements in muscle strength ($r = -0.498$, $P = .002$).

CONCLUSION: Robust physical and psychological adaptations to exercise are linked, although volumes and intensities of multiple exercise modalities sufficient to cause significant adaptation appear difficult to prescribe and adhere to simultaneously in older adults. **J Am Geriatr Soc 55:1–10, 2007.**

Key words: multimodal exercise; retirement community; aged

Declining physical function is associated with institutionalization, morbidity, and mortality.[1] Various modalities of exercise have been demonstrated to improve physical function and quality of life in older adults. Current guidelines stress the importance of multimodal exercise for this cohort,[2] including strengthening exercises, cardiovascular training, and balance training. Recommended doses have been established, or theorized, for each of these modalities, but few studies have attempted to simultaneously prescribe doses and intensities of resistance, aerobic, and balance training at levels known to produce robust physiological adaptation in older adults. No studies to the authors' knowledge have attempted to implement such a program in a retirement village community setting.

The Balance, Endurance and Strength Training Study was a randomized, controlled trial in a retirement village community setting that tested the feasibility and efficacy of

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such a prescription to improve exercise capacity, functional limitations, and psychological health in older adults. It was hypothesized that exercise adoption and adherence would be high and that significant improvements in exercise capacity in all three physiological domains (strength, balance, endurance) would be achieved.

METHODS

Study Design

The study was a single-blind, 10-week, randomized, controlled trial in a retirement village population using an intention-to-treat analytical strategy. The University of Sydney Human Ethics Committee and the University of New South Wales Human Research Ethics Committee approved this study, which was registered with the Australian Clinical Trials Registry (ACTRN126000029594).

Randomization Procedures

Subjects were randomized using a computerized program (http://www.randomization.com), using the method of randomly permuted blocks, stratified by sex in blocks of four, by an investigator not on site (MAFS) and not involved in testing or training subjects. Randomization assignments were placed in opaque envelopes and distributed to participants at the conclusion of all baseline testing.

Participants

Subjects were recruited from two retirement villages through an intensive promotional campaign over 12 months, using local media, distribution of flyers to individual apartments, and on-site presentations by senior investigators. Inclusion criteria were age 60 and older, residence in the retirement villages, and willingness to be randomized. Exclusion criteria were acute or terminal illness, unstable metabolic or cardiovascular disease, contraindications to planned exercise, or inability to commit to a 10-week exercise program. Written informed consent was obtained from all subjects.

Primary Outcome Measures

All testing was blinded. Baseline testing was conducted before randomization. A single highly experienced assessor (JG) obtained all postintervention measures. Success of assessor blinding was evaluated by asking the assessor to guess group assignment.

Exercise Capacity Testing

Dynamic Muscle Strength: One-Repetition Maximum

A one-repetition maximum (1RM) protocol[3] was used to assess muscle strength on pneumatic resistance machines (Keiser Sports Health Equipment Inc., Fresno, CA), using the best of two measures at baseline and one measure at follow-up. Five bilateral exercises (knee extension, knee flexion, latissimus pull down, chest press and seated row) and three unilateral exercises (hip abduction, hip flexion, and hip extension) were used. The coefficient of variation (CV) was 14.5% for repeat measurements.

6-Minute Walk

The 6-minute walk was used to assess walking endurance, or overall exercise capacity.[4] Although originally conceptualized as a proxy for aerobic capacity, recent use in geriatric cohorts has documented contributions of aerobic fitness, strength, balance, gait stability, health status, depression, and body composition to 6-minute walk performance.[5,6] The greater distance of two trials was used for analysis. The CV was 3.7% for repeat measurements.

Static and Dynamic Balance

Balance tests were performed once each. Static balance was measured using a progressive test protocol. Progression to stances of increasing difficulty was achieved by narrowing the base of support and then by removing visual input. Stance levels were wide-base stand, narrow-base stand, semitandem stand, tandem stand, one-legged stand, and one-legged stand with eyes closed, similar to the Frailty and Injuries: Cooperative Studies of Intervention Techniques-4 scale.[7] One attempt was allowed for successful completion of each level. A balance index was recorded as the most difficult stance level successfully completed, with higher scores indicating better static balance. Dynamic balance was assessed using time and errors during a tandem walk. A dynamic balance score was calculated using time (seconds)+errors (n), with higher scores indicating worse balance.

Secondary Outcome Measures

Physical Performance

Habitual Gait Velocity. Time taken for subjects to walk a distance of 2 meters at normal pace was recorded using an ultrasonic transmitter/receiver (Ultratimer, Glasgow, Scotland) and converted to a velocity (m/s).[8] The average of two gait velocities was taken. The CV was 5.7% for repeat measurements.

