

Improved Cardiorespiratory Endurance Following 6 Months of Resistance Exercise in Elderly Men and Women

Kevin R. Vincent, PhD; Randy W. Braith, PhD; Ross A. Feldman, MS; Henrique E. Kallas, MD; David T. Lowenthal, MD, PhD

Objective: To examine the effect of 6 months of high- or low-intensity resistance exercise on aerobic capacity and treadmill time to exhaustion in adults aged 60 to 83 years.

Methods: Sixty-two men and women completed the study protocol. Subjects were matched for strength and randomly assigned to a control (n=16), low-intensity exercise (LEX, n=24), or high-intensity exercise (HEX, n=22) group. Subjects trained at either 50% of their one repetition maximum (1-RM) for 13 repetitions (LEX) or 80% of 1-RM for 8 repetitions (HEX) 3 times per week for 24 weeks. One set each of 12 exercises was performed. Strength was measured for the leg press, chest press, leg curl, leg extension, overhead press, biceps curl, seated row, and triceps dip. Muscular endurance was measured for the leg press and chest press. Aerobic capacity (peak oxygen consumption [$\dot{V}O_{2peak}$]) was measured during an incremental treadmill test (Naughton). Treadmill time to exhaustion was

measured as the time to exhaustion during the incremental exercise test.

Results: The 1-RM significantly increased ($P \leq .05$) for all exercises tested for both the HEX and LEX groups. Aerobic capacity increased ($P \leq .05$) by 23.5% (20.2 to 24.7 mL·kg⁻¹·min⁻¹) and by 20.1% (20.9 to 24.4 mL·kg⁻¹·min⁻¹) for the LEX and HEX groups, respectively. Treadmill time increased ($P \leq .05$) by 26.4% and 23.3% for the LEX and HEX groups, respectively.

Conclusions: Significant improvements in aerobic capacity and treadmill time to exhaustion can be obtained in older adults as a consequence of either high- or low-intensity resistance exercise. These findings suggest that increased strength, as a consequence of resistance exercise training, may allow older adults to reach and/or improve their aerobic capacity.

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From the College of Medicine (Drs Vincent, Braith, and Lowenthal) and Center for Exercise Science, College of Health and Human Performance (Dr Braith and Mr Feldman), University of Florida, and Geriatric Research, Education and Clinical Center, Veteran's Administration Hospital (Drs Kallas and Lowenthal), Gainesville, Fla.

CARDIORESPIRATORY fitness, measured as maximum oxygen consumption ($\dot{V}O_{2max}$) or peak oxygen consumption ($\dot{V}O_{2peak}$), is related to all-cause mortality.¹ Specifically, reduced cardiorespiratory fitness is associated with increased risk of cardiovascular disease, stroke, hypertension, and mortality.²⁻⁵ Interventions that improve cardiorespiratory endurance can have important health implications by decreasing the probability of disease, disability, and mortality.^{1,6}

Endurance exercise is traditionally viewed as the primary means of increasing aerobic capacity.⁷ Resistance exercise, in contrast, is not typically viewed as a means for improving cardiorespiratory endurance.⁸⁻¹⁰ Indeed, studies^{11,12} of young and middle-aged subjects using traditional resistance exercise regimens consisting of multiple sets and long rest periods (>2 minutes) have failed to

demonstrate significant improvements in aerobic capacity. The absence of cardiorespiratory adaptation may be explained by the fact that a session of resistance exercise has been shown to correspond to an oxygen uptake of only 36% to 45% of $\dot{V}O_{2max}$.^{13,14} These values are lower than what is commonly recommended to elicit improvements in aerobic capacity.⁷ An alternative explanation is that augmentation of peripheral skeletal muscle strength does not influence cardiorespiratory performance in young and middle-aged individuals because they possess normal leg strength values.

Recent reports¹⁵⁻¹⁷ from several laboratories suggest that the measurement of aerobic capacity in elderly subjects may be compromised by skeletal muscle weakness and strength loss. Flegg and Lakatta¹⁶ suggested that the age-related decline in aerobic capacity can be explained in part by decreased muscle mass. Frontera et al¹⁸ observed increases in $\dot{V}O_{2max}$ (when ex-

SUBJECTS, MATERIALS, AND METHODS

SUBJECTS

Eighty-four apparently healthy adults between the ages of 60 and 83 years volunteered to participate in a 6-month training study. Sixty-two of the volunteers completed the study protocol. Only subjects who had not participated in regular resistance training for at least 1 year, but may have engaged in low-intensity aerobic training equal to or less than 3 times per week were eligible. Subjects also had to be free from any orthopedic or cardiovascular problems that would limit exercise.

