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Exercise training below and above the lactate threshold in the elderly

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ABSTRACT

BELMAN, M. J. and G. A. GAESSER. Exercise training below and above the lactate threshold in the elderly. *Med. Sci. Sports Exerc.*, Vol. 23, No. 5, pp. 562–568, 1991. In this study we report the effects of training at intensities below and above the lactate threshold on parameters of aerobic function in elderly subjects (age range 65–75 yr). The subjects were randomized into high-intensity (HI, $N = 8$; 75% of heart rate reserve = ~82% $\dot{V}O_{2max}$ = ~121% of lactate threshold) and low-intensity (LI, $N = 9$; 35% of heart rate reserve = ~53% $\dot{V}O_{2max}$ = ~72% of lactate threshold) training groups which trained 4 $d \cdot wk^{-1}$ for 30 $min \cdot session^{-1}$ for 8 wk. Before and after the training, subjects performed an incremental exercise test for determination of maximal aerobic power ($\dot{V}O_{2max}$) and lactate threshold (LT). In addition, the subjects performed a 6-min single-stage exercise test at >75% of pre-training $\dot{V}O_{2max}$ (SST-High) during which cardiorespiratory responses were evaluated each minute of the test. After training, the improvements in $\dot{V}O_{2max}$ (7%) for LI and HI were not different from one another ($\Delta\dot{V}O_{2max}$ for LI = 1.8 ± 0.7 $ml \cdot kg^{-1} \cdot min^{-1}$; $\Delta\dot{V}O_{2max}$ for HI = 1.8 ± 1.0 $ml \cdot kg^{-1} \cdot min^{-1}$) but were significantly greater ($P = 0.02$) than the post-testing change observed in the control group ($N = 8$). Training improved the LT significantly (10–12%; $P < 0.01$) and equally for both LI and HI (ΔLT for LI = 2.3 ± 0.6 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$; ΔLT for HI = 1.8 ± 0.8 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$). In comparison with controls, during the post-training SST-High for LI and HI, there were significant training-induced reductions in the exercise heart rate, $\dot{V}_E$, and $\dot{V}CO_2$. These results demonstrate that, for previously sedentary elderly subjects, 8 wk of low-intensity training (i.e., below the LT) provide comparable increases in $\dot{V}O_{2max}$ and LT and decreases in cardiorespiratory responses to high-intensity exercise, as compared with 8 wk of high-intensity training (i.e., above the LT). We conclude that low-intensity, sub-LT walking training (as defined herein) is an adequate aerobic training stimulus for producing modest gains in aerobic power in previously sedentary elderly subjects.

AGED, PHYSICAL TRAINING, AEROBIC POWER, EXERTION, HEART RATE

Various authorities, such as the Council on Scientific Affairs of the American Medical Association (7), have encouraged the elderly to exercise on a regular basis. However, considerably more is known about the nature of the training response and the roles of intensity, frequency, and duration of exercise in eliciting adaptations in younger, as compared with older, individuals (1,22,30).

The most frequently used criteria to evaluate training effects in the elderly are $\dot{V}O_{2max}$ and reduced heart rate responses to submaximal exercise (2,9,12,15,18,24,25,27,29,31–33). The lactate threshold (LT), a parameter of aerobic function used to assess physical working capacity (10), is increased by exercise training in young populations (26) but has not been systematically evaluated in elderly individuals engaged in training programs. The ventilation threshold (used as an index of the LT (10)) also has been shown to be increased in young (26) and middle-aged (11) males after intensive endurance training. However, studies of the adaptation of the ventilation threshold to endurance training in the elderly are inconsistent. Thomas et al. (33) reported no change in the ventilation threshold in elderly subjects after 12 months of training. In contrast, Blumenthal et al. (5) reported a 13% increase in the ventilation threshold in elderly subjects after 4 months of training.

In all previous studies in the elderly, exercise training has been prescribed on the basis of a percentage of $\dot{V}O_{2max}$ or maximum heart rate. However, thus far in the elderly, training intensities have not been prescribed on the basis of the LT. It remained to be established whether improvement in this parameter required a training intensity above the LT. With this purpose in mind, we compared training adaptations in elderly subjects (ages 65–75 yr) assigned to low- and high-intensity groups, with the low-intensity exercise group training below their LT and the high-intensity exercise group training above their LT. We were specifically

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interested in the effects of training on $\dot{V}O_{2max}$, LT, and cardiorespiratory responses during high-intensity submaximal exercise.

