# Cardiovascular responses of 70- to 79-yr-old men and women to exercise training

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HAGBERG, JAMES M., JAMES E. GRAVES, MARIAN LIMACHER, DEIDRA R. WOODS, SCOTT H. LEGGETT, CARMEN CONONIE, JOSEPH J. GRUBER, AND MICHAEL L. POLLOCK. *Cardiovascular responses of 70- to 79-yr-old men and women to exercise training.* J. Appl. Physiol. 66(6): 2589–2594, 1989.—This study determined the effects of endurance or resistance exercise training on maximal $O_2$ consumption ($\dot{V}O_{2\,max}$) and the cardiovascular responses to exercise of 70- to 79-yr-old men and women. Healthy untrained subjects were randomly assigned to a control group ($n$ = 12) or to an endurance ($n$ = 16) or resistance training group ($n$ = 19). Training consisted of three sessions per week for 26 wk. Resistance training consisted of one set of 8–12 repetitions on 10 Nautilus machines. Endurance training consisted of 40 min at 50–70% $\dot{V}O_{2\,max}$ and at 75–85% $\dot{V}O_{2\,max}$ for the first and last 13 wk of training, respectively. The endurance training group increased its $\dot{V}O_{2\,max}$ by 16% during the first 13 wk of training and by a total of 22% after 26 wk of training; this group also increased its maximal $O_2$ pulse, systolic blood pressure, and ventilation, and decreased its heart rate and perceived exertion during submaximal exercise. The resistance training group did not elicit significant changes in $\dot{V}O_{2\,max}$ or in other maximal or submaximal cardiovascular responses despite eliciting 9 and 18% increases in lower and upper body strength, respectively. Thus healthy men and women in their 70s can respond to prolonged endurance exercise training with adaptations similar to those of younger individuals. Resistance training in older individuals has no effect on cardiovascular responses to submaximal or maximal treadmill exercise.

maximal oxygen uptake; heart rate; aging; perceived exertion

UNTIL RECENTLY most available data indicated that men and women >60 yr old could not increase their maximal oxygen consumption ($\dot{V}O_{2\,max}$) as a result of endurance exercise training (1, 5, 15, 22). These data could indicate that older men and women have lost the ability to elicit adaptations in response to endurance exercise training, since younger individuals generally increase their $\dot{V}O_{2\,max}$ by 10–30% in response to exercise training (23). However, studies published in the last 5 yr that have used longer and more intense exercise training programs now indicate that men and women between 60 and 70 yr of age can increase their $\dot{V}O_{2\,max}$ to the same degree as younger individuals, at least when the change is expressed on a relative basis (3, 15, 26, 29). However, no definitive data exist to answer this question in individuals >70 yr old. The only endurance exercise training studies assessing the adaptations of men and women >70 yr old have either shown no change in $\dot{V}O_{2\,max}$ (7) or did not measure true $\dot{V}O_{2\,max}$ values (4, 28). Because muscle strength and mass decrease with age (11, 14) and because these people are another 10 yr older, it is possible their ability to adapt to exercise training may be compromised. Therefore, because $\dot{V}O_{2\,max}$ is a commonly accepted index of maximal cardiorespiratory function, one purpose of the present investigation was to assess the effect of 26 wk of endurance exercise training on the $\dot{V}O_{2\,max}$ and cardiovascular responses to exercise of healthy men and women 70–79 yr old.

As noted above, muscular strength and mass decrease with age (11, 14) and recently a cross-sectional study indicated that most of the reduction in $\dot{V}O_{2\,max}$ that occurs with aging is eliminated if $\dot{V}O_{2\,max}$ is expressed relative to muscle mass (10). In young subjects, resistance training programs designed specifically to increase muscle strength and mass do not increase $\dot{V}O_{2\,max}$ (2, 17, 18, 21); however, it is possible that in older subjects, who already have lost some muscle mass and who may be more limited by muscle strength, an increase in muscle mass and/or strength may result in an increase in $\dot{V}O_{2\,max}$. The second purpose of this study was to determine whether 26 wk of resistance training would increase $\dot{V}O_{2\,max}$ and alter the cardiovascular responses to treadmill exercise of healthy men and women 70–79 yr old.

