Weighted Stair Climbing in Mobility-Limited Older People: A Pilot Study

Jonathan Bean MD, MS,†‡ Seth Herman BA,† Dan K. Kiely MPH, MS,† Damien Callahan BS,‡ Kelly Mizer BS,‡ Walter R. Frontera MD, PhD,* and Roger A. Fielding PhD‡*

OBJECTIVES: To evaluate weighted stair climbing exercise (SCE) as a means of increasing lower extremity muscle power in mobility-limited older people.

DESIGN: Single-blinded, randomized controlled pilot study

SETTING: Human physiology laboratory of a metropolitan university.

PARTICIPANTS: Forty-five community-dwelling people aged 65 and older who had baseline mobility limitations manifested by scores of 11 or lower on the Short Physical Performance Battery (SPPB).

INTERVENTIONS: Subjects were randomized into one of two 12-week exercise programs. The intervention group (SCE) (n = 23) ascended and descended stairs, at a set pace, while wearing a weighted vest. The control group (WALK) (n = 22) participated in a standardized walking program.

MEASUREMENTS: Primary and secondary outcomes included measures of muscle power and strength, submaximal aerobic capacity, and physical performance.

RESULTS: SCE produced 17% improvement in double leg press peak power in comparison with WALK (P = .013) and significant improvement in stair climbing power from baseline (12%). Improvement in submaximal aerobic performance was equivalent for both groups. Although not statistically significant, effect size estimates suggest that SCE can potentially influence knee extension power and strength. Stair climb time was improved in both groups, whereas SCE produced significant improvements from baseline SPPB score in a subcohort of participants.

CONCLUSIONS: These findings suggest that SCE may be a useful component of a home exercise program designed to enhance lower extremity muscle power, aerobic capacity, and functional performance. Further investigation is needed involving larger sample sizes and direct comparisons with other forms of resistance training. **J Am Geriatr Soc 50:663–670, 2002.**

Key words: exercise; muscle power; mobility; stair climbing; physical performance

Skeletal muscle power has been recently highlighted as an important gerontological research topic.[1] Evans recently identified the importance of investigating interventions that enhance muscle power in mobility-limited older people.[1] This interest is primarily due to the association between impairments in muscle power and measures of function and disability.[2–5] Impaired ankle and leg muscle power is associated with limitations in functional performance in prefrail and frail older people.[3–5] When compared with strength, muscle power may have a preferential influence on functional performance.[4] In a cohort of older women, muscle power has been strongly associated with self-reported disability.[2]

Power is a physiological attribute related to strength but is different from strength and reflects the ability to perform muscular work per unit of time. In simpler terms, if strength refers to the ability to generate force, power refers to the ability to generate force *quickly*. Although often discussed in a sports medicine context, it is an important gerontological topic, because muscle power declines more precipitously than strength in late life.[6]

Progressive resistance training (PRT) using exercise machines can improve muscle power in mobility-limited older people.[7,8] In addition to strength gains, Fiatarone et al. demonstrated improvements in the stair climbing power of long-term care residents participating in PRT.[7] More recently, using similar exercise equipment and methodology, Jozsi et al. reported power gains of approximately 10% to 30% in healthy older men and women.[8] Additionally, in a study evaluating a potential form of home-based PRT, Skelton et al. reported the potential for 18% improvements in leg extensor power.[9] Further review of these studies reveals that classical PRT disproportionately favors gains in strength as opposed to gains in power.[7–9] Therefore, if power training is the goal, more-specific programs

From the *Department of Physical Medicine and Rehabilitation, Harvard Medical School, Spaulding Rehabilitation Hospital, Boston, Massachusetts; †Research and Training Institute, Hebrew Rehabilitation Center for Aged, Boston, Massachusetts; and ‡Department of Health Sciences, Sargent College of Health and Rehabilitation Sciences, Boston University, Boston, Massachusetts

Address correspondence to Jonathan Bean, MD, Director, Geriatric Physical Medicine and Rehabilitation, Hebrew Rehabilitation Center for Aged, 1200 Centre Street, Boston, MA 02131. E-mail: bean@mail.hrca.harvard.edu

0002-8614/02/$15.00

of power training need to be developed. Furthermore, if such exercise is to be useful to large numbers of mobility-limited older people, it should be easily adaptable to the environments in which they reside.

One potential form of home-based power training is weighted stair climbing. Weighted vest exercise has been used safely in older adults, producing benefits in strength, balance, and bone mass.[10–12] Specifically, weighted stair climbing exercise has been reported to be a safe means of enhancing muscle strength and function in healthy older people.[10,13] Previous research has not included mobility-limited older people, and none have used this form of exercise as a well-controlled method of increasing muscle power. We conducted a pilot study evaluating weighted stair climbing exercise as a means of increasing muscle power in mobility-limited older people.

