Comparison of Effect of Aerobic Cycle Training and Progressive Resistance Training on Walking Ability After Stroke: A Randomized Sham Exercise–Controlled Study

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OBJECTIVES: To determine whether changes in strength or cardiorespiratory fitness after exercise training improve walking ability in individuals who have had a stroke.

DESIGN: A sham exercise-controlled, randomized two-by-two factorial design, in which the two factors investigated were cycle training (AEROBIC) and resistance training (STRENGTH).

SETTING: University exercise laboratory.

PARTICIPANTS: Fifty-two individuals with a history of stroke (aged 63 ± 9; time since stroke, 57 ± 54 months).

INTERVENTION: Participants undertook 30 exercise sessions over 10 to 12 weeks. Depending on group allocation, individuals underwent aerobic cycling plus sham progressive resistance training (PRT) ($n = 13$), sham cycling plus PRT ($n = 13$), aerobic cycling plus PRT ($n = 14$), or sham cycling plus sham PRT ($n = 12$).

MEASUREMENTS: Primary outcomes were 6-minute walk distance, habitual and fast gait velocities, and stair climbing power. Secondary outcomes included measures of cardiorespiratory fitness; muscle strength, power, and endurance; and psychosocial attributes.

RESULTS: Neither AEROBIC nor STRENGTH improved walking distance or gait velocity significantly more than sham exercise, although STRENGTH significantly improved participants' stair climbing power by 17% ($P = .009$), as well as their muscle strength, power, and endurance; cycling peak power output; and self-efficacy. Conversely, AEROBIC improved indicators of cardiorespiratory fitness only. Cycling plus PRT produced larger effects than either single modality for mobility and impairment outcomes.

CONCLUSION: Single-modality exercises targeted at existing impairments do not optimally address the functional deficits of walking but do ameliorate the underlying impairments. The underlying cardiovascular and musculoskeletal impairments are significantly modifiable years after stroke with targeted robust exercise. **J Am Geriatr Soc 56:976–985, 2008.**

Key words: cerebrovascular disease; exercise training; randomized, controlled trial; walking

Stroke is a common disease that is associated with aging, with 72% of people who suffer a stroke in any year aged 65 and older.[1] It is the leading cause of serious, long-term disability in the United States.[2] Whereas the major physical impairments as a consequence of stroke are weakness and loss of coordination,[3] many everyday activities are unachievable or are accomplished with great effort and difficulty. Walking, for example, is often slower (e.g., from 0.16 to 0.88 m/s) than in healthy persons aged 60 to 80, who typically walk at speeds greater than 1.23 m/s.[4] The slow velocity of gait is not only unsafe for some activities of daily living such as crossing streets, particularly in metropolitan regions,[5] but also requires considerable effort because of poor walking efficiency.[6] It is also a barrier to walking independently within the community, because a person needs to be able to walk relatively long distances.[7,8] As such, persons who have recovered from a stroke often have poor walking skills and endurance, usually being unable to walk continuously for 6 minutes.[9] Strategies to reduce the underlying impairments after stroke and thereby improve physical ability are needed if quality of living is to be enhanced in these older adults.

Strength conditioning and aerobic training used singularly or together may address the impairments and improve participants' ability to perform everyday activities. It has been shown that stroke survivors tolerate exercise programs

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that comprise aerobic and resistance training components well.[10–12] One benefit of such exercise training is that it can be implemented in community gyms with an exercise specialist and can thereby be performed after discharge from poststroke rehabilitation units. If training occurs at sufficient intensity, it can lead to improvement in fitness and strength,[10–12] although it is unknown whether improvements in aerobic capacity or strength lead to a decrease in disability after stroke.

Several studies have demonstrated the benefits of high-intensity resistance training in older persons with a disability. For example, women with congestive heart failure were able to walk 49 m further after 10 weeks of high-intensity resistance training.[13] Similarly, frail, very old men and women in a nursing home improved their walking velocity after high-intensity resistance training.[14] Because persons with stroke often have muscle weakness, similar benefits may be achieved for this population.

Aerobic exercise training may target deficits of cardiorespiratory fitness[15] and a stroke survivor's loss of coordination.[3] Cycle ergometry may be the preferred mode of aerobic exercise for persons after stroke, because previous studies have shown that stroke patients do not have the capacity to walk at a sufficient pace to provide adequate stimulus to the cardiovascular system.[16] In addition, there is a danger of falls in stroke patients with suboptimal posture control and balance.

The purpose of this study was to determine whether participation in a 10-week high-intensity exercise program comprising aerobic training, progressive resistance training (PRT), or a combination of the two would improve walking ability. It was hypothesized that walking distance would improve a minimum of 20% after PRT or aerobic exercise interventions. Furthermore, it was hypothesized that PRT and aerobic training would lead to improvement in the associated underlying impairments, although only for individuals whose training focused on that specific impairment (muscle weakness or poor cardiorespiratory fitness).

METHODS

Study Design and Sample

This study employed a sham-exercise controlled, randomized two-by-two factorial design in which the two interventions investigated were progressive resistance training (STRENGTH factor) and aerobic cycle training (AEROBIC factor). The study was registered with the U.S. National Institutes of Health Clinical Trials Registry (http://clinicaltrials.gov; NCT00107068).

