Effects of gender, age, and fitness level on response of $\dot{V}O_{2\,max}$ to training in 60–71 yr olds

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KOHRT, WENDY M., MARY T. MALLEY, ANDREW R. COGGAN, ROBERT J. SPINA, TAKESHI OGAWA, ALI A. EHSANI, RAYMOND E. BOUREY, WADE H. MARTIN III, AND JOHN O. HOLLOSZY. *Effects of gender, age, and fitness level on response of $\dot{V}O_{2\,max}$ to training in 60–71 yr olds.* J. Appl. Physiol. 71(5): 2004–2011, 1991.—The adaptive response of maximal aerobic power ($\dot{V}O_{2\,max}$) to endurance exercise training was compared in 53 men and 57 women, aged 60–71 yr. The subjects were healthy and had been sedentary for at least 2 yr. Pretraining $\dot{V}O_{2\,max}$ was measured during graded treadmill walking on two occasions. These values were reproducible (24.4 ± 4.7 vs. 24.4 ± 4.6 (SD) ml · min^{-1} · kg^{-1}; r = 0.96). Subjects trained primarily by walking and running for 9–12 mo, averaging 3.9 ± 0.6 days/wk and 45 ± 5 min/day at 80 ± 5% of maximal heart rate (HR_{max}). Average improvement in $\dot{V}O_{2\,max}$ (ml · min^{-1} · kg^{-1}) was 24 ± 12% (range 0–58%). Relative improvement was not significantly different in men and women (26 ± 12 vs. 23 ± 12%, ml · min^{-1} · kg^{-1}; 21 ± 10 vs. 19 ± 10%, l/min). When subjects were divided into three groups by age (60–62, 63–66, 67–71 yr), there were no significant differences among the groups in the relative increase in $\dot{V}O_{2\,max}$ (21% vs. 19% vs. 18%, l/min). Correlation analysis also yielded a nonsignificant relationship between improvement and age (r = −0.13). To examine the effect of initial fitness level on the adaptive response to exercise, pretraining $\dot{V}O_{2\,max}$ was correlated with the absolute improvement in $\dot{V}O_{2\,max}$. This relationship was not significant in either men (r = 0.04) or women (r = −0.23). In conclusion, in healthy people aged 60–71 yr, $\dot{V}O_{2\,max}$ adapts to endurance exercise training to the same relative extent as in young people, and this adaptation is independent of gender, age, and initial level of fitness.

aging; maximal aerobic power; cardiovascular function

SEVERAL STUDIES have shown little or no effect of endurance exercise training on maximal aerobic power ($\dot{V}O_{2\,max}$) of elderly subjects (2, 6, 19, 23). It is likely that the lack of adaptation in these studies was due to an insufficient training stimulus, rather than to the age of the participants, because studies that examined the effect of more vigorous exercise training indicate that older people can improve $\dot{V}O_{2\,max}$ (4, 5, 9, 13–15, 22, 24) to the same relative degree (~20%) as young people (3). Although older women have been included in some of these investigations (7, 13–15, 22), direct comparisons of the training response in older men and women are lacking. Some investigators have either not provided data regarding training responses separately for men and women (14, 15) or have studied women only (13). While no significant difference in the adaptability of older men and women to training has been reported, a tendency toward less improvement in women has been noted by Seals et al. (22) (19 vs. 27%) and by Blumenthal et al. (7) (9 vs. 14%). Gender-related differences in the cardiac response to acute exercise (17, 18) may influence adaptability to exercise training. Thus one objective of the present study was to compare the adaptive responses of healthy older men and women with vigorous endurance exercise training.

The degree to which $\dot{V}O_{2\,max}$ improves in older people with training is quite variable, with average improvements in different studies ranging from 10 to 28% (4, 7, 9, 13–15, 22, 24). A high degree of variability in the response to training among individuals has also been observed (22). It has been suggested (9, 21, 24) that the magnitude of the response to exercise training is dependent on age and initial level of fitness (i.e., pretraining $\dot{V}O_{2\,max}$), as well as on parameters of the exercise prescription, particularly exercise intensity (15, 22, 24). Although the age range of the subjects in the present study was limited, it is in the seventh decade that world age records in such events as the 10,000-m run begin to slow exponentially rather than linearly (Masters Age Records 1988, *National Masters News*, Pasadena, CA); this may indicate physiological changes in function because of age, per se. Therefore, a second objective of the present study was to investigate whether the magnitude of the training response was dependent on age, initial fitness level, or the frequency, duration, or intensity of the exercise program.

METHODS

Subjects and study design. Three hundred twenty men and women, 60–71 yr of age, volunteered for this study, which was approved by the Human Studies Committee of the Washington University School of Medicine. The study was explained in detail to all volunteers, and all participants provided written informed consent before the study was begun. Subjects were assigned to an endurance exercise-training experimental group or to a nonexercise control group. Assignment to groups was not done on a random basis because the intent of the study was to determine the extent to which physiological adaptations to endurance exercise training occur in older men and women. This could not be accomplished if people who did not want to exercise or could not comply with the conditions of the study were assigned to the experimental group. Typically, the subjects in the control group were those who wanted to exercise but lived too far away or did not have sufficient time to participate.