GROUP ASSIGNMENTS

After baseline testing, the subjects were rank ordered by composite strength (one repetition maximum [1-RM] chest press plus 1-RM leg press) and randomly stratified to 1 of the 2 training groups or a control group that did not train. Subjects were randomly assigned to the control, low-intensity exercise (LEX), or high-intensity exercise (HEX) groups using a random numbers table. To be considered compliant and remain in the study, subjects had to attend more than 85% of the possible exercise sessions. All subjects received a comprehensive explanation of the proposed study, its benefits, its inherent risks, and the expected commitments with regard to time. Following the explanation, all subjects signed an informed consent document approved by the Institutional Review Board at the University of Florida and in adherence with the guide-

lines of the American College of Sports Medicine, Indianapolis, Ind.

MUSCLE STRENGTH ASSESSMENT

Dynamic muscular strength was measured using the following 8 resistance exercises: leg press, leg curl, knee extension, chest press, seated row, overhead press, triceps dip, and biceps curl. For each dynamic exercise, a 1-RM was determined. A detailed description of the 1-RM testing procedure can be found elsewhere.¹⁹ In brief, the subject began the test by lifting a light weight and incremental increases were then made according to the difficulty with which the subject executed the previous lift. The investigator continued to increase the weight lifted until reaching the maximum weight that could be lifted in 1 repetition with proper form. Maximal strength was defined as the maximum weight that could be lifted through a full range of motion with proper form.

AEROBIC POWER ASSESSMENT

The subject performed a walking symptom-limited graded exercise test (GXT) using an incremental treadmill exercise protocol (Naughton) to determine $\dot{V}O_{2peak}$. The initial workload was 2.0 mph at 0% grade, and the workload progressed every 2 minutes by increasing the grade 3.5%. Once the test time reached 12 minutes, the treadmill speed increased to 3.0 mph and the incline decreased to a 12% grade. From this point, the grade again increased 3.5% every 2 minutes until the subject reached voluntary maximal exertion or became symptomatic with positive hemodynamic or medical indexes.²⁰ The following criteria

pressed as $mL \cdot kgFFM^{-1} \cdot min^{-1}$ (FFM indicates fat free mass) following 12 weeks of resistance training in the elderly. In addition to strength gains, the authors reported that the aerobic adaptations were accompanied by increased capillary density and citrate synthase activity.¹⁸ To date, however, no studies have been specifically designed to assess aerobic adaptations during a traditional, total body resistance exercise regimen in an elderly population.

Accordingly, the purpose of this study was to measure aerobic power in subjects 60 to 85 years of age before and after 6 months of resistance exercise training. We hypothesized that a traditional resistance exercise regimen consisting of single sets and long rest periods (2 minutes) could elicit increases in aerobic capacity and endurance in elderly people. In an attempt to determine the quantity of resistance exercise necessary to elicit aerobic adaptations, we trained our elderly subjects at both low and high intensity.

RESULTS

SUBJECTS

Sixty-two of the original 84 subjects completed the study (controls=16, LEX=24, HEX=22). Of the 22 who did not finish, 11 were dropped by the investigators for not ad-

hering to the training protocol or dropped out voluntarily for reasons of inconvenience. The other 11 dropped out because of one of the following reasons: moved out of the area, financial difficulties, or surgery or injury not related to the study protocol. Six of the training subjects experienced joint discomfort (3 had pain in the knee, 2 suffered soreness in the back, and 1 encountered pain in the elbow) and had to reduce training for 2 weeks. The 6 subjects were distributed as follows: one of the subjects who had knee pain and one who suffered back soreness were assigned to the LEX group, and 2 subjects who experienced knee pain, 1 who suffered back soreness, and 1 who encountered pain in the elbow were assigned to the HEX group. Only subjects who completed both pre-study and poststudy testing sessions and more than 85% of the possible exercise sessions were included in the statistical analysis. Characteristics of those subjects who completed the study are listed by group in **Table 1**. There were no statistically significant differences among groups for age, height, and weight either before or after the study.