Chair Stand. Time was recorded for each subject to complete five chair stands with no hands from the sitting position to a fully erect standing position.[1]

Stair Climb. The time taken for subjects to climb a flight of stairs was recorded as a proxy for lower extremity power, converted to watts using vertical stair height and body mass.[9] The fastest time of two trials was used for analysis. The CV was 6.3% for repeat measurements.

Short Physical Performance Battery. A Short Physical Performance Battery (SPPB) score was calculated from performance in gait velocity, chair stand, and static balance. The SPPB has been shown to be associated with mortality, institutionalization, and functional status.[1]

Questionnaires

All questionnaires were interviewer-administered.

The Geriatric Depression Scale is a 30-item yes/no questionnaire used to assess depressive symptoms over the previous week in elderly individuals.[10] Higher scores reflect greater depression.

The Physical Activity Scale for the Elderly was used as a measure of daily leisure-time, household, and occupational activity over the previous week.[11]

The Ewart Physical Self-Efficacy Scale was used to assess current exercise self-efficacy.[12]

Compliance was determined as a percentage: training sessions attended (n) divided by the number of sessions held (30), multiplied by 100, reported with and without dropouts. Number of minutes of aerobic exercise was summed over the 10 weeks. Progressive resistance training (PRT) intensity was determined as the final training load that was achieved at week 10 divided by the baseline 1RM load and multiplied by 100, expressed as a percentage.

Control Group

Subjects randomized to the control group were given no treatment or intervention but were placed on a waiting list giving them access to the training facilities at the completion of the study.

Exercise Protocol

Initially, it was intended that the exercise group would train in each modality (strength, endurance, and balance) three times per week. It became clear within 2 weeks that the study participants were unwilling to commit to this volume of training, and thus training frequency was reduced for the balance and aerobic training components. The rationale for this selective reduction in frequency was that it would maintain resistance training at an optimal frequency for adaptation,[2] in light of the strong contribution of sarcopenia to functional dependency,[13] while still providing levels of aerobic (2 days/week)[14] and balance (1 day/week over 10 weeks)[15] training that have been shown to result in improvements in physical function and other health outcomes. Exercise intensity and progression prescription (see below) were not altered, and the tri-modal training prescription was thus accomplished in approximately 3 to 4 hours per week divided over 3 days. All sessions were conducted in a gymnasium set up by the investigators within the retirement village and directly supervised by an experienced trainer in small groups of one to five.

Strength Training

PRT was performed 3 days per week (two sets of eight repetitions of knee flexion and extension, hip flexion and extension, hip abduction, chest press, seated row, and latissimus pull down). The training load was advanced to 80% of the subject's 1RM by the fourth training session, and the 1RM was re-evaluated every 2 to 3 weeks to maintain the training stimulus goal of 80% of the most recent 1RM. Progressive increase of the training load by 3% was attempted at each training session and adjusted as required to keep the rate of perceived exertion[16] between 15 and 18 (approximately 80% of the 1RM).[17]

Aerobic Endurance Training

Subjects trained 2 days per week for 20 minutes on a semirecumbent stepper (TRS 4000, Nu-Step Inc., Ann Arbor, MI) or on a semirecumbent cycle ergometer (D360 Recline XT PRO600, Technogym, Gambettola, Italy.). Training sessions were performed at a moderate intensity (rate of perceived exertion 11–14).[16]

Balance Training

Balance training was conducted 1 day per week. Subjects trained in static exercises (single-leg stand, side-to-side weight shift, forward and backward weight shift) and dynamic exercises (anterior-posterior and lateral stepping over objects, 20-foot tandem walk, heel walk, and toe walk). The eight exercises were performed in sequence twice at the highest level of difficulty not yet mastered. Mastery was defined as ability to hold a static posture twice for 15 seconds or to complete a dynamic task twice without errors. Increasing levels of difficulty were achieved by decreasing the base of support, removing external support, removing vision, and increasing the height of the objects in 5-cm increments from 0 to 45 cm.

Sample Size

Sample size estimate was based on a projected change in muscle strength in the exercise group of 30% versus 0% in the control group, with a standard deviation of 30% (effect size = 1), based on previous studies of the investigators and published literature.[18] A priori, two-tailed power calculations at an alpha of 0.05 and beta of 0.20 gave an actual power of 0.807 for a total sample size of 34 using G-Power software (University of Trier, Trier, Germany). The sample size was inflated to accommodate an anticipated dropout rate of 10%.

Ascertainment of Adverse Events

Adverse events were defined a priori as injuries or changes in health status potentially related to exercise testing or training. Monitoring for adverse events was conducted weekly in person or by telephone using specific questions about changes in health status, any physical or mental health symptoms, visits to healthcare professionals, changes in medications, falls, or anything the subject felt was attributable to program participation.

