

Once Weekly Combined Resistance and Cardiovascular Training in Healthy Older Men

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ABSTRACT

IZQUIERDO, M., J. IBAÑEZ, K. HÄKKINEN, W. J. KRAEMER, J. L. LARRIÓN, and E. M. GOROSTIAGA. Once Weekly Combined Resistance and Cardiovascular Training in Healthy Older Men. *Med. Sci. Sports Exerc.*, Vol. 36, No. 3, pp. 435–443, 2004. **Purpose:** To compare the effects of the 16-wk training period ($2 \times \text{wk}^{-1}$) of resistance training alone (S), endurance training alone (E), or combined resistance (once weekly) and endurance (once weekly) training (SE) on muscle mass, maximal strength and power of the leg and arm extensor muscles, and maximal workload (W_{max}) by using an incremental cycling test in older men. **Methods:** Thirty-one healthy men (65–74 yr) were divided into three treatment groups to train $2 \times \text{wk}^{-1}$ for 16 wk: S ($N = 10$), E ($N = 11$), or SE ($N = 10$; $1 \times \text{wk}^{-1}$ S + $1 \times \text{wk}^{-1}$ E). The subjects were tested at 8-wk intervals (i.e., weeks 8 and 16). **Results:** There were no significant differences between S- and SE-induced muscle hypertrophy (11% and 11%) and maximal strength (41% and 38%) gains of the legs as well as between E- and SE-induced W_{max} (28% and 23%) gains. The increase in arm strength in S (36%) was greater than that recorded in SE (22%) and greater than that recorded in E (0%). **Conclusions:** Prolonged combined resistance and endurance training in older men seemed to lead to similar gains in muscle mass, maximal strength, and power of the legs as resistance training alone and to similar gains in maximal peak power output measured in an incremental cycling test as endurance training alone. These findings may have an effect on how resistance exercise is prescribed to older adults. **Key Words:** STRENGTH, ENDURANCE, POWER, MUSCLE HYPERTROPHY

Exercise interventions that improve endurance as well as neuromuscular performance in older people are becoming recognized as an effective strategy to increase functional independence and to decrease the prevalence of many age-associated diseases (1). For example, it is well established that endurance training leads to substantial improvements in cardiovascular fitness and that resistance training leads to substantial improvements in muscle mass and strength in older people (8, 10–12,17). Based on the existing evidence concerning exercise prescription for young adults, it has been recommended to include both cardiovascular (a minimum of $3 \times \text{wk}^{-1}$) for developing cardiorespiratory fitness and resistance training (a minimum of $2 \times \text{wk}^{-1}$) for developing muscle mass and strength (1). However, prescription guidelines for a combined resistance and cardiovascular training regimen have not been reported for older healthy adults. Only one study has examined the

benefits of training programs that include both resistance and cardiovascular components in healthy older adults. Wood et al. (25) found that healthy older adults engaged in concurrent resistance and cardiovascular training, $3 \times \text{wk}^{-1}$ during the 12-wk period, had similar cardiovascular and strength gains as those training with cardiovascular and resistance training alone, respectively.

Some reports suggest that older adults can obtain substantial strength or cardiovascular gains from a less weekly training frequency (once weekly or twice weekly for resistance or cardiovascular training, respectively) (3,22). As optimization of gain in physical fitness is critical for this population based on adherence and social cost, it is important to ascertain whether combined programs of lower weekly frequency of training will obtain significant endurance and strength development in older adults. To date, no studies have compared in older adults the effects of low frequency (twice weekly) resistance and endurance training conducted alone and combined on endurance and neuromuscular performance. These low frequency training regimens may have higher exercise adherence as well as being more practical for some sedentary older men and women.

Previous studies suggest that strength gains will be compromised when trained simultaneously with aerobic power, and this has been referred to as the interference phenomenon (6,15). For example, some studies have shown that combined training of strength and endurance results in compromised strength development (6,15). Other studies, however,

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have shown that concurrent resistance and endurance training can result in similar strength and muscle power gains as resistance training alone in previously untrained men (20,21). To date, we are unaware of any research investigating the effects of a whole body concurrent training program on strength and endurance performance in older men.

Accordingly, the purpose of this study was to compare the effects of the 16-wk training period of 2 d·wk⁻¹ of resistance training alone (S), endurance training alone (E), or combined resistance (once weekly) and endurance (once weekly) training (SE) on muscle mass, maximal strength and muscle power, and cardiovascular performance in older men. Based on the recommendation for developing and maintaining muscular strength and cardiovascular fitness (1), we hypothesized that the S and E groups would obtain specific gains in strength or endurance performance and that the SE group would obtain less or no gains in strength and cardiovascular fitness compared with those of the S and E groups, respectively.

METHODS

Subjects. Thirty-three apparently healthy men between the ages of 65 and 74 yr, recruited through advertisement and personal letters from a private social and recreational club, volunteered to participate in a 20-wk training study. Thirty-one of the volunteers completed the study protocol. Two subjects dropped out for not adhering to the training protocol. Before inclusion in the study, all candidates were thoroughly screened using an extensive medical history, resting and maximal exercise electrocardiogram, and blood pressure measurements. Cardiovascular, neuromuscular, arthritic, pulmonary, or other debilitating diseases as determined via one or all of the screening tools were reasons for exclusion from the study. Only subjects who had not participated in regular resistance and/or endurance training or competitive sports of any kind for the last 5 yr or more were eligible. All subjects were carefully informed about the possible risks and benefits of the project, which was approved by the ethical committee of the regional Health Department. Thereafter, the subjects signed a written consent form before participation in the study. The physical characteristics of the subject groups are presented in Table 1.

