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ORIGINAL ARTICLE

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Abstract The purpose of this study was to determine the physiological effects of a programmed accommodating circuit exercise (PACE) program consisting of aerobic exercise and hydraulic-resistance exercise (HRE) on fitness in older adults. Thirty-five volunteers were randomly divided into two groups [PACE group (PG) 8 men and 10 women, 68.3 (4.9) years, and non-exercise control group (CG) 7 men and 10 women, 68.0 (3.4) years). The PG participated in a 12-week, 3 days per week supervised program consisting of 10 min warm-up and 30 min of PACE (moderate intensity HRE and aerobic movements at 70% of peak heart rate) followed by 10 min cool-down exercise. PACE increased ($P < 0.05$) oxygen uptake ($\dot{V}O_2$) at lactate threshold [PG, pre 0.79 (0.20) l min^{-1}, post 1.02 (0.22) l min^{-1}, 29%; CG, pre 0.87 (0.14) l min^{-1}, post 0.85 (0.15) l min^{-1}, −2%] and at peak $\dot{V}O_2$ [PG, pre 1.36 (0.24) l min^{-1}, post 1.56 (0.28) l min^{-1}, 15%; CG, pre 1.32 (0.29) l min^{-1}, post 1.37 (0.37) l min^{-1}, 4%] in PG measured using an incremental cycle ergometer. Muscular strength evaluated by a HRE machine increased at low to high resistance dial settings for knee extension (9–52%), knee flexion (14–76%), back extension (18–92%) and flexion (50–70%), chest pull (6–28%) and press (3–17%), shoulder press (18–31%) and pull (26–85%), and leg press (21%). Body fat (sum of three skinfolds) decreased (16%), and high-density lipoprotein cholesterol (HDLC) increased (10.9 mg dl^{-1}) for PG. There were no changes in any variables for CG. These results indicate that PACE training incorporating aerobic exercise and HRE elicits significant improvements in cardiorespiratory fitness, muscular strength, body composition, and HDLC for older adults. Therefore, PACE training is an effective well-rounded exercise program that can be utilized as a means to improve health-related components of fitness in older adults.

Keywords Programmed accommodating circuit exercise training · Circuit exercise · Aerobic combined resistance training · Older adults

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Introduction

Previous reports have described the benefits of aerobic exercise on cardiorespiratory capacity in older adults (Brechue and Pollock 1996; Kasch et al. 1999). However, aerobic exercise has little role in the improvement of muscle strength. Loss of muscle strength is one of the major causes of physical disability in aged people (Doherty 2003). Reduction of muscle strength decreases mobility and impairs the ability to perform normal activities of daily living, which ultimately leads to a dependent lifestyle. Muscular deficits are also closely associated with falling, which is the most common accident and a leading cause of accidental death in older adults (National Safety Council 2000).

The beneficial effects of resistance training on muscle strength and mass in older adults have been reported in several studies (Fiatarone and Evans 1990; Hagerman et al. 2000; Hunter et al. 2001; Labarque et al. 2002; MacCartney et al. 1996; Newton et al. 2002). Reflecting the results of these studies and others, the exercise guidelines developed by the American College of Sports Medicine (ACSM) (1998a, b) for healthy adults and the elderly give special emphasis to resistance exercise. However, resistance training has little effect on other health-related components of fitness such as cardiorespiratory capacity, joint flexibility, and body adiposity. Engaging in aerobic exercise can reduce body fat levels, but has little effect on flexibility. Therefore, stretching exercises are recommended to improve flexibility, a capacity required to perform self-care activities such as bathing and dressing.

There is a need to maintain each of the components of fitness throughout life. Considering the above factors, any single type of exercise seems to be inadequate for improving overall fitness. Therefore, a well-rounded exercise program consisting of aerobic, resistance, and stretching exercises is preferred, rather than one that focuses only on a single mode of exercise.

Progressive accommodating circuit exercise (PACE) training has been developed as a program that combines multiple modes of exercise (Tanaka 1998). PACE training is composed of aerobic exercise and hydraulic resistance exercise (HRE), which are completed in a combined circuit fashion following a warm-up session consisting of stretching exercises. Previous studies have described the effect of PACE training on aerobic capacity (Okugawa et al. 1998; Saku et al. 1998). Although these studies concluded that PACE training improved aerobic capacity, they did not determine the effects of PACE training on other health-related components of fitness.

The combined nature of PACE training may provide an effective well-rounded exercise program to improve the overall fitness of older adults. Therefore, the present study was performed to determine the effect of a 12-week supervised PACE training program on aerobic capacity, muscular strength, flexibility, and body composition in older men and women.

Methods

Participants

In response to a local newspaper advertisement, 42 older men and women volunteered to participate in the study. Prior to acceptance into the study, a medical examination was performed and questionnaires regarding medical history and physical activity were completed. Seven volunteers were excluded based on the medical examination report or the questionnaires because they were taking medication prescribed for hypertension, hypercholesterolemia, or hormone replacement therapy, had diagnosed coronary heart disease, or were participating in regular physical activity beyond that required for normal daily living. The remaining 35 volunteers (60–83 years of age) were considered sedentary but apparently healthy. The ethical committee of the Institute of Natural Sciences at Nagoya City University approved the study. All participants received written and oral instructions for the study and each gave their written informed consent prior to participation.