METHODS

Study Population

Before subject recruitment, the Institutional Review Board at Boston University and the Human Subjects Committee at Spaulding Rehabilitation Hospital approved this study. Recruitment of subjects (N = 45) was conducted in the greater Boston metropolitan area and facilitated through the Harvard Cooperative Program on Aging and through advertising in local newspapers.[14] During the initial visit, consent was obtained, a screening physical performance test was conducted, and a comprehensive medical history and physical examination was performed. Inclusion criteria were age 65 and older, a score of 11 or lower on the Short Physical Performance Battery (SPPB), and the ability to climb a flight of stairs independently without the use of an assistive device, although the use of the handrail unilaterally was allowed.[15] Exclusion criteria were unstable acute or chronic disease, a score of less than 23 on the Folstein Mini-Mental State Examination, and a neuromusculoskeletal impairment interfering with independent stair climbing.[16] Subjects who met the inclusion criteria were invited back for a second visit that included a submaximal exercise tolerance test conducted according to the American College of Sports Medicine guidelines.[17] If eligible, subjects returned to the laboratory for a subsequent visit to complete baseline testing. All subjects lived independently in the community.

One hundred eighty-six inquiries were solicited via advertising in local newspapers, newsletters, and direct mailings. After initial screening via telephone, and eliminating subjects who were ineligible or were unable to commit to the study, 57 potential subjects were invited to participate in a screening assessment. Of these, four were excluded for medical reasons and eight chose not to commit to the study. Therefore, 45 subjects (34 women, 11 men) were eligible and randomized, representing 79% of the invitees.

Exercise Programs

Twenty-three subjects were randomized to a Stair Climbing Exercise program (SCE) and 22 to a walking program (WALK). Both the SCE (intervention) and the WALK (control group) were conducted three times per week at our research laboratory under the direct supervision of a research assistant. Both programs included identical 5- to 10-minute warm-up and cool-down activities consisting of stretching and breathing exercises.

Stair Climbing Exercise

Subjects climbed stairs while wearing a weighted vest (Power Vest, All Pro Co., Jericho, NJ). An audible metronome was attached to the vest and set to correspond to a stepping pace consistent with the target training pace. During each exercise session, stair climbers ascended and descended 12 flights (126 steps) divided into three sets of four flights, with a 2-minute rest period between each set. Heart rate and perceived exertion were recorded twice during each set. On a weekly basis, habitual stair climbing speed was measured using similar methods to those described below, in which subjects were timed as they climbed a single flight of stairs (10 steps) at their self-determined comfortable pace. This speed served as the target training pace. Once a subject was capable of completing all three sets while maintaining the target pace, the weight of the vest was increased by 2% of the subject's body mass at the next training session. During the initial session of the 12-week training program, subjects wore only the vest with no added weight. If a subject consistently exceeded 16 on the Borg Scale or their heart rate exceeded 85% of the predicted maximal heart rate, training for that day was terminated and resistance was reduced by 1% the subsequent session. Successful completion of each week was defined by a subject's ability to complete three sets at the target pace without exceeding 16 on the Borg scale. Once acclimated to the training, sessions did not last longer than 10 minutes.

Walking Program

The walking program was designed in accordance with the national recommendations of the Surgeon General and U.S. Department of Health and Human Services.[19] This consisted of a self-paced walking program, which was initially 15 minutes in duration and was increased by 10 minutes per week to a maximum of 45 minutes. Subjects were instructed to walk at pace at which their level of exertion was characterized as being "somewhat hard," or equivalent to 13 on the Borg Scale.[18] As with the SCE, subjects participated in three exercise sessions per week. Walking was conducted in small groups on the streets outside our laboratory when possible and in the hallway of an adjacent building if the weather was inclement.

Physiological Measures

Leg Power and Strength Measurements

Dynamic strength of the lower extremities was assessed by one-repetition maximum (1RM) measures for both bilateral leg press (N) and individual left and right knee extensors (N-meters). The 1RM measurements were conducted using recumbent pneumatic resistance machines customized with software and digital displays (Keiser Sports Health Equipment Inc., Fresno, CA). An ultrasonic system measuring position, and therefore relative motion, aided examiners in establishing a subject's full range of motion (ROM) by observing the excursion of a lighted bar on the output screen during performance of the measure with minimal resistance. Subjects performed the concentric phase, maintained full extension, and performed the eccentric phase of each repetition over 2, 1, and 2 seconds, respectively. The examiner progressively increased the resistance for each repetition until the subject could no longer move the lever arm one time through the full ROM. An adapted version of the Borg Scale was used to evaluate the subject's perceived effort for each repetition and to assist the examiner in tailoring increments of resistance to achieve the 1RM in approximately eight to 10 repetitions. Measures were performed at baseline and 12 weeks.