Group assignment. The total duration of the present study was 20 wk. The subjects were tested on four different occasions using identical protocols. Baseline testing was completed twice during the first 4 wk of the study (at weeks 4 and 0) during which time no strength or endurance training was carried out, but the subjects maintained their customary recreational physical activities. In a pilot study, calculation of the coefficient of variation and reproducibility coefficients was conducted for muscle CSA, blood lactate accumulation, and maximal workload attained during progressive cycling exercise. This was followed by a 16-wk period of supervised experimental training with the measurements repeated at 8-wk intervals (i.e., weeks 8 and 16). After baseline testing, the subjects were rank ordered by composite strength (one repetition maximum [1RM] from a half

TABLE 1. Physical characteristics of the strength (S), endurance (E), and combined strength endurance (SE) training groups.

	Strength Group	Endurance Group	Combined Strength Endurance
	(N = 11)	(N = 10)	(N = 10)
Age (yr)	64.8 ± 2.6	68.2 ± 1.7	66.4 ± 4.5
Height (m)	1.67 ± 0.04	1.67 ± 0.03	1.63 ± 0.04
Weight (kg)			
Pretraining	81.3 ± 11.3	76.7 ± 7.4	74.7 ± 7.5
8 wk	81.3 ± 11.7	77 ± 7.1	74.8 ± 7.6
16 wk	80.1 ± 9.7*#	76.9 ± 6.8	74.8 ± 7.5
Body fat (%)			
Pretraining	24 ± 5.7	21.8 ± 4.6	21.2 ± 2.3
8 wk	24.2 ± 5.5	22 ± 4.7	21.8 ± 2.7
16 wk	22.2 ± 4.3*#	21.8 ± 4.7	20.8 ± 2.5
Fat-free mass (kg)			
Pretraining	61.3 ± 5.4	59.7 ± 3.4	58.6 ± 5.3
8 wk	61.1 ± 4.8	59.8 ± 3.1	58 ± 5.4
16 wk	62 ± 5	60.8 ± 4.6	58.8 ± 5.3
BMI			
Pretraining	29.6 ± 4.1	27.6 ± 2.7	25.2 ± 8.7
8 wks	29.6 ± 4.5	27.7 ± 2.5	25.2 ± 2.3
16 wk	29.3 ± 3.5	27.6 ± 2.4	25.1 ± 9.2

* Significantly different ($P < 0.05$) from pretraining.

Significantly different ($P < 0.05$) from week 8.

squat position), muscle power output, age, and peak power output during incremental cycling test. Thereafter, the subjects were randomly assigned to one of the three training groups that performed 2 × wk⁻¹ heavy resistance training (S; $N = 10$), endurance training (E; $N = 11$), or combined resistance and endurance training (SE; $N = 10$, 1 × wk⁻¹ S + 1 × wk⁻¹ E). To be considered compliant and remain in the study, subjects had to attend at the minimum of 90% of the exercise sessions organized.

Muscle cross-sectional area and body composition. Thigh bone-free muscle cross-sectional area (CSA) of the quadriceps femoris (QF) muscle group (rectus femoris, vastus lateralis, vastus medialis, and vastus intermedialis; CSA_{QF}) was measured at week 0 and after the experimental period (week 16) with a compound ultrasonic scanner (Toshiba SSA-250) and a 5-MHz convex transducer. The CSA was measured at the lower third portion between the greater trochanter and the lateral joint line of the knee. Two consecutive measurements were taken from the right thigh and then averaged for further analyses. The CSA was then calculated from the image by the computerized system of the apparatus. The percentage of fat in the body was estimated from the measurements of skinfold thickness (18).

Muscle strength and power assessment. Lower and upper body maximal strength was assessed using 1RM actions in a half-squat (1RM_{HS}) and in a bench press (1RM_{BP}) position, respectively. A detailed description of the 1RM testing procedure can be found elsewhere (17). In brief, in the 1RM_{HS} the subjects began the test by lifting a bar in contact with the shoulders with weight plates added to both ends of the bar. On command, the subject performed a concentric extension (as fast as possible) of the leg muscles starting from a knee angle of 90 degrees to reach the full extension of 180 degrees. In the 1RM_{BP} the bar was positioned 1 cm above the subject's chest supported by the bottom stops of the measurement device. The subject was instructed to perform from the starting position a purely concentric action maintaining the shoulders in a 90 degree

abducted position to ensure consistency of the shoulder and elbow joints throughout the testing movement. Four to five separate single attempts were performed until the subject was unable to extend the legs/arms to the required position. Those incremental increases of weight were made according to the difficulty with which the subject executed the previous lift. Maximal strength ($1RM_{HS}$) was defined as the maximum weight that could be lifted through a full range of motion with proper form.

The power output of the leg and arm extensor muscles was measured concentrically in a half-squat and bench-press position using the relative load 45% of their respective 1RM. In this case the subject was instructed to move the load as fast as possible. Two testing actions were recorded and the best reading (with the best velocity) was taken for further analyses. During the power test action, bar displacement, maximal average velocity ($m \cdot s^{-1}$), and power (W) were recorded by linking a shuttle to the end part of the bar locked to an infrared sensor. The accuracy of the electronic device reached the $10 \mu s$ time resolution with an optical transducer interruption each 3 mm of displacement. The velocity (v ; $m \cdot s^{-1}$) was calculated each instantaneous displacement (Δd) of 3 mm by using the following equation.

$$V = \Delta d \cdot \Delta t^{-1}$$

Where Δt is the time (s) to perform the instantaneous range of displacement (3 mm) with a resolution of $10 \mu s$. The calculation of instantaneous power was then calculated by multiplying the velocity over each displacement period by force derived from the product of mass of the load and acceleration due to gravity. Average velocity and power were calculated through all the range of motion utilized to perform a complete repetition, as a most representative mechanical parameter associated to a contraction cycle of each muscle group.