## METHODS

Men and women 70–79 yr old recruited from the Gainesville area were first screened via telephone and invited to the laboratory for further medical screening. The protocol was approved by the University of Florida College of Medicine Institutional Review Board, and all subjects provided their written informed consent to participate in the study.

*Screening.* Initially, subjects completed a medical history questionnaire that dealt with their cardiovascular health, orthopedic limitations, and physical activity status. Subjects' blood pressure was then measured by auscultation in both arms after sitting in a quiet room for 15 min; their blood pressure at rest was also determined during two other morning visits, and if these blood pres-

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sures averaged >160/100 mmHg they were excluded from the study. Subjects who were on medications to control their blood pressure maintained the same medication regimen throughout the study. Subjects were then administered a resting 12-lead electrocardiogram (ECG), a physical examination by a physician, and a Naughton protocol diagnostic graded exercise test (GXT) with 2-min stages (24). This test was terminated when the subject was unable to continue or when signs or symptoms of cardiovascular decompensation became evident. Subjects were excluded from the study if they had >0.3 mV of flat or upsloping ST-segment depression 0.08 s from the J-point, ≤0.3 mV of flat ST-segment depression 0.08 s from the J-point and a positive maximal exercise thallium scan, significant arrhythmias, a drop in systolic blood pressure during the latter stages of the test, an inadequate rise in systolic blood pressure with exercise, angina pectoris, or exercise-induced bundle branch block. Thus the subjects were free of any overt evidence of coronary artery disease and other conditions that would limit their participation in a vigorous exercise program. On another day subjects had a blood sample drawn for a fasting blood chemistry.

*$\dot{V}O_{2\,max}$ test.* All subjects who were included in the study after the screening returned to the laboratory 6–7 days after their initial GXT to undergo a treadmill $\dot{V}O_{2\,max}$ test. The modified Naughton protocol was used again; however, for those who exercised >12 min on their initial GXT, the initial speed was 3, rather than 2, mile/h. A 12-lead ECG was recorded before exercise, every 2 min during exercise, in the last 15 s of exercise, immediately after exercise, and during each of the first 7 min of recovery; a 3-lead ECG tracing was recorded every other minute during exercise. Blood pressure was measured by auscultation at rest before exercise, every 2 min during exercise, immediately after the end of exercise, and at 1, 3, 5, and 7 min of supine recovery after exercise. Ratings of perceived exertion (RPE) (6) were determined at the end of each minute of exercise and during maximal exercise.

The $\dot{V}O_{2\,max}$ test was terminated when the subject was unable to continue or when signs or symptoms indicated the exercise should be terminated. Subjects were not included further in the study if the test was terminated for anything other than subjective fatigue. During each of the last 4–5 min of exercise the subject's expired gases were collected in meteorological balloons. The $O_2$ and $CO_2$ contents of these gases were analyzed with Ametek-Thermox gas analyzers calibrated with the use of precision tank gases. Volumes were measured with a 120-l Tissot spirometer. To be assured that a true $\dot{V}O_{2\,max}$ had been achieved two of the following three criteria had to be met: an increase in $\dot{V}O_2$ <100 ml in the final minute of exercise, a heart rate considered to be maximal for a subject's age, or a respiratory exchange ratio >1.10. The $\dot{V}O_{2\,max}$ test typically lasted 10–14 min in these subjects. The heart rate and blood pressure values measured at the end of each of the first 4–5 stages of this test were used to characterize the subjects' cardiovascular responses to submaximal exercise.