After measurement of the 1RM, assessment of bilateral leg press and individual left and right knee extension peak muscle power was performed using the same pneumatic resistance machines used for 1RM testing. Performance of power tests using the pneumatic resistance machines as summarized below has previously been described and validated.[2,20] Peak power (W) was computed in sequence at eight relative intensities (40%, 50%, 60%, 70%, 75%, 80%, 85%, and 90%) of the 1RM. Beginning with 40%, subjects performed the lift at each established percentage of their 1RM as fast as possible through the full ROM. At each force setting, subjects performed one maximal effort with a 30- to 45-second rest between repetitions. The software engineered for the testing equipment calculated work and power during the concentric phase of each repetition by sampling the system pressure (force) and position 400 times a second. Data collected between the start and stop positions of the concentric phase of the repetition were used to compute work (J). Data collected between 5% and 95% of the concentric phase were used to calculate power (W). After each repetition, work and power data were stored and then displayed on the output screen. Regardless of percentage of the 1RM at which it was achieved, the highest power recorded was designated the peak power. Peak muscle power measures were recorded at baseline and 12 weeks in coordination with 1RM measures. A research assistant blinded to exercise program conducted all strength and power measurements.

Submaximal Aerobic Capacity

Subjects underwent an exercise tolerance test on a treadmill (Woodway, Waukesha, WI). Electrocardiogram was monitored throughout testing, and heart rate, blood pressure, and perceived exertion were recorded at the termination of each stage. Perceived exertion was measured using the Borg Scale.[18] The protocol began with a 2-minute warm-up at 1.5 mph and was maintained at a speed of 80% of the subject's habitual gait speed. The initial stage was at 0% grade for 3 minutes, then the incline was increased 2% every 2 minutes until termination. Testing was terminated once participants achieved a Borg Scale rating of 17 or greater or a heart rate greater than 85% of their predicted maximal heart rate. Submaximal heart rate, blood pressure, and perceived exertion were recorded at the last fully completed stage of baseline testing. At 12 weeks, testing was completed according to the same protocol, and submaximal heart rate, blood pressure, and perceived exertion were recorded at the identical stage at which baseline measurements were obtained. Differences in these physiological parameters at this designated submaximal stage served as the basis for comparison.

Physical Performance Testing

The performance tests have been detailed elsewhere[4] but are summarized below.

Tandem Gait

Forward and backward tandem walking over a 20-foot course was timed to the nearest 0.01 second and the number of errors recorded. The average of two trials for each direction was recorded. Tandem gait was determined by summing the forward and backward tandem walk times.

Stair Time

The subjects were instructed to ascend a standard 10-stair flight of stairs as quickly as possible, using the handrail if necessary. Time was recorded to the nearest 0.01 second, and the average of two trials was taken.

Chair Stand Time

The subject was instructed to stand erect and sit back down as fast as they could for 10 repetitions from a standardized chair 0.43 meters in height. One trial was conducted, with time recorded to the nearest 0.01 second.

Habitual and Maximal Gait Velocities

Habitual and maximal gait velocities were measured to the nearest 0.01 second as the mean of two trials using an ultrasonic gait speed monitor (Ultratimer, DCPB Electronics, Glasgow, Scotland).

Short Physical Performance Battery

The SPPB is a reliable and valid measure of lower extremity performance.[15,21] Testing was performed as previously described and involved an assessment of standing balance, a timed 2.4-meter walk, and a timed test of five repetitions of rising from a chair and sitting down.[15] All timing was measured to the nearest 0.1 seconds using a stopwatch. Each of the three tests was scored, based on performance between 0 and 4, leaving a maximum score of 12 for those individuals performing at the highest levels. Because of potential ceiling effects of this measure, 12-week testing was performed only on those subjects who had baseline scores less than 10.

Six-Minute Walk Test

Subjects were instructed to walk at their normal walking pace in a hallway near the laboratory for 6 minutes. The distance walked was recorded using a rolling measuring wheel.

Questionnaires

Subjects completed the Falls Efficacy Scale, the Physical Activity Scale for the Elderly, and Center for Epidemiological Studies—Depression. These are well-established, reliable, and valid measures of self-efficacy regarding falls, physical activity, and depression, respectively.[22,23] Additionally, subjects provided demographic and medical history information.