Persons with a history of stroke were recruited from local hospitals, peer support groups through advertisement in community and seniors' newspapers, and from a database of previous participants of research projects. Inclusion criteria were 3 months or longer poststroke, aged 45 and older, unilateral hemiparesis of a leg, residing in a community-based living environment, self-selected gait velocity between 0.15 and 1.4 m/s, no longer receiving physiotherapy after stroke, and able to understand simple spoken English. Exclusion criteria were significant musculotendinous or bony restrictions (contractures), complete hemiplegia of a leg, severe cognitive deficits, or any contraindication to moderate exercise outlined by American College of Sports Medicine guidelines for cardiac disease rehabilitation[17] or for frail and elderly adults.[18] Written informed consent was obtained from each participant, and the Human Research Ethics Committee at the University of Sydney, Australia, approved the study.

Group Allocation

Participants underwent telephone screening followed by a history and physical examination and a 12-lead electrocardiogram at rest and during a physician-supervised maximal effort cycling test. After completion of baseline measures, participants were randomized to one of four intervention groups using concealed coded cards compiled in permuted blocks of eight without stratification.

Interventions

Each intervention comprised thirty 60-minute supervised sessions conducted three times per week over 10 to 12 weeks, with makeup sessions allowed within this time frame. To assess the efficacy of AEROBIC, semi-recumbent cycling was employed as the exercise mode; for STRENGTH, PRT was used. The intensity and duration at which participants trained were based on the guidelines provided by the American College of Sports Medicine[17] specifically for older adults.[18] Each participant received both modalities per session: real or sham cycling followed by real or sham PRT. Trained personnel supervised all exercise sessions in a university exercise laboratory. Subjects were asked not to start any other exercise regimen during the course of the study, but habitual activity levels were maintained.

Cycling

Participants undertook 30 minutes of leg cycling per session using a semi-recumbent motorized isokinetic cycle ergometer with calf supports (MOTOMed VIVA Cycle, Reek Medizintechnik GmBH, Betzenweiler, Germany). Pedaling cadence was set at 40 rev/min, and resistance was adjusted to elicit a target heart rate (HR) equivalent to 50% of peak oxygen uptake (VO_2peak) in the initial 1 to 2 weeks; this was increased to 70% VO_2peak by Week 4. The initial exercise prescription was based on the maximal effort cycling test performed at baseline assessment. The Borg Scale of Perceived Exertion[19] was used to adjust the intensity to achieve an effort of hard to very hard. Participants were reassessed after 6 weeks on a maximal effort cycle test to adjust their training HR for the final 4 to 6 weeks. Participants wore an HR monitor during all exercise sessions, and HR and blood pressure were monitored before, every 5 minutes during, and 5 minutes after completion of training.

After each cycling session, participants undertook bilateral "sham" resistance training of two sets of eight repetitions for each exercise. Leg extensors and knee flexors and extensors were trained with a minimum amount of resistance to counter the weight of a machine (Keiser Sports Health Equipment, Inc., Fresno, CA) against gravity, and ankle plantarflexors and dorsiflexors and hip abductors were trained without any resistance.

PRT

Participants commenced 30 minutes of sham aerobic exercise of motorized passive leg cycling whereby the motor rotated their legs in the same cycle ergometer as that used in the cycling group. In addition, the participants' HR and blood pressure were monitored in a fashion identical to that of those who were undertaking the aerobic training. After sham cycling, participants undertook PRT of the lower limb extensors, knee extensors and flexors, and ankle plantarflexors using pneumatic resistance equipment (Keiser Sports Health Equipment, Inc.) except hip abductors and dorsiflexors, which used free weights and isometric training, respectively. Participants performed two sets of eight repetitions unilaterally, commencing at 50% of baseline 1 repetition maximum (1RM) and progressing to 80% 1RM by Week 2. The load was increased after each session to achieve theoretical gains of strength approximating 3% per session[20] and adjusted using the Borg Scale of Perceived Exertion to achieve an effort of very hard. In addition, for each exercise, the 1RM was assessed fortnightly for the purpose of represcribing the resistance dose.

Combined

Participants undertook 30 minutes of cycling followed by PRT, as described above.

Control

Participants undertook 30 minutes of sham cycling and sham PRT, as described above.

Outcome Measurements

All baseline testing was blinded, because it was completed before randomization, and a single blinded observer assessed the primary outcome measures related to walking ability at both time points. A single nonblinded assessor measured secondary outcomes related to the underlying impairments of poor cardiorespiratory fitness and muscle strength, power, and endurance at posttesting (within 1 week of final exercise session).

Walking Ability

A 6-minute walking endurance test and 10-m habitual- and fast-gait velocities were conducted with participants wearing shoes and using their usual assistive devices (e.g., cane, ankle-foot orthosis). For the stair climbing test, participants ascended a standardized flight of 10 stairs as quickly and safely as possible, using a handrail for postural support if necessary. Stair climb power was calculated from the time taken to ascend the stairs, the known vertical height, and body mass.[21]

Cardiorespiratory Fitness and Associated Measures

A progressive-intensity maximal-effort cycling test was conducted following a standardized protocol.[15] The data collected included peak power output (POpeak), and cardiorespiratory fitness assessed from peak HR and VO_2peak using a metabolic cart (CardiO2 and CPX/D system, Medical Graphics Co., Saint Paul, MN). Cardiorespiratory responses were also assessed during a gait-specific treadmill task. Participants were instructed to identify the velocity they could maintain comfortably over a period of 5 to 7 minutes. A 5-point speed scale was used to determine whether the velocity was too slow, a little slow, comfortable, a little fast, or too fast. Subjects were encouraged to increase their velocity until they indicated that it was a little fast. Once they achieved this level, the velocity was maintained for the duration of the test. The endpoint of the test was the point at which their cardiorespiratory responses reflected those of steady-state exercise (nonchanging oxygen uptake during effort).