Subjects were recruited in response to advertisements for volunteers for a study of the effects of endurance exercise training in older adults. The subjects were healthy nonsmokers who were normally active but had not engaged in exercise training (defined as 30 min of aerobic activity ≥2 days/wk) for at least 2 yr. Health status was evaluated from the following screening procedures: medical history, physical examination, SMA-12 blood chemistry, hematologic evaluation, urinalysis, chest X-ray, resting electrocardiogram (ECG), and a Bruce treadmill exercise test with ECG and blood pressure monitoring. Subjects were excluded from the study if they had any medical problems that could contraindicate exercise, interfere with interpretation of results, and/or interfere with performance of vigorous exercise. Experimental subjects were studied before and after a 2-mo flexibility exercise program that preceded the endurance exercise and at 3-mo intervals during the endurance exercise-training program.

Control subjects met the same criteria as the experimental subjects in terms of health status and underwent the same tests and procedures as the experimental subjects on two occasions, 12 mo apart. A group of young sedentary controls (28 men, 18 women), age 20–30 yr, was studied on one occasion.

Of the 320 older people screened for the study, 71 were excluded for medical reasons and 20 chose not to participate. The remaining 229 subjects were admitted to the experimental (n = 181) or control (n = 48) group. Data are reported on the 110 people who completed the exercise program and the 35 control subjects who completed the second test.

Measurement of $\dot{V}O_{2\,max}$. $\dot{V}O_{2\,max}$ was determined during graded treadmill walking or running. The protocol was designed to increment exercise intensity by ~3–4 $ml \cdot min^{-1} \cdot kg^{-1}$ every 2 min and to elicit fatigue in 6–12 min. Speed and grade increments were therefore varied according to the exercise capacity of the individual. For the initial $\dot{V}O_{2\,max}$ test, exercise capacity was estimated from the results of the Bruce treadmill test performed during the medical evaluation. In general, during a 5- to 10-min warm-up on the treadmill at 0% grade, the speed was adjusted so that heart rate (HR) was 60–70% of maximal HR (HR_{max}). The elevation of the treadmill was then raised by 2–3% every 2 min. When the subject was near fatigue, the grade was incremented by 1–1.5%/min. Cardiorespiratory data were collected at 30-s intervals using a computerized system that included a Parkinson-Cowan CD-4 dry gas meter, O_2 (Applied Electrochemistry S3-A) and CO_2 (Beckman LB-2) analyzers, and a 5-liter mixing chamber. O_2 uptake ($\dot{V}O_2$) for each minute of exercise was determined by averaging consecutive 30-s values; the highest value was designated $\dot{V}O_{2\,max}$. For assurance that $\dot{V}O_{2\,max}$ had been attained, at least two of the following criteria had to be satisfied: plateau in $\dot{V}O_2$, HR within 10 beats/min of age-predicted HR_{max}, and respiratory exchange ratio (RER) >1.10.

Pretraining $\dot{V}O_{2\,max}$ was measured on two occasions in the experimental subjects, ~2 mo apart. In the interim, subjects participated in a flexibility exercise program for 40 min, 4 days/wk. These exercises were designed to improve flexibility and range of motion of all major joints and muscle groups, with the intent of reducing the likelihood of injury in the subsequent exercise-training program. $\dot{V}O_{2\,max}$ was also measured at 3-mo intervals throughout the endurance exercise-training program to monitor improvement and to provide information for adjusting exercise prescriptions.

Endurance exercise training. The experimental subjects participated in a 9- to 12-mo supervised exercise program consisting primarily of walking (including uphill treadmill walking) and running on an indoor track. Some participants also trained on cycle and/or rowing ergometers. Individual exercise prescriptions were updated weekly. The rates at which the frequency, duration, and intensity of exercise were increased were determined by measured improvements in $\dot{V}O_{2\,max}$ and by the ability of the individual to tolerate the prescription in terms of fatigue and musculoskeletal symptoms. The subjects were required to attend a minimum of three sessions per week, but were encouraged to attend five sessions per week.

Initially, subjects exercised ~30 min/day (not including warm-up or cool-down activities) at 60–70% of HR_{max}. During the first 3 mo, the duration and intensity of exercise were gradually increased so that by the 3rd mo subjects were exercising ~40 min/day at ~75% of HR_{max}. During the remainder of the training program, subjects were encouraged to progress toward exercising 50 min/day at an intensity of 75–85% of HR_{max}. The original design of the study required 12 mo of endurance exercise training. However, as discussed in greater detail below, if the improvement in $\dot{V}O_{2\,max}$ had reached a plateau by 9 mo, subjects were given the option to exit the study early.

Activity logs from which training frequency, duration, and intensity were quantified were maintained for each subject. Exercise intensity was monitored using self-reported HR (palpation of carotid or radial artery), as well as periodic ECG recording of HR and measurement of $\dot{V}O_2$. For subjects who performed more than one type of activity, measures of intensity (e.g., HR) were recorded in each mode and weighted according to the time spent in each activity. Total caloric expenditure during exercise sessions was determined by estimating the $\dot{V}O_2$ during exercise (1) and assuming a rate of expenditure of 5 kcal/l of O_2 consumed.