Statistical Analysis

Descriptive statistics were calculated for specific baseline resident characteristics by exercise protocol. *T* tests (two-sample) were performed on continuous variables to determine whether their mean baseline values were significantly different by exercise group. Sample size, means, standard deviations, and *P*-values were calculated. Analysis of covariance was used to determine whether the difference (change) between assessments for specific variables differed significantly by exercise group. This analysis was age adjusted to account for group differences at baseline. The mean change value and a 95% confidence interval were calculated for each variable by exercise group. The confidence intervals (95%) within each exercise group were used to determine whether a specific subject characteristic changed significantly over time (i.e., the interval did not include the value 0). The percentage change (defined as the difference between the baseline and 12-week assessment value, divided by the baseline value) was calculated to provide an estimate of the magnitude of change for each variable by exercise group. All analyses were performed using SAS (SAS, Inc., Cary, NC), and an alpha level of .05 was used to determine statistical significance.

RESULTS

Subject Participation

Three subjects from the SCE and two from WALK dropped out of the study, leaving 20 subjects in the SCE group (15 female, 5 male) and 20 in the WALK group (14 female, 6 male). Two of the SCE subjects dropped out because of injury unrelated to the study, and the remaining three dropped out because of other personal commitments. There were material differences between the baseline characteristics of the dropouts and the remaining subjects. Attendance for SCE was 91% and for WALK was 87%. Throughout the study, exercise sessions were completed in full for all subjects with the exception of one subject for whom two SCE sessions were terminated after two sets because of an excessive perceived workload. Excluding time for warm-up and cool-down, once subjects were acclimated to the SCE program, the duration of exercise was 10 minutes or less for all participants. In contrast, after the ninth week, all WALK participants were exercising for 45 minutes.

Baseline Characteristics and Physiological Measures

Baseline characteristics stratified by exercise group are illustrated in Table 1. The SCE group was younger than the WALK group. There was no significant difference between the groups in measures of health status, cognitive function, depression, physical activity, or functional status. Mean SPPB scores indicate overall mild to moderate levels of mobility limitation in our participants, despite relatively high habitual gait speeds.[15,21] Baseline physiological measurements are also illustrated in Table 1 and were not significantly different between the two exercise groups.

Validation of SCE Training

Weekly mean values for maximum stair climbing power and stair climbing power are presented in Figure 1. Maximal stair climbing power was calculated from the weekly subject weight and maximal stair climbing speed (used to

Table 1. Baseline Characteristics for Subjects Stratified by Exercise Program

Characteristic	Protocol: SCE (n = 23)*	Protocol: WALK (n = 22)†	*P*-value‡
	mean ± standard deviation		
Age, years	71.0 ± 4.3	74.5 ± 4.3	.011
Weight, kg	69.8 ± 12.6	73.2 ± 19.7	.492
Height, cm	159.4 ± 7.4	159.3 ± 9.8	.969
Body mass index, kg/m^2	27.3 ± 3.8	28.6 ± 5.6	.365
Medications per day, n	2.5 ± 2.2	2.6 ± 1.9	.911
Major medical conditions, n	2.1 ± 1.6	2.2 ± 1.4	.835
Mini-Mental State Examination	29.3 ± 1.5	29.5 ± 1.0	.527
Center for Epidemiological Studies–Depression	14.7 ± 3.6	13.5 ± 3.0	.237
Physical Activity Scale for the Elderly	128.4 ± 74.0	114.9 ± 74.3	.545
Short Physical Performance Battery	9.7 ± 1.3	9.1 ± 1.4	.205
Habitual gait speed, meters/second	1.22 ± 0.15	1.13 ± 0.26	.170
Leg press power, W	386.5 ± 176.2	363.4 ± 186.8	.671
Leg press strength, N	2,108.0 ± 723.6	2,127.2 ± 958.7	.940
Knee extensor power, W	98.4 ± 33.6	99.2 ± 60.0	.957
Knee extensor strength, N-meters	54.9 ± 18.9	54.0 ± 27.7	.892
Stair climbing power, W	215.1 ± 45.6	214.8 ± 84.1	.988
Six-minute walk, meters	466.2 ± 46.8	429.0 ± 103.2	.132
Rate pressure product, mmHg × beats/minute§	20,190.0 ± 2,113.4	19,907.0 ± 3,363.6	.746
Perceived exertion (Borg Scale)§	13.9 ± 1.1	14.1 ± 2.1	.643

*18 women, 5 men.
†16 women, 6 men.
‡from *t* test.
§n = 22 for the stair climbing exercise (SCE) group and n = 19 for the control (WALK) group.