Seventy subjects were scheduled for the screening GXT. Five subjects were excluded from the study because of blood pressures at rest >160/100 mmHg. Another eight subjects were excluded because of positive GXT results. Thus a total of 57 subjects 70–79 yr old were randomly allocated to the endurance training group ($n$ = 21), the resistance training group ($n$ = 23), and the control group ($n$ = 13). The subjects assigned to the exercise training groups had their $\dot{V}O_{2\,max}$ assessed after 13 and 26 wk of training; the control group was retested only after 26 wk. All retests followed exactly the same protocol as the subject's initial treadmill $\dot{V}O_{2\,max}$ test.

*Additional testing.* All subjects also had their upper and lower body strength measured as the maximal resistance they could move through a complete range of motion on a Nautilus dual decline press and leg extension machine, respectively. The sum of the skinfold thicknesses at seven sites was used as an index of body composition (19, 20). To provide an estimate of potential changes in lean body mass, the sum of seven skinfolds were used in age-adjusted equations (19, 20) to estimate body density. Body density was converted to percent body fat using the Siri equation (27), and percent body fat was then used along with body weight to estimate lean body mass.

*Endurance exercise training program.* Subjects completed three exercise sessions per week for the duration of the 26-wk training program. During the first 2 wk of training, subjects were taught to monitor heart rate by palpating their radial pulse. Heart rate and RPE were recorded at the middle and end of each training session. All training sessions were supervised by study personnel, and the accuracy of the subject's palpated heart rates were checked at least once in each training session. All sessions were preceded by 5–10 min of stretching and warmup exercises and followed by 5 min of cool-down exercises. Subjects started training by walking for 20 min at 50% of their $\dot{V}O_{2\,max}$; walking duration was increased 5 min every 2 wk until subjects were walking for 40 min. Training intensity gradually increased until subjects could walk at 60–70% of $\dot{V}O_{2\,max}$. All subjects progressed to this point by the 8th wk of training and continued these workouts until the 13th wk of training. The RPE during these training sessions averaged 11–12 (light) initially and increased to 12–13 (somewhat hard). At the beginning of the 14th wk of training, the intensity of training was increased further by alternating fast walk/moderate walk or fast walk/slow jog intervals. Five subjects increased their training intensity by walking uphill on a treadmill. By the 26th wk of training all subjects were exercising at 75–85% of $\dot{V}O_{2\,max}$ for 35–45 min at an RPE of 14–15 (hard).

*Resistance exercise training program.* Subjects exercised three times per week for ~30 min per session for the 26-wk duration of the study. All workouts were preceded by the same 5–10 min of warmup exercises used by the endurance training group and concluded with 5 min of cool-down activities. Workouts consisted of one set of 10 variable resistance Nautilus exercise machines (leg extension, leg flexion, super pull-over, dual decline press, 10° chest, overhead press, abdominal curl, low back extension, multiple biceps, and multiple triceps);

these machines stressed the major skeletal muscle groups. The resistance training program was designed to primarily develop muscular strength; thus some rest was allowed between exercises. During the first week of training, subjects were instructed on proper technique. During the first 13 wk of training, subjects used light to moderate weights, performed 8–12 repetitions of each exercise, and were not required to go until they were unable to complete the entire movement; the goal of this phase of training was to allow for slow adaptation to prepare the subjects for more intense training, which was to begin the 14th wk of training. During the last 13 wks of training, subjects were encouraged to train on each apparatus until they could not complete the entire range of motion. Resistance increased substantially and when subjects could complete 12 repetitions on a given machine, the resistance was increased.

Sixteen of the 21 subjects (76%) in the endurance training group and 19 of the 23 subjects (83%) in the resistance training group completed the training and testing. Subjects in both groups had >95% compliance to the training program over the course of the study. Twelve of 13 subjects (92%) completed their commitments to the control group. The average age of the subjects completing the study was 72 ± 3 yr. The males and females in each group generally responded similarly to training except as where noted in the RESULTS presented below.