MUSCULAR STRENGTH

A detailed description of the results for muscular strength changes can be found elsewhere.¹⁹ Muscle strength did not differ among groups at study entry. The percent changes for muscular strength are shown in **Table 2**.

recommended by the American College of Sports Medicine were used for termination of the symptom-limited GXT.²⁰ During the test, expired gases were collected through a low-resistance 1-way valve (Hans Rudolph, Inc, Kansas City, Mo). Breath-by-breath analysis of expired gases was performed continuously throughout the test using a metabolic cart (CPS/Max; Medical Graphics, St Paul, Minn). The oxygen and carbon dioxide analyzers were calibrated daily and immediately before and after each test using a known gas mixture of 12% oxygen and 5% carbon dioxide. Ventilatory responses (tidal volume and frequency of breathing) were measured with a pneumotachograph. Volume calibration was performed with a 3-L calibration syringe. Twelve-lead electrocardiograms were recorded throughout the test using standard lead placement (Quinton Q 2000 system; Quinton Instruments, Seattle, Wash). Blood pressure measurements were taken every other minute using a standard sphygmomanometer, and rating of perceived exertion was obtained at the end of each minute throughout the test using the Borg Scale of Perceived Exertion, a 6 (no exertion at all) to 20 (maximal exertion) point rated scale.

RESISTANCE EXERCISE TRAINING

The exercise training regimen is described in detail elsewhere.¹⁹ In brief, the exercise training equipment used in this investigation was MedX resistance machines (MedX Corp, Ocala, Fla). The machines used for this study were abdominal crunch, leg press, leg extension, leg curl, calf press, seated row, chest press, overhead press, biceps curl, seated dip, leg abduction, leg adduction, and lumbar extensions.

Subjects in both the LEX and HEX groups were asked to report to the training facility 3 times per week for 6

months to perform dynamic variable resistance exercise. Each set consisted of 8 repetitions for the HEX group and 13 repetitions for the LEX group at the appropriate resistance load. To examine the effects of training intensity on the outcome variables and criterion measures, the LEX group trained at an intensity equivalent to 50% of their 1-RM, whereas the HEX group used loads corresponding to 80% of their 1-RM. For the LEX and HEX groups, the load was increased by 5% when their rating of perceived exertion dropped below 18. All exercise sessions were supervised by trained study personnel, and all resistance loads were evaluated and adjusted daily.

STATISTICAL ANALYSES

Statistical analyses were performed using the Statistical Package for the Social Sciences software, version 9.0 (SPSS Inc, Chicago, Ill). Experimental analysis was performed with a 3 × 2 repeated-measures analysis of variance (ANOVA) model to determine differences within and between groups over time. If a significant (group-by-time) interaction was found, a Scheffé post hoc test was used to determine if and where there was a difference between the group means. Although no statistical differences were observed between groups at study entry, an analysis of covariance (ANCOVA) was performed on outcome variables at the conclusion of the study. When the ANCOVA revealed that the covariate significantly contributed to the outcome, then the predicted means generated by the ANCOVA were analyzed with a 1-way ANOVA and a Scheffé post hoc test. Pearson bivariate correlations were performed to examine the degree of association between variables. A priori α levels were set at .05.

Muscular strength significantly increased in both training groups, ranging from 10.8% to 25.3% and from 14.6% to 27.6% for the LEX and HEX groups, respectively. Total strength values, calculated by summing the 1-RM values from the 8 tested exercises, increased significantly from pretraining to posttraining ($P \leq .05$), but were not different between the 2 training groups (17.2% and 17.8% for the LEX and HEX groups, respectively).

OXYGEN CONSUMPTION

Absolute values for $\dot{V}O_2$ peak are presented in Table 1. $\dot{V}O_2$ peak did not differ among groups at study entry. $\dot{V}O_2$ peak significantly increased as a consequence of resistance training from 20.2 to 24.7 mL · kg⁻¹ · min⁻¹ and from 20.9 to 24.4 mL · kg⁻¹ · min⁻¹ for the LEX and HEX groups, respectively ($P \leq .05$). The percent changes for $\dot{V}O_2$ peak are shown in **Figure 1**. Both the LEX (23.5%) and HEX (20.1%) groups significantly increased their $\dot{V}O_2$ peak during the 6 months of resistance exercise ($P \leq .05$). However, $\dot{V}O_2$ peak in the control group did not change.