Statistical analyses. Analysis of variance for repeated measures was used to examine the effects of age and gender on changes across time within the exercise and control groups. Analysis of variance was used to compare parameters of training (frequency, duration, intensity) among subjects grouped according to the magnitude of the increase in $\dot{V}O_{2\,max}$. Correlational analyses were also used to assess the relationships of age, initial fitness level, and parameters of the exercise prescription with the adaptive response to exercise training. The level of statistical significance was set at $P < 0.05$. All data are reported as means ± SD.

TABLE 1. *Physical characteristics of older and young subjects*

	Older		Young	
	Men	Women	Men	Women
	Control subjects			
n	19	16	28	18
Age, yr	64.8±3.6*	63.3±2.9*	25.0±2.8	24.5±3.9
Weight, kg	78.1±8.0†	66.8±9.2	75.1±9.3†	61.6±12.5
Height, m	1.73±0.05†	1.63±0.06	1.80±0.05†	1.67±0.08
$\dot{V}O_{2\,max}$				
$ml \cdot min^{-1} \cdot kg^{-1}$	28.3±4.3*†	21.8±2.6*	47.9±5.4†	35.6±4.7
l/min	2.20±0.33*†	1.45±0.23*	3.58±0.40†	2.16±0.34
	Experimental subjects			
n	53	57		
Age, yr	63.7±3.1*	64.0±3.1*		
Weight, kg	83.8±14.0†	68.6±11.9		
Height, m	1.77±0.06†	1.64±0.06		
$\dot{V}O_{2\,max}$				
$ml \cdot min^{-1} \cdot kg^{-1}$	27.5±4.2*†	21.6±2.9*		
l/min	2.28±0.35*†	1.46±0.21*		

Values are means ± SD; n, no. of subjects. $\dot{V}O_{2\,max}$, maximal aerobic power. * Older different from young ($P < 0.01$); † men different from women ($P < 0.01$).

RESULTS

Endurance exercise training. The physical characteristics of the young and older (experimental and control) subjects are presented in Table 1. In the experimental subjects, pretraining $\dot{V}O_{2\,max}$ was assessed before and after the flexibility exercise program; these values were reproducible in men (27.5 ± 4.2 vs. 27.4 ± 4.1 $ml \cdot min^{-1} \cdot kg^{-1}$; $r = 0.95$) and women (21.6 ± 2.9 vs. 21.6 ± 3.0 $ml \cdot min^{-1} \cdot kg^{-1}$; $r = 0.91$). The means of the individual coefficients of variation for $\dot{V}O_{2\,max}$ of men and women were 2.7 and 3.3%. The pretraining $\dot{V}O_{2\,max}$ values reported are the average of the two baseline tests in all but three subjects, in whom there was strong evidence [lower $\dot{V}O_2$, HR, expired ventilation ($\dot{V}E$), and RER] that one of the tests was not a maximal effort.

Analysis of variance indicated there were no differences between the subjects who completed the study and those who did not in age, $\dot{V}O_{2\,max}$ (l/min or $ml \cdot min^{-1} \cdot kg^{-1}$), $\dot{V}E_{max}$, RER_{max}, weight, height, or body composition in either the men or the women. However, HR_{max} was significantly lower in both the men (164 ± 12 vs. 170 ± 11 beats/min) and women (160 ± 16 vs. 166 ± 11 beats/min) who dropped out of the study. Because of the large number of subjects, this is not likely to be a sampling error. The physiological significance of this finding is not known.

Descriptive information on the frequency, duration, and intensity of exercise performed by the men and women is presented in Tables 2 and 3, respectively; values represent the means for each of the specified months of training. Data are presented separately for subjects completing either 9 or 12 mo of training. Although the study was originally designed to include 12 mo of supervised endurance exercise training, it became apparent that most of the change in $\dot{V}O_{2\,max}$ occurred within the first 6 mo of training. Therefore, those subjects who showed little or no further improvement in $\dot{V}O_{2\,max}$ from 6 to 9 mo were given the option of discontinuing the exercise program after 9 mo. For the entire exercise-training program, average frequency, duration, and intensity of exercise training were similar for men and women (4.0 ± 0.6 vs. 3.9 ± 0.6 days/wk, 46 ± 6 vs. 45 ± 4 min/day, and 80 ± 5 vs. 79 ± 5% of HR_{max}).

As might be expected, this vigorous exercise program resulted in occasional orthopedic problems. Approximately 66% of the participants who completed the study experienced painful episodes (primarily knee, foot, or hip pain) that limited the ability to exercise for up to 1 wk. Only three subjects incurred injuries (2 stress fractures, 1 muscle strain) that resulted in a cessation or modification of exercise for >1 wk. Two additional subjects did not complete the endurance exercise program because of injury (stress fracture, foot pain).