Testing protocol

Following baseline measurements of body composition, cardiorespiratory fitness, muscular strength, blood lipids, and flexibility, the participants were randomly divided into two groups: a PACE group [PG, 8 men and 10 women, 68.3 (4.9) years] and a non-exercise control group [CG, 7 men and 10 women, 68.0 (3.4) years] (Table 1). The PG participated in a 12-week PACE training program. The CG was instructed to continue their normal physical activity patterns. All participants were asked to not change their nutrition practices during the duration of the study. After 12 weeks, all measurements were repeated in both groups.

Skinfold and girth measurements were taken in triplicate on the right side of the body (Sidney et al. 1977) and the median values were used for analysis. Triceps, subscuplar, and abdominal skinfolds were measured using calipers (Eiken MK-60, Meiko, Tokyo, Japan) and these values were summed for analysis. Using a non-elastic tape measure, thigh girth was measured at the midpoint between the inguinal crease and the proximal border of the patella, and arm girth was measured at the midpoint between the acromion process and the olecrenon process. An experienced tester who was blind to group assignment performed all skinfold and girth measurements.

After lying supine for 5 min, resting heart rate (HR) and blood pressure (BP) were measured by an automated machine (STBP-680 BP monitor, Colin, Komaki, Japan). Maximum rate of oxygen uptake ($\dot{V}O_{2max}$) was determined using an incremental cycle ergometer (Monark, Model 81E, Stockholm, Sweden) exercise protocol (Takeshima et al. 1993). Following a warm-up, the load was increased by 12.5-W increments every

Table 1 General characteristics of participants at baseline [mean (SD)]. *HRrest* resting heart rate, *SBPrest* resting systolic blood pressure, *DBPrest* resting diastolic blood pressure, $\dot{V}O_2LT$ oxygen uptake corresponding to lactate threshold, *peak* $\dot{V}O_2$ oxygen uptake corresponding to peak exercise level

	PACE group $n=18$	Control group $n=17$
Age (years)	68.3 (4.9)	68.0 (3.4)
Height (cm)	154.2 (6.3)	155.4 (8.5)
Body mass (kg)	57.5 (9.6)	60.6 (10.2)
Skinfold thickness (sum of three sites, mm)	75.9 (27.4)	79.5 (22.8)
HRrest (beats min^{-1})	67 (7)	70 (7)
SBPrest (mmHg)	131 (19)	139 (18)
DBPrest (mmHg)	74 (10)	80 (8)*
$\dot{V}O_2LT$ (l min^{-1})	0.79 (0.20)	0.87 (0.14)
Peak $\dot{V}O_2$ (l min^{-1})	1.36 (0.25)	1.32 (0.29)

*Significantly different ($P < 0.05$) between groups minute until volitional exhaustion. Pedal rate was maintained at 50 rpm with the assistance of an auditory–visual metronome. A $\dot{V}O_{2max}$ was accepted if oxygen uptake ($\dot{V}O_2$) reached a plateau (increased less than 0.15 l min^{-1} with an increase in work load), respiratory exchange ratio (R) became greater than 1.1, or predicted maximal HR (220−age) was achieved (Takeshima et al. 1993).

Measurements of $\dot{V}O_2$ and carbon dioxide production were made via indirect calorimetry using the open-circuit spirometry method. Expired gas was passed through a mixing chamber and analyzed continuously (Anima Gas Analyzer Telemetry System, AT-1000, Tokyo, Japan). Gas analyzers were calibrated immediately prior to each test with a known concentration of oxygen and carbon dioxide. Ventilation was measured with the system's ventilation module. HR was monitored (12-lead ECG; Lifescope 8, Nihon-Koden, Tokyo, Japan) continuously throughout the test, and BP was measured by an automatic device (STBP-680, Colin, Tokyo, Japan). Ratings of perceived exertion (RPE, Borg's 6–20 point scale) were scored during the last 15 s of each stage of exercise.

Lactate threshold (LT) was determined from a series of venous blood samples (1 ml each) drawn from an antecubital vein every minute during exercise. Blood was analyzed by an electrochemical enzymatic method (Toyobo Lactate Analyzer, HEK-30L, Toyobo, Osaka, Japan) immediately after collection. The $\dot{V}O_2$ at LT ($\dot{V}O_2$LT) was defined as the point at which the rate of production and diffusion of lactate exceeded the rate of removal, and was identified as the point at which lactate concentration ([La$^-$]) abruptly increased in a nonlinear fashion (Beaver et al. 1985). For discerning the nonlinear point of [La$^-$] increase, the log[$\dot{V}O_2$]−log[La$^-$] transformation method was used (Beaver et al. 1985). HR corresponding to the LT (HRLT) and blood pressure (systolic and diastolic) corresponding to the LT were also obtained during the exercise stage at which the LT occurred.

Muscle strength (peak torque or force) for knee flexion and extension, low back flexion and extension, chest press and pull, and shoulder press and pull was evaluated using a hydraulic-resistance machine (Hydra Omintron, Henley Healthcare, Sugarland, Tex.) (Takeshima et al. 2002). The resistance produced by this hydraulic-resistance machine is regulated by selecting dial settings of 1–11 that control the diameter of the aperture through which the hydraulic fluid passes. The aperture openings range from 0.120 mm (setting 1, low resistance) to 0.025 mm (setting 11, high resistance). In this study, the machine was set at dial settings 2 (low intensity), 5 (moderate intensity), 8 (high intensity), and 11 (very high intensity) levels. The participants were asked to move through their full range of motion as rapidly and forcefully as possible. Peak torque (newton meters) and force (newtons) were recorded for knee extension/flexion, shoulder press/pull, chest press/pull, and lumbar flexion/extension. These exercises simulated the strength training components that were utilized during PACE training. Each exercise was performed three times and the highest value was used for analysis.