TREADMILL TIME TO EXHAUSTION

Treadmill time to exhaustion during the GXT is presented in Table 1 and **Figure 2**. The control, LEX, and

HEX groups increased treadmill time by 6.2%, 26.4%, and 23.3%, respectively. However, only the LEX and HEX groups significantly increased their treadmill time from pretraining to posttraining ($P \leq .05$).

CORRELATIONS BETWEEN STRENGTH, $\dot{V}O_2$ peak, AND TREADMILL TIME

Correlation coefficients between $\dot{V}O_2$ peak and muscular strength are shown in **Table 3**. $\dot{V}O_2$ peak was significantly correlated with leg press, leg curl, leg extension 1-RMs, and total strength, with correlation coefficients ranging from 0.40 to 0.54 ($P \leq .05$).

Correlation coefficients between treadmill time to exhaustion and muscular strength are shown in Table 3. Treadmill time to exhaustion was significantly correlated with 1-RM leg extension and total strength ($P \leq .05$). However, treadmill time was not significantly correlated with leg press or leg curl 1-RM ($P \geq .05$).

COMMENT

This was the first study designed to assess the beneficial effects of both low- and high-intensity traditional resistance exercise training regimens on $\dot{V}O_2$ peak in elderly subjects. The principal findings of this study were that $\dot{V}O_2$ peak increased 23.5% and 20.1% and treadmill time

Table 1. Subject Characteristics*

Variable	Control (n = 16)		LEX (n = 24)		HEX (n = 22)	
	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest
Age, y	71.0 ± 4.7	...	67.6 ± 6.3	...	66.6 ± 6.7	...
Height, cm	169.9 ± 10.0	...	167.2 ± 11.5	...	167.1 ± 9.7	...
Weight, kg	73.1 ± 13.8	71.0 ± 14.3	77.4 ± 19.3	74.4 ± 16.5	74.1 ± 14.8	74.8 ± 15.0
Skinfold, % fat	30.3 ± 7.5	28.9 ± 7.4	30.9 ± 6.0	29.0 ± 5.1	32.0 ± 7.8	29.9 ± 7.8
DXA, % fat	33.5 ± 7.4	34.4 ± 7.2	34.1 ± 8.9	34.1 ± 8.4	35.9 ± 8.6	36.2 ± 9.0
FFM, kg	46.5 ± 10.5	46.0 ± 10.6	50.5 ± 14.6	48.7 ± 13.3	47.7 ± 12.0	47.9 ± 12.0
$\dot{V}O_2$ peak, mL·kg ⁻¹ ·min ⁻¹	22.6 ± 3.4	22.4 ± 3.4	20.2 ± 4.3	24.7 ± 4.8†	20.9 ± 6.1	24.4 ± 5.8†
Treadmill time, min	11.5 ± 2.5	12.1 ± 2.5	11.2 ± 2.3	14.0 ± 3.1†	12.2 ± 3.4	15.0 ± 4.9†‡
Heart rate, per min						
Rest	77 ± 18	84 ± 15	78 ± 16	80 ± 13	82 ± 18	80 ± 13
50% $\dot{V}O_2$ max	111 ± 14	111 ± 12	117 ± 17	113 ± 17	119 ± 20	122 ± 18
$\dot{V}O_2$ max	144 ± 18	142 ± 17	150 ± 21	150 ± 22	158 ± 29	157 ± 17‡

*Data are presented as mean ± SD. LEX indicates low-intensity exercise group; HEX, high-intensity exercise group; DXA, dual-energy x-ray absorptiometry; FFM, fat-free mass; treadmill time, treadmill time to exhaustion during graded exercise test; $\dot{V}O_2$ max, maximum oxygen consumption.

†*P* < .05 vs pretest (analysis of covariance).

‡*P* < .05 vs controls (analysis of covariance).

Table 2. Percent Change in One Repetition Maximum Values Before and After 6 Months of Resistance Training*

Variable	Controls	LEX	HEX
Chest press	-1.2 ± 22.0	17.5 ± 14.0†	16.0 ± 17.0†
Leg press	1.5 ± 22.0	15.7 ± 16.0	27.6 ± 18.0†
Leg curl	-0.7 ± 10.0	25.3 ± 13.0†	17.3 ± 10.0†
Biceps curl	-3.8 ± 16.0	17.8 ± 10.0†	24.6 ± 14.0†
Seated row	6.5 ± 16.0	19.2 ± 11.0†	22.1 ± 16.0†
Overhead press	-3.6 ± 18.0	18.8 ± 12.0†	16.1 ± 10.0†
Triceps dip	-0.7 ± 6.0	18.5 ± 9.0†	16.1 ± 10.0†
Leg extension	-4.6 ± 8.0	10.8 ± 7.0†	14.6 ± 12.0†
Total strength	-1.1 ± 6.0	17.2 ± 10.0†	17.8 ± 8.0†

*Data are presented as mean ± SD. LEX indicates low-intensity exercise group; HEX, high-intensity exercise group.