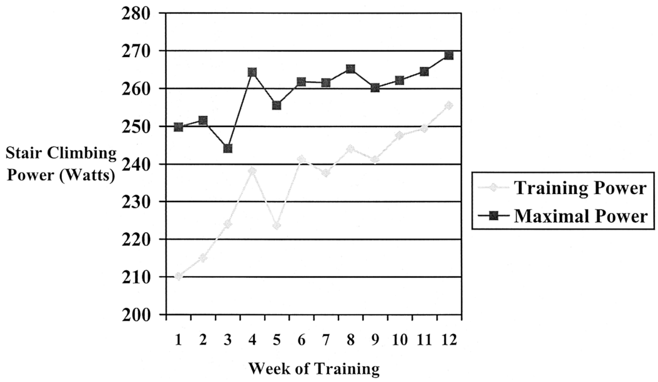

Figure 1. Weekly mean stair climbing power during 12 weeks of stair climbing exercise. Mean training power over the 12 weeks was 90.9% maximum (range 84.1–95.0%).

determine training pace). The upward slope of the graph validates SCE as a well-controlled means of PRT. Overall, training was conducted at an average of 90.9% (range 84.1–95.1%) of the maximum stair climbing power. Variations in subject number reflect dropouts and missed training days. The figure illustrates the weekly progression of the training and maximum stair climbing power.

Power and Strength Measures

The effects of SCE and WALK on strength and power are presented in Table 2. SCE produced significant improvements in leg press power from baseline (mean 0.89 W, 95% confidence interval (CI) = 0.43–1.35) representing an unadjusted improvement of 16.5%. No significant improvement in leg press strength (mean 0.72 N, 95% CI = −0.20–1.65) was seen from baseline. SCE did not produce significant changes in knee extensor power from baseline but did produce significant changes in strength (mean 0.08 N-meters, 95% CI = 0.02–0.13), representing a 9.6% unadjusted improvement from baseline. WALK did not produce any significant changes from baseline in regard to leg press and knee extensor strength or power measurements.

In group comparisons, SCE produced significant improvements in leg press power compared with WALK (P = .013). No significant group comparisons were seen for leg press strength or for knee extensor power or strength measurements despite observable differences in effect size. A significant improvement from baseline in stair climb power was seen for both SCE (mean 24.8 W, 95% CI = 13.4–36.2) and WALK (mean 13.6 W, 95% CI = 2.2–25) representing 11.7% and 6.1% unadjusted improvements respectively. However, group differences did not reach statistical significance (P = .129).

Submaximal Aerobic Performance

Table 2 illustrates the effects of the interventions on submaximal aerobic performance. SCE did not produce significant improvements from baseline in the 6-minute walk distance but did produce significant reductions in submaximal rate-pressure product (RPP) and perceived exertion, representing 13.2% and 9.8% improvements, respectively. WALK produced significant improvements from baseline in the 6-minute walk (4.1%) and RPP (10.8 %) but not in perceived exertion (5.5%). WALK significantly improved 6-minute walk in comparison to SCE (P = .037), but no difference between groups was seen for RPP (P = .735) or perceived exertion (P = .412).

Physical Performance

The effects of SCE and WALK on physical performance are illustrated in Table 3. Although measured in only

Table 2. Changes in Peak Power, Strength, and Aerobic Performance After 12 Weeks of Stair Climbing Exercise (SCE) or Control (WALK)

Variable	Protocol	Mean Change*	95% CI	P-Value†	Unadjusted % Change
Leg press power, W/kg	SCE	0.89	0.43–1.35	.013	16.5§
	WALK	0.09	−0.37–0.54		2.9
Leg press strength, N/kg	SCE	0.72	−0.20–1.65	.443	4.9
	WALK	0.35	−0.57–1.28		0.06
Knee extensor power, W/kg	SCE	0.03	−0.08–0.14	.307	3.1
	WALK	−0.02	−0.13–0.09		−3.7
Knee extensor strength, N/kg	SCE	0.08	0.02–0.13	.705	9.6§
	WALK	0.04	−0.02–0.09		6.9
Stair climb power, W	SCE	24.8	13.4–36.2	.129	11.7§
	WALK	13.6	2.2–25.0		6.1§
Six-minute walk, meters	SCE	−6.72	−22.53–9.10	.037	−1.2
	WALK	18.5	2.67–34.3		4.1§
Submaximal RPP, mmHg × beats/minute‡	SCE	−2,667.40	−4,696.21 to −638.59	.735	−13.2§
	WALK	−2,157.38	−4308.90 to −5.86		−10.8§
Submaximal perceived exertion‡	SCE	−1.36	−2.33 to −0.40	.412	−9.8§
	WALK	−0.77	−1.79–0.25		−5.5

*Average change score from baseline to 12 weeks.
†From analyses of covariance (age adjusted).
‡n = 22 for SCE; n = 19 for WALK.
§Significant change from baseline according to 95% confidence interval (CI).
RPP = rate-pressure product.