METHODS

Subjects. Subjects were recruited from the surrounding community by means of advertisements in the local newspapers. Criteria for selection included the following: age between 65 and 75 yr and absence of cardiac, pulmonary, and bone or joint disease as determined by history, physical examination, resting and exercise electrocardiogram, and pulmonary function tests, which included spirometry and lung volumes. In addition, only subjects who had not participated in endurance exercise activities such as walking, running, cycling, or swimming for at least 3 months prior to the study were acceptable. Written consent was obtained from all subjects, and the experimental procedures were approved by the Institutional Review Board. Of the 18 subjects accepted (nine men and nine women), 17 completed all components of the study. One female subject developed leg pain and was unable to complete the last incremental exercise test. Descriptive physical data are presented in Table 1.

We used control subjects from a concurrent study (4) in our laboratory which involved subjects of the same age and physical characteristics (Table 1). These subjects were recruited by the same means as the trained subjects and underwent identical testing procedures, with the exception of the measurement of the lactate threshold.

Testing series. Prior to initiating the training program, each subject underwent a series of exercise tests on a treadmill. These included two incremental exercise tests (IET) and one 6-min high-intensity single-stage test (SST-High). The first IET was used as a practice test to acquaint the subjects with the exercise protocol (described below). The second IET, which was administered approximately 1 wk after the first IET, was used for determination of maximal cardiorespiratory indices and the lactate threshold (described later). The SST-High was administered within a week of the second IET and was used to evaluate steady-rate submaximal exercise cardiorespiratory responses. After training, the IET and SST-High were administered again, with the IET being conducted within 2 d after the last training session and the SST-High 2 d after the IET. For each subject, tests were conducted at the same time of day throughout pre- and post-training testing sessions. Subjects refrained from food and from drinks containing caffeine for a minimum of 2 h prior to each test.

Incremental exercise test (IET). The IET began with the subject walking for 2 min at 1.4 mph on a level grade and then for 2 min at 2.5 mph on a level grade. Thereafter, the grade was increased by 2% every minute until a grade of 20% was reached. If the subject could continue, the speed was increased each minute to the following speeds (3.0, 3.3, 3.6, 4.0, 4.3, 4.6, and 5.0 mph) until the subject signaled for the termination of the test. During the test the subject breathed humidified air through a low-resistance valve (Koegel & Co., San Antonio, TX). Inspired air was measured by a turbine ventilation measurement module (Alpha Technologies, Laguna Hills, CA), while mixed expired air was sampled from a 5-l mixing chamber for concentrations of O_2 and CO_2 using a mass spectrometer (Perkin Elmer MD #1100). After analog-to-digital conversion of signals from these instruments, pulmonary gas exchange measures were calculated every 15 s by an IBM PC-AT microcomputer using standard open-circuit indirect calorimetry procedures (21). The data from the last 15 s of each minute were taken as the value for that minute. Heart rate was recorded continuously by electrocardiogram. At the end of each minute of exercise during the IET, blood was drawn from an indwelling catheter in a forearm vein and immediately deproteinized in ice-cold 8% perchloric acid. The acid extracts were stored at −5°C until analyzed for lactate (19).

In all subjects accepted into the study, the final R value of the IET was greater than 1.10 and there was a <50 ml increase in $\dot{V}O_2$ between the last two $\dot{V}O_2$ measurements (expected $\dot{V}O_2$ increase was 100–200 ml, based upon slope of $\dot{V}O_2$ vs treadmill intensity relationship).

High-intensity single-stage test (SST-High). The $\dot{V}O_2$ during the SST-High ranged between 77 and 95% of the pretraining $\dot{V}O_{2max}$ and represented a $\dot{V}O_2$ above the lactate threshold for all subjects in the training groups. The duration of the SST-High was 6 min. During each minute of each SST, pulmonary gas exchange measures and heart rate were determined as described for the IET. Data are reported for the final minute of the test. For the SST-High, the $\bar{X}$ (± SE)

TABLE 1. Age and physical characteristics of subjects.