Statistical Analysis

An intention-to-treat analysis was performed using StatView version 5.0 (SAS Institute, Inc., Cary, NC). Missing outcome scores were imputed from subjects' baseline scores (last measure carried forward). For two control subjects, all outcome data were replaced. Occasional missing data were replaced for other subjects. To ensure that this procedure had minimal effect on the results, the baseline scores were only used if they lay close to the median of the outcome distribution. All data were visually inspected for normality using histograms and descriptive statistics. Nonnormally distributed variables were log transformed and analyzed using parametric testing if successful or using nonparametric testing if unsuccessful. Data are reported as the mean ± standard deviation. Groups were compared using chi-square and t tests; intervention effects were analyzed using repeated measures analysis of variance, and relationships were analyzed using simple linear regression. Covariates considered for inclusion in additional analysis of covariance models of change scores included potential confounders selected a priori based on their relationship to the dependent variable of interest (e.g., age), as well as any relevant baseline characteristics found to be different between groups. Alpha level for significance was set to $P < .05$.

RESULTS

Recruitment

The flow of participants through the trial is shown in Figure 1. From the total population of 358 residents, 86 showed

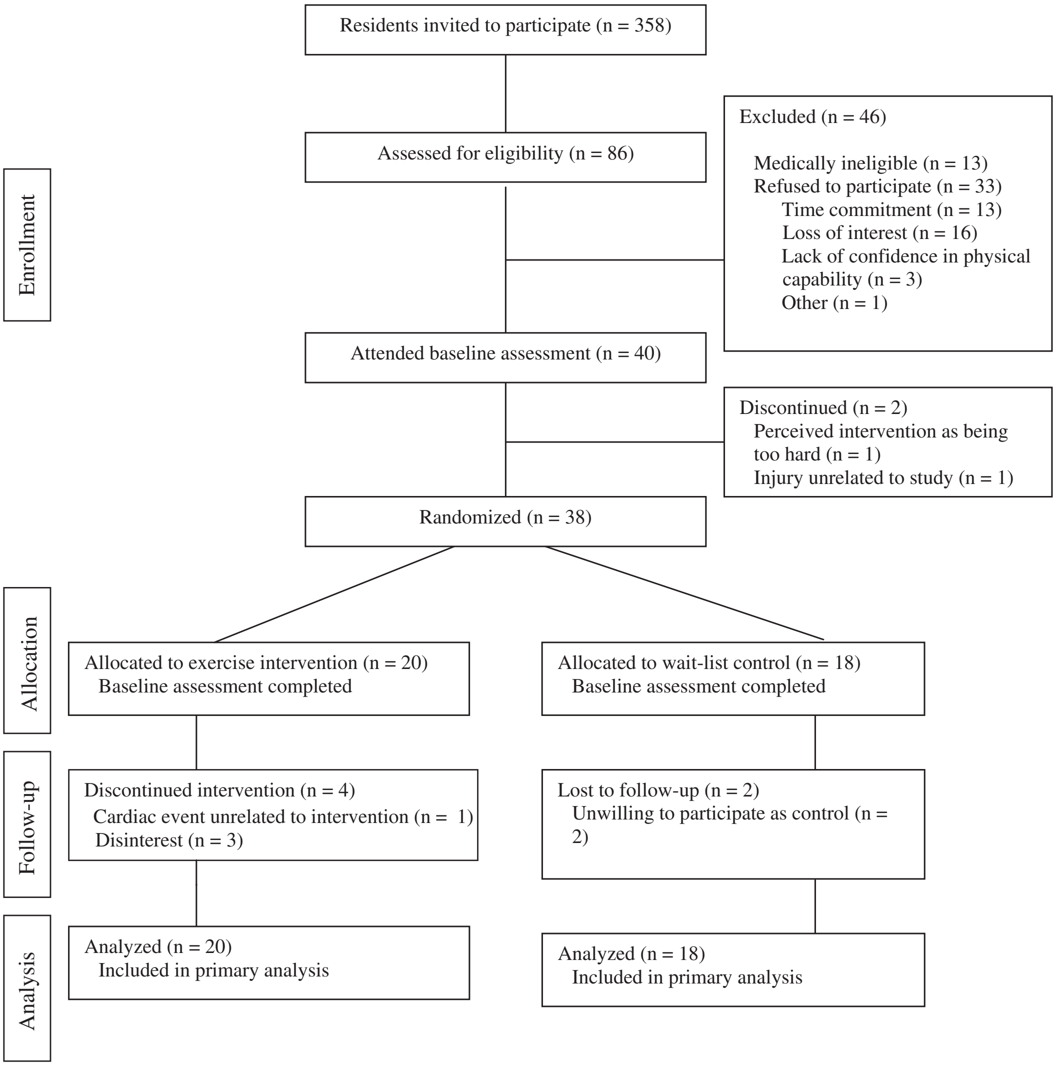

Figure 1. Flow of participants through the study. Recruitment and enrollment took place between November 2004 and March 2005. Forty-four percent of the original respondents were eligible and randomized.

interest in participating (24%), and 38 were deemed eligible and were randomized (10.6%). Of those screened, loss of interest or inability to commit (33/46, 72%), rather than medical ineligibility (13/46, 28%), was the primary reason for nonenrollment.