*Statistics.* The significance of differences among groups was assessed using a priori planned comparisons on the changes elicited during the study within an analysis of variance framework. A $P \leq 0.05$ was required for statistical significance. All values are expressed as means ± SD.

## RESULTS

*$\dot{V}O_{2\,max}$.* $\dot{V}O_{2\,max}$ increased by 16% in the endurance training group after the first 13 wk of training (Table 1); this change, whether expressed as milliliters per kilogram per minute or liters per minute, was significant compared with that in the resistance training group after 13 wk of training or in the control group over the 26 wk of the study. $\dot{V}O_{2\,max}$ increased another 6% in the endurance training group with the second 13 wk of training, so that their $\dot{V}O_{2\,max}$ increased by 22% during the 26 wk of training. $\dot{V}O_{2\,max}$ in the resistance training group increased by 5 and 4% after 13 and 26 wk of training, respectively, but these changes were not significant compared with the control group.

*Strength.* The resistance training group increased its lower and upper body strength by 9 and 18%, respectively, with 26 wk of training (Table 2); both of these changes were significant compared with the control and the endurance training groups. Neither the control or the endurance training groups increased their lower or upper body strength significantly during the course of the study.

*Body composition.* Body weight decreased somewhat in the endurance training group after 26 wk of training; however, this change and those in the control and resistance training groups were not significant (Table 2). The sum of seven skinfolds decreased significantly by 6–8% in both the endurance and resistance training groups after 26 wk of training. Estimated lean body mass did not change significantly in any of the three groups during the course of the study.

*Cardiovascular responses during maximal exercise.* Maximal heart rates were similar in all groups, initially averaging 158 ± 12 beat/min, and they did not change significantly with training (Table 1). Maximal $O_2$ pulse

TABLE 1. *Cardiovascular responses to maximal exercise*

| Variable | Group | | |
|---|---|---|---|
| | Endurance training | Resistance training | Control |
| $\dot{V}O_{2\,max}$, ml·kg$^{-1}$·min$^{-1}$ | | | |
| Initial | 22.5±5.7 | 22.5±4.6 | 22.2±5.1 |
| 13 wk | 25.8±6.7* | 23.6±5.5 | |
| Final | 27.1±6.5† | 23.3±4.8 | 22.0±6.4 |
| $\dot{V}O_{2\,max}$, l/min | | | |
| Initial | 1.59±0.55 | 1.68±0.50 | 1.51±0.57 |
| 13 wk | 1.81±0.58* | 1.75±0.56 | |
| Final | 1.88±0.63† | 1.73±0.49 | 1.48±0.64 |
| Maximal HR, beats/min | | | |
| Initial | 157±12 | 156±12 | 159±12 |
| 13 wk | 160±9 | 158±12 | |
| Final | 160±11 | 160±11 | 159±13 |
| Maximal $O_2$ pulse, ml/beat | | | |
| Initial | 10.2±3.6 | 10.9±3.5 | 9.4±3.5 |
| 13 wk | 11.3±3.6* | 11.1±3.7 | |
| Final | 11.9±4.5† | 10.8±3.0 | 9.2±3.8 |
| SBP during maximal exercise, mmHg | | | |
| Initial | 216±20 | 210±23 | 200±18 |
| 13 wk | 226±24* | 210±18 | |
| Final | 219±22* | 204±18 | 193±19 |
| DPB during maximal exercise, mmHg | | | |
| Initial | 86±25 | 90±11 | 92±11 |
| 13 wk | 98±19 | 93±15 | |
| Final | 90±17 | 89±11 | 94±14 |

Values are means ± SD. $\dot{V}O_{2\,max}$, maximal $O_2$ consumption; HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure. Difference from initial value different from that in both resistance training and control group: * $P < 0.05$, † $P < 0.01$.