In all tests of neuromuscular performance, strong verbal encouragement was given for each subject to motivate them to perform each test action as maximally and as rapidly as possible. The time period of rest between the actions was always 1.5 min.

Cycling test. Maximal workload was measured at weeks 0, 8, and 16 by using a maximal multistage discontinuous incremental cycling test on a mechanically braked cycloergometer (Monark Ergonomic 818E, Vargberg, Sweden). During the exercise test, the subject was fitted with toe clips and pedaled at a constant rate of 60 rpm, while blood pressure and a 12-lead electrocardiogram were monitored. Each subject started with unloaded cycling for 3 min, whereupon the load was increased by 30 W every 3 min, until volitional exhaustion or the required pedaling frequency of 60 rpm could not be maintained. Following each workload the test was interrupted for 60 s.

Heart rate was recorded every 15 s during cycling (Sport Tester, Polar Electro, Kempele, Finland) and averaged during the last 60 s of each workload. Subjects were verbally encouraged during the test. Before exercise and immediately after each exercise bout, capillary blood samples for the determination of lactate concentration were obtained from a

hyperaemic earlobe. Samples for the whole blood lactate determination ($100 \mu L$) were deproteinized, stored at $4^\circ C$, and analyzed within 5 d after completing the test. The blood lactate analyzer (YSI 1500, Yellow Springs, OH) was calibrated after every fifth blood sample dosage with three known controls (5, 15, and $30 \text{ mmol} \cdot L^{-1}$). Individual data points for the exercise blood lactate values were plotted as a continuous function against time. The exercise lactate curve was fitted with a second degree polynomial function. From the equation describing the exercise blood lactate and heart rate curves, the workloads and heart rate that brought about a level of $2 \text{ mmol} \cdot L^{-1}$ (W_2), $3 \text{ mmol} \cdot L^{-1}$ (W_3), $4 \text{ mmol} \cdot L^{-1}$ (W_4), and $5 \text{ mmol} \cdot L^{-1}$ (W_5) were interpolated. W_4 has been shown to be important determinants of endurance performance capacity (23).

A detailed description of the formula for calculating maximal workload of each cycling test (W_{max}) can be found elsewhere (19). In a pilot study, intertest reliability for measuring W_{max} , W_4 , and W_2 was assessed performing two cycling tests separated by 4 wk in 11 elderly men. No significant differences were observed between the 4-wk measurements in W_{max} , W_4 , and W_2 . Cycling testing variables showed reproducibility coefficients ranging from 0.92 to 0.98. The coefficient of variation (CV) for W_{max} was 3.5%. The CV for W_4 and W_2 ranged between 3.2% and 6.1%.

Training Programs

Resistance exercise training (S group). The strength training program utilized in the present study was similar to that reported previously (17) and was a combination of heavy resistance and “explosive” strength training. The subjects in the S group were asked to report to the training facility $2 \times \text{wk}^{-1}$ for 16 wk, to perform dynamic resistance exercise, from 45 to 60 min per session. A minimum of 2 d elapsed between two consecutive training sessions. Each training session included 2 exercises for the leg extensor muscles (bilateral leg press and bilateral knee extension exercises), 1 exercise for the arm extensor muscle (the bench press), and 4 to 5 exercises for the main muscle groups of the body (chest press, lateral pull-down, and/or shoulder press for the upper body; abdominal crunch and/or rotary torso and/or another exercise for the trunk extensors; and the standing leg curl and/or adductor-abductor exercises). Only the resistance machines (Technogym, Gambetta, Italy) were used throughout the training period. Resistance used in this study was progressively increased or decreased every week for the 16-wk training period using a repetition maximum approach so that the loads that brought about a given relative intensity remained unchanged from week to week.

During the first 8 wk of the training period, the subjects trained with the loads of 50–70% of the individual 1RM, 10–15 repetitions per set, and 3–4 sets of each exercise. During the last 8 wk of the training period the loads were 70–80% of the maximum, 5–6 repetitions per set (higher loads), and performed 3–5 sets. In addition, from week 8 to

week 16 the subjects performed a part (20%) of the leg extensor and bench press sets with the loads ranging from 30% to 50% and 30% to 40% of the maximum, respectively. In these training occasions, the subjects now performed 6–8 repetitions per set and 3–4 sets of each exercise but executed all of these repetitions as rapidly as possible.

Endurance exercise program (E group). The subjects in the E group were asked to report to the training facility $2 \times \text{wk}^{-1}$, for 16 wk on nonconsecutive days, to perform endurance cycling exercise at a constant rate of 60 rpm from 30 to 40 min per session. From weeks 0 to 8, the intensity level corresponded to the workloads and heart rate that brought about a blood lactate levels of $2 \text{ mmol}\cdot\text{L}^{-1}$ (W_2), $3 \text{ mmol}\cdot\text{L}^{-1}$ (W_3), and $4 \text{ mmol}\cdot\text{L}^{-1}$ (W_4), for 5–10, 10–25, and 10–20 min per training session, respectively. From weeks 8 to 16, the intensity level corresponded to blood lactate levels of W_2 (5–10 min), W_3 (5–10 min), W_4 (10 min), and W_5 (2.5–5 min). The cycling training at W_2 and W_4 was performed continuously, whereas the training at W_5 was performed with 30 s work interspersed with 30 s rest. The exercise intensity during the cycling training corresponded to a heart rate between 70% and 90% of the maximal individual heart rate or between 55% and 85% of W_{max} attained during the maximal incremental discontinuous cycling test. Heart rate was monitored (Favor, Oulu, Finland) through every training session. Work rates were progressively increased or decreased within training periods so that the exercising heart rate that brought about blood lactate levels from W_2 to W_5 remained unchanged from session to session. To avoid an “experimental factor,” a mathematical formula was used to decide when and how to change training work rates. Specifically, average work-rate levels were increased or decreased by 2.5% when average heart rate during training at W_3 was decreased or increased by 5%.