Table 3. Changes in Physical Performance After 12 Weeks of Stair Climbing Exercise (SCE) or Control (WALK)

Variable	Protocol	Mean Change*	95% CI	*P*-Value†	Unadjusted % Change
Short Physical Performance Battery‡	SCE	1.14	0.04–2.25	.184	12.1§
	WALK	.35	−0.41–1.10		3.6
Chair stand time, seconds	SCE	−2.07	−4.75–0.62	.870	-6.2
	WALK	−1.22	−3.91–1.47		-4.9
Stair climb time, seconds	SCE	−.66	−1.00 to −0.33	.706	-10.6§
	WALK	−.51	−.84 to −0.18		-8.2§
Tandem walk, seconds	SCE	−5.98	−12.40–0.45	.982	7.5
	WALK	−5.60	−12.21–1.0		7.5
Habitual gait speed, meters/second	SCE	.05	−0.01–0.10	.236	4.1
	WALK	.10	0.04–0.15		8.0§
Maximal gait speed, meters/second	SCE	.07	−0.01–0.15	.639	4.9
	WALK	.07	−0.001–0.15		3.8

*Average change score from baseline to 12 weeks.
†From analyses of covariance (age adjusted).
‡n = 6 for SCE and n = 10 for WALK.
§Significant change from baseline according to 95% confidence interval (CI).

those individuals whose baseline SPPB score was less than 10, SCE produced significant improvements in SPPB (mean 1.14, 95% CI = 0.04–2.25). Additionally, SCE produced significant improvements in stair climb time (mean −0.66 seconds, 95% CI = −1.0 to −0.33).

WALK produced significant improvements in stair climb time (mean −0.51 seconds, 95% CI = −0.84 to −0.18) and habitual gait speed (mean 0.10 m/s, 95% CI = 0.04–0.15). None of the other performance measures were significantly different from baseline within WALK. Despite a threefold difference in unadjusted change from baseline (SCE 12.1%; WALK 3.6%) group differences for the SPPB were not significant ($P = .184$). None of the other group comparisons was significant in regard to physical performance.

DISCUSSION

The major finding of this pilot study in mobility-limited older people is that weighted stair climbing exercise produced significant improvements in peak leg press power compared with a standardized walking program and significant changes from baseline in stair climbing power. This short-duration exercise (10 minutes) produced improvements (17%) similar in magnitude to those achieved with 60 minutes of PRT using high-cost exercise equipment.[8] Also, observing the effect sizes demonstrated in Table 2 is suggestive that SCE has the potential to influence leg press strength and knee extension power and strength as well.

Our subjects were older people with mild to moderate mobility limitations as defined by the SPPB.[15,21] Our baseline habitual gait speeds suggest mild mobility limitations. There are two likely causes for this apparent discrepancy. First, other investigators have used methods of measuring gait speed that initiates timing when a subject is at rest,[15,21] whereas we began measurements once the participant had already reached a steady gait velocity. This alternative method eliminates differences in acceleration time due to potential confounding factors. These factors, which include neuroprocessing of the command to start and the time to initiate movement, may contribute to the slower habitual gait speeds observed with other methodologies. Additionally, this finding may suggest that our participants were more limited on the other SPPB functional tasks, which include static balance and rising from a chair, than for gait speed. However, it should not be surprising that subjects with mild to moderate mobility limitations can climb stairs. Guralnik et al. have reported that less than 10% of such individuals need help with stair climbing.[15]

Figure 1, which demonstrates progressive increases in resistance at approximately 90% of peak stair climbing power, emphasizes the potential for SCE to serve as a well-controlled, progressive means of power training. It is again important to consider the relationship between strength and power. Previously, we found that peak lower extremity power is most commonly obtained at 70% to 75% of 1RM.[4] Therefore, SCE most likely occurred at 60% to 70% of 1RM, which represents a lower resistance than that commonly used in PRT, which is generally at 80% of 1RM.[7,8]

Although much shorter in duration than a standardized walking program, SCE produced similar improvements in submaximal aerobic performance, as measured by an exercise tolerance test. Strength gains were more limited, demonstrating only baseline improvements in knee extensor strength in stair climbers. Stair climb time was improved in both groups, and habitual gait was improved in WALK. These findings are consistent with prior work in healthy older people. Lastly, within a subcohort of SCE participants with moderate mobility limitations, improvements in physical performance from baseline were seen as measured by the SPPB.