TABLE 2. *Muscular strength and body composition changes*

| Variable | Group | | |
|---|---|---|---|
| | Endurance training | Resistance training | Control |
| Body wt, kg | | | |
| Initial | 69.6±10.4 | 74.5±13.6 | 64.9±14.5 |
| Final | 68.7±10.4 | 74.1±13.8 | 64.6±15.4 |
| Sum of 7 skinfolds, mm | | | |
| Initial | 152.3±45.9 | 158.4±50.1 | 166.6±49.9 |
| Final | 139.8±45.7* | 148.2±46.8* | 164.6±47.1 |
| Estimated lean body mass, kg | | | |
| Initial | 51.2±11.3 | 53.5±11.8 | 45.7±13.4 |
| Final | 52.0±10.5 | 54.3±11.6 | 45.3±14.3 |
| Lower body strength, kg | | | |
| Initial | 50.1±20.4 | 48.9±18.6 | 45.7±19.5 |
| Final | 52.8±22.7 | 53.4±21.1† | 43.2±20.3 |
| Upper body strength, kg | | | |
| Initial | 36.8±19.5 | 38.5±15.0 | 34.3±18.2 |
| Final | 34.5±19.1 | 45.4±18.1† | 32.0±21.2 |

Values are means ± SD. * Difference from initial value different from that in control group, $P < 0.05$. † Difference from initial value different from that in both control and endurance training group, $P < 0.05$.

changed significantly only in the endurance exercise training group, increasing by 10 and 16% after 13 and 26 wk of training, respectively. Systolic blood pressure during maximal exercise increased significantly in the endurance training group after 13 and 26 wk of training compared with the control and the resistance training groups; however, most of this difference was the result of decreases in the maximal systolic blood pressure in the resistance training and the control groups. Diastolic blood pressure during maximal exercise did not change significantly in any of the groups during the study.

*Respiratory and perceptual responses during maximal exercise.* Maximal respiratory exchange ratio averaged 1.16 ± 0.08 U in all subjects, initially indicating a high degree of hyperventilation during the $\dot{V}O_{2\,max}$ tests (Table 3). Maximal respiratory exchange ratio did not change significantly in any of the groups during the study. Maximal ventilation ($\dot{V}E_{max}$) increased significantly both after 13 and 26 wk in the endurance exercise training group, while no increase was evident in the resistance training group. $\dot{V}E_{max}$ increased in the endurance training group to the same degree as its $\dot{V}O_{2\,max}$, so that its and all other groups' maximal ventilatory equivalent for $\dot{V}O_2$ did not change significantly. Perceived exertion during maximal exercise averaged 18.9 ± 1.4 U (very hard) in all subjects before training and did not change significantly in any of the groups during the study.

*Cardiovascular responses during submaximal exercise.* Heart rate and blood pressure were compared before and after training among the three groups at the same absolute submaximal work rates (Table 4). Heart rates were significantly lower after training in the endurance training group by 4–12 beat/min during the first 10 min of the $\dot{V}O_{2\,max}$ test compared with both the control and the resistance training groups.

Systolic blood pressures during submaximal exercise did not change in the exercise training groups compared with the control group; however, they increased significantly, but by only 4–8 mmHg, in the endurance training group during the later stages of the exercise test (data not shown). Diastolic blood pressures during submaximal exercise were not affected by training in either the resistance or the endurance training groups (data not shown).

*Perceptual responses during submaximal exercise.* RPE during submaximal exercise were consistently lower by ~2 U on Borg's scale in the endurance training group (Table 5). All these differences were significant compared with the resistance training group; the differences were significant compared with the control group during 5 of the first 10 min of the $\dot{V}O_{2\,max}$ test.