Participants performed a single-stage test before training (baseline) and a dual-stage test after training (follow-up), with the first stage set to their baseline velocity and the second stage self-selected to their comfortable walking velocity after training. Physical cost index (HR/gait velocity; b/m),[22] and oxygen cost (VO_2/gait velocity; mL/kg per m)[17] were calculated.

Strength and Related Measures

Dynamic muscle strength (1RM) or maximal isometric force was assessed unilaterally for leg extensors, knee extensors and flexors, and plantar- and dorsiflexors using pneumatic resistance machines or a fixed dynamometer (Chatillon Medical Dynamometers, Ametek, Largo, FL) and a standardized protocol.[23] The total maximal force of these muscles for each side was calculated.[23] The peak power achieved during a single explosive contraction was determined for leg extension, knee extension, and knee flexion using a standardized protocol.[23] The total peak power of the three muscle groups for each side was determined. For measurement of muscle endurance of the leg extensors, knee extensors and flexors, and plantarflexors, participants completed as many repetitions as possible in 30 seconds at 90% baseline 1RM. The average number of repetitions for these four muscles was determined.

Quality of Life and Self-Efficacy

The 36-item Short Form Medical Outcomes Survey (SF-36)[24] assessed health-related quality of life, psychological function, and general health. Participants' confidence in their ability to walk, jog, climb stairs, lift weights, and do push-ups was determined using Ewart's physical self-efficacy scales.[25] Adverse events were recorded at every session in all subjects and were defined a priori as injuries, symptoms, or exacerbations of underlying diseases potentially attributable to the exercise regimens.

Statistical Analysis

Following an intention-to-treat paradigm, any missing values at follow-up were brought forward from baseline data for the primary outcomes (walking ability). This study was a two-by-two factorial design, whereby the main effects of AEROBIC and STRENGTH component factors were contrasted to sham interventions of each. The main effects of AEROBIC or STRENGTH and the AEROBIC-by-STRENGTH interaction effect were analyzed using a "factorial" linear regression model with a single covariate (baseline score). The regression model included dummy-coded values for the AEROBIC and STRENGTH component factors. The model initially included a term for the interaction effect between AEROBIC and STRENGTH factors, and the intention was to retain this interaction term if it was significant, but the interaction term was not significant for any primary or secondary variable ($P > .05$). A planned a posteriori comparison was conducted to evaluate the possible effects of combined PRT plus cycling against the control condition using a linear regression model with baseline scores as a covariate.

Significant changes in the efficacy with which participants performed their everyday activities identified according to factorial analyses were correlated using Pearson correlations with changes in their physical ability and underlying impairments to determine whether these factors were related.

All data are expressed as means ± standard deviations, and statistical analyses were conducted using SPSS version 14 (SPSS Inc., Chicago, IL) with 95% confidence intervals (CIs). Statistical significance was set at $P<.05$.

RESULTS

A flowchart of participant recruitment is presented in Figure 1. Of a sample of 122 individuals screened using a telephone interview, 54 underwent baseline assessments. People with stroke who declined or were unable to participate were aged 65 ± 11 (range 35–85), which was not significantly different from the age of participants in the study. There were no significant intergroup differences at baseline in participants' characteristics or any other variables (Table 1; $P>.1$). All exercise training was well tolerated, with no serious adverse events during testing or training. Four participants dropped out during training and declined to come back for the follow-up assessment because of illness unrelated to exercise training or for personal reasons.

Efficacy of Treatment

Table 2 displays the baseline and 12-week outcome measures, and Figure 2 displays the change scores for the primary outcomes. The primary analysis assessed the effects of AEROBIC and STRENGTH factors within four exercise training groups upon measures of walking ability (shaded cells; Table 3). The effect of AEROBIC (the adjusted difference in outcomes between the cycling and sham cycling groups) was 12.1 m (95% CI = –2.9–27.1 m) on the 6-minute walk test, 0.00 m/s (95% CI = −0.08–0.08) on fast walking velocity, −0.06 m/s (95% CI = −0.13–0.01) on habitual walking velocity, and 9.2 W (95% CI = −1.0–19.3) on stair climbing power. The effect of STRENGTH (the adjusted difference in outcomes between the PRT and sham PRT groups) was 7.6 m (95% CI = −7.4–22.7 m) on the 6-minute walk test, 0.01 m/s (95% CI = −0.07–0.09) on fast walking velocity, −0.03 m/s (95% CI = −0.10–0.04) on habitual walking velocity, and 13.9 W (95% CI = 3.4–24.4) on stair climbing power. All component factors were nonsignificant, except the effect of STRENGTH on stair climbing power ($P=.01$).