Group	Age (yr)	Height (cm)	Pre-Training Weight (kg)	Post-Training Weight (kg)	Resting Heart Rate (bpm)
Low-intensity (LI) (5 males; 4 females)	68.4 ± 1.1	167 ± 4	71.2 ± 5.3	70.6 ± 4.9	69 ± 4
High-intensity (HI) (4 males; 4 females)	69.4 ± 1.1	167 ± 4	70.0 ± 7.5	70.0 ± 7.2	68 ± 2
Control (4 males; 4 females)	67.3 ± 1.3	166 ± 3	74.7 ± 4.3	74.9 ± 4.7	

Values are means ± SEM.

speed and grade for all subjects were 2.5 ± 0.1 mph and 10.5 ± 1.2%, respectively.

Determination of the lactate threshold. The lactate threshold was determined using a modification of the method of Beaver et al. (3), in which log lactate vs log $\dot{V}O_2$ is plotted on a linear set of coordinates. It has been reported that the abrupt transition from a slow increase in blood lactate to a phase of rapidly accelerating increase is more easily defined using a log-log model as compared with a rectilinear plot (3). An example of the log-log plot is presented in Figure 1. In the original method of Beaver et al., the lactate threshold was determined as follows. A breakpoint was determined by visual inspection of data points, and, subsequently, linear regressions were performed on the data points below and above the breakpoint, with the lactate threshold defined as the intersection of the two regression lines. In exercise testing of the elderly, it was our observation that in many individuals few points were present above the breakpoint so that regression analysis of the post-threshold points was unreliable. Therefore, we defined the lactate threshold as the point on the log-log plot at which blood lactate concentration increased rapidly. Both investigators determined the LT by using coded photocopies of the data, thus having no knowledge of subject, group, or date of test. The average of the two independent determinations was taken to be the LT. Data from only 13 subjects were included in the analyses of training effects on the LT. In two of the subjects (one in each group), LT could not be identified, primarily because of low blood lactates (<2 mM during the last minute of exercise). One subject could not perform the post-training IET (leg pain), and in one subject we were unable to maintain a patent venous catheter in the post-training IET. In 17 of the 26 tests, both investigators selected the same point as the LT. In eight of the 26 tests, the differences in LT determined by the two investigators were between 20 and 90 ml $O_2 \cdot min^{-1}$ (2–7% difference). In one test the difference was 140 ml $O_2 \cdot min^{-1}$ (15% difference).

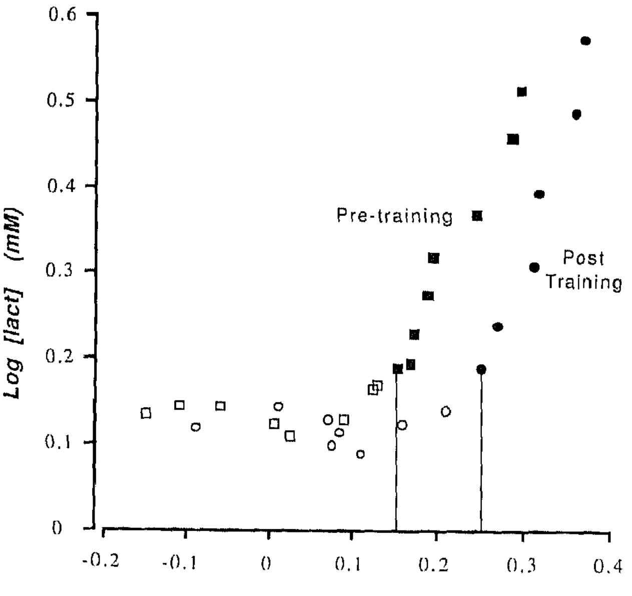

Figure 1—Illustrates the method of lactate threshold determination (see text). Pre-training values are shown as *squares*, post-training values as *circles*. *Solid symbols* represent points above the LT.