Flexibility was measured by: (1) trunk flexion from a standing position (Takeshima et al. 1993), and (2) trunk extension from a prone position (Takeshima et al. 2002; Tokyo Metropolitan University 1996). For trunk flexion, participants stood in bare feet on a specially designed measuring bench, placing the toes even with the front edge of the bench. While standing on the bench, participants were asked to bend over and reach down as far as possible without bouncing, while keeping the knees locked. Performance was scored as the distance from the toes reached by the middle fingers and held for at least 1 s. For trunk extension, participants were asked to lie prone with the hands clasped behind the back. Participants were asked to extend the spine by lifting the shoulders and chin off the floor as far possible. The distance between the floor and the chin as measured by a specially designed measuring scale (Trunk Extension Meter, TKK 5104 Extension-D, Takei Scientific Instrument, Niigata, Japan) was recorded as maximal trunk extension. Each flexibility test was performed twice and the maximum values were used for analysis.

After an overnight fast of approximately 12–14 h, a blood sample (7–8 ml) was collected from an antecubital vein. Participants were instructed to not engage in physical activity beyond their basic daily activities 24 h prior to the blood draw. Following the separation of serum, concentrations of cholesterol (TC) and triglycerides (TG) were measured by an enzymatic procedure (Hitachi 7450 analyzer, Hitachi, Tokyo, Japan). High-density lipoprotein cholesterol (HDLC) was measured using the tungstophosphlic acid–magnesium chloride precipitation method (Hitachi 7150 analyzer, Hitachi, Tokyo, Japan) and low-density lipoprotein cholesterol was calculated as (TC−HDLC−TG/5) (Friedewald et al. 1972).

Exercise program

The PG participated in a 12-week PACE training program, three sessions per week and 50 min per session. Each session was led by trained fitness instructors and supervised by the researchers. Training was performed on 3 different days of the week with at least 1 day of rest between sessions. The daily exercise program consisted of stretching and warm-up exercise (10 min), PACE training (30 min), and cool-down/relaxation exercise (10 min). Twelve individual exercise stations designed to work all major muscle groups and 12 aerobic dancing boards were arranged alternatively in a circular manner to perform PACE. The exercise circuit consisted of 30 s of resistance exercise interspersed with 30 s of "aerobic-dance" movements. The aerobic dance consisted of marching in place and raising the arms for 30 s. The HR was monitored continuously for all participants during training sessions by a HR monitoring device (Accurex

Plus, Polar Electro, Kempele, Finland) to ensure that the training intensity was maintained as prescribed. The mean HRLT at baseline for the participants was used as an indicator of the prescribed intensity while performing the PACE training. To determine the exercise intensity more accurately, $\dot{V}O_2$ was monitored in all 13 participants, in turn, during the 12-week training program using a telemetric gas analyzer system. The availability of only one telemetry unit precluded simultaneous measurement of participants' $\dot{V}O_2$.

The resistance exercises were performed using HRE machines (Henley Healthcare, Tex.). These devices were used to perform upper body exercises (chest press, biceps curl, lumbar rotation) and lower body exercises (knee extension and flexion, leg extension and flexion, leg press and leg curl, calf press, leg abduction and adduction). The participants were instructed to move through the full range of motion for each exercise as rapidly as possible while performing each repetition. Each resistance exercise machine used to perform PACE training had a regulator to control the intensity of exercises. Marked with dial settings of 1–6, the regulator at dial setting 1 produced very low intensity and at 6 produced very high intensity. To progressively increase the resistance during this study, the regulator was initially (0~4 weeks) set to 2, then to 3 (5~8 weeks), and finally to 4 (9~12 weeks).

Force monitors (Omnikinetics force monitor, Mizuno, Japan) were attached to each HRE machine used during the training sessions. Research assistants recorded the force (newtons) as it appeared on the monitor immediately after a participant performed the resistance exercise, and then reset the monitor for the next participant. The relative intensity of each resistance exercise was then determined by comparing these values to the maximum force values determined with the Hydra Omnitron during baseline testing.

The RPE was also obtained from each participant immediately after each exercise session. The RPE value was also used to regulate the exercise intensity at or near the prescribed level. Each exercise was performed for 10–15 repetitions per 30-s station. The cool-down consisted of floor exercises and muscular relaxation.

Statistical analysis

The data are presented as means (SD). Comparisons of means at baseline between the two groups were performed using a two-tailed, independent Students *t*-test. Training effects (i.e., comparisons of pre and post values) were evaluated using a two-way ANOVA with repeated measures to determine main effects and interaction for time and group. Percentage changes from pre to post were calculated from the differences in pre and post scores. Data from men and women were combined because no significant differences existed between genders with respect to the training response (i.e., pre to post changes). A P value, set a priori, of less than 0.05 was considered statistically significant.