Tables 4 and 5 summarize changes in $\dot{V}O_{2\,max}$ and related parameters that occurred in men and women in response to endurance exercise training. Two-way analyses of variance for repeated measures were performed to determine whether training duration had a significant impact on the adaptive responses to training. The analyses, which included group (9 vs. 12 mo) as a between-subjects factor and training (pre- vs. posttraining) as a within-subjects factor, were conducted separately for men and women for each of the determinant variables listed in Tables 4 and 5. The results indicate no significant differences between the groups for any of the variables analyzed in either men or women. Furthermore, none of the interactive effects (group by training) was significant, indicating that the changes that occurred with training were not different in those subjects who trained 12 mo compared with those who trained for 9 mo. Posttraining data from subjects who trained either 9 or 12 mo were therefore pooled for subsequent analyses and are summarized in Table 6, along with data from the nonexercising control subjects.

With the exception of a decline in HR_{max} in women, control subjects exhibited no change in the physiological responses to maximal exercise over a 12-mo period (Table 6). The training resulted in 26 ± 12% (range 4–58%) and 23 ± 12% (range 0–51%) increases in $\dot{V}O_{2\,max}$

TABLE 2. *Exercise frequency, duration, and intensity during 9 or 12 mo of endurance exercise training in older men*

	Month of Training Program			
	3	6	9	12
12 mo of training (n = 24)				
Frequency, days/wk	4.0±0.8	4.0±0.7	3.6±0.7	4.1±0.9
Duration, min/day	45±5	47±7	46±6	46±9
Intensity				
kcal/wk	1,777±712	1,942±653	1,884±734	2,154±756
$kcal \cdot kg^{-1} \cdot h^{-1}$	7.1±1.3	7.9±1.6	8.3±2.0	8.7±1.7
Heart rate, beats/min	131±10	140±12	146±10	144±14
$\%HR_{max}$	76±5	80±5	84±4	83±7
9 mo of training (n = 29)				
Frequency, days/wk	4.0±0.8	4.0±0.8	3.9±0.8	
Duration, min/day	44±8	42±9	44±8	
Intensity				
kcal/wk	1,704±533	1,857±742	1,926±576	
$kcal \cdot kg^{-1} \cdot h^{-1}$	7.1±2.1	8.1±2.3	8.4±2.2	
Heart rate, beats/min	134±11	141±11	141±12	
$\%HR_{max}$	78±5	81±6	81±6	

Values are means ± SD. HR_{max}, maximal heart rate.

($ml \cdot min^{-1} \cdot kg^{-1}$) in men and women, respectively. When changes in body weight were controlled, the respective improvements in $\dot{V}O_{2\,max}$ (l/min) were 21 ± 10% (range 2–42%) and 19 ± 10% (range 0–39%). Although the absolute increase in $\dot{V}O_{2\,max}$ was greater in men than in women (Table 6), the percent improvement was not significantly different. Responses influenced by gender included HR_{max} and weight loss. HR_{max} declined significantly with training in men but not in women, and although both groups lost weight, the absolute change in body weight was greater in men. In relative terms, however, weight loss was similar in men and women (5% for men vs. 4% for women).

Effects of age. Because the relative increase in $\dot{V}O_{2\,max}$ (l/min) varied so markedly (0–42%) among individuals, we sought to determine whether the magnitude of improvement was dependent on age, initial fitness level, or some component of the exercise prescription. When subjects were divided into three groups by age (60–62 yr, n = 42; 63–66 yr, n = 43; and 67–71 yr, n = 25), there were no differences among the groups in the relative increase in $\dot{V}O_{2\,max}$ (l/min; 22 vs. 19 vs. 18%; P = 0.21). Correlation analysis also indicated a weak, nonsignificant association (r = −0.13) between improvement and age (Fig. 1).

The rate of increase in $\dot{V}O_{2\,max}$ was not dependent on age. At 3 mo, the increase in $\dot{V}O_{2\,max}$ averaged 10 ± 8, 9 ± 7, and 10 ± 9 for the three age groups, and at 6 mo increases were 16 ± 10, 13 ± 9, and 13 ± 9%.

Effects of initial fitness level. To examine the effect of initial fitness level on the adaptive response to exercise, pretraining $\dot{V}O_{2\,max}$ was correlated with the absolute improvement (l/min) in $\dot{V}O_{2\,max}$. Pretraining $\dot{V}O_{2\,max}$ was expressed relative to body weight ($ml \cdot min^{-1} \cdot kg^{-1}$) to standardize for differences in body size, but the increase with training was expressed in absolute units (l/min) to eliminate the influence of a change in body weight. The corre-

TABLE 3. *Exercise frequency, duration, and intensity during 9 or 12 mo of endurance exercise training in older women*

	Month of Training Program			
	3	6	9	12
12 mo of training (n = 17)				
Frequency, days/wk	3.9±0.9	4.0±0.8	3.8±0.8	4.0±0.8
Duration, min/day	43±5	46±5	48±6	50±10
Intensity				
kcal/wk	940±351	1,126±520	1,133±289	1,277±379
$kcal \cdot kg^{-1} \cdot h^{-1}$	5.0±1.0	5.6±1.3	5.9±1.5	6.1±1.3
Heart rate, beats/min	129±14	133±11	139±10	140±12
$\%HR_{max}$	76±7	78±6	82±5	82±6
9 mo of training (n = 40)				
Frequency, days/wk	3.7±0.9	3.8±0.7	4.0±0.8	
Duration, min/day	43±6	45±5	46±6	
Intensity				
kcal/wk	966±372	1,085±370	1,249±379	
$kcal \cdot kg^{-1} \cdot h^{-1}$	5.1±1.4	5.5±1.5	6.1±1.8	
Heart rate, beats/min	130±11	135±11	137±11	
$\%HR_{max}$	76±5	79±6	80±5	

Values are means ± SD.