Baseline Characteristics

Baseline characteristics are presented in Table 1. Thirty-eight residents (24 (63.2%) women) aged 76.6 ± 6.1 (range 58–92) were recruited. The retirement village as a whole included 69.5% women with an average age of 79, similar to the sample. On average, the participants were overweight, with 12 normal weight, 13 overweight, and 11 obese. Most had one or more chronic illnesses, and two had depressive symptom scores of 9 or greater, suggestive of at least mild depression. Gait velocity was consistent with those observed in healthy community-dwelling people of a similar age.[19] Mean SPPB score (10.4), although in the highest quartile of the measure, was consistent with greater risk of institutionalization and death than for older adults of similar age scoring 12.[1] Exercise self-efficacy was low for all categories other than walking. There were no significant group differences in any baseline characteristic.

At baseline, better overall exercise capacity (longer 6-minute walk distance) was associated with greater strength ($r = 0.501$, $P = .004$) and fewer depressive symptoms ($r = -0.352$, $P = .03$). Better stair climb performance was also associated with greater muscle strength ($r = 0.486$, $P = .005$). Age and burden of disease (number of medications) were unrelated to any measures of physical performance or psychological health (data not shown).

Compliance and Adverse Events

There were two dropouts from the control group and four intervention subjects who did not complete the training (16% dropout rate), with a mean dropout time for these six subjects of 2.5 ± 2.3 weeks. The two controls who dropped out refused follow-up assessments. Median compliance was 86.6% (6.6–93.3%) including and 90% (50.0–93.3%) excluding dropouts. There were no exercise- or assessment-related adverse events.

Table 1. Baseline Characteristics

Characteristic	Whole Cohort (n = 38)	Exercise Group (n = 20)	Control Group (n = 18)	*P*-value
Age, mean ± SD	76.6 ± 6.1	78.3 ± 7.1	74.7 ± 4.3	.07†
Female, %	63.2	60.0	66.6	.67*
Body mass index, kg/m^2, mean ± SD	27.4 ± 4.8	26.9 ± 4.8	28.0 ± 5.0	.53†
Number of prescription and nonprescription medications and nutritional supplements, mean ± SD	4.2 ± 2.7	4.8 ± 2.8	3.7 ± 2.5	.20†
Chronic illness, %	81.6	90.0	72.2	.16*
Osteoarthritis, %	28.9	35.0	22.2	.39*
Hypertension, %	28.9	30.0	27.8	.88*
Geriatric Depression Scale score, mean ± SD (range 0–30)§	3.8 ± 2.5	3.6 ± 2.7	3.9 ± 2.4	.68†
Physical Activity Scale for the Elderly score, mean ± SD‖	108.5 ± 53.2	119.7 ± 54.1	96.0 ± 50.8	.17†
6-minute walk, m, mean ± SD	543.1 ± 100.6	543.5 ± 91.9	542.6 ± 112.1	.98†
Habitual gait velocity, m/s, mean ± SD	1.21 ± 0.25	1.23 ± 0.28	1.19 ± 0.23	.58†
Short Physical Performance Battery score, mean ± SD (range 0–12)¶	10.4 ± 1.1	10.4 ± 1.2	10.5 ± 0.9	.65†
Ewart Self Efficacy Questionnaire (range 0–100)#				
Walking, median (range)	81.0 (2.7–100.0)	59.8 (28.7–100.0)	85.3 (2.7–100.0)	.33‡
Jogging, median (range)	0.8 (0.0–98.3)	5.0 (0.0–64.0)	0.0 (0.0–98.3)	.11†
Lifting, mean ± SD	49.3 ± 18.9	51.5 ± 16.6	46.8 ± 21.3	.46†
Stairs, mean ± SD	59.5 ± 28.5	54.1 ± 32.3	65.5 ± 22.9	.22†
Push-ups, mean ± SD	20.9 ± 21.1	24.0 ± 24.0	17.2 ± 16.8	.33†

* Chi-square test.
† Unpaired *t*-test.
‡ Mann-Whitney U Test.
§ 30-item yes/no questionnaire used to assess depressive symptoms over the previous week in elderly individuals.[10]
‖ To estimate habitual physical activity.[11]
¶ Associated with mortality, morbidity, and functional status.[1]
\# To assess current exercise self-efficacy.[12]
SD = standard deviation.

Adequacy of Blinding

Eighty percent of the time, the blinded assessor guessed the group allocation correctly, suggesting incomplete maintenance of blinding.