Analysis of secondary outcomes (impairments) revealed that training-induced improvements were in most cases specific to the mode of training employed. All participants completed the maximal effort test on the cycle ergometer, although five participants (2 in the cycling group and 1 in each of the other groups) were unable to ambulate on the treadmill and so were excluded from the analysis of

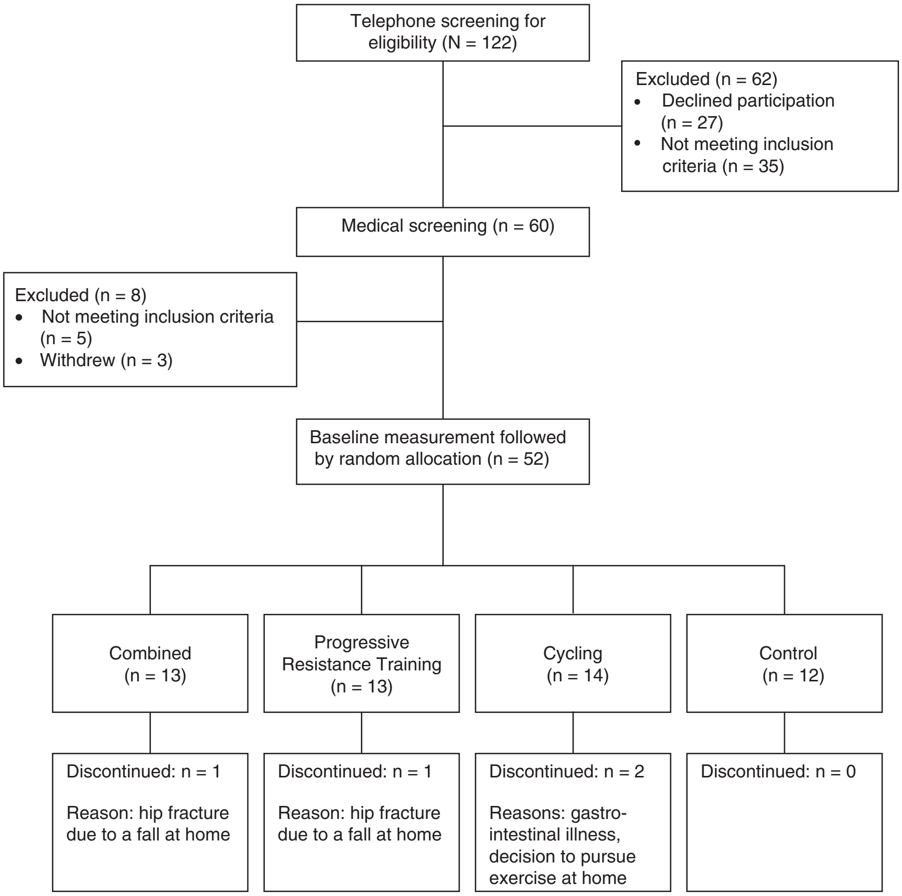

Figure 1. Flowchart of participants and study design through the trial.

Table 1. Participant Characteristics According to Group Allocation

Characteristic	All Participants	Combined n = 12	Progressive Resistance Training n = 12	Cycle n = 12	Control n = 12
Age, mean ± SD	63.2 ± 9.0	60.5 ± 10.6	62.9 ± 9.3	67.2 ± 10.6	65.3 ± 6
Months since stroke, mean ± SD	57.0 ± 54.2	63.2 ± 40.5	44.2 ± 63.9	52.4 ± 2.2	65.8 ± 42.3
Male:female	28:20	8:4	8:4	6:6	6:6
Affected side: right:left	27:21	7:5	7:5	7:5	6:6
Type of cerebrovascular accident, n					
Infarct	33	7	8	9	9
Hemorrhage	9	4	2	2	1
Other	6	1	2	1	2
Participants taking β-blockers, n	8	2	3	1	2
Number of chronic illnesses, mean ± SD	1.8 ± 1.0	1.8 ± 1.1	1.5 ± 0.5	2.0 ± 1.1	1.8 ± 1.2
Participants with cardiovascular disease, n					
Coronary artery disease	15	3	6	3	3
Diabetes mellitus	8	4	1	2	1
Hypertension	28	6	4	9	9

SD = standard deviation.

treadmill walking outcomes. AEROBIC had significant benefits in terms of VO$_2$peak and POpeak during the maximal effort cycling test and physical cost index during treadmill walking. For example, AEROBIC increased cycling VO$_2$peak by 2.5 mL/kg per minute (95% CI = 1.9–4.9; $P = .002$), whereas STRENGTH augmented VO$_2$peak by 0.5 mL/kg per minute (95% CI = − 1.0–2.0; $P = .51$).

STRENGTH was associated with significant improvements in POpeak (Table 3); examination of each group revealed that the group receiving cycling and PRT and not the group receiving only PRT drove the improvements (Table 2). Overall, the effect of STRENGTH on POpeak was 19.8 W, whereas the group receiving only PRT improved their POpeak by 6 W, compared with 31.4 W by the combined group.