†*P* < .05 vs controls.

to exhaustion increased 26.4% and 23.3% for the LEX and HEX groups, respectively. These data suggest that resistance exercise of either or both low or high intensity may be a valid means of increasing cardiorespiratory endurance in older adults.

CARDIORESPIRATORY ENDURANCE

Previous investigations^{8,10} examining the effects of resistance exercise on aerobic endurance have produced mixed results. One factor that influences the disparate results is the style of resistance exercise used by each study. For example, traditional circuit weight training, characterized by high repetitions and short rest periods, modestly increases $\dot{V}O_2$ peak (3%-11%).^{8,18,21} Conversely, more traditional programs consisting of multiple sets and longer rest periods (2-4 minutes) have reported no change or sometimes a decrease in $\dot{V}O_2$ peak.^{12,22,23} However, Gettman et al,²⁴ Hagberg et al,²⁵ and Marcinik et al²⁶ all reported nonsignificant changes in $\dot{V}O_2$ peak following 12 to 26 weeks of circuit weight training when the values were normalized to body weight. Another confounding factor is the training program duration. Training pro-

gram durations have varied from 8 to 20 weeks, making comparisons among studies difficult. For the remainder of this discussion, only studies that used regimens similar in design and length to the present investigation will be presented.

In the present study, a 23.5% and 20.1% increase in $\dot{V}O_2$ peak was observed for the LEX and HEX groups, respectively. These values are considerably higher than the 5% to 12% increases reported by Frontera et al¹⁸ and Gettman et al.²¹ Both Frontera et al and Gettman et al trained their subjects for only 12 weeks compared with 24 weeks in this study. Furthermore, the average age for the subjects in the study by Gettman et al was 35.7 years, considerably younger than the subjects in the present study. Younger subjects may experience less adaptation compared with older subjects. This fact may explain why the subjects in the present study demonstrated a greater increase than is commonly reported. The exercise regimen in the study by Gettman et al only consisted of leg flexion and extension, whereas the present study used a comprehensive training regimen with exercises for all major muscle groups. Wilmore et al¹⁴ reported an 11% increase in $\dot{V}O_2$ peak for their female subjects, but no change for their male subjects. The authors speculated that the increase in the female subjects occurred because they were less fit than their male counterparts. It is known that less fit subjects commonly demonstrate greater increases in strength or fitness when compared with fit subjects.⁸

The mechanism underlying the increase in $\dot{V}O_2$ peak following resistance exercise training is unclear. It is possible that the measurement of true $\dot{V}O_2$ peak in untrained subjects, particularly elderly subjects, is prohibited or prevented by inadequate leg strength. Because devices used to measure $\dot{V}O_2$ peak place an enormous premium on leg strength, the subjects may be unable to reach their true maximum because of a lack of strength in the lower extremities, not because they have central cardiovascular limitations or exhaustion. Therefore, training-induced increases in $\dot{V}O_2$ peak may not necessarily be due