Training program. After completion of the preliminary testing, subjects were randomly assigned to either a low-intensity (LI) or high-intensity (HI) walking exercise group. Both groups walked 30 $min \cdot d^{-1}$, 4 $d \cdot wk^{-1}$ for 8 wk. The low-intensity group exercised at a heart rate calculated to elicit 35% of the heart rate reserve (HRR); i.e., exercise heart rate = ((maximum − resting) × 0.35) + resting. For all subjects in the low-intensity training group, this exercise intensity elicited a $\dot{V}O_2$ below the lactate threshold, with the group mean = ~72% of LT and = ~53% $\dot{V}O_{2max}$. The high-intensity group exercised at a heart rate calculated to elicit 75% of the HRR. For all subjects in the high-intensity training group, this exercise intensity elicited a $\dot{V}O_2$ above the lactate threshold, with the group mean = ~121% of LT and = ~82% $\dot{V}O_{2max}$. During training the heart rate of each subject was monitored continuously by means of a wristwatch pulse monitor (Vital Signs, model 61330, Country Technology Inc., Gays Mills, WI). The accuracy of these pulse monitors was established by comparing pulse rate obtained by the wristwatch monitor with actual ECG recordings obtained during exercise on the treadmill. The monitors were set so that the target heart rate fell within a 10 beat range of the upper and lower limits set on the monitor (i.e., subjects could exercise within ±5 bpm of prescribed intensity). An alarm sounded when the heart rate of the subject was out of the preselected range. Subjects were instructed in the use of the monitors and were accompanied by one of the investigators or a laboratory technician during the first few training walks to ensure that each subject exercised at the appropriate intensity. All training sessions were performed outdoors on the hospital grounds, and the subjects checked in and out before and after each session. Each of the 17 subjects exercised the full 30 min of all 32 training sessions.

Statistical analysis. To evaluate differences between groups as a result of training, the following procedures were employed. Post-testing changes were calculated as differences between pre- and post-testing values for each subject in each group. Planned comparisons (14) were then performed on the differences (i.e., delta scores) to detect statistical significance between groups. Two comparisons were of interest: 1) LI training vs HI training and 2) either LI or HI vs control group of (LI + HI) vs control group (if LI and HI were not significantly different from one another). For the LT analysis, a two-way analysis of variance with repeated measures

(BMDP2V) was used to evaluate differences between LI and HI in response to training (13).

RESULTS

Incremental exercise. Results of the IET are presented in Table 2. Statistical analysis revealed that post-training increases in $\dot{V}O_{2max}$ and total exercise time during the IET for the two training groups were significantly greater than the changes observed in the control group. The changes in $\dot{V}O_{2max}$ and exercise time during the IET for both trained groups were not different from one another. In the trained groups, the mean improvements in aerobic power were the same (1.8 $ml \cdot kg^{-1} \cdot min^{-1}$; 7%). Maximal values for $\dot{V}_E$, R, and HR were not changed after training.

We analyzed the training adaptations as a function of gender after combining the two training groups (since no intergroup differences were observed). For all maximal cardiorespiratory measures that changed after training, including time of test, there was a trend for greater improvement demonstrated by the females. However, the gender differences in training adaptation did not reach the minimum probability level required for statistical significance ($0.05 \leq P < 0.10$).

High-intensity single-stage exercise. During the post-training SST-High, reductions in $\dot{V}_E$, $\dot{V}CO_2$, and HR for groups LI and HI were significantly greater than the changes observed in the control group but were not different from one another (Table 3). $\dot{V}O_2$ demonstrated a trend toward being lower in the post-training test for LI and HI; however, the planned comparison analysis revealed P values that were not quite sufficient to reach statistical significance (i.e., $0.06 < P < 0.07$). The changes after training for males and females were virtually identical, with statistical analysis indicating no gender influence in the training adaptations.

Lactate threshold. The LT was increased for both the LI and HI groups after training (Table 4). For LT data, the statistical comparisons were performed on $N = 13$. The mean (± SE) improvement in LT for the LI group (2.3 ± 0.6 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$; 12%) was not significantly different from the improvement shown by the HI group (1.8 ± 0.8 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$; 10%). Statistical analysis indicated that the males and females did not differ in their improvement in LT after training. As a percentage of $\dot{V}O_{2max}$, the LT was not increased after training. The training effect on the LT for one of the subjects is displayed graphically in Figure 1.