Results

Pre-training data

No significant differences at baseline were present between PG and CG in age, height, body mass, resting HR, skinfold thickness, and resting systolic BP (Table 1). The resting diastolic BP was significantly lower in PG compared to CG (Table 1). As some of the participants (PG 2, CG 6) failed to achieve $\dot{V}O_{2max}$ during cycle ergometry, the peak value of $\dot{V}O_2$ (peak $\dot{V}O_2$) was used for analysis. There were no significant differences at baseline in $\dot{V}O_2$LT and peak $\dot{V}O_2$ between the groups (Table 1). The [L^-] values at LT [PG, 1.08 (0.20) mM; CG, 1.03 (0.16) mM] and at peak $\dot{V}O_2$ [PG, 2.88 (0.66) mM; CG, 2.47 (0.54) mM] were also similar between groups. The peak R [PG, 1.17 (0.25); CG, 1.00 (0.12)], peak exercise systolic BP [PG, 215 (32) mmHg; CG, 222 (24) mmHg], and RPE [PG, 17 (2); CG, 17 (2)] were also similar between groups at baseline.

Training data

All participants continued the PACE training through the full length of the study without any case of injury. The PG trained at a moderate intensity as indicated by weekly averages of training HR during exercise. Participants were exercising at 103 (9) beats min^{-1} (70% peak HR) during the final week. The $\dot{V}O_2$ measured during PACE training was 16 (4) ml kg^{-1} min^{-1} [69 (14)% peak $\dot{V}O_2$, $n=13$]. The training intensity of HRE, determined from the force monitor data in relation to the baseline maximum force (newtons) evaluated by a Hydra Omnitron machine, for shoulder press and pull were 25% and 10% (0~4 weeks), respectively, 73% and 30% (5~8 weeks) and 84% and 40% (9~12 weeks); chest press and pull were 15% and 12% (0~4 weeks), 49% and 45% (5~8 weeks), and 58% and 57% (9~12 weeks); knee extension and flexion were 44% and 40% (0~4 weeks), 55% and 51% (5~8 weeks), and 84% and 53% (9~12 weeks); and low back flexion and extension were 15% and 14% (0~4 weeks), 27% and 42% (5~8 weeks), and 32% and 65% (9~12 weeks). The RPE averaged 11.8 (1.2) during the first week and 13.5 (1.4) during the final week. No significant changes were noticed in resting HR, resting systolic BP, and resting diastolic BP in PG or CG.

The PACE training increased $\dot{V}O_2$LT [pre, 0.79 (0.20) l min^{-1}; post, 1.02 (0.22) l min^{-1}, 29%] and peak $\dot{V}O_2$ [pre, 1.36 (0.24) l min^{-1}; post, 1.56 (0.28) l min^{-1}, 15%] significantly in the PG (Fig. 1). There was no significant change in [L^-] at peak $\dot{V}O_2$ [pre, 2.88 (0.66) mM; post, 2.78 (0.80) mM], and in [L^-] at LT [pre, 1.08 (0.20) mM; post, 1.09 (0.21) mM] in the PG. Peak HR was not different [pre, 145 (13) beats min^{-1}; post, 152 (10) beats min^{-1}] but HRLT [pre, 100 (13) beats min^{-1}; post 108 (10)beats min^{-1}] increased

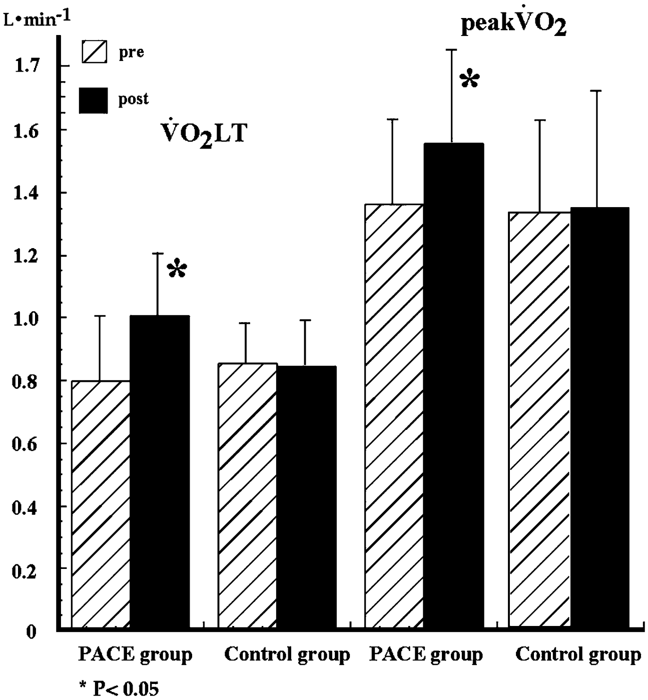

Fig. 1 Effects of programmed accommodating circuit exercise (*PACE*) training on cardiorespiratory fitness in older adults. $\dot{V}O_2LT$ Oxygen uptake corresponding to lactate threshold, *peak* $\dot{V}O_2$ oxygen uptake corresponding to peak exercise level

significantly in the PG. There were no significant changes in peak $\dot{V}O_2$ [pre, 1.32 (0.29) l min^{-1}; post, 1.37 (0.37) l min^{-1}, 4%] or $\dot{V}O_2$LT [pre, 0.87 (0.14) l min^{-1}; post, 0.85 (0.15) l min^{-1}, −2%] (Fig. 1), [L$^-$] at peak $\dot{V}O_2$ [pre, 2.4 (1.1) mM; post, 2.0 (0.70 mM], [L$^-$] at LT [pre, 0.9 (0.3) mM; post, 0.9 (0.2) mM], peak HR [pre, 148 (12) beats min^{-1}; post, 146 (18) beats min^{-1}], and HRLT [pre, 104 (8) beats min^{-1}; post, 95 (8) beats - min^{-1}] in the CG.