STRENGTH was also significantly associated with enhanced muscle strength, power, and endurance for the stroke-affected and unaffected legs. For example, on the stroke-affected side, strength increased 255.4 N (95% CI = 184.6–326.2), power increased 77.4 W (95% CI = 31.9–122.8), and the average number of repetitions during the endurance test increased by 6 (95% CI = 4.4–7.6). In addition, dynamic muscle strength increased 54 ± 5%, power improved 65 ± 15% and the number of repetitions increased 184 ± 25%. Smaller relative changes were seen on the intact side. By contrast, aerobic training led to no improvements in power, strength, or endurance on the affected or intact sides, except for a small improvement in endurance on the intact side.

A planned a posteriori comparison of cycling plus PRT (combined) against the control condition in which participants received sham cycling plus sham PRT was undertaken for primary and secondary outcome measures (Table 3). It revealed a larger effect for the combined intervention than for AEROBIC or STRENGTH on measures of walking ability and underlying impairments of aerobic fitness and strength scores. The effects were significantly different from those of the control group for habitual-gait walking velocity and stair climbing power, although the effect was in the opposite direction for habitual-gait velocity. The control group increased its habitual-gait velocity more than the combined cycling plus PRT group (Δ velocity: 0.12 vs 0.02 m/s). At the level of impairment (i.e., aerobic fitness and strength scores), the effect of the combined training was larger than AEROBIC or STRENGTH alone and was statistically significant for all but peak HR during maximal-effort cycling and treadmill walking oxygen cost (Table 3).

Two participants did not complete questionnaires because of a language barrier. There were no significant effects of AEROBIC or STRENGTH factors on the domains within the SF36, although factorial analyses revealed that STRENGTH, but not AEROBIC, was associated with enhanced participant self-efficacy for stair climbing (strength: Δ 22.4 ± 25.1; sham strength: Δ 2.3 ± 21.4; $P = .007$) and walking ability (strength: Δ 10.70 ± 15.71; sham strength: Δ.6.5 ± 21.65; $P = .02$). Neither PRT nor cycle training significantly improved the other domains investigated, including jogging, lifting weights, and doing push-ups ($P > .05$). Change in self-efficacy of walking showed weak, but significant, associations with change in fast walking velocity ($r = 0.35$, $P = .03$) and change in the intact leg's muscle strength ($r = 0.30$, $P = .04$). It was not associated with change in distance walked or change in strength or power of the stroke-affected limb. Similarly, change in self-efficacy of stair climbing ability was not associated with change in stair climbing power but demonstrated weak associations with change in strength in the the intact leg ($r = 0.30$, $P = .046$) and power ($r = 0.40$, $P = .006$).

DISCUSSION

The present study was the first randomized, controlled trial that rigorously investigated the effects of PRT and aerobic exercise training alone and in combination with sham exercise in community-dwelling stroke survivors to address underlying physiological impairments on disability. It was found that underlying impairments such as low strength, power, or endurance reduced peak aerobic power and high physical cost index during treadmill walking were

Table 2. Primary Outcomes Related to Walking, and Secondary Outcomes Related to Aerobic and Strength Fitness

	Combined	Cycle	Progressive Resistance Training	Control
Variable	**Mean ± Standard Deviation**			
Walking variables				
6-minute walk, m				
Baseline	266.0 ± 123.5	249.3 ± 158.3	239.8 ± 141.0	273.2 ± 162.1
12 weeks	290.2 ± 136.2	261.5 ± 162.7	247.2 ± 148.8	278.1 ± 162.1
Habitual gait velocity, m/s				
Baseline	0.74 ± 0.30	0.71 ± 0.42	0.67 ± 0.36	0.66 ± 0.36
12 weeks	0.76 ± 0.32	0.74 ± 0.41	0.73 ± 0.41	0.78 ± 0.43
Fast gait velocity, m/s				
Baseline	0.97 ± 0.46	0.93 ± 0.56	0.81 ± 0.48	0.92 ± 0.55
12 weeks	0.98 ± 0.46	0.94 ± 0.55	0.84 ± 0.53	0.93 ± 0.54
Stair climbing power, W				
Baseline	88.3 ± 40.0	109.7 ± 71.2	77.6 ± 41.0	117.8 ± 67.1
12 weeks	108.7 ± 41.6	121.3 ± 80.9	92.4 ± 49.2	116.5 ± 67.8
AEROBIC fitness				
Peak power output, W				
Baseline	59.6 ± 19.0	54.3 ± 24.8	53.7 ± 18.4	58.3 ± 27.1
12 weeks	91.0 ± 38.7	60.9 ± 26.7	59.7 ± 25.9	46.9 ± 21.4
Peak heart rate, beats/min				
Baseline	133 ± 14	124 ± 23	119 ± 21	125 ± 24
12 weeks	137 ± 24	124 ± 28	113 ± 24	118 ± 15
Peak oxygen uptake, mL/kg per minute				
Baseline	14.4 ± 3.1	13.0 ± 4.5	14.0 ± 3.3	13.5 ± 3.5
12 weeks	16.6 ± 5.2	14.5 ± 3.9	13.5 ± 3.8	12.7 ± 4.3
Treadmill walking physical cost index, beats/min				
Baseline	7.01 ± 2.85	7.38 ± 5.62	4.51 ± 2.48	6.57 ± 5.79
12 weeks	6.31 ± 2.30	5.84 ± 3.95	4.73 ± 2.57	6.90 ± 5.90
Treadmill walking oxygen cost, mL/kg per minute				
Baseline	0.71 ± 0.26	0.78 ± 0.61	0.47 ± 0.21	0.65 ± 0.49
12 weeks	0.65 ± 0.25	0.64 ± 0.47	0.52 ± 0.23	0.61 ± 0.38
STRENGTH scores				
1RM in affected leg, N				
Baseline	602.3 ± 203.2	732.1 ± 353.1	569.6 ± 207.0	682.8 ± 280.7
12 weeks	907.2 ± 304.8	768.0 ± 352.7	848.2 ± 249.9	714.1 ± 225.9
1RM in unaffected leg, N				
Baseline	1,408.5 ± 323.6	1,276.4 ± 284.4	1,263.9 ± 310.1	1,167.9 ± 332.2
12 weeks	1,802.2 ± 432.7	1,297.6 ± 337.1	1,603.3 ± 373.3	1,158.5 ± 321.8
Power in affected leg, W				
Baseline	190.5 ± 102.2	234.4 ± 180.4	209.0 ± 106.7	230.4 ± 102.2
12 weeks	290.9 ± 148.6	229.1 ± 162.8	287.3 ± 126.4	269.8 ± 140.2
Power in unaffected leg, W				
Baseline	649.1 ± 242.9	489.6 ± 186.1	525.9 ± 192.7	476.8 ± 214.0
12 weeks	819.3 ± 245.6	513.7 ± 155.6	702.8 ± 235.6	493.6 ± 163.6
Endurance in affected leg, average number of repetitions				
Baseline	4.3 ± 2.0	4.8 ± 2.1	4.2 ± 2.0	5.1 ± 1.8
12 weeks	11.5 ± 5.0	5.7 ± 4.0	9.7 ± 2.4	5.1 ± 3.2
Endurance in unaffected leg, average number of repetitions				
Baseline	7.3 ± 2.1	6.4 ± 1.3	6.5 ± 2.3	5.9 ± 1.7
12 weeks	17.5 ± 3.5	8.2 ± 4.3	13.7 ± 1.9	6.4 ± 3.0