Combined resistance and endurance training (SE group). The subjects in the SE group were asked to report to the training facility $2 \times \text{wk}^{-1}$, for 16 wk on nonconsecutive days, to perform $1 \times \text{wk}^{-1}$ resistance exercise and $1 \times \text{wk}^{-1}$ endurance exercise. For the resistance exercise, the subjects were assigned an exercise prescription based upon the training principles applied to the S group, with the only difference being that resistance training was conducted only once weekly instead of twice weekly. For the endurance exercise, the subjects were assigned an exercise prescription based upon the training principles applied to the E group, with the only difference being that endurance training was conducted only once weekly instead of twice weekly. During the 16-wk training period, the SE subjects trained with the same relative intensity as the S and E group. Each training session was closely supervised and monitored by researchers. In over 95% of all the individual exercise sessions performed by the three groups, one of the researchers was present to direct and assist each subject toward performing the appropriate work rates and loads.

Statistical analysis. Standard statistical methods were used for the calculation of the means and standard deviations (SD). Statistical comparison during the control period

(from weeks -4 to week 0) was performed by Student's paired t -test. One-way analysis of variance (ANOVA) was used to determine any differences among the three groups' initial strength, endurance, and muscle CSA. The training-related effects were assessed using a two-way ANOVA with repeated measures (groups \times time). When a significant F -value was achieved, Sheffé *post hoc* procedures were performed to locate the pair wise differences between the means. Selected absolute changes were analyzed via one-way ANOVA. Statistical power calculations for this study ranged from 0.75 to 0.80. The $P \leq 0.05$ criterion was used for establishing statistical significance.

RESULTS

Muscle CSA and physical characteristics. There were no statistically significant differences within the groups for any of the variables tested at the two measurements during the control period (from weeks -4 to 0). At the beginning of the training program, no significant differences were observed among the groups in the pretraining age, height, body mass, body fat, or muscle CSA values. Percent body fat and body mass decreased significantly ($P < 0.05$) during the 16-wk training period in S, while no significant changes were observed in the E and SE groups (Table 1). Significant increases ($P < 0.05$) took place in muscle CSA of the quadriceps femoris muscle during the 16-wk training period in S and SE, while no change occurred in the E group. The increases in the CSA of the quadriceps femoris muscle in S (11%) and SE (11%) were greater ($P < 0.01$) than that recorded in E (4%) (Fig. 1).

Maximal strength and muscle power. The results of the maximal strength values are presented in Figure 2. Maximal 1RM_{HS} increased only slightly (2–3%) but significantly ($P < 0.03$ – 0.04) during the 4-wk control period (from weeks -4 to 0) in all treatment groups. There were no statistically significant differences within the groups for 1RM_{BP} at the two measurements during the control period (from weeks -4 to 0). No significant differences were observed between the groups in the pretraining strength level for the 1RM_{HS} and 1RM_{BP} . Significant increases took place in maximal concentric 1RM_{HS} for the S, SE, and E groups at weeks 8 and 16. The increases in leg strength at weeks 8 and 16 in S (27% and 41%) and SE (22% and 38%) were greater ($P < 0.01$ – 0.001) than those recorded in E (8% and 11%), respectively. No significant differences were observed in the magnitude of the increase in 1RM_{HS} between S and SE.

Significant increases took place in maximal concentric 1RM_{BP} for the S and SE groups at weeks 8 and 16, while it remained unaltered for E. The increase observed in arm strength at week 16 in S (36%) was greater ($P < 0.001$) than that recorded in SE (22%) and greater than that recorded in E (0%).

Muscle power output of the lower and upper extremities at the load of 45% 1RM remained unaltered during the 4-wk control period in S, SE, and E. No significant differences were observed between the groups in the pretraining muscle