Body mass and limb girths did not change significantly but the sum of three skinfolds decreased significantly in the PG. No changes in any of these variables were noticed in the CG (Table 2). The HDLC (10.9 mg dl^{-1}) increased significantly in the PG following PACE training (Table 2). TC and TG did not change in either group. Improvement in trunk extension and trunk flexion did not reach a statistically significant level in either group; however, trunk flexion in PG showed a tendency ($P < 0.1$) towards improvement (Table 2).

In general, muscle strength increased in the PG following PACE training. Although knee extension strength at hydraulic setting 2 (low resistance) was not different from pre-test values, knee flexion strength increased significantly by 76% in the PG. Knee extension/flexion strength increased significantly at setting 5 (moderate resistance) (13% and 29%, respectively), at setting 8 (moderately high resistance) (9% and 15%, respectively), and at setting 11 (high resistance) (9% and

Table 2 Effects of PACE training on fitness and blood lipid parameters in older adults. *TC* total cholesterol, *HDLC* high-density lipoprotein cholesterol, *LDLC* low-density lipoprotein cholesterol, *TG* triglycerides

	Pre		Post		Change	ANOVA
	Mean	SD	Mean	SD	(%)	Group × time
Body mass (kg)						
PACE group	57.5	9.6	57.2	9.3	−0.5	$F_{(1,33)} = 0.003$; $P > 0.10$
Control group	60.6	10.2	60.3	10.2	−0.5	
Skinfold thickness (mm)						
PACE group	75.9	27.4	63.6	25.2	−16.2	$F_{(1,33)} = 26.979$; $P < 0.05$
Control group	79.5	22.8	84.4	20.7	6.2	
Arm girth (cm)						
PACE group	28.8	2.9	28.8	2.4	0	$F_{(1,33)} = 0.002$; $P > 0.10$
Control group	30.3	2.5	30.4	2.5	0.3	
Thigh girth (cm)						
PACE group	45.7	4.1	46.6	4.1	2.0	$F_{(1,33)} = 12.662$; $P < 0.10$
Control group	48.5	2.6	48.6	2.6	0.2	
Trunk extension (cm)						
PACE group	30.5	11.0	32.1	9.8	5.2	$F_{(1,33)} = 3.282$; $P < 0.10$
Control group	30.7	6.5	30.2	6.9	−1.6	
Trunk flexion (cm)						
PACE group	2.7	10.7	5.1	10.5	88.9	$F_{(1,33)} = 2.920$; $P < 0.10$
Control group	5.7	9.5	6.4	9.6	12.3	
TC (mg dl^{-1})						
PACE group	222.0	34.9	214.6	27.8	−3.3	$F_{(1,33)} = 1.405$; $P > 0.10$
Control group	216.8	25.0	200.0	26.0	−7.7	
HDLC (mg dl^{-1})						
PACE group	60.7	14.5	71.6	18.7	18.0	$F_{(1,33)} = 16.934$; $P < 0.05$
Control group	60.8	17.6	60.2	18.3	−1.0	
LDLC (mg dl^{-1})						
PACE group	129.3	49.7	110.0	42.1	−14.6	$F_{(1,33)} = 0.476$; $P > 0.10$
Control group	132.7	59.4	104.9	50.3	−20.9	
TG (mg dl^{-1})						
PACE group	222.4	34.9	214.6	27.8	−3.5	$F_{(1,33)} = 1.405$; $P > 0.10$
Control group	216.8	25.0	200.0	26.0	−7.7	

14% respectively) following training (Table 3). Lower back flexion/extension increased significantly at setting 2 (low resistance) (50% and 92%, respectively), at setting 5 (moderate resistance) (56%, 50%, respectively), at setting 8 (moderately high resistance) (66%, 18%, respectively), and at setting 11 (high resistance) (70%, 40%, respectively) (Table 3). Chest press/pull strength did not change significantly except chest pull at dial setting 2 (low resistance) (28%) (Table 3). Shoulder press/pull strength increased significantly at setting 2 (low resistance) (31% and 85%, respectively), at setting 5 (moderate resistance) (18%, 37%, respectively), at setting 8 (moderately high resistance) (20%, 31%, respectively), and at setting 11 (high resistance) (22%, 26%, respectively) (Table 3). None of the muscular strength variables changed significantly in the CG.

Discussion

Incorporating both aerobic and resistance training via PACE training for older adults is an effective means to improve multiple aspects of fitness with a single exercise program that is performed at a moderate intensity. Although some studies have examined the combined effects of walking and weight training in similar populations, to our knowledge this is the first study using HRE as part of a concurrent circuit-style aerobic and resistance exercise program to effectively improve health-related components of physical fitness, including cardiorespiratory endurance and muscle strength, in older adults.