DISCUSSION

The main finding of this investigation was that, following an 8-wk exercise program, low-intensity walking training was just as effective as high-intensity walking training for improving physical working capacity in a previously sedentary group of elderly individuals. This was shown by equal improvements in the LT and $\dot{V}O_{2max}$ and equal reductions in cardiorespiratory measures while exercising at a high intensity (SST-High). We acknowledge the fact that our conclusion concerning the increase in LT demonstrated by our two training groups was made without having control data for this parameter; however, results of the post-test IET and

TABLE 2. Effects of training on maximal cardiorespiratory measures during incremental exercise

Parameter	Group	Pre	Post	Change	LI vs HI*	LI + HI vs Control*
$\dot{V}_{Emax}$ ($l \cdot min^{-1}$)	LI	71.4 ± 7.0	78.6 ± 7.3	+7.2	0.189	0.802
	HI	66.0 ± 10.3	66.4 ± 6.9	+0.4		
	Control	66.7 ± 7.7	69.4 ± 9.1	+2.5		
$\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	LI	25.4 ± 1.8	27.2 ± 1.6	+1.8	0.936	0.020
	HI	24.3 ± 2.3	26.1 ± 2.2	+1.8		
	Control	25.9 ± 2.0	25.3 ± 2.4	−0.6		
$\dot{V}CO_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	LI	30.1 ± 2.2	32.8 ± 1.7	+2.7	0.533	0.260
	HI	28.5 ± 3.8	30.5 ± 2.9	+2.0		
	Control	28.3 ± 2.4	29.2 ± 3.1	+0.9		
R_{max}	LI	1.19 ± 0.01	1.21 ± 0.03	+0.02	0.847	0.340
	HI	1.14 ± 0.05	1.17 ± 0.04	+0.03		
	Control	1.09 ± 0.02	1.15 ± 0.02	+0.06		
HR_{max}	LI	156 ± 3.2	151 ± 5	−5	0.752	0.051
	HI	146 ± 6	140 ± 5	−6		
	Control	146 ± 4	148 ± 6	+2		
Time of Test (s)	LI	848 ± 61	912 ± 52	+64	0.734	0.042
	HI	773 ± 78	856 ± 64	+83		
	Control	825 ± 60	832 ± 69	+7		

All values are means ± SEM ($n = 8$ for all groups). One female subject in the LI group did not complete the post-training IET; therefore, for IET analysis the LI group was reduced to five males and three females. The age and physical characteristics of this subgroup were not changed from those reported in Table 1 for the LI group (i.e., age = 68.8 ± 1.2 yr; height = 167 ± 4 cm; pre-training weight = 71.2 ± 6.1 kg; post-training weight = 70.5 ± 5.5 kg).

* P values are for comparison of delta values (pre–post) for groups indicated.

TABLE 3. Effects of training on cardiorespiratory responses during high-intensity submaximal exercise.

Parameter	Group	Pre	Post	Change	LI vs HI*	LI + HI vs Control*
$\dot{V}_E$ (l·min^{-1})	LI	52.8 ± 6.6	46.5 ± 5.1	−6.3	0.950	0.011
	HI	55.3 ± 7.1	48.8 ± 7.4	−6.5		
	Control	45.5 ± 5.5	45.8 ± 4.9	+0.4		
$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	LI	21.8 ± 1.2	20.6 ± 1.1	−1.2	0.906	0.067
	HI	23.2 ± 2.2	22.0 ± 2.5	−1.2		
	Control	20.2 ± 2.0	20.3 ± 1.6	+0.1		
$\dot{V}CO_2$ (ml·kg^{-1}·min^{-1})	LI	23.0 ± 1.6	21.2 ± 1.4	−1.2	0.977	0.020
	HI	24.7 ± 3.1	22.9 ± 3.3	−1.8		
	Control	19.4 ± 2.2	19.4 ± 2.0	0		
R	LI	1.05 ± 0.02	1.03 ± 0.02	−0.02	0.813	0.520
	HI	1.05 ± 0.04	1.02 ± 0.03	−0.03		
	Control	0.96 ± 0.02	0.95 ± 0.02	−0.01		
HR (bpm)	LI	133 ± 7	125 ± 5	−8	0.341	0.002
	HI	135 ± 5	124 ± 5	−11		
	Control	126 ± 5	128 ± 6	+2		

Values are means ± SEM ($N = 9$ for LI; $N = 8$ for HI; $N = 8$ for controls).