1RM = 1 repetition maximum.

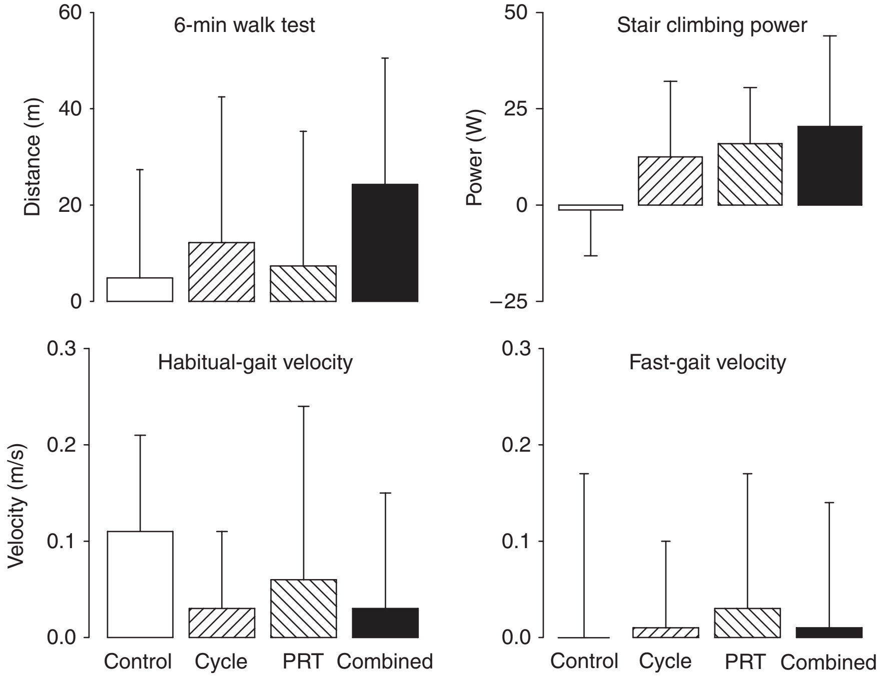

Figure 2. Effects of cycling and progressive resistance training (PRT) on walking ability. Mean ± standard deviation of change scores for each of four groups is shown. Walking endurance and velocity did not improve with cycling or PRT, but those who received PRT (Combined, PRT) significantly improved in stair climbing power.

Table 3. Effect of Aerobic, Strength, and Combined Training on Functional Mobility and Underlying Impairment