The ACSM (1998b) recommends a variety of exercise modes for older adults to improve fitness, and it has been suggested that combined training programs may be effective in the prevention of falls and injuries in the older population (Skelton 2001; Skelton and Beyer 2003). Some studies examining well-rounded exercise programs have reported improvements in either strength or aerobic capacity, but not both, as a result of training (Puggaard et al. 1994; Skelton et al. 1995). For example, Pugaard (2003) reported that a program of combined walking, muscle strength and endurance training, flexibility, and balance activities improved $\dot{V}O_{2max}$ and walking speed, but not strength, after training. Other studies have examined the effects of combined training in older adults and reported results similar to those of the current study. In a study of patients with heart conditions, circuit weight training combined with traditional cardiac rehabilitation activities resulted in gains of 24% in strength and 12% in treadmill walking time (Kelemen et al. 1986). Cress et al. (1999) reported gains of 33% and 11% in strength and $\dot{V}O_{2max}$, respectively, following a combined training program in older adults. Wood et al. (2001) demonstrated that concurrent cardiovascular and resistance training improved treadmill walking time by 19% and five repetition-maximum (5RM) strength performance by 21–64% in older adults. In that study, participants performed 30 min of aerobic exercise (walking and cycling) and one set of 8–12 repetitions of eight resistance exercises. Therefore, participants engaged in 50–60 min of exercise per session. The duration of each exercise session was similar to our PACE program. However, the exercise mode was very different as PACE training is a circuit exercise program using HRE performed with a group of people, while the program utilized by Wood et al. (2001) was not a circuit program and used stackable weight plates that can be difficult and dangerous to use.

In the present study, the aerobic exercise during PACE was performed at an intensity level that corresponded to that of the mean HRLT and/or $\dot{V}O_2$LT for the participants at the time of baseline graded exercise testing. Moreover, the estimated training intensities of HRE were moderate, ranging from 32% to 84% of the baseline 1RM measures during the final 4 weeks of the study. Our results indicate that PACE training involving aerobic exercise and HRE elicits significant improvements in cardiorespiratory fitness, muscular strength, body composition, and HDLC in older adults. HRE has previously been shown to be an effective training modality in young males (Weltman et al. 1986). It has also been reported that, when performed in a circuit fashion, cardiovascular benefits can be gained from HRE in other populations, including patients who have undergone coronary artery bypass surgery and individuals with spinal cord injuries (Cooney and Walker 1986; Haennel et al. 1991).

Cardiorespiratory endurance is defined as the ability to perform dynamic, moderate-to-high intensity work using a large muscle mass for an extended period of time (Brechue and Pollock 1996). The accepted single best measure of cardiorespiratory fitness is $\dot{V}O_{2max}$ in healthy subjects. However, in the present study, approximately half of the participants failed to reach $\dot{V}O_{2max}$ as defined by a plateau in $\dot{V}O_2$ with a corresponding increase in workload. Therefore, to evaluate cardiorespiratory fitness, peak $\dot{V}O_2$ was used. The PACE training produced an increase in peak $\dot{V}O_2$ of 15%. This improvement is similar to the increase in $\dot{V}O_{2max}$ (10%) in our previous 12-week study using cycling exercise in Japanese older adults (Takeshima et al. 1993).

Further evidence of an improvement in cardiorespiratory fitness is provided by the increased $\dot{V}O_2$LT (29%) in the PG. This improvement in $\dot{V}O_2$LT (29%) was even greater than that observed in peak $\dot{V}O_2$ following PACE training. This outcome is also similar to our previous cycle-training study that found an 18% increase in $\dot{V}O_2$ at LT during aerobic training (Takeshima et al. 1993). The LT is a term that refers to the $\dot{V}O_2$ or exercise intensity above which the rate of La^- production exceeds the rate of removal, thus inhibiting the increase excretion of $[La^-]$ in the blood (Wasserman et al. 1981). The LT is known to be affected by many factors including oxygen transport, activity of the oxidative enzymes in mitochondria of skeletal muscle, and composition of the muscle fibers. The resulting increase in LT after PACE training may

Table 3 Effects of PACE training on muscular strength in older adults. *PG* PACE group, CG control group