* P values are for comparison of delta values (pre–post) for groups indicated.

TABLE 4. Effects of training on the lactate threshold.

Parameter	Group	Pre-Training	Post-Training	Pre-Post*	Interaction*
LT (ml·kg^{-1}·min^{-1})	LI	19.4 ± 1.8	21.7 ± 1.4	0.002	0.57
	HI	18.0 ± 1.5	19.8 ± 1.5		
LT (%$\dot{V}O_{2max}$)	LI	75.7 ± 1.9	78.7 ± 2.2	0.43	0.63
	HI	68.0 ± 2.9	68.7 ± 2.3		

Values are means ± SEM ($N = 7$ for low-intensity group; $N = 6$ for high-intensity group). See Methods, "Determination of the lactate threshold," for explanation of reduced N for each group.

* P values are from results of a repeated measures ANOVA.

SST-High revealed no changes in the controls, and we deem it unlikely that the LT would have changed in the control group without concomitant changes in any of the other indices of training adaptation.

There is very little information on the LT and training in the elderly. The data of Seals et al. (28) could be interpreted to show that 6–12 months of training improved the LT in their elderly subjects (ages 61–67). With respect to studies (5,33) using noninvasive estimates of the LT (i.e., ventilation threshold), the results are inconsistent. Thomas et al. (33) reported that 12 months of training (3 d·wk^{-1}, 30 min·session^{-1}, 65–80% $\dot{V}O_{2max}$) failed to improve the ventilation threshold in elderly subjects (mean age = 62 yr), although $\dot{V}O_{2max}$ was increased by 18%. In contrast, Blumenthal et al. (5) reported that 4 months of training (3 d·wk^{-1}, 30 min·session^{-1}, 70% HRR) improved the ventilation threshold in elderly subjects (mean age = 67) by an average of 13%. Our data are consistent with the results of Seals et al. and Blumenthal et al. The improvement in the LT in our elderly subjects occurred in a relatively short period of time, which is similar to the results of training studies of the same, or shorter, duration in younger subjects (26). Our data on the LT demonstrate that this parameter can be changed with 8 wk of low-intensity (sub-LT) training in previously untrained elderly subjects.

In all previous studies, exercise intensity has been prescribed on the basis of a percentage of $\dot{V}O_{2max}$ or maximum heart rate. None of the previous studies on training adaptations in the elderly have assigned exercise intensities on the basis of the LT. Consequently, it remained to be established for the elderly whether improvement in this index with training was dependent upon training at an exercise intensity above the lactate threshold. Our data demonstrate that, for the elderly, training at an intensity below the LT (~72% of LT) is sufficient stimulus to improve the LT and $\dot{V}O_{2max}$. Furthermore, although subjects in the LI group trained at an intensity below their LT, when compared with the HI group, which trained above their LT, they demonstrated equal post-training reductions in cardiorespiratory responses during a high-intensity exercise bout (SST-High). Thus, exercise training at a sub-LT intensity improved functional working capacity for exercise above the LT in our elderly subjects.