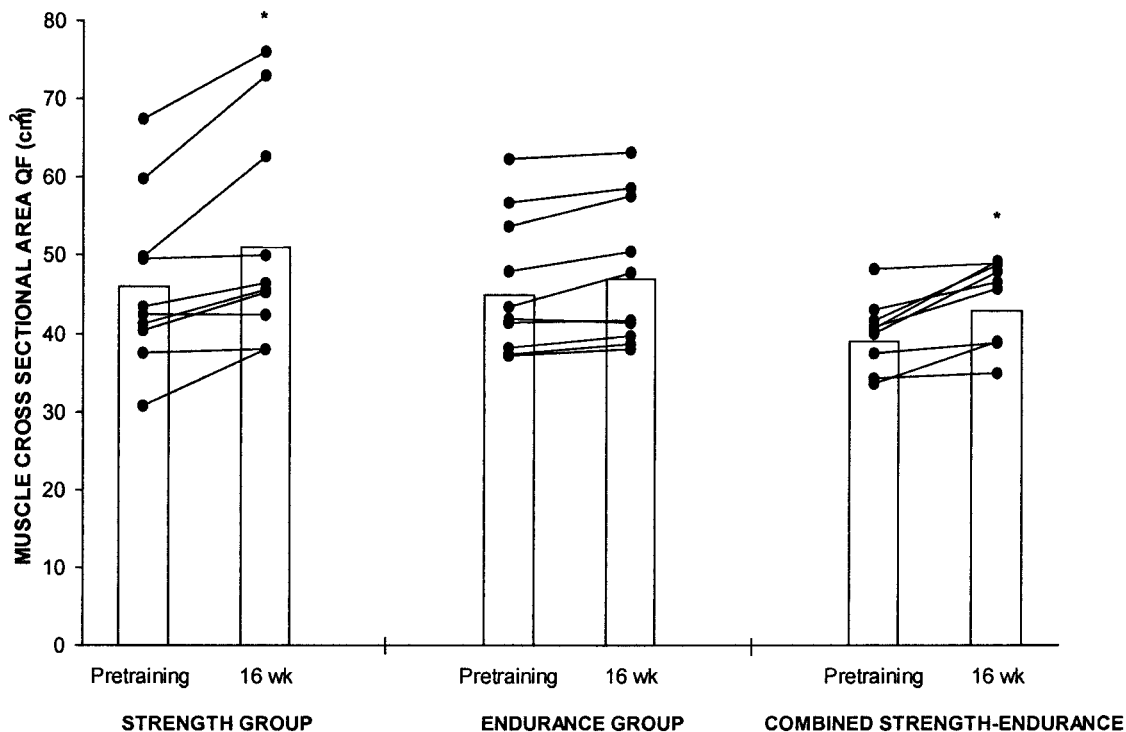


FIGURE 1—Muscle cross-sectional area of the quadriceps femoris muscle group for the strength, endurance and combined strength and endurance groups at pretraining and the subsequent 16 wk of training for each subject. *Significantly different ($P < 0.05$) from the corresponding pretraining value. Values are means \pm SD. See text for significant changes between the groups. The bars indicate the mean values.

power output values of either the lower or upper extremity. Significant increments took place in muscle power output at the 45% of $1RM_{HS}$ during the 16-wk training period in S (37%) and in SE (38%), while it remained unaltered in E group (5%). The increases in power at the 45% of $1RM_{HS}$ at week 16 in S and SE were larger ($P < 0.05$) than that recorded in E.

Significant increments took place in muscle power output at the 45% of $1RM_{BP}$ during the 16-wk training period in S (18%) and in SE (11%), while it remained unaltered in E (0%). The increases in power at the 45% of $1RM_{HS}$ at week 16 in S and SE were larger ($P < 0.05$) than that recorded in E.

Cycling test to exhaustion. Peak power output (W_{max}) measured during the incremental cycling test is presented in Figure 3. During the 16-wk training period, the E and SE groups increased W_{max} by 16% and 18% ($P < 0.05$), respectively, whereas the S group increased W_{max} by 10% ($P < 0.05$). The increases in W_{max} at week 16 in SE (18%) and E (16%) were greater ($P < 0.01-0.001$) than that recorded in the S group (10%). No significant differences were observed in the magnitude of the increase in W_{max} between SE and E. From week 0 to week 16, maximal blood lactate accumulation in S (from 8.5 ± 1 to 8.6 ± 1 $mmol \cdot L^{-1}$), E (from 7.7 ± 1 to 9.0 ± 1 $mmol \cdot L^{-1}$) and SE (from 7.34 ± 1 to 8.4 ± 1 $mmol \cdot L^{-1}$) remained unaltered. Similarly, maximal heart rate in S (from 162 ± 16 to 160 ± 14 $beats \cdot min^{-1}$), E (from 151 ± 10 to 153 ± 14 $beats \cdot min^{-1}$), and SE (from 164 ± 17 to 159 ± 15 $beats \cdot min^{-1}$) did not change during the training period.

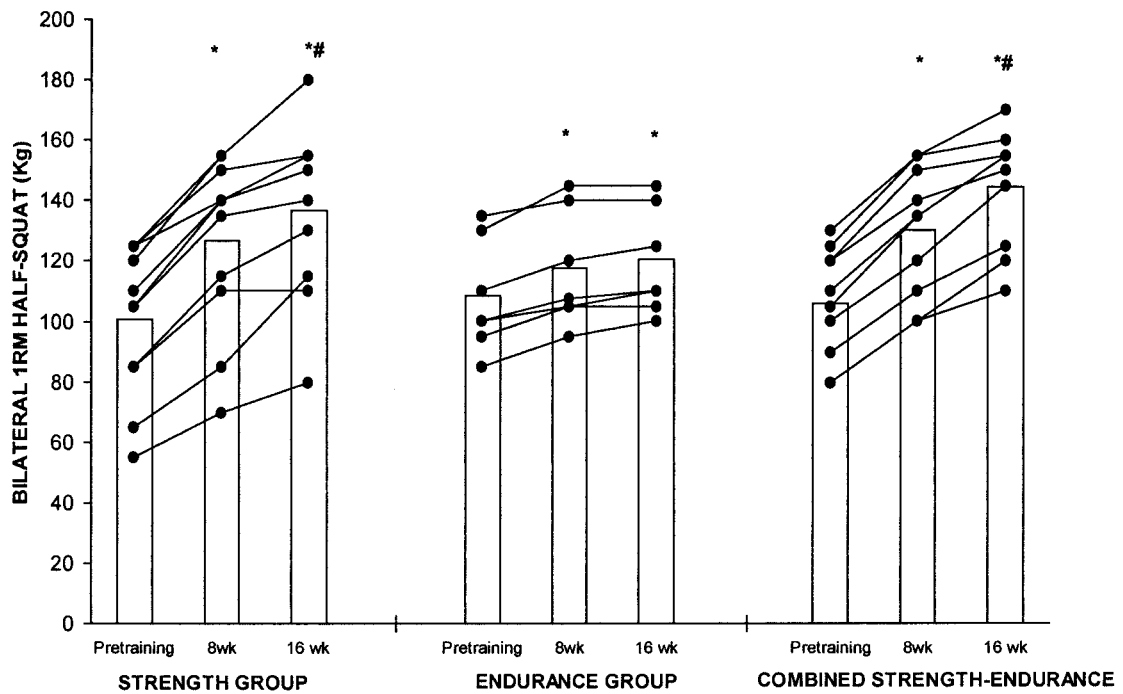
No significant differences were observed between the groups in pretraining workloads expressed in watts which