Primary Outcomes

Outcome data are shown in Table 2. Overall strength gains tended to be higher in the exercise group (39 ± 31%, range 17.4–66.2%) than in controls (21 ± 24%, range 5.9–47.2%; $P = .10$), with significantly greater improvements in hip flexion ($P = .01$), hip abduction ($P = .02$), and chest press ($P = .04$) in the exercise group.

Adherence to the intended progression during training in the muscle group in which the greatest exercise adaptation was observed (right hip flexion) was compared with that with the poorest adaptation (latissimus pull down), in an attempt to understand the wide variation in muscle strength gains observed. As shown in Figure 2, actual load progression for hip flexion was close to the intended 3% increment for each session, with a final training load of 154.0% of the baseline 1RM, whereas there was minimal progression in loading for the latissimus pull down exercise, which had a final training load of 102.4% of the baseline 1RM. Overall, the progression in loading across all exercises resulted in a final training load at Week 10 that averaged 125.5 ± 19.5% of baseline 1RM, which was significantly less ($P < .001$) than a theoretical goal of 172.5% if 3% increments had been achieved uniformly from Session 4 to 30. Higher levels of progression were related to lower baseline strength ($r = -0.758$, $P = .01$). This load progression was related to the primary outcome: average percent change in strength ($r = 0.667$, $P = .01$).

There were no significant changes in 6-minute walk performance (Table 2). Subjects with the lowest baseline 6-minute walk performance showed the greatest improvement in that measure at 10 weeks ($r = -0.508$, $P = .001$). Static balance improved over time and tended to improve more in exercisers.

Secondary Outcomes

Stair climb power (12.3 ± 15%; $P = .002$) and chair stand time (−7.1 ± 15%; $P = .007$) improved significantly and similarly in both groups. Although gait velocity did not improve significantly, subjects with the lowest baseline gait velocity showed the greatest increase in that outcome ($r = -0.527$; $P = .001$).

Depression did not change significantly, although subjects with the highest baseline depression scores showed the greatest improvements ($r = -0.533$; $P < .001$). Reduction in depressive symptoms was also significantly related to exercise compliance (in terms of overall attendance, aerobic exercise volume, and PRT progression of loading intensity ($r = -0.587$, $P = .02$)) and lower-body-strength improve-

Table 2. Outcome Measures

	Exercise Group (n = 20)			Control Group (n = 18)				
	Baseline	Final		Baseline	Final		*P*-value	*P*-value
Outcome	Mean ± SD		Change	Mean ± SD		Change	(Time)	(Group by Time)
Primary								
1-repetition maximum, pounds								
Right hip flexion	14.2 ± 7.4	20.2 ± 10.9	44.1%	16.6 ± 9.0	18.1 ± 7.8	5.9%	.01	.01
Left hip flexion	15.1 ± 7.0	21.0 ± 10.8	43.0%	14.9 ± 6.5	18.2 ± 7.6	32.7%	.006	.28
Right hip extension	28.6 ± 14.3	35.5 ± 18.2	23.7%	24.1 ± 8.7	35.1 ± 12.9	47.2%	.001	.48
Left hip extension	25.1 ± 14.3	34.8 ± 16.6	46.6%	26.1 ± 11.2	36.4 ± 15.1	41.7%	.002	.76
Right hip abduction	15.4 ± 7.8	23.2 ± 10.6	66.2%	17.2 ± 9.4	20.6 ± 9.4	13.0%	<.001	.01
Left hip abduction	15.5 ± 8.1	24.3 ± 10.0	59.1%	18.8 ± 8.3	22.9 ± 12.0	7.1%	<.001	.02
Chest press	52.4 ± 19.3	65.0 ± 21.6	25.5%	51.7 ± 21.2	58.2 ± 27.0	12.8%	<.001	.04
Knee flexion	67.5 ± 19.0	86.0 ± 24.5	25.0%	65.1 ± 21.0	77.7 ± 24.9	18.4%	<.001	.23
Knee extension	49.8 ± 20.9	70.6 ± 29.0	42.1%	48.8 ± 18.7	68.2 ± 22.4	32.1%	<.001	.32
Latissimus pull down	62.2 ± 17.9	80.9 ± 30.8	17.4%	59.6 ± 24.5	73.5 ± 23.8	17.0%	<.001	.56
Seated row	45.7 ± 15.2	61.2 ± 18.1	36.5%	48.1 ± 21.5	58.2 ± 20.6	26.4%	<.001	.14
Upper-body strength	162.8 ± 48.9	207.8 ± 69.3	18.6%	161.6 ± 66.4	191.6 ± 69.5	16.0%	<.001	.38
Lower-body strength	234.2 ± 87.8	320.6 ± 113.1	36.2%	231.5 ± 72.7	297.2 ± 98.2	21.1%	<.001	.12
6-minute walk, m	543.5 ± 90.7	548.4 ± 75.0	1.0%	542.6 ± 110.5	531.7 ± 101.9	0.3%	.81	.57
Static balance index	2.0 ± 0.69	3.3 ± 0.92	73.3%	2.5 ± 0.86	3.2 ± 1.06	47.7%	<.001	.09
Dynamic balance score	20.6 ± 8.3	19.4 ± 5.3	4.4%	18.0 ± 7.4	20.3 ± 8.6	20.5%	.64	.16
Secondary								
Stair climb power, W	226.8 ± 80.7	254.7 ± 79.3	28.3	239.2 ± 77.9	251.3 ± 82.8	15.3	<.001	.65
Chair stand time, s	13.1 ± 2.6	12.1 ± 3.1	−0.99	13.2 ± 2.0	12.2 ± 2.8	−0.95	.007	.96
Short Physical Performance Battery score*	10.4 ± 1.2	10.6 ± 1.5	0.26	10.5 ± 0.9	10.7 ± 1.8	0.5	.08	.70
Gait velocity (m/s)	1.23 ± 0.28	1.12 ± 0.23	−0.12	1.19 ± 0.23	1.16 ± 0.25	−0.003	.09	.10
Geriatric Depression Scale score (range 0–30)†	3.6 ± 2.7	3.3 ± 1.9	−0.3	3.9 ± 2.4	3.4 ± 2.9	−0.67	.19	.62
Physical Activity Scale for the Elderly score‡	119.7 ± 54.1	110.0 ± 83.5	−9.8	96.0 ± 50.8	100.3 ± 55.0	2.4	.30	.81