Variable	AEROBIC	STRENGTH	Combined vs Control
	Effect Size (95% Confidence Interval) *P*-Value		
Walking variables			
6-minute walk distance, m	**12.1 (− 2.9 to 27.1) .11**	**7.6 (− 7.4 to 22.7) .31**	19.6 (− 1.0 to 40.1) .06
Fast-gait velocity, m/s	**0.00 (− 0.08 to 0.08) .95**	**0.01 (− 0.07 to 0.09) .82**	0.01 (− 0.12 to 0.14) .90
Habitual-gait velocity, m/s	**− 0.06 (− 0.13 to 0.01) .09**	**− 0.03 (− 0.10 to 0.04) .39**	− 0.10 (− 0.18 to − 0.01) .04
Stair climbing power, W	**9.2 (− 0.1 to 19.3) .07**	**13.9 (3.4–24.4) .01**	20.6 (3.9–37.3) .02
AEROBIC fitness			
Peak power output, W	19.9 (7.7–32.2) .002	19.8 (7.6–32.1) .002	43.2 (20.2–66.2) .001
Peak heart rate, b/min	8.7 (− 0.8 to 18.2) .07	2.3 (− 7.1 to 11.6) .63	15.2 (− 0.4 to 31.6) .06
Peak oxygen uptake, mL · kg/min	2.5 (1.9–4.9) .002	0.5 (− 1.0 to 2.0) .51	3.0 (0.3–5.6) .03
Treadmill walking physical cost index, beats/min	− 0.53 (− 0.98 to − 0.09) .02	− 0.30 (− 0.74 to 0.14) .18	− 0.84 (− 1.66 to − 0.01) .048
Treadmill walking oxygen cost, mL/kg per m	− 0.01 (− 0.06 to 0.05) .84	0.02 (− 0.03 to 0.07) .39	.02 (− 0.05 to 0.08) .55
STRENGTH scores			
1RM in affected leg, N	16.4 (− 52.7 to 85.5) .63	255.4 (184.6–326.2) .00	268.9 (148.2–389.7) .00
1RM in unaffected leg, N	34.4 (− 59.7 to 128.6) .47	353.3 (259.5–447.0) .00	398.1 (228.3–567.9) .00
Power in affected leg, W	− 5.6 (− 50.6 to 39.3) .80	77.4 (31.9–122.8) .001	84.2 (4.7–163.7) .04
Power in unaffected leg, W	7.8 (− 54.3 to 69.9) .80	167.0 (103.7–230.2) .00	189.0 (80.6–297.5) .002
Endurance in affected leg, average number of repetitions	1.4 (− 0.2 to 3.0) .09	6.0 (4.4–7.6) .00	7.4 (4.6–10.3) .00
Endurance in unaffected leg, average number of repetitions	2.0 (2.5–3.7) .02	7.5 (5.8–9.1) .00	9.1 (7.0–11.3) .00
Psychological function			
SF-36 physical health	0.7 (− 2.9 to 4.3) .70	1.2 (− 2.9 to 4.8) .50	0.7 (− 0.9 to 2.1) .47
SF-36 mental health	0.2 (− 3.9 to 4.3) .93	0.0 (− 4.2 to 4.1) 1.00	0.1 (− 1.8 to 2.0) .95
Ewart self-efficacy walking	− 7.7 (− 17.1 to 1.7) .11	10.9 (1.6–20.3) .02	1.0 (− 3.7 to 5.6) .68
Ewart self-efficacy stair climbing	− 5.9 (− 19.3 to 7.5) .38	19.5 (6.4–32.7) .005	4.3 (− 2.9 to 11.6) .23

Note: Bolded cells are primary outcomes. "Treadmill" refers to Stage 1 of the dual-stage treadmill test, as described in text. Effects are differences between trained and sham-trained groups for each factor, in original, nonstandardized units adjusted for baseline scores. *P*-value refers to significance of f-ratio in analysis of covariance models.

SF-36 = 36-item Short Form Medical Outcomes Study Questionnaire.

improved after exercise training. Although PRT augmented stair climbing ability, there was no effect of single-modality training on overground gait velocity or walking endurance. The observed improvements were highly specific to the exercise mode; aerobic fitness or muscle strength was enhanced but with no obvious "cross-transfer of training effect"[26] between them.

It was hypothesized that the effect of undertaking both cycling and resistance training might be superior to single-mode training. Secondary exploratory analyses of only the data from the combined and controlled groups revealed that this hypothesis appeared to be supported; the effect of combined training was greater than single modality training at the level of functional ability, as well as at the level of the impairments. It is conceivable that type II error may have contributed to the lack of statistical significance in walking endurance, because the greatest improvement did occur in the combined cycling plus PRT group (+19.6 m vs sham exercise; Table 3).

The 6-minute walking distance of the combined group improved by 24 m, whereas the control group improved by 5 m, demonstrating a trend toward improved walking ability ($P = .06$), although regardless of whether a single mode or dual mode of training was employed, walking ability did not improve to the predicted level (~ 50 m). This lack of improvement is consistent with similar reports from other stroke trials whereby single-modality training has been used to address impairments in strength[27,28] or cardiovascular fitness.[29,30] Walking ability has significantly improved when aerobic training was deployed using treadmill walking or when a combination of exercise modalities included tasks targeting balance and gait.[31,32] Although there was no significant improvement in walking endurance or speed, participants allocated to the PRT groups exhibited improved self-efficacy for tasks involving walking and stairway ascent. Although gait biomechanics were not assessed, participants who undertook PRT may have enhanced their quality of walking or at least raised their perception of walking ability expressed through self-efficacy assessments.