elicited a blood lactate concentration at 4 $mmol \cdot L^{-1}$ (W_4). Significant increments ($P < 0.01-0.05$) took place in W_4 during the 16-wk training period in E (11%; from 115 ± 20 W to 128 ± 25 W), SE (15%; from 114 ± 31 W to 130 ± 26 W), and S (7%; from 117 ± 20 W to 126 ± 21 W). No significant differences between the groups were observed in the training-induced changes in W_4 .

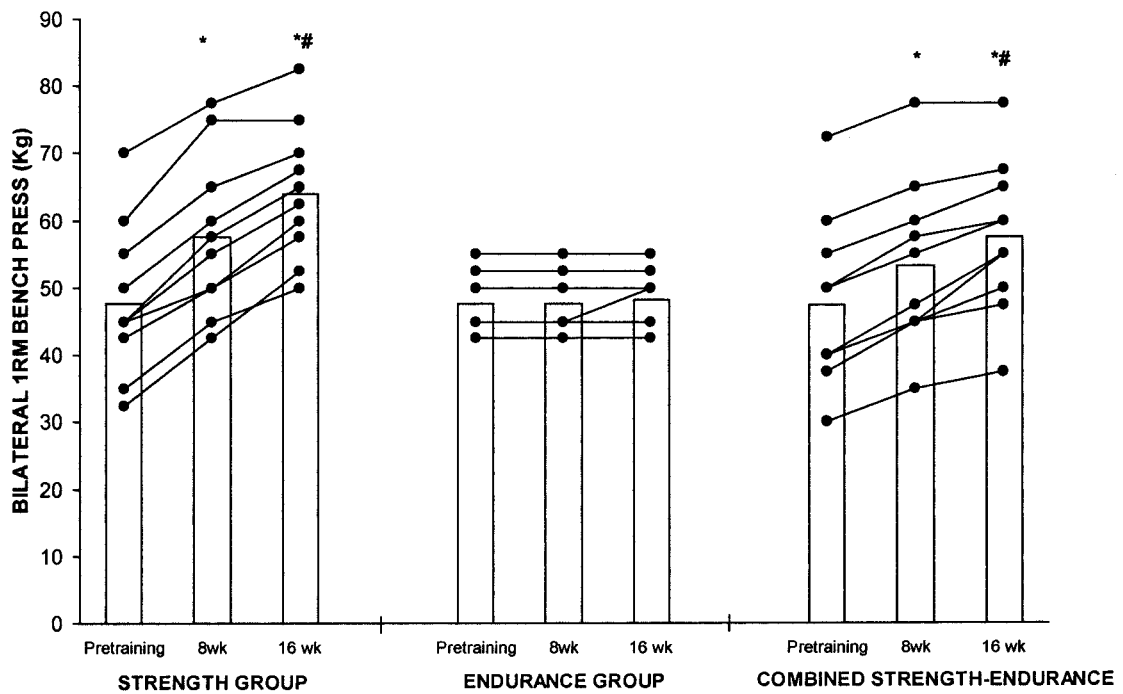
Table 2 shows the average heart rate values observed at submaximal workloads (from 90 to 150 W) in all groups. Significant decreases ($P < 0.05-0.001$) in average heart rate were observed after 16 wk of training at 90, 120, and 150 W in SE, at 120 W in E, and at 90 and 120 W in S. The decreases in average heart rate at 90 W and 120 W in E and 150 W in S approached statistical significance ($P = 0.06$).

DISCUSSION

This was the first study designed to compare the effects of low-frequency ($2 \times wk^{-1}$) combined resistance and endurance training with those attained by resistance training or endurance training alone on neuromuscular and endurance cycling performance in older men. The main findings of this study were that prolonged combined resistance and endurance training (SE group) in older men seemed to lead to similar gains in muscle mass, maximal leg strength, and muscle power output as resistance training alone (S group) and to similar gains in maximal peak power output measured in an incremental cycling test as endurance training alone (E group). The present observations suggest that the combination of only once-weekly resistance training session and once-weekly endurance-training session may be a valid



(A)



(B)

FIGURE 2—Maximal bilateral concentric 1RM half-squat (A) and maximal bilateral 1RM bench-press (B) at pretraining, after 8 and 16 wk of training for each subject. Values are means \pm SD. *Significantly different ($P < 0.05$) from the corresponding pretraining value; #significantly different ($P < 0.05$) from week 8. See text for significant changes between the groups. The bars indicate the mean values.