* Associated with mortality, morbidity, and functional status.[1]

† 30-item yes/no questionnaire used to assess depressive symptoms over the previous week in elderly individuals.[10]

‡ To estimate habitual physical activity.[11]

SD = standard deviation; W=watts.

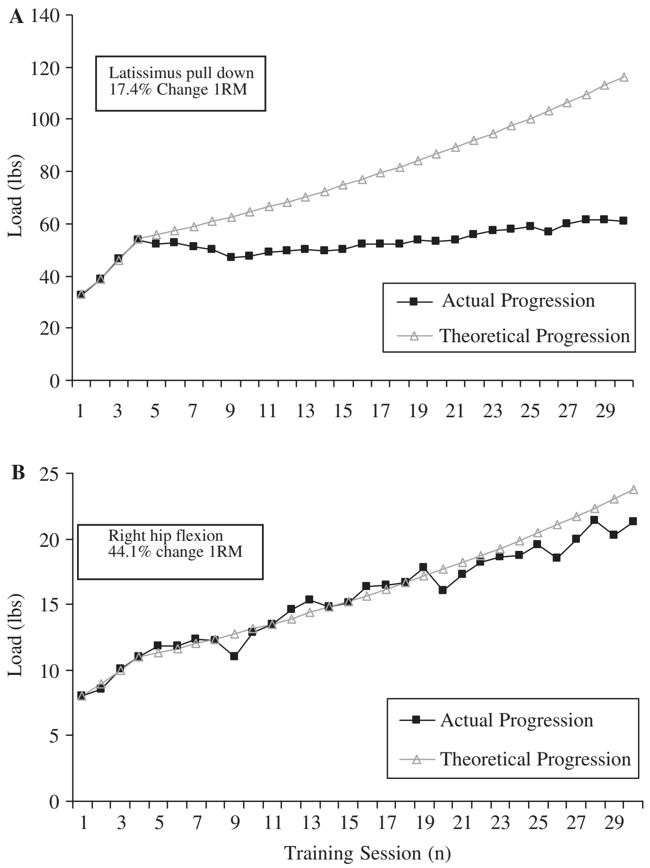

Figure 2. Theoretical progression of mean load (pounds) per subject throughout intervention versus actual progression of mean load (pounds) per subject for (A) latissimus pull down and (B) right hip extension. 1RM = one-repetition maximum.

ment, as shown in Figure 3. There was no change in current exercise self-efficacy (data not shown).

DISCUSSION

This study sought to determine the feasibility and efficacy of a multimodal exercise intervention in a retirement village community. The enrollment rate was lower than anticipated and dropout rate higher than expected. It was found that muscle strength, but no other primary or secondary outcomes, improved differentially in exercisers than in controls.