This study suggests that SCE may be a useful means of increasing lower extremity power. It was well tolerated by a cohort of mobility-limited older people. The additional use of an audible metronome was acceptable even to those subjects who had partial hearing impairments. Its potential benefits in increasing lower extremity power may in part be explained by the specificity of training.

Leg power and strength are important attributes required for stair climbing. An understanding of stair climbing biomechanics helps explain our findings.[24,25] It has been demonstrated that the ability to ascend stairs is strongly dependent upon hip extension, which is the same muscle action used in leg press testing.[25] The greatest knee extension forces are generated with stair descent.[25] For reasons of safety, stair climbers were less able to maintain target pace while descending stairs. Having this component of the exercise potentially less dependent on velocity may explain in part why improvements in knee extension strength and not power were seen in SCE participants.

The improvements in submaximal aerobic performance as measured by an exercise tolerance test are worth emphasizing. They were equivalent in magnitude to those seen with walking, which is perhaps the most common form of aerobic exercise recommended to older adults.[19,26] This is a surprising finding, because the duration of exercise was dramatically different: approximately 10 minutes for SCE and 45 minutes for WALK. In contrast, such improvements were not seen with another measure of submaximal aerobic performance, the 6-minute walk test. The validity of the 6-minute walk test in a cohort such as ours has been recently questioned. It has been suggested that, in older people, this test is influenced by nonphysiological factors, including motivation and self-efficacy.[27] Taking these factors into account, differences in the 6-minute walk may have been due more to the walker's familiarity with walking than actual differences in aerobic performance.

Stair climbing exercise using a stair climber exercise machine has been reported to produce substantially higher responses in blood pressure and heart rate than other forms of aerobic exercise such as walking.[28] For this reason and others, stair climbing as a form of exercise has not been a first choice for older people. In contrast to the constant resistance of a stair climber machine, SCE has built-in periods of reduced workload during stair descent and rest periods. Additionally, by having both ascent and descent, this method of training uses concentric and eccentric actions of the lower extremity muscles. This is important because both types of muscle actions are used in common mobility tasks. Further investigation of the cardiovascular and biomechanical effects of SCE is warranted.

There are potential limitations of this study. Because this was a pilot study, we used a relatively small sample size that was highly variable. In combination, these facts suggest that real differences between the groups may not have been detected, because of type 2 error. This finding is supported by the percentage changes shown in Tables 2 and 3, which demonstrate apparent mean differences between physiological (stair climb power) and functional performance (SPPB) outcomes that did not reach significance, likely because of the relatively small sample size, and high variability of the measures. Walking was chosen as a comparison group for this pilot study because it represents the criterion standard of exercise often recommended by primary care physicians. Also, Rantanen et al. have demonstrated that leg power and walking speed were positively correlated in community-dwelling older people.[29] These factors served as the theoretical rationale for using walking as a comparison group. Nevertheless, resistance training has been the form of exercise that has proven to be most beneficial to functional performance. If SCE is to be demonstrated as beneficial to functioning, comparisons with resistance-training programs should be performed. SPPB scores were obtained at 12 weeks only on subjects who at baseline had scores of nine or less. Inspection of the mean change in SPPB values (Table 3) suggests that, by further reducing our sample size, we were unable to detect meaningful differences between the groups. Despite this, significant changes from baseline were seen in the SCE participants. Given the strong association between this functional measure and disability, the influence of power training on the SPPB and other functional measures should be further investigated.

Despite these limitations, SCE is worthy of further inquiry. Potential home-based forms of power training should be developed. Given its short duration and potential influence on aerobic performance, SCE may best serve as a component of a home-based exercise program designed to enhance muscle power, aerobic capacity, and functional performance. Future studies should involve more-comprehensive power-training exercises, larger sample sizes, and direct comparisons with existing PRT programs.