Resistance dial		Pre		Post		Change %	ANOVA Group × time
		Mean	SD	Mean	SD		
Knee extension (N m)[a]							
PG	2	12.6	4.3	19.2	5.6	52.4	$F_{(1,33)} = 0.687$; $P > 0.10$
CG	2	11.7	4.2	16.5	10.1	41.0	
PG	5	36.5	11.5	41.4	13.0	13.4	$F_{(1,33)} = 4.711$; $P < 0.05$
CG	5	33.9	12.3	34.4	12.3	1.5	
PG	8	82.9	21.7	90.7	24.8	9.4	$F_{(1,33)} = 7.125$; $P < 0.05$
CG	8	81.0	25.4	79.4	24.7	−2.0	
PG	11	128.4	39.9	140.3	42.5	9.3	$F_{(1,33)} = 8.329$; $P < 0.05$
CG	11	124.2	36.8	121.8	35.6	−1.9	
Knee flexion (N m)[a]							
PG	2	14.6	7.2	25.7	9.6	76.0	$F_{(1,33)} = 11.939$; $P < 0.05$
CG	2	15.1	8.2	15.8	9.5	4.6	
PG	5	38.0	15.3	48.9	16.5	28.7	$F_{(1,33)} = 10.650$; $P < 0.05$
CG	5	38.9	22.9	34.5	14.7	−11.3	
PG	8	69.1	21.4	79.5	24.7	15.1	$F_{(1,33)} = 6.297$; $P < 0.05$
CG	8	67.8	20.9	66.7	21.1	−1.6	
PG	11	91.2	33.2	104.3	35.6	14.4	$F_{(1,33)} = 9.930$; $P < 0.05$
CG	11	87.6	26.2	86.1	26.4	−1.7	
Low back flexion (N m)							
PG	2	31.1	13.0	46.8	17.0	50.5	$F_{(1,33)} = 19.974$; $P < 0.05$
CG	2	40.7	15.2	34.7	12.4	−14.7	
PG	5	72.8	26.6	113.3	41.4	55.6	$F_{(1,33)} = 42.996$; $P < 0.05$
CG	5	89.9	31.6	77.8	24.8	−13.5	
PG	8	132.3	55.3	220.1	87.3	66.4	$F_{(1,28)} = 34.695$; $P < 0.05$
CG	8	163.6	71.3	133.0	41.1	−18.7	
PG	11	158.9	76.6	269.7	95.0	69.7	$F_{(1,33)} = 56.199$; $P < 0.05$
CG	11	206.5	93.6	166.2	53.7	−19.5	
Low back extension (N m)							
PG	2	43.9	21.4	84.5	63.3	92.5	$F_{(1,33)} = 0.270$; $P < 0.05$
CG	2	63.3	26.8	58.1	24.5	−8.2	
PG	5	126.9	61.0	189.8	73.2	49.6	$F_{(1,33)} = 29.579$; $P < 0.05$
CG	5	161.8	66.3	128.6	51.8	−20.5	
PG	8	273.3	94.8	321.7	119.7	17.7	$F_{(1,33)} = 20.719$; $P < 0.05$
CG	8	272.3	106.4	236.2	83.1	−13.3	
PG	11	275.9	120.7	386.6	150.3	40.1	$F_{(1,33)} = 20.719$; $P < 0.05$
CG	11	316.9	118.6	276.6	92.7	−12.7	
Chest press (N m)							
PG	2	67.8	26.4	79.4	26.8	17.1	$F_{(1,33)} = 1.618$; $P > 0.10$
CG	2	63.9	21.2	69.0	28.1	8.0	
PG	5	161.5	60.0	166.9	69.8	3.3	$F_{(1,33)} = 1.670$; $P > 0.10$
CG	5	160.2	61.4	151.1	63.1	−5.7	
PG	8	298.1	114.6	312.8	116.0	4.9	$F_{(1,28)} = 1.369$; $P > 0.10$
CG	8	295.8	122.9	293.2	114.6	−0.9	
PG	11	424.4	161.7	445.7	174.0	5.0	$F_{(1,33)} = 2.449$; $P > 0.10$
CG	11	413.7	156.6	410.5	146.0	−0.8	
Chest pull (N m)							
PG	2	74.9	23.8	96.2	30.9	28.4	$F_{(1,33)} = 7.315$; $P < 0.05$
CG	2	78.9	31.2	81.9	35.3	3.8	
PG	5	194.7	79.3	206.1	70.5	5.9	$F_{(1,33)} = 0.698$; $P > 0.10$
CG	5	183.8	66.8	183.0	71.4	−0.4	
PG	8	312.5	109.4	329.9	100.3	5.6	$F_{(1,33)} = 0.682$; $P > 0.10$
CG	8	284.5	88.2	286.7	80.6	0.8	
PG	11	379.9	133.1	419.0	128.3	10.3	$F_{(1,33)} = 2.642$; $P > 0.10$
CG	11	353.6	98.8	355.9	90.2	0.7	
Shoulder press (N m)							
PG	2	22.9	9.4	30.1	13.0	31.4	$F_{(1,33)} = 13.663$; $P < 0.05$
CG	2	27.8	12.6	26.3	11.5	−5.4	
PG	5	55.8	23.9	65.9	26.6	18.1	$F_{(1,33)} = 5.893$; $P < 0.05$
CG	5	64.2	27.5	63.5	27.7	−1.1	
PG	8	115.2	48.5	138.6	54.2	20.3	$F_{(1,33)} = 9.292$; $P < 0.05$
CG	8	118.4	47.7	117.4	48.4	−0.8	
PG	11	168.8	68.9	205.6	76.7	21.8	$F_{(1,33)} = 13.001$; $P < 0.05$
CG	11	164.2	55.4	157.2	64.6	−4.3	
Shoulder pull (N m)							
PG	2	10.4	7.0	19.2	15.0	84.6	$F_{(1,33)} = 17.803$; $P < 0.05$
CG	2	14.7	12.2	12.3	9.9	−16.3	

Table 3 (Contd.)

Resistance dial		Pre		Post		Change %	ANOVA Group × time
		Mean	SD	Mean	SD		
PG	5	24.5	20.5	33.6	25.9	37.1	$F(1,33) = 28.856; P < 0.05$
CG	5	29.4	23.0	24.0	18.8	−18.4	
PG	8	29.9	21.4	39.2	26.9	31.1	$F_{(1,33)} = 19.139;\ P < 0.05$
CG	8	31.9	22.4	28.1	19.9	−11.9	
PG	11	17.5	11.0	22.1	18.7	26.3	$F_{(1,33)} = 4.220;\ P < 0.05$
CG	11	16.1	8.8	14.6	7.8	−9.3	

[a]Values are mean averages between right and left knee extension and flexion

be of great interest as this should allow older adults to engage in sustained rigorous work for longer periods of time. However, information regarding LT in older adults is lacking and much more research on this topic is required.