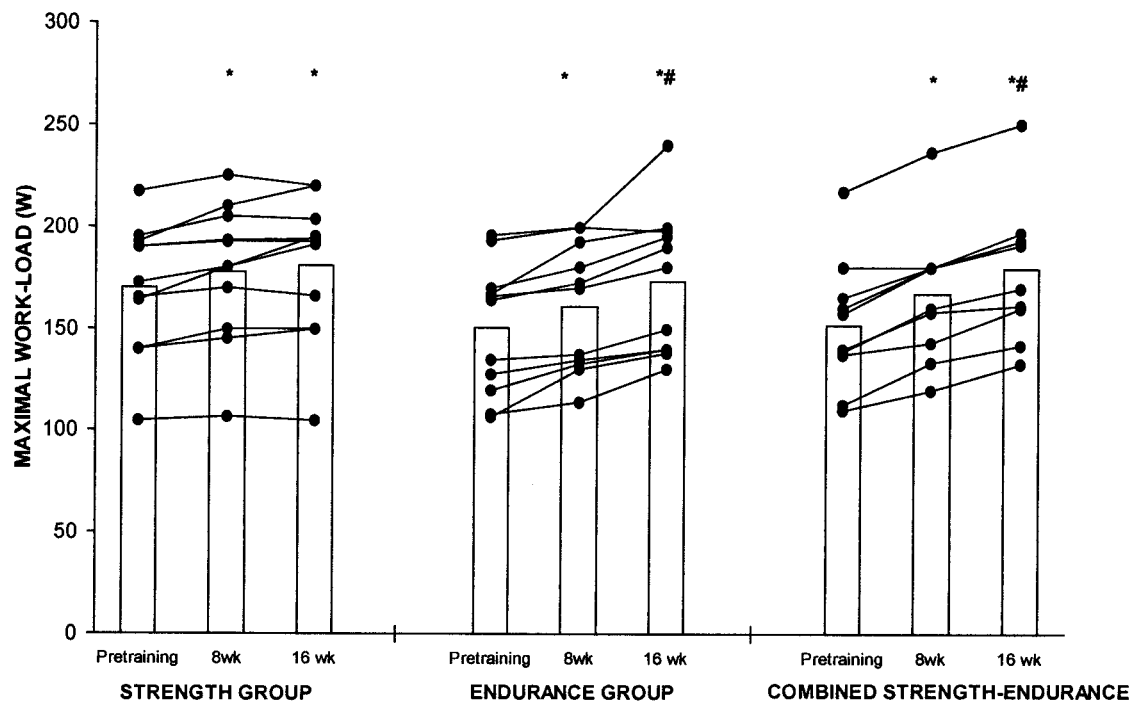


FIGURE 3—Maximal workload attained during a maximal multistage discontinuous incremental cycling test at pretraining, after 8 and 16 wk of training for each subject. Values are means \pm SD. *Significantly different ($P < 0.05$) from the corresponding pretraining value; #significantly different ($P < 0.05$) from week 8. See text for significant changes between the groups. The bars indicate the mean values.

means to promote neuromuscular and cycling endurance fitness in older males. These findings may have an important practical relevance for optimal construction of strength and endurance training programs for older men since muscle strength, the ability to develop force rapidly, and endurance performance are important health-related fitness components contributing to several tasks of daily life such as climbing stairs, walking requiring submaximal efforts and to preserve the independent lifestyle.

Resistance training alone. It is generally accepted that systematic resistance training can lead in older individuals to considerable improvements of strength of all muscle groups examined independent of age and gender, when both the loading intensity (10–12 RM; 50–80% of 1RM) of training and duration (2–3 \times wk⁻¹) of the resistance training

period are sufficient (1,12,17). The initial increases in strength can be as large as 10–30% during the first 4–8 wk of resistance training in older subjects of both genders (9,12,17). The present results agree with these studies because the progressive low-frequency (2 \times wk⁻¹) heavy resistance training program combined with explosive types of exercises lead to great gains in maximal dynamic strength characteristics of the leg extensors muscles in older men. It was also interesting to observe that leg power at the 45% of 1RM_{HS} also increased by the resistance training in the S group. The mechanism responsible for resistance training-induced increases in strength and muscle power in the elderly are not entirely understood, but increases in motor unit firing frequency, maximal motor unit recruitment rates (12) accompanied by gradually increasing muscle hypertrophy, such as increases in the sizes of type I and type II muscle fibers (13,16), and exercise-induced acute increases in serum levels of anabolic hormones and growth factors (i.e., testosterone, growth hormone, IGF-1) are probable mechanisms explaining the substantial increases for training-induced hypertrophy and strength development due to resistance training (13,17).

There is a limited amount of information about the effect of resistance training on cycling maximal workload and cardiovascular adaptation in older men. In the present study, peak power output (W_{max}) was increased by 10% and heart rate and blood lactate responses to a similar absolute submaximal workload were decreased by 6–9% during an incremental cycling test in the S group. This result agrees with previous studies showing that older men respond to low- or high-intensity resistance training by increasing the

TABLE 2. Average heart rate (mean \pm SD) during a maximal multistage discontinuous incremental cycling test of the strength (S), endurance (E), and combined strength endurance (SE) training groups at week 0 and week 16 during the 16-wk training period.