Participants in the control group improved their habitual-gait velocity slightly more than the combined group. Further analysis of the gait velocity data revealed that participants who had a significant difference between their habitual- and fast gait-velocities showed improvement in their habitual-gait velocity. For example, one subject who demonstrated a habitual-gait velocity of 0.49 m/s and fast-gait velocity of 0.72 m/s changed her habitual-gait velocity to 0.63 m/s, but her fast-gait velocity increased only to 0.76 m/s. Seven of 12 of subjects in the control group (58%) and five of 13 subjects in the combined group (38%) showed these changes. Probably any walking, such as from the parking lot to the gymnasium (~ 40 m) and back again for their sham treatments might have improve slower walking ability in the control group

The current study raises important issues in training walking ability after hemiparetic stroke. Even if the study had been powered sufficiently, with 24 participants per group, the mean improvement in walking distance for the combined group was only 24 m, not the approximately 50 m that has been observed in other populations, such as for cardiac or pulmonary rehabilitation.[13,33] Furthermore, the improvement in gait speed in the combined group was only about one-quarter of that achieved by a community group of stroke survivors; after a 4-week exercise program using a treadmill and overground walking, the stroke survivors achieved an improvement of 99 ± 70 m[34] in the 6-minute walk. Thus, it may be that improvement in gait velocity and walking endurance are attainable for community-based stroke survivors, although cycling and slow-velocity resistance training, which are seated activities (i.e., not requiring balance), are less effective in addressing this functional limitation. Although elderly individuals and stroke patients exhibit reduced muscle strength and poor cardiorespiratory fitness, another major impairment in the stroke population is a loss of dexterity.[35] Loss of dexterity and strength are separate problems,[36] so although it is necessary to have strength to acquire dexterity for performance of everyday tasks,[36] augmenting muscle strength without concomitantly training gait is unlikely to be the most effective way to improve walking performance.

Stair climbing ability is also important for ambulation within the community and has demonstrated good correlation with discharge habitat after acute hospitalization.[37] Stair climbing is important not only for ascending and descending steps, but also for other everyday activities such as ascending and descending curbs and ramps. Power output during stair climbing has not been targeted during rehabilitation to the same extent as has walking ability. The results from the current study showed that participants allocated to PRT improved their stair climbing power as well as their self-efficacy more than participants allocated to sham PRT. Because rapid stair ascent is closely related to power in the lower limb muscles,[14,21] it is not surprising that participants who underwent PRT significantly improved their stair climbing power output. Thus, addressing low muscle power after stroke can lead to improvement in stair climbing, an important ability for community ambulation. Power training (high-velocity progressive resistance training) produces even greater gains in muscle power than the slow-velocity PRT employed in this study and would therefore theoretically confer even greater benefit, although this remains to be tested.[23]

Training specificity is an expected outcome in healthy populations,[38–40] although in older adults, maximal aerobic power is strongly related to muscle mass, and sarcopenia has been shown to explain at least 40% of the loss in aerobic power with aging.[41] PRT is known to result in improved aerobic fitness in healthy elderly people.[42,43] For example, older women with congestive heart failure were able to walk 49 m further after 12 weeks of PRT; this improvement was related to increases in citrate synthase activity in the vastus lateralis muscle.[13] It was hypothesized that the severe muscle atrophy and weakness associated with hemiparetic stroke might exaggerate a "cross-transfer of training effect" suggested to exist between AEROBIC and STRENGTH. This was not the case, because only "mode specific" adaptation occurred in the current study. It is possible that a longer duration or higher volume of PRT than the 30 sessions of 16 repetitions deployed might be required to elicit the peripheral musculoskeletal adaptations that contribute to augmented VO_2peak. Although PRT improved 1RM on the stroke-affected side by 54%, after PRT training, 1RM was still only 52% of that of the intact side at posttraining, because the intact side had improved by 26% as well.

A major finding of this study was that stroke survivors can participate in high-intensity exercise programs like their healthy elderly peers and experience similar magnitudes of adaptation in strength and cardiorespiratory fitness.[14,39] Standard principles of PRT were followed. Participants progressed 3% after every PRT session, and reassessment was performed every 2 weeks to adjust the resistance intensity based on changes in 1RM. In contrast, many studies that have sought to increase muscle strength in individuals who have had a stroke have employed overload stimuli such as lifting body mass[12,44] or Thera-Bands,[10,12] which are insufficient for a high-intensity training regimen.[14] For aerobic training, the stimulus intensity was increased from 50% to 85% of an individuals' VO_2peak, and the HR-based exercise prescription was reassessed after a maximal-effort cycling test during Week 7. Previous studies have trained participants at 30% to 60% of VO_2peak,[30,45] measured only at pretraining, so any training-induced changes in aerobic fitness or HR during the program duration were not considered in the individual's exercise prescription. Other studies failed to quantify the dose at which participants trained.[32] By employing high exercise intensity with a strong potency for cardiorespiratory adaptation or muscle strength development, significant changes in underlying impairments were observed in the present study.

In conclusion, persons surviving stroke are at risk of becoming socially isolated and more disabled after discharge from rehabilitation, particularly because most are discharged with a residual functional disability, and rehabilitation is time-limited. This study has shown that provision of theoretically grounded,[17] progressive-intensity, robust exercises targeted at existing impairments, although ameliorating the impairments, does not optimally address the functional deficits in walking. To improve walking ability after stroke, other exercise prescription paradigms such as task-specific training, standing exercises, balance and coordination training, and power training may be needed, and such treatments require future study in robustly designed randomized, controlled trials.

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