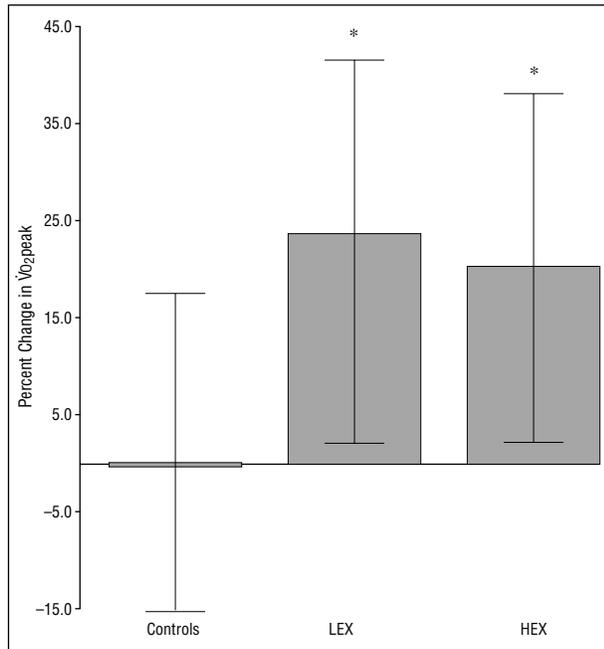


Figure 1. Percent change in peak oxygen consumption ($\dot{V}O_{2peak}$) for the control (n=16), low-intensity exercise (LEX, n=24), and high-intensity exercise (HEX, n=22) groups following 6 months of resistance exercise training. Asterisk indicates $P \leq .05$ from corresponding percent change in the control group.

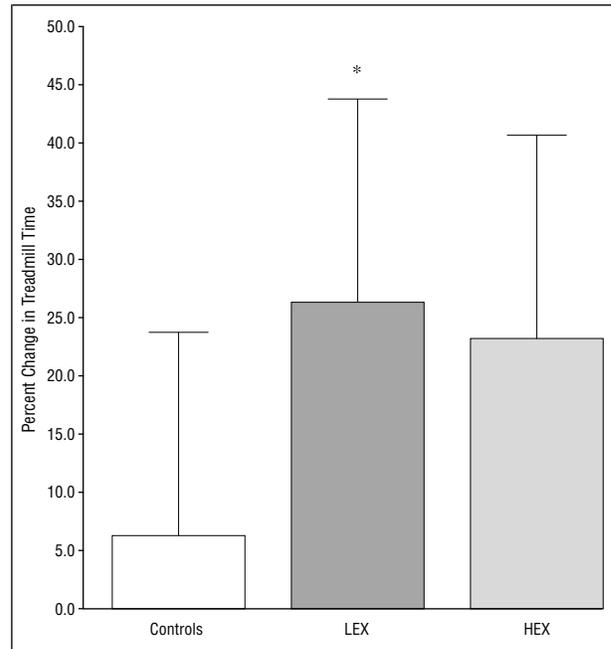


Figure 2. Percent change in treadmill time during a graded exercise test for the control (n=16), low-intensity exercise (LEX, n=24), and high-intensity exercise (HEX, n=22) groups following 6 months of resistance exercise training. Asterisk indicates $P \leq .05$ from corresponding percent change in the control group. Error bars signify SEM.

to an increased ability to consume oxygen, but rather it may be that the person now has the leg strength to approach or to reach central cardiovascular limitations. In support of this postulate, $\dot{V}O_{2peak}$ was significantly correlated to total strength, leg press, leg curl, and leg extension strength ($P < .01$). This finding is in accord with that reported by Gettman and Ayers.²⁷ That study examined the effects of 2 different isokinetic resistance training regimens on aerobic performance. Each of the 2 groups performed the same number of repetitions, but one group performed more work than the other by moving at a slower speed and against a greater resistance. The authors reported that the slow speed group increased $\dot{V}O_{2peak}$ 7% more than the fast speed group, suggesting a relationship between resistance training volume and aerobic capacity improvement.

It is also possible that the increase in aerobic capacity in those people who undergo resistance training may be in part due to an increase in oxidative enzyme activities. Frontera et al¹⁸ reported a 38% increase in citrate synthase enzyme activity following 12 weeks of resistance exercise. They also reported a 15% increase in capillaries per fiber. The regimen used in the study by Frontera et al consisted of 3 sets of 8 repetitions at 80% of 1-RM for the knee flexors and extensors. The authors reported that the increases in citrate synthase and capillary density were most likely due to the resistance exercise and not an increase in daily activity due to their increased strength, because their daily activity logs showed no change from pretraining to posttraining. It is reasonable to conclude that a similar enzymatic or metabolic adaptation may have occurred for our population, particularly considering that the duration and volume of training was double that for the study by Frontera et al.¹⁸

Table 3. Correlations Between Absolute $\dot{V}O_{2peak}$, Treadmill Time, and Select Strength Measures*

Variable	$\dot{V}O_{2peak}$	Treadmill Time
LP 1-RM	0.45 (0.00)‡	0.28 (0.07)
LC 1-RM	0.42 (0.01)‡	0.29 (0.054)
LE 1-RM	0.54 (0.00)‡	0.43 (0.01)‡
Total strength	0.40 (0.01)‡	0.31 (0.04)†

*r values are shown followed by significance value in parentheses. $\dot{V}O_{2peak}$ indicates peak oxygen consumption during graded exercise test (GXT); treadmill time, time to exhaustion during GXT; LP 1-RM, leg press on repetition maximum; LC 1-RM, leg curl one repetition maximum; and LE 1-RM, leg extension one repetition maximum.
†Correlation significant at $P < .05$.
‡Correlation significant at $P < .01$.