	Cycling Work loads		
	90 W Heart Rate (beats \cdot min ⁻¹)	120 W Heart Rate (beats \cdot min ⁻¹)	150 W Heart Rate (beats \cdot min ⁻¹)
Strength group			
Week 0	117 \pm 13	135 \pm 11	152 \pm 11
Week 16	110 \pm 10*	123 \pm 6**	141 \pm 3 ^{P=0.06}
Endurance group			
Week 0	114 \pm 7	129 \pm 8	144 \pm 4
Week 16	106 \pm 5 ^{P=0.06}	120 \pm 4*	134 \pm 5 ^{P=0.06}
Combined Strength Endurance			
Week 0	127 \pm 12	141 \pm 15	162 \pm 15
Week 16	113 \pm 11***	129 \pm 12**	145 \pm 8***

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

capacity of some components of the oxygen transport system, leading to a small, but statistically significant increase in $\dot{V}O_{2\max}$ and W_{\max} (14,16,24). Because $\dot{V}O_{2\max}$ was not measured in the present study it is difficult to conclude whether the increases on maximal workload were due to improved oxygen transport or due to some neuromuscular adaptations, such as increases in muscle strength combined with increases in fatigue resistance of the muscle. However, the attenuated heart rate responses at a similar absolute work rate after training in the S group represents a significant reduction in cardiovascular stress during submaximal exercise. This is consistent with the well-known cardiovascular training effect.

Endurance training alone. Twenty years ago, it was believed that older individuals could not respond to endurance exercise training with an increase in $\dot{V}O_{2\max}$ or peak power output (W_{\max}) measured in an incremental exercise test, as do younger individuals (10). This absence of changes was probably due to an inadequate training stimuli, too short a training program, or both (1). However, recent studies indicate that older people significantly increase in $\dot{V}O_{2\max}$ (10–30%) or W_{\max} as young adults, if the training stimulus is of adequate intensity (50–85% of $\dot{V}O_{2\max}$ or W_{\max}), duration (more than 20 min per session), and weekly frequency (3–5 sessions per week) (5,10,23). The endurance training-related increase in $\dot{V}O_{2\max}$ or W_{\max} in the elderly has been ascribed to greater maximal stroke volume and cardiac output and greater cardiac reserve as well as to peripheral adaptations such as increases in the resting values for muscle glycogen concentration, in the capacity of the skeletal muscles for oxidative metabolism, and in muscle capillary density (5,10,14).

In the present study, a 16% increase in W_{\max} and a 7% decrease in heart rate and blood lactate concentration at absolute submaximal workloads were observed for the E group. These training adaptations are comparable with recent studies in this age population where 9–40% increases in $\dot{V}O_{2\max}$ and decreases in submaximal heart rate and/or blood lactate concentration have been reported after 8–52 wk of endurance training (4,10,14,23). However, the weekly training frequency of these studies (3–5 training sessions) was higher than in the present study (2 training sessions). It is possible that the training-induced increase in W_{\max} found with only two weekly frequency training sessions in the present study may be in part due to the high training intensity (70–90% of maximal heart rate) prescribed and to the continual work rate adjustment made during each training session to optimally maintain the relative training intensity (based on monitoring heart rate). The present results suggest that a endurance cycling training program of only two sessions per week may prove useful in improving cycling maximal work load in older untrained adults if the training intensity is adequate and adjusted during each training session based on monitoring heart rate.

There is a paucity of information about the effects of endurance training on neuromuscular adaptations in older adults. In the present study, maximal strength in the leg extensor muscles was increased by 11% in the E group. The

magnitude of increase in maximal strength in the E group was lower than in the S (41%) and SE (38%) groups and it occurred mainly during the first 8 wk of endurance cycling and was not accompanied by changes in the cross-sectional area of the quadriceps muscle. This agrees with previous studies showing that endurance training induces increase in maximal leg extensor strength (25) and power (4) as well as an increase in some of the anaerobic muscle enzymes (creatine phosphokinase) in older adults (2,4,7,25).

Combined resistance and cycling endurance training. A unique finding of the present study was that in healthy older adults, the 16-wk training program combining once-weekly endurance cycling exercise with once-weekly resistance exercise was as effective in eliciting improvements in maximal strength, muscle power output, and endurance cycling fitness as twice-weekly resistance or endurance training alone. These results are consistent with those of Wood et al. (25) who reported that in older healthy adults, concurrent cardiovascular and resistance training during a 12-wk period, $3 \times \text{wk}^{-1}$, was as effective in eliciting improvements in cardiovascular fitness and maximal strength as cardiovascular or strength training alone, respectively. This similar increase in fitness in the combined group observed in the present study is even more interesting considering its low training frequency (two training sessions per week) and the fact that this group performed one-half the volume and weekly training frequency of resistance and endurance training compared with the S and E group, respectively. However, these results disagree with studies showing an “interference” effect of combined training on strength development in younger adults (6,15). The difference in the training frequency used during these studies could explain in part the presence or absence of an “interference effect.” Thus, when the training frequency is high ($6 \cdot \text{wk}^{-1}$) (6,15) a reduced improvement in muscular strength has been observed with combination training as the result of the development of residual fatigue in the neuromuscular system (15). However, when the training frequency is low ($2\text{--}3 \cdot \text{wk}^{-1}$), there may be a synergistic effect of a combined strength and endurance-training program in the increase observed in maximal strength. This suggests that in previously untrained older subjects performing a low-frequency training program, strength training may complement the adaptation to endurance training and endurance training may complement the adaptation to strength training.

In summary, the present results indicate that a training program combining once-weekly endurance cycling exercise with once-weekly resistance exercise is as effective in eliciting improvements in maximal strength and peak power output as twice-weekly resistance training or endurance cycling alone, respectively. However, for optimal muscle power development, especially of the arm extensor muscles, higher training volume may be required. This low-frequency combined strength and endurance-training program for older adults may be more acceptable, effective, and practical in optimizing aspects of physical fitness than programs that involve only one component or higher frequency. It is suggested that the choice of this low frequency regimen will be

made when the individual's ability to withstand a vigorous program or his willingness to devote a high weekly training frequency is a constrain.

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