Baseline overweight status; low exercise self-efficacy; and risk for functional decline, institutionalization, and excess mortality characterized this older cohort with a demographic profile similar to the retirement village from which they were drawn. Despite attempts to remove most barriers to exercise adoption and adherence (by provision of pre-enrollment educational sessions and motivational activities, medical screening, liaison with personal physicians, supervision, eliminating cost and need for transportation, etc.), a low percentage of village residents enrolled, and the dropout rate was higher than expected at one of five exercisers by 10 weeks. Older individuals have commonly cited these barriers as reasons for exercise nonparticipation,[20] yet disinterest and perceived lack of time continued to dominate as reasons for not participating. The largest proportion of nonexercising older adults is “precontemplators” in the transtheoretical model of behavioral change,[21] and educational efforts appeared insufficient to motivate such individuals in the retirement community.

Muscle strength (not balance or aerobic capacity) was related to functional limitations at baseline, supporting prioritization of PRT in exercise prescriptions for frail older people, as has been suggested in the literature.[13,22] Muscle strength improved robustly and differentially only when high-intensity progressive training was effectively implemented, consistent with dose–response effects that have been observed.[23]

Aerobic capacity (as represented by 6-minute walk distance) did not improve significantly. It is likely that this was due to the compromise in the volume of aerobic training that had to be adopted to maintain adherence to the program. In addition, the non-weight-bearing aerobic exercise training paradigm may have limited transference of any improvements to the walking test of aerobic capacity or overall exercise capacity.[24] Subjects with a lower baseline 6-minute walk distance had the greatest improvement after training, similar to what as has been observed in previous studies measuring aerobic capacity in a retirement community population.[25]

Change in balance scores tended to be almost twice as large in exercisers (73.3%) as controls (47.7%), with this difference approaching significance. A higher volume of training, as well as larger sample size, would have likely been required to produce more-robust changes and achieve statistical significance.

Functional limitations did not improve with training, and the study was not powered to identify such changes, although it was observed that those with the greatest mobility impairment improved the most. Thus, targeting specifically for mobility impairment may be an important strategy to focus efforts on those who are at high risk for further decline and have a high likelihood of robust adaptation to exercise. Additionally, it has been shown that high-intensity PRT is superior to range of motion and moderate-intensity PRT for functional limitations,[26] and the intended PRT intensity, although prescribed, was not achieved uniformly in this study. The study, by design, did not address other potential risk factors that contribute to functional impairment.[27]

Depressive symptom reduction was greatest in those with the most symptoms at baseline; the highest attendance rate, PRT progression, and aerobic exercise volume; and the greatest adaptations in strength. These results are consistent with literature describing a dose–response relationship between the intensity of PRT[28,29] and the volume of aerobic exercise training[30] as a treatment for clinical depression. The mechanism for the reduction in depressive symptoms is likely to be biological in nature. The increased level of social contact with increased attendance was shown not to be a factor in previous dose–response studies.[29] Increased self-efficacy, which has been previously stated as a possible mechanism,[31] is also an unlikely explanation, because an increase was not observed in the present study, and increases have not been related to reduced depressive symptoms in previous studies.[28,29] A possible mechanism could be a reduction in cytokine and cortisol levels that have been shown to occur in high-intensity resistance training and