TABLE 3. *Respiratory and perceptual responses during maximal exercise*

| Variable | Group | | |
|---|---|---|---|
| | Endurance training | Resistance training | Control |
| $\dot{V}E_{max}$, l/min STPD | | | |
| Initial | 51.1±18.8 | 57.3±15.0 | 53.5±22.6 |
| 13 wk | 55.3±18.9* | 56.6±16.5 | |
| Final | 61.1±22.2† | 56.6±13.6 | 49.1±20.7 |
| Maximal RER, units | | | |
| Initial | 1.17±0.10 | 1.15±0.08 | 1.15±0.06 |
| 13 wk | 1.10±0.12 | 1.14±0.05 | |
| Final | 1.14±0.09 | 1.13±0.06 | 1.15±0.12 |
| Maximal $\dot{V}E/\dot{V}O_2$ | | | |
| Initial | 32.2±4.4 | 34.6±4.2 | 35.5±6.6 |
| 13 wk | 30.5±3.8 | 32.9±4.7 | |
| Final | 32.4±4.4 | 33.3±3.3 | 33.5±5.4 |
| Maximal RPE, units | | | |
| Initial | 18.7±1.7 | 18.8±1.5 | 19.4±0.6 |
| 13 wk | 18.3±1.4 | 18.7±1.6 | |
| Final | 18.3±1.7 | 18.7±1.3 | 19.6±0.6 |

Values are means ± SD. $\dot{V}E_{max}$, maximal ventilation; RER, respiratory exchange ratio; $\dot{V}E/\dot{V}O_2$, ventilatory equivalent; RPE, perceived exertion. * Difference from initial value different from that in both resistance training and control group: * $P < 0.05$, † $P < 0.01$.

TABLE 4. *Change in heart rate from the initial to the final test during submaximal exercise*

| Minute of Exercise | Group | | |
|---|---|---|---|
| | Endurance training | Resistance training | Control |
| *1* | −4±9* | 6±9 | 2±9 |
| *2* | −6±9* | 5±12 | 2±8 |
| *3* | −6±10* | 7±11 | 3±11 |
| *4* | −7±8† | 5±9 | 3±12 |
| *5* | −7±9† | 5±7 | 2±10 |
| *6* | −8±9† | 3±7 | 5±10 |
| *7* | −8±10† | 2±8 | 5±10 |
| *8* | −12±9† | 0±8 | 3±8 |
| *9* | −9±11* | 0±8 | 3±5 |
| *10* | −10±6* | 3±5 | 2±5 |

Values are means ± SD of difference in heart rate (beats/min) for that minute of exercise in subject's initial $\dot{V}O_{2\,max}$ test compared with final $\dot{V}O_{2\,max}$ test. Significantly different compared with both resistance training group and control group: * $P < 0.05$, † $P < 0.01$.

TABLE 5. *Change in rating of perceived exertion from the initial to the final test during submaximal exercise*

| Minute of Exercise | Group | | |
|---|---|---|---|
| | Endurance training | Resistance training | Control |
| *1* | −0.4±1.5‡ | 0.9±1.2 | 0±1.7 |
| *2* | −0.8±2.4§ | 0.2±1.4 | −0.1±2.7 |
| *3* | −1.5±2.6‡ | 0.4±1.8 | −0.3±1.9 |
| *4* | −1.9±2.9* | 0.6±1.8 | −0.1±2.2 |
| *5* | −2.2±2.8* | 0.8±2.1 | 0±2.2 |
| *6* | −2.2±2.9† | 0.2±1.8 | 0.5±2.6 |
| *7* | −2.4±3.0* | −0.5±1.8 | 0.5±2.0 |
| *8* | −2.6±2.3† | −0.5±1.4 | 0±1.6 |
| *9* | −2.5±2.8§ | −0.4±1.3 | 0±1.7 |
| *10* | −2.0±2.5 | −0.2±1.1 | −0.5±3.5 |

Values are means ± SD of difference in perceived exertion in units from the Borg scale (6) for that minute of exercise in subject's initial $\dot{V}O_{2\,max}$ test compared with final $\dot{V}O_{2\,max}$ test. Significantly different compared with both resistance training group and control group: * $P < 0.05$, † $P < 0.01$. Significantly different compared with resistance training group: ‡ $P < 0.01$, § $P < 0.05$.