Aging is associated with a gradual decrease in muscle strength (Holloszy 1995; Rogers and Evans 1993). This contributes to decreased mobility, decreased function, and increased risk of falling in older individuals (Bendall et al. 1989; Fiatarone et al. 1994). The ACSM has recognized the benefits that can result from adding strength training to the exercise programs of healthy people (ACSM 1998a, b). In the present study, muscle strength improved 9–92% for knee flexion/extension, shoulder press/pull and low back flexion/extension at almost every movement speed tested. These strength improvements are similar to studies that have used only resistance exercises (ACSM 1998b; Brown et al. 1990), as well as concurrent aerobic and resistance exercise (Friedewald et al. 1972) in older adults. It is difficult to compare results directly because strength-testing protocols in these studies were different. However, the present improvements are much greater than those observed after a 12-week water-based well-rounded exercise program in older adults (4–13%) (Takeshima et al. 2002) using the same muscular strength testing protocol.

The only muscular strength measure that was not improved with PACE training in the current study was chest press/pull (except at setting 2 when chest press improved). This lack of enhancement in strength compared with the lower body tests is likely due to the type of resistance training employed. The program used one upper body exercise for the chest/triceps and back/biceps muscle groups (bench press), whereas a greater number of exercises were used for the lower body (e.g., leg extension/flexion, leg press, etc.). Thus, one leg exercise could have contributed to performance improvements in others (e.g., leg press training may have enhanced leg extension performance and vice versa). The lack of improvement in bench press performance may also be related to the lesser ability of older individuals to respond to bench press training compared with leg training (Brown et al. 1990; Chrusch et al. 2001).

In this study, flexibility improved but did not reach a statistically significant level ($P < 0.1$). Typically, PACE training does not include flexibility exercise. However, flexibility is important for the performance of activities of daily living as well as in the avoidance of falls. Lower body strength and flexibility have been associated with deficits in balance (increased postural sway) and impairments in gait function (e.g., slower velocity and decreased stride length) (Woolacott 1993). The absence of significant improvements in flexibility is surprising given that the participants performed stretching exercises prior to and following each training session. It is possible that greater amounts of stretching exercises must be performed in combination with PACE training. Further study is needed to explore the effect of exercise on these parameters in older adults.

Significant improvements in skinfold thickness were associated with PACE training. Results from this study indicate a decrease of 16% in the sum of these skinfolds for PG and an increase of 6% in the CG after 12 weeks. Skinfold thickness has been previously reported to be reduced by 17% at the subscapular site and 14% at the triceps site after 7 and 14 weeks of endurance training (Sidney et al. 1977). Although this method does not estimate body composition per se, it is an indication of subcutaneous adiposity. The finding that skinfold thickness decreased, yet arm and thigh girth did not change, suggests that the PG group may have gained lean mass. Many studies using weight training ranging from moderate to high intensity have produced increases of muscle strength and hypertrophy in elderly men and women (Fiatarone and Evans 1990). Although muscle mass was not measured directly, this morphological change deserves attention in future studies.

The PACE program significantly raised HDLC. Two other 12-week training studies have failed to show improvements in HDLC, one using cycle ergometers in older Japanese adults (Takeshima et al. 1993) and the other using water-based well-rounded exercises (Takeshima et al. 2002). Others have reported that a minimal exercise intensity of 75% of the maximum HR is required to improve HDLC in a group of healthy middle-aged men (Stein et al. 1990). In the present study, the baseline HR at LT was used to prescribe the target HR during PACE and the HR was monitored continuously as previously described. The mean values for HR during aerobic exercise in PACE training indicate that the intensity was of moderate intensity (70% peak HR). Furthermore, the average percentage peak $\dot{V}O_2$ was 69% during PACE training. Perhaps, this level of intensity when combined with strength training is sufficient to cause improvements in HDLC. However, it must be realized that serum lipid concentrations are affected not only by exercise, but also by other factors including food intake (Huttunen et al. 1979; Nakamura et al. 1983). Although participants were instructed to not change their dietary habits, no measure of nutritional intake was performed. Given that dietary intake is an important factor in determining body composition and blood lipid concentrations, further research is needed to determine how nutrition and PACE training may interact to affect the blood lipid profiles of older adults.

There also seem to be additional benefits of PACE training for older adults. PACE training is unique because it demands that the body adapt to brief, alternating bouts of aerobic and resistance exercise that involve different muscle groups. A short pause while moving from a HRE station to an aerobic dance station and vice versa may allow some recovery time that may minimize cardiovascular hazards resulting from extended performance of exercise. The exercise program was found to be safe for older adults, as training-related injuries were not reported during this study. Furthermore, participating in PACE training as a group may have provided additional psychological and social benefits (e.g., enjoyment, new friendships) that contributed to a willingness to continue participation in the programs. The older adults appeared to enjoy PACE training as evidenced by the high attendance rate during the program. Although the training was physically challenging, the enthusiasm demonstrated by the participants during the exercise sessions suggests that they enjoyed the program. Furthermore, as the exercise program was conducted in a group setting, it provided an opportunity for the participants to interact socially with their peers.

In conclusion, our results indicate that PACE training involving aerobic exercise and HRE elicits significant improvements in cardiorespiratory fitness that are similar to changes observed in exercise programs that utilize only aerobic training. In addition to these improvements, which may be expected with any aerobic training program, the PACE program improved several other health-related components of physical fitness including muscle strength, and subcutaneous fat. Furthermore, the PG demonstrated an improvement in HDLC, another health-related factor. Therefore, we recommend that PACE training be used as a means to improve overall physical fitness in older adults.

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