TABLE 4. *Physiological responses to 9 or 12 mo of endurance exercise training in older men*

	Baseline	Month of Training Program 3	6	9	12
		12 mo of training (n = 24)			
$\dot{V}O_{2\,max}$					
$ml \cdot min^{-1} \cdot kg^{-1}$	27.6±4.6	31.7±5.5*	33.7±6.0*	33.8±5.2	35.2±6.0†
l/min	2.22±0.29	2.51±0.39*	2.62±0.40*	2.63±0.40	2.71±0.49†
RER_{max}	1.23±0.09	1.16±0.08*	1.18±0.05	1.17±0.06	1.18±0.07
$\dot{V}E_{max}$, l/min	78.4±15.8	84.6±14.6*	87.6±12.7	88.0±14.5	90.8±15.7
HR_{max}, beats/min	169±11	168±10	167±10	165±9	166±9
HR_{rest}, beats/min	83±11	77±15†	75±13	73±14	73±10
Weight, kg	81.5±11.9	80.0±11.0*	78.7±10.5*	78.4±9.9	77.6±9.8†
		9 mo of training (n = 29)			
$\dot{V}O_{2\,max}$					
$ml \cdot min^{-1} \cdot kg^{-1}$	28.1±3.8	31.5±4.9*	32.8±4.7†	34.2±4.9*	
l/min	2.37±0.39	2.58±0.39*	2.66±0.39†	2.72±0.39	
RER_{max}	1.25±0.09	1.18±0.07*	1.17±0.07	1.18±0.06	
$\dot{V}E_{max}$, l/min	81.2±14.6	87.0±14.4*	89.0±13.6	90.8±13.1	
HR_{max}, beats/min	170±11	167±12	169±8	168±8	
HR_{rest}, beats/min	79±13	73±11†	75±11	73±12	
Weight, kg	84.9±13.5	82.9±12.8*	81.9±11.9†	80.6±11.0	

Values are means ± SD. RER, respiratory exchange ratio; $\dot{V}E$, expired ventilation. Significantly different from preceding value: * $P < 0.01$; † $P < 0.05$.

lation between initial $\dot{V}O_{2\,max}$ and the increase in $\dot{V}O_{2\,max}$ was not statistically different from zero in either men ($r = 0.04$) or women ($r = -0.23$).

To determine whether rate of improvement was related to initial $\dot{V}O_{2\,max}$, correlation analyses of the increase in $\dot{V}O_{2\,max}$ at 3 and 6 mo with initial $\dot{V}O_{2\,max}$ were performed. These relationships were not statistically significant in either men (3 mo, $r = -0.003$, $P = 0.98$; 6 mo, $r = 0.06$, $P = 0.70$) or women (3 mo, $r = -0.10$, $P = 0.47$; 6 mo, $r = -0.11$, $P = 0.43$).

Effects of exercise frequency, duration, and intensity. Subjects were categorized into quartiles by percent improvement in $\dot{V}O_{2\,max}$ to determine whether the magnitude of the training response was related to the frequency, duration, or intensity of exercise. Average increases in $\dot{V}O_{2\,max}$ (l/min) for the four groups were 8, 15, 23, and 32%. There were, however, no significant differences among the groups in any of the exercise training parameters. Regression analyses also yielded no significant relationships between improvement in $\dot{V}O_{2\,max}$ and exercise frequency, duration, or intensity.

DISCUSSION

There is little information in the literature regarding the ability of older women to adapt to vigorous exercise training. Blumenthal et al. (7) measured $\dot{V}O_{2\,peak}$ on a cycle ergometer in 17 men and 16 women (age 66.5 yr) before and after 16 wk of exercise training. Although the magnitude of improvement in $\dot{V}O_{2\,peak}$ ($ml \cdot min^{-1} \cdot kg^{-1}$)

TABLE 5. *Physiological responses to 9 or 12 months of endurance exercise training in older women*