## DISCUSSION

As recently as 5–8 yr ago it was believed that individuals >60 yr old could not respond to endurance exercise training with an increase in $\dot{V}O_{2\,max}$, as do younger individuals (1, 5, 15, 21). However, we and others have reported recently that both healthy and hypertensive men and women between 60 and 70 yr of age can elicit sizable increases in $\dot{V}O_{2\,max}$ when they are submitted to a prolonged program of endurance exercise training with progressively increasing training intensities (3, 26, 29; J. M. Hagberg, S. J. Montain, W. H. Martin, and A. A. Ehsani, unpublished observations). We found that 11 men and women with an average age of 63 yr increased their $\dot{V}O_{2\,max}$ by 30% with a year-long training program (26) and, more recently, we have reported that hypertensive men and women in their 60s increased their $\dot{V}O_{2\,max}$ by 28% with a 9-mo training program (Hagberg et al., unpublished observations).

However, the previous data describing the effects of endurance exercise training on individuals 70–79 yr old provide no, or at best very weak, support for the belief that they can elicit increases in $\dot{V}O_{2\,max}$. Benestad (5) trained 13 men aged 75.5 ± 2.8 yr on treadmills three times per week for 5–6 wk and found no change in peak $\dot{V}O_2$ measured on a cycle ergometer. DeVries (7) found that 68 men with an average age of 70 yr did not increase their estimated peak $\dot{V}O_2$ on a cycle ergometer with either 6 or 42 wk of training when they were compared with an inactive control group of the same age.

Two studies have indicated that individuals in their 70s might be capable of adapting to endurance exercise training. Barry et al. (4) found that 5 men and 3 women with a mean age of 70 yr increased their "$\dot{V}O_{2\,max}$" by 38%. However, this group had a higher respiratory exchange ratio (by 0.11 U), a higher heart rate (by 14 beat/min), and a higher blood lactate level (by ~2.5 mM) during maximal exercise after training, which may indicate that they had not achieved a true $\dot{V}O_{2\,max}$ before training, thus confounding the interpretation of the supposed 38% increase in $\dot{V}O_{2\,max}$. Stamford (28) reported that 21 men with a mean age of 71.5 yr decreased their heart rate response to a given absolute level of submaximal exercise as a result of exercise training; however, he made no measurements of $\dot{V}O_2$.

The present study shows that healthy men and women in their 70s can increase their true $\dot{V}O_{2\,max}$ and can elicit cardiovascular adaptations in response to an endurance exercise training program. In fact, the 22% increase in $\dot{V}O_{2\,max}$ that they achieved with the 6-mo training program is within the range expected in much younger individuals (23, 25), and similar to the relative increase in $\dot{V}O_{2\,max}$ elicited by slightly longer training programs in healthy and hypertensive men and women in their 60s (26; Hagberg et al., unpublished observations). It is important to bear in mind that the maximal heart rates and respiratory exchange ratios in the present study indicate that the $\dot{V}O_{2\,max}$ tests both before and after training resulted in valid $\dot{V}O_{2\,max}$ values. Thus it appears that these individuals ranging in age from 70 to 79 yr have not lost their ability to respond to a prolonged and vigorous program of endurance exercise training. However, the increases in $\dot{V}O_{2\,max}$ are similar in these groups of different ages only when compared on a relative basis, since a 25% increase in $\dot{V}O_{2\,max}$ in a younger individual with an initial $\dot{V}O_{2\,max}$ of 40 $ml \cdot kg^{-1} \cdot min^{-1}$ is much larger in absolute terms than the same relative increase in an individual with an initial $\dot{V}O_{2\,max}$ of 25 $ml \cdot kg^{-1} \cdot min^{-1}$.