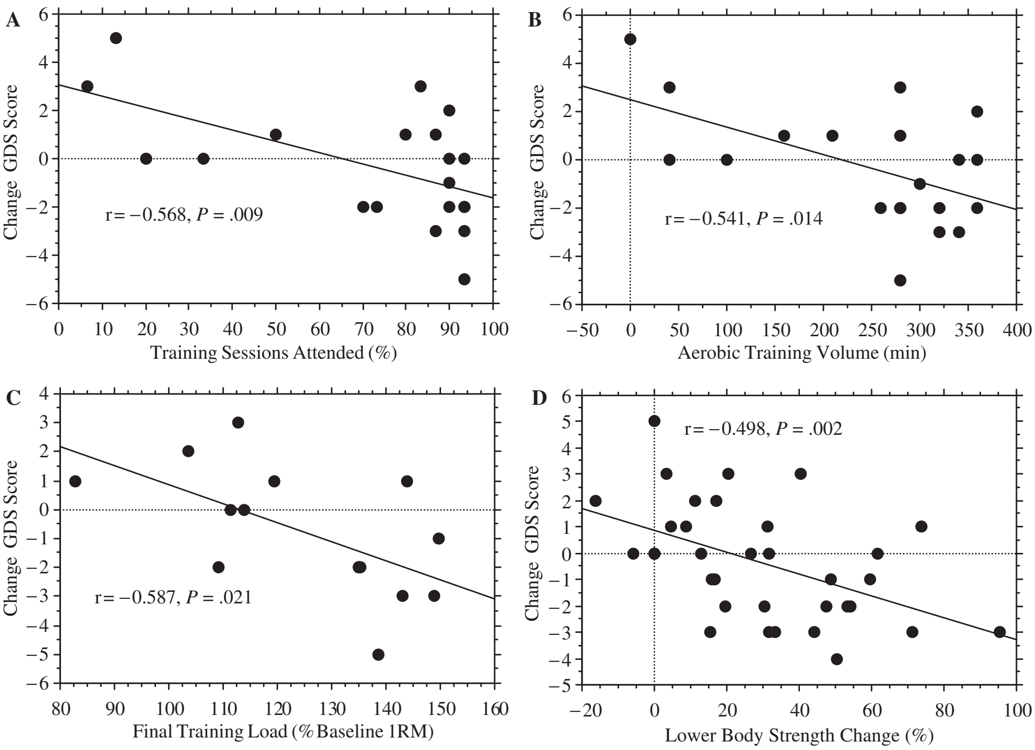

Figure 3. Change in depression (Geriatric Depression Scale (GDS)[10]) and (A) training sessions attended (%), (B) aerobic training volume (minutes), (C) final training load (% baseline one-repetition maximum (1RM), and (D) change in lower body strength (%).

aerobic exercise.[32,33] Reduced cytokine and cortisol levels, oxidative stress, and increased brain-derived neural growth factor after exercise have been shown in animal models to result in reversal of neurodegenerative changes in the hippocampus linked to cognitive impairment and depression.[34–37] Thus, physical and psychological benefits appear to be strongly linked to resistive exercise intensity and aerobic exercise volume in this and other older cohorts.

There is minimal research using multimodal exercise interventions for older people. Three studies were found for comparison because of their use of a moderate- to high-intensity tri-modal exercise program (strength, balance, and endurance training) and age demographics similar to those in the current study.[38–40]

In a previous study[40] of a larger, older (83 ± 4), frailer cohort, a multimodal exercise intervention (3 days/week for 9 months) successfully increased strength, aerobic capacity, and balance more than a low-intensity home-based exercise protocol. The higher volume of aerobic and balance training and greater baseline frailty of subjects may explain the differences from the findings of the current study, given that the frailest subjects in the current study improved the most. In addition, the measurement of aerobic capacity was obtained using a treadmill test, more specific to the training modality (treadmill walking and other machine-based exercise) than in the present study. The strength changes observed (39%) were higher than in the previous study (approximately 21%, similar to the control group changes in the current study), but the controls increased in strength far more than expected, attenuating the significance of the effect on strength. There is no apparent explanation for the large increase in control strength measures, because the incomplete blinding of the assessor would presumably have had the opposite effect. In a second study,[39] women (mean age 69.2 ± 3.5) were trained three times per week for 8 months with a balance, strength, and aerobic exercise prescription. Balance improved; strength, adjusted for baseline differences in bone density, did not; and aerobic capacity was not measured. Again, it is likely that the higher volume of balance training resulted in significantly greater balance improvements than the nonsignificant trend in the current study. The lack of significant strength gains, despite adequate prescribed intensity (75% 1RM) and the 8-month duration, in the previous study may reflect inadequate adherence to the intensity prescribed (no information is presented) or difficulty achieving robust physiological gains in this cohort with multimodal training. Finally, another study[38] prescribed tri-modal exercise to women for 6 months (3 days/week). Balance measures did not improve significantly more than for controls. Strength improved in leg extension but not leg press differentially to controls. Aerobic capacity was not measured. The prescribed intensity (70% 1RM) and frequency of resistance training was similar to that of the current study, but only one of the two muscle groups trained improved. As in the current study, balance did not improve, even though the frequency was higher (3 vs 1 day/week) and the duration longer (6 months vs 10 weeks). Thus, only one[40] of the four studies[38,39] of moderate-to-high intensity multimodal exercise (balance, strength, aerobic) in older adults has reported simultaneous improvements in all three physiological domains, although the strength improvements in one study[40] were small considering the 9-month intervention and may reflect difficulty adhering to the prescribed PRT intensity.

The findings of the current study may be important when considering exercise prescription in a practical setting. The lower limits on guidelines for exercise prescription may have to be defined as greater than those used in the current study for aerobic and balance training.

Because of the unwillingness of the study participants to undertake any greater volumes of training, despite agreeing to undertake the program initially, prescribing a novel multimodal exercise program seems to be difficult in this population and setting. If improvement of functional deficits is the primary goal of an exercise program in an elderly population, then a system to triage individuals to the mode of exercise targeted to their most-urgent requirements may be needed. In the current study cohort, for example, baseline functional impairment was related to strength but not walking endurance or balance. Thus, adding balance and aerobic training after a period of successful PRT may have proven more effective across multiple physiological domains.

In conclusion, physical and mental frailties are strong indications for exercise training in older adults and appear to improve in concert with each other. However, robust physical and psychological adaptations require adherence to ample volumes and intensities of prescribed exercise. Such volumes and intensities of multiple modalities prove difficult to prescribe for and to adhere to simultaneously in older adults, and a triaging or staged prescriptive approach should be used in future trials to improve outcomes.

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