	Baseline	Month of Training Program 3	6	9	12
		12 mo of training (n = 19)			
$\dot{V}O_{2\,max}$					
$ml \cdot min^{-1} \cdot kg^{-1}$	22.1±3.0	24.1±3.4*	24.9±3.2†	25.6±3.1	26.7±3.8†
l/min	1.40±0.22	1.49±0.21*	1.54±0.20†	1.58±0.21	1.61±0.22
RER_{max}	1.20±0.12	1.16±0.09	1.20±0.09	1.19±0.08	1.20±0.07
$\dot{V}E_{max}$, l/min	48.4±8.6	49.6±7.7	53.0±8.8†	54.2±6.6	57.0±7.2†
HR_{max}, beats/min	166±11	163±15	165±13	166±13	167±11
HR_{rest}, beats/min	88±14	80±13†	76±15	81±15	82±13
Weight, kg	63.9±11.6	62.7±11.0†	62.5±10.4	62.2±9.4	61.1±9.9*
		9 mo of training (n = 38)			
$\dot{V}O_{2\,max}$					
$ml \cdot min^{-1} \cdot kg^{-1}$	21.3±2.8	23.8±3.1*	25.2±3.6*	26.0±3.8*	
l/min	1.49±0.21	1.62±0.19*	1.69±0.21*	1.74±0.23*	
RER_{max}	1.20±0.12	1.14±0.07*	1.16±0.07†	1.16±0.07	
$\dot{V}E_{max}$, l/min	50.8±10.1	53.7±8.7†	57.0±9.5*	58.4±10.4†	
HR_{max}, beats/min	166±11	163±13	163±12	165±10	
HR_{rest}, beats/min	86±13	82±13	78±12	78±12	
Weight, kg	70.7±12.0	69.1±11.6*	66.6±15.5	67.8±12.2	

Values are means ± SD. Significantly different from preceding value: * $P < 0.01$; † $P < 0.05$.

TABLE 6. *Initial and final responses in experimental (9–12 mo of endurance exercise training) and control (12 mo, no intervention) subjects*

	Men		Women	
	Initial	Final	Initial	Final
Experimental subjects				
$\dot{V}O_{2\,max}$				
$ml \cdot min^{-1} \cdot kg^{-1}$	27.5±4.2	34.6±5.7*	21.6±2.9	26.5±3.5*
l/min	2.28±0.35	2.74±0.43*	1.46±0.21	1.72±0.21*
RER_{max}	1.24±0.09	1.18±0.06†	1.21±0.12	1.17±0.07†
$\dot{V}E_{max}$, l/min	80.2±15.5	90.8±14.2*	50.1±9.8	57.9±9.5*
HR_{max}, beats/min	170±11	167±9†	166±11	166±10
HR_{rest}, beats/min	81±12	73±11*	86±13	79±13*
Weight, kg	83.8±14.0	79.9±12.0*	68.6±11.9	66.0±11.7*
Control subjects				
$\dot{V}O_{2\,max}$				
$ml \cdot min^{-1} \cdot kg^{-1}$	28.3±4.3	27.8±4.1	21.8±2.6	21.6±2.8
l/min	2.20±0.33	2.16±0.36	1.45±0.23	1.43±0.23
RER_{max}	1.20±0.10	1.22±0.10	1.22±0.10	1.22±0.11
$\dot{V}E_{max}$, l/min	75.8±14.0	76.1±17.3	48.8±9.4	49.9±10.6
HR_{max}, beats/min	161±15	160±15	164±10	161±12*
HR_{rest}, beats/min	79±14	75±12	79±10	83±13
Weight, kg	78.1±8.0	77.7±8.4	66.8±9.2	67.0±9.5

Values are means ± SD. Significantly different from initial value: * $P < 0.01$; † $P < 0.05$.

was not significantly different, average improvement was 14% in men and 9% in women. Similarly, in eight men and three women (age 63 yr) studied by Seals et al. (22) before and after 12 mo of endurance exercise training, the gender difference was not statistically significant, but men tended to improve to a greater extent (l/min; 27 vs. 19%). The lack of statistically significant gender-related differences in these studies may have been due to the relatively small number of subjects studied and/or the large variability in training responses (22). Furthermore, neither of these investigations addressed whether the frequency, duration, and intensity of training were similar in the men and women studied.

In this study, the 53 men and 57 women showed comparable average improvements in $\dot{V}O_{2\,max}$ (l/min) of 21 and 19%. Average frequency, duration, and intensity of exercise training were also similar for men and women. Thus

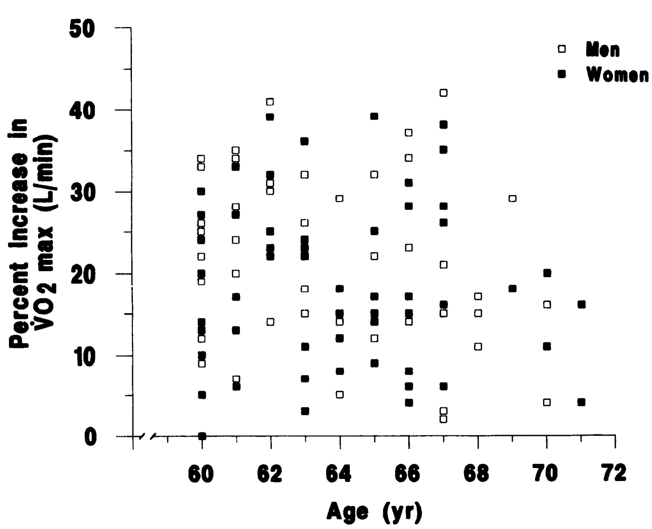

FIG. 1. Percent improvement in maximal aerobic power ($\dot{V}O_{2\,max}$) with endurance exercise training as a function of age.

it appears that older women are able to improve $\dot{V}O_{2\,max}$ to the same relative degree as men in response to a given training stimulus.