We have previously reported that 6 mo of training consisting of walking at 40% of $\dot{V}O_{2\,max}$ in men and women with a mean age of 63 yr resulted in a 12% increase in $\dot{V}O_{2\,max}$ (26), although in another study (Hagberg et al., unpublished observations) with hypertensive men and women of the same age 9 mo of training at 50–55% of $\dot{V}O_{2\,max}$ did not result in an increase in $\dot{V}O_{2\,max}$. In the present study the first 13 wk of training at 50–70% of each subject's $\dot{V}O_{2\,max}$ resulted in a 16% increase in $\dot{V}O_{2\,max}$. The common denominator among these studies is that all subjects completed their training prescriptions while walking. Thus perhaps because the subjects in the present study were older and had lower initial $\dot{V}O_{2\,max}$ values, they were able to elicit a higher relative work rate while still walking and thus a larger increase in $\dot{V}O_{2\,max}$ than in previous studies using only walking in older individuals. In addition, it is possible for individuals with lower initial $\dot{V}O_{2\,max}$ values to increase their $\dot{V}O_{2\,max}$ more with training (25) and also to elicit increases in $\dot{V}O_{2\,max}$ at lower training intensities (7). Thus the present data support the conclusion that fast walking can result in substantial improvements in $\dot{V}O_{2\,max}$ in healthy individuals 70–79 yr old.

The subjects in the resistance training group in the present study increased their lower and upper body strength substantially; however, their increases were somewhat less, in relative terms, than those reported in a recent review (9) of strength gains in young subjects. However, despite these substantial gains in lower and upper body strength, they failed to increase their $\dot{V}O_{2\,max}$ or alter their cardiovascular responses to submaximal and maximal exercise. Training using heavy resistance exercise increases muscular strength in young to middle-aged subjects with concomitant increases in muscle mass but has not been shown to increase $\dot{V}O_{2\,max}$ (13). Circuit weight training, where moderate weights (usually 40–50% of one repetition maximum) are used and little rest is taken between exercises (15 s), results in increases in muscular strength and modest increases in $\dot{V}O_{2\,max}$ (13). The present study was designed to develop muscular strength in the resistance training group and thus subjects were allowed to have 1–2 min rest between exercises. Thus the lack of improvement in $\dot{V}O_{2\,max}$ in the resistance training group in the present study is consistent with findings in younger subjects performing resistance training not of the circuit weight training type.

Recently, the reduction in muscle mass that occurs with aging has been shown to account for a large portion of the decline in $\dot{V}O_{2\,max}$ associated with aging (10). Thus it could be proposed that an increase in muscle mass, and perhaps even only muscular strength, might result in an increase in $\dot{V}O_{2\,max}$ in older individuals. However, while the subjects in the present study did increase their muscular strength, they did not increase their lean body mass or their $\dot{V}O_{max}$. Recently, Frontera et al. (12) have reported that men aged 60–72 yr submitted to a 12-wk training program that was more intense than that in the present study increased their peak torque more, in relative terms, than strength increased in the present study. These men also increased their muscle mass as determined by computerized tomographic muscle scans as a result of this training program. Thus it is possible that a larger quantity of high intensity resistance training that increases muscle mass as well as muscular strength may result in an increase in $\dot{V}O_{2\,max}$ in older individuals who may be more limited during exercise by reductions in muscle strength as a result of a loss of muscle mass.

In summary, healthy men and women in their 70s increased their $\dot{V}O_{2\,max}$ to the same relative degree as would be expected in younger individuals in response to a prolonged and vigorous program of endurance exercise training. This increase in $\dot{V}O_{2\,max}$ was accompanied by a decrease in heart rate and perceived exertion at the same submaximal absolute work rate after training. Twenty-six weeks of resistance training did not result in any significant alterations in $\dot{V}O_{2\,max}$ or cardiovascular responses to exercise in healthy men and women in their 70s. Thus these data indicate that healthy men and women in their eighth decade of life have not lost the ability to adapt to endurance exercise training.

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