REFERENCES

1. Evans WJ. Exercise strategies should be designed to increase muscle power. J Gerontol A Biol Sci Med Sci 2000;55A:M309–M310.
2. Foldvari M, Clark M, Laviolette MJA et al. Association of muscle power with functional status in community dwelling elderly women. Med Sci Sports Exerc 1999;31:S378.
3. Suzuki T, Bean J, Fielding R. Muscle strength and power of the ankle plantar and dorsiflexors predict functional performance in community-dwelling older women. J Am Geriatr Soc 2001;49:1161–1167.
4. Bean J, Kiely DK, Herman S et al. The relationship between leg power and physical performance in mobility limited elders. J Am Geriatr Soc 2002;50: 461–467.
5. Bassey EJ, Fiatarone MA, O'Neill EF et al. Leg extensor power and functional performance in very old men and women. Clin Sci 1992;82:321–327.
6. Metter EJ, Conwit R, Tobin J et al. Age associated loss of power and strength in the upper extremities in women and men. J Gerontol A Biol Sci Med Sci 1997;52A:B267–B276.
7. Fiatarone MA, O'Neill EF, Ryan ND et al. Exercise training and nutritional supplementation for physical frailty in very elderly people. N Engl J Med 1994;330:1769–1775.
8. Jozsi AC, Campbell WW, Joseph L et al. Changes in poser with resistance training in older and younger men and women. J Gerontol A Biol Sci Med Sci 1999;54A:M591–M596.
9. Skelton DA, Greig CA, Davies JM et al. Strength, power and related functional ability of health people aged 65–89 years. Age Ageing 1994;23:371–377.
10. Cress ME, Thomas P, Johnson J et al. Effect of training on $V0_2$max, thigh strength, and muscle morphology in septuagenarian women. Med Sci Sports Exerc 1991;23:752–758.
11. Shaw JM, Snow CM. Weighted vest exercise improves indices of fall risk in older women. J Gerontol A Biol Sci Med Sci 1998;53A:M53–M58.
12. Snow CM, Shaw JM, Winters KM et al. Long-term exercise using weighted vests prevents hip bone loss in postmenopausal women. J Gerontol A Biol Sci Med Sci 2000;55A:M489–M491.
13. Rooks DS, Kiel DP, Parsons C et al. Self-paced resistance training and walking exercise in community-dwelling older adults: Effects on neuromotor performance. J Gerontol A Biol Sci Med Sci 1997;52A:M161–M168.
14. Rosenberg R, Gagnon M, Murphy-Gismondi P et al. Factors influencing subject willingness to participate in clinical gerontological research. Aging Clin Exp Res 1996;8:400–408.
15. Guralnik JM, Simonsick EM, Ferucci L et al. A short physical performance battery assessing lower extremity function: Association with self-reported disability and prediction of mortality and nursing home admission. J Gerontol A Biol Med Sci 1994;49A:M85–M94.
16. Folstein MF, Folstein SF, McHugh PR. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 1975;12:189–198.

17. Kenney WL, Humphrey RH, Bryant CX. ACSM's Guidelines for Exercise Testing and Prescription. Baltimore, MD: Williams and Wilkins, 1995.
18. Borg GA. Psychophysical bases of perceived exertion. Med Sci Sports Exerc 1982;14:377.
19. United States Department of Health and Human Services. Physical Activity and Health: A Report of the Surgeon General. Atlanta, GA: United States Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, 1996.
20. Thomas M, Fiatarone MA, Fielding RA. Leg extensor power in young women: Functional correlates and relationship to body composition and strength. Med Sci Sports Exerc 1996;28:1321–1326.
21. Guralnik JM, Ferrucci L, Pieper CF et al. Lower extremity function and subsequent disability: Consistency Across studies, predictive models, and value of gait speed alone compared with the Short Physical Performance Battery. J Gerontol A Biol Sci Med Sci 2000;55A:M221–M231.
22. Tinetti ME, Richman D, Powell L. Falls efficacy as a measure of fear of falling. J Gerontol 1990;45:239–243.
23. Washburn R, Smith K, Jette A. The physical activity scale for the elderly (PASE): Development and evaluation. J Clin Epidemiol 1993;48:153–162.
24. Cavanagh P, Mulfinger LM, Owens DA. How do the elderly negotiate stairs? Muscle Nerve Suppl 1997;5:S52–S55.
25. Andriacchi TP, Andersson GB, Fermier RW et al. A study of lower-limb mechanics during stair-climbing. J Bone Joint Surg Am 1980;62:749–757.
26. American College of Sports Medicine. Position stand: Exercise and physical activity for older adults. Med Sci Sports Exerc 1998;30:992–1008.
27. Simonsick EM, Montgomery PS, Newman AB et al. Measuring fitness in healthy older adults: The Health ABC Long Distance Corridor Walk. J Am Geriatr Soc 2001;49:1544–1548.
28. Benn SJ, McCartney N, McKelvie RS. Circulatory responses to weight lifting, walking, and stair climbing in older males. J Am Geriatr Soc 1996;44:121–125.
29. Rantanen T, Avela J. Leg extension power and walking speed in very old people living independently. J Gerontol A Biol Sci Med Sci 1997;52A:M225–M231.