Another objective was to determine whether the response to training was dependent on a specific component of the exercise prescription (i.e., frequency, duration, or intensity). Although the magnitude of improvement in older individuals has been linked to training intensity in some studies (15, 22, 24), others (4, 13) found that exercise intensity was not a critical determinant of the training response. We detected no effect of exercise frequency, duration, or intensity on percent improvement in $\dot{V}O_{2\,max}$ within the constraints of this study. It should be noted, however, that because the general goals of the exercise program were similar for all participants, the parameters for exercise prescription were also quite similar. The limitations of precisely quantifying parameters of exercise training, particularly exercise intensity, for a large group of subjects must also be recognized. These factors may have limited our ability to identify specific determinants of the magnitude of increase in $\dot{V}O_{2\,max}$. In general, however, the exercise programs, including this study, that have generated the greatest improvement in $\dot{V}O_{2\,max}$ (18 to 28%) in older people (14, 15, 22) have lasted ≥26 wk and consisted of endurance exercise performed ≥3 days/wk, 40 min/day, progressing to intensities of ~80–90% of HR_{max}. With this type of vigorous exercise training, people in the 60- to 70-yr-old age range are able to improve $\dot{V}O_{2\,max}$ to the same relative degree as are young people.

Individual improvements in $\dot{V}O_{2\,max}$ (l/min) ranged from 0 to 42%. Because the magnitude of change did not appear to be related to the training stimulus, we sought to determine whether other factors, specifically age and the initial fitness level of participants, could account for this wide variation in the magnitude of the improvement in $\dot{V}O_{2\,max}$. Figure 1 depicts the percent increase in $\dot{V}O_{2\,max}$ (l/min) of all subjects relative to age. Although the relationship between improvement and age was not significant ($r = -0.13$, $P = 0.17$), there did appear to be a trend for the oldest participants to improve less. Yet when subjects were divided into three groups by age (60–62, 63–66, and 67–71 yr), there were no significant differences among the groups in the response to training (22 vs. 19 vs. 18%). Recently, Hagberg et al. (14) reported an 18% increase in $\dot{V}O_{2\,max}$ of 70- to 79-yr-old men and women with 26 wk of endurance exercise training at a relative intensity comparable with that used in the present study. Taken with the results of the present study, this suggests that age, at least through the eighth decade, does not impair the ability to adapt to endurance exercise.

It has been suggested that the degree of improvement in $\dot{V}O_{2\,max}$ with training is inversely related to pretraining $\dot{V}O_{2\,max}$ (9, 21, 24). For example, Cunningham et al. (9) found modest gains in $\dot{V}O_{2\,max}$ with training (10%) compared with those reported by Seals et al. (22) (25%) and suggested that the discrepancy was related, in part, to the difference in initial $\dot{V}O_{2\,max}$ values of the subjects (30.3 vs. 25.4 $ml \cdot min^{-1} \cdot kg^{-1}$). The difference in the training response might be better explained, however, by the exercise regimens. During the final 6 mo of training, the average exercise frequency (2.4 vs. 3.6 days/wk), duration (32 vs. 45 min/day), and intensity (HR of 131 vs. 156 beats/min) were all lower in the study of Cunningham et al. (9).

To examine the effect of initial fitness level on the response to training in the present study, we correlated the absolute gain in $\dot{V}O_{2\,max}$ with pretraining $\dot{V}O_{2\,max}$ value. In men, initial fitness level did not have a significant impact on the magnitude of improvement in $\dot{V}O_{2\,max}$. This relationship was unchanged if the training response was expressed as a percent gain. When men were categorized by initial $\dot{V}O_{2\,max}$, those in the lowest quartile (initial $\dot{V}O_{2\,max}$ = 22.5 $ml \cdot min^{-1} \cdot kg^{-1}$) improved 20%, and individuals in the highest quartile (initial $\dot{V}O_{2\,max}$ = 33.3 $ml \cdot min^{-1} \cdot kg^{-1}$) improved 19%. Although the relationship between improvement and fitness level was also not significant for women, there was a tendency ($P = 0.09$) for those with the lowest initial $\dot{V}O_{2\,max}$ values to show the largest gains. This was also the case when percent gains were examined, as the lowest quartile (initial $\dot{V}O_{2\,max}$ = 18.1 $ml \cdot min^{-1} \cdot kg^{-1}$) improved an average of 19% and the highest quartile (initial $\dot{V}O_{2\,max}$ = 25.4 $ml \cdot min^{-1} \cdot kg^{-1}$) improved 14%. Nevertheless, initial $\dot{V}O_{2\,max}$, which varied markedly among the men (range 19–38 $ml \cdot min^{-1} \cdot kg^{-1}$) and women (range 15–28 $ml \cdot min^{-1} \cdot kg^{-1}$) in this study, does not appear to be a strong determinant of the training response in sedentary older people. These data corroborate the finding by Thomas et al. (24) that initial $\dot{V}O_{2\,max}$ was only weakly associated ($r = 0.20$) with the increase in $\dot{V}O_{2\,max}$ attained by older men after 12 mo of less vigorous exercise training.