TREADMILL TIME TO EXHAUSTION

Treadmill time to exhaustion during the GXT was improved by 26.4% and 23.3% in the LEX and HEX groups, respectively. Since this increase was observed during a maximal exercise bout, it is reasonable to conclude that endurance performance during submaximal activities or activities of daily living would also be improved. This could indicate that the trained elderly subjects from this study may be better able to perform activities that require muscular endurance, such as recreational exercise, shopping in a mall, or mowing the lawn, compared with their untrained counterparts.

Several investigators^{12,26,28} have reported an increase in endurance performance without a concomitant increase in $\dot{V}O_{2peak}$. Marcinik et al²⁶ reported a 33% increase in cycle time to exhaustion at 75% of $\dot{V}O_{2max}$ following 12 weeks of resistance training in young adults.

The subjects performed a circuit weight training regimen consisting of 3 sets of 10 exercises separated by 30-second rest periods. The authors also reported a 12% increase in lactate threshold. The increased time to exhaustion was significantly ($P < .001$) correlated to increased lactate threshold ($r = 0.78$) and 1-RM leg extension strength ($r = 0.89$). Ades et al²⁸ reported a 38% increase in submaximal treadmill walking time following 12 weeks of resistance exercise in older adults. Hickson et al¹² reported increases in stationary cycle (47%) and treadmill running (12%) time to exhaustion following 10 weeks of resistance training. The authors also reported that $\dot{V}O_{2\text{peak}}$ only increased 4% as a consequence of the exercise training. These data suggest that examining improved cardiorespiratory endurance through measuring $\dot{V}O_{2\text{peak}}$ alone may be too limiting. Functional assessment of improved muscular endurance may be more relevant in terms of activities of daily living as opposed to strict changes in $\dot{V}O_{2\text{peak}}$ alone.

In the present investigation, resting heart rate was not reduced following 6 months of resistance training. However, the HEX group did have a significantly higher peak heart rate compared with controls. The HEX group significantly improved treadmill time, which may have allowed the trained subjects to achieve a proportionately higher exercise intensity and heart rate. Therefore, the most probable cause of a training-induced elevation in exercise heart rate for the HEX group is the improved ability to sustain exercise, increase muscle recruitment, and increase workload during the GXT.

PRACTICAL APPLICATION

Increased levels of cardiorespiratory endurance have been associated with decreased rates of disease and mortality.^{1,6} Traditionally, aerobic exercise has been viewed as the primary means of increasing cardiorespiratory endurance. However, the data from the present study suggest that resistance exercise may be a viable means of improving cardiorespiratory endurance. This may be due to increased oxidative enzyme activities or by increasing leg strength so that muscle weakness does not preclude achievement of $\dot{V}O_{2\text{peak}}$. Increased leg strength may allow aerobic exercise training bouts to be performed at a greater intensity or for a longer duration, also leading to improvements in aerobic capacity. Similar findings have not been demonstrated in younger adults, indicating that the aerobic adaptations to resistance exercise may be influenced by age and conditioning. Therefore, it seems likely that improvements in aerobic capacity and endurance would be greater in people who are more deconditioned, such as frail elderly people or patients rehabilitating from an illness.

In summary, these are the first data that demonstrate improved aerobic power in healthy elderly subjects following both low- and high-intensity resistance exercise training regimens. Our data suggest that, in older adults, $\dot{V}O_{2\text{peak}}$ and endurance during a treadmill test are associated with and possibly limited by muscular strength. These data indicate that resistance exercise should be incorporated into a comprehensive exercise regimen to increase muscular strength, cardiorespiratory endurance, and physical function.

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Corresponding author and reprints: Kevin R. Vincent, PhD, College of Medicine, University of Florida Health Sciences Center, PO Box 101012, Gainesville, FL 32610 (e-mail: kvincent@ufl.edu).

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