Heath et al. (16) estimated that $\dot{V}O_{2\,max}$ declines ~9% per decade in healthy untrained men, with values being relatively lower in those men who are overweight and/or very physically inactive and higher in those men who remain lean and/or moderately active (Fig. 2*A*). Because aging is typically accompanied by an increase in adiposity (10) and a decline in physical activity level (20), it might be expected that the mean for older men would fall

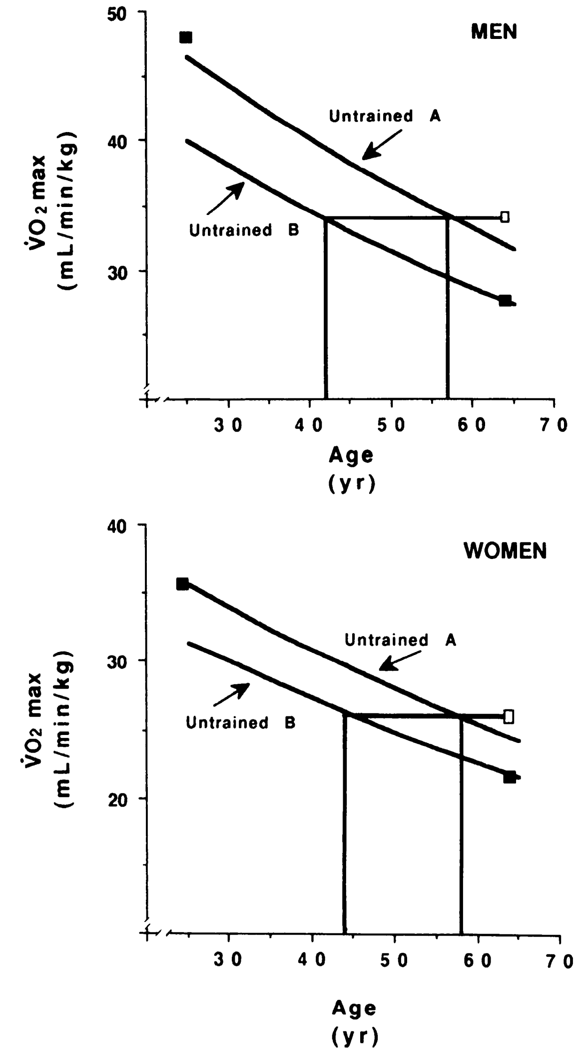

FIG. 2. Decline in $\dot{V}O_{2\,max}$ with age in sedentary men, estimated by Heath et al. (16). Lines for sedentary women were generated using same relative rate of decline proposed in men. ■, Untrained young and older subjects; □, trained older subjects.

on the lower line, whereas the mean for normally active young men would be expected to fall on the upper line (Fig. 2, *top*). Indeed, when average $\dot{V}O_{2\,max}$ values for young and older men in the present study are superimposed (Fig. 2, *top*) on the lines generated by Heath et al. (15), the proposed rates of decline in $\dot{V}O_{2\,max}$ are virtually identical. Assuming that $\dot{V}O_{2\,max}$ values for women in the present study are characteristic of young lean and older overweight women, the rate of decline in $\dot{V}O_{2\,max}$ appears to be similar in men and women (Fig. 2, *bottom*), as previously reported (8, 11). Thus the combined effects of aging, decreasing physical activity level, and increasing adiposity translate to a decline in $\dot{V}O_{2\,max}$ of ~13–14%/decade in both men and women. These data correspond closely with the data from 204 men and women, aged 20–75 yr, studied by Hossack and Bruce (17), who assumed a linear decline in $\dot{V}O_{2\,max}$ with age.

Figure 2 shows the mean posttraining $\dot{V}O_{2\,max}$ values of the older men and women in this study. Noteworthy are the hypothetical improvements in "functional age" that occurred with exercise training. Because ~80% of the improvement in $\dot{V}O_{2\,max}$ could be attributed to training independent of weight loss, the level of cardiovascular function in these older adults after training was equivalent to a level of function typical of people 20 yr or more younger, based on the aging curves in Fig. 2.

In summary, we have shown that the adaptive response to endurance exercise training in healthy older men and women is not dependent on gender, age, or pretraining $\dot{V}O_{2\,max}$. The relative gains in $\dot{V}O_{2\,max}$ that can be attained by healthy 60–70 yr olds are of the same magnitude as those observed in young adults (3) (~20%). Furthermore, we believe that the results are generalizable to a large portion of men and women in this age group, because comparable improvements have been reported for people with coronary artery disease (11) and hypertension (15). From this study and others (14, 15, 22), it appears that the realization of these gains in older people may require a long duration of training (≥26 wk), with gradual progression toward relatively high-intensity exercise (80–90% of HR_{max}).

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