Previous studies have produced inconclusive results regarding the influence of exercise intensity on training adaptations in the elderly (2,12,25,27,29). These studies have generally shown that high-intensity training elicits greater increases in aerobic capacity than low-intensity training. However, Badenhop et al. (2) published data similar to ours, demonstrating that low-intensity training (57% $\dot{V}O_{2max}$; 30–45% HRR) was as effective as high-intensity training (70% $\dot{V}O_{2max}$; 60–75% of HRR) for improving exercise capacity in the elderly. Also, Foster et al. (15) recently reported that low-intensity training (40% of HRR) was as effective as higher-intensity training (60% of HRR) for improving $\dot{V}O_{2max}$ in elderly women (ages 67–89). However, in neither of these studies (2,15) was the LT evaluated. Seals et al. (27,28) reported that 6 months of low-intensity unsupervised exercise (primarily walking) improved $\dot{V}O_{2max}$ by 11% and lowered blood lactate levels during submaximal exercise by 25–30% and that 6 months of additional high-intensity training produced even greater results (a further 16.6% improvement in $\dot{V}O_{2max}$ and 21–25% reduction in submaximal exercise blood lactate). It cannot be determined whether the low-intensity unsupervised exercise in the subjects of Seals et al. (27) represented a sub-LT intensity. In the study of Seals et al., the low-intensity training elicited average heart rates of 107 bpm. However, pulse measurements were made by carotid artery palpation, a technique that may artifactually lower measured heart rate because of pressure on the carotid sinus (6). The low-intensity group in the present investigation exercised at an average heart rate of 100 bpm (compared with 127 bpm for the HI group). Thus, it is likely that the relative exercise intensity of our LI group was lower than the low-intensity exercise of the subjects of Seals et al. The work of de Vries (12) indicated that exercise heart rates in the range of 95–100 bpm were sufficient to improve aerobic capacity in the elderly. In his study, however, changes in $\dot{V}O_{2max}$ were estimated indirectly from submaximal tests using the Åstrand nomogram, a method considered to be unreliable (23).

The improvement in $\dot{V}O_{2max}$ (7%) demonstrated by our subjects is at the lower end of the range of improvements in this parameter reported by others who have trained elderly subjects; most of the previous studies have reported increases in $\dot{V}O_{2max}$ of 5–22% (2,12,15,18,24,25,29,31–33), with one report of an increase of 30% (range = 1–49%) after 12 months of training (27). However, all but one (31) of these studies used training programs of longer duration than ours, with several (9,27,28,33) lasting 52 wk. Thus, the relatively smaller improvement in $\dot{V}O_{2max}$ after training observed in our subjects is likely attributable in part to the shorter training program. Nevertheless, when using other indices of training adaptation, our subjects demonstrated improvements quite comparable to those reported by others. The training-induced reductions in HR (6–8%) and $\dot{V}_E$ (12%) during the SST-High are similar to the posttraining changes reported by others (2,25,27,28) using training programs of longer (9–52 wk) duration. Additionally, the improvement in LT by our subjects (~2 $ml \cdot kg^{-1} \cdot min^{-1}$; ~140 $ml \cdot min^{-1}$) is similar to, or greater than, the improvement in ventilation threshold in elderly subjects trained by Blumenthal et al. (5) for 4 months (~1.3 $ml \cdot kg^{-1} \cdot min^{-1}$; ~100 $ml \cdot min^{-1}$).

In the present study, both male and female subjects were used. Since the training adaptations of both groups were not different, we combined the training groups and performed ANOVAs with gender as the independent variable. For all measurements taken during the SST, the changes after training for males and females were virtually identical. However, for parameters measured during the IET, there was a tendency for greater improvement exhibited by females ($0.05 < P < 0.10$). Our results indicating statistically nonsignificant differences in training adaptations between males and females are consistent with the literature demonstrating that cardiorespiratory adaptations to training are not gender related (2,27,30,31).

Since both the LT and $\dot{V}O_{2max}$ were improved by roughly the same amount, the LT as a percentage of $\dot{V}O_{2max}$ (i.e., relative LT) did not change Table 4). In previous investigations, it has been reported that endurance training increases the relative LT (or ventilation threshold) in young and middle-aged males (11,26). It should be noted, however, that in the sedentary elderly the LT occurs at a higher percentage of $\dot{V}O_{2max}$ (68–76% $\dot{V}O_{2max}$Table 4) than in younger sedentary individuals (40–50% $\dot{V}O_{2max}$ (10,11,26)). Thus, it may be more difficult to raise the relative LT in the elderly. Alternatively, since the upper limit for improvement in $\dot{V}O_{2max}$ as a result of training may be reached sooner than that for the LT, the relative LT could be expected to increase after a more prolonged training period than that used in the present study. In the present study, changes in the LT and $\dot{V}O_{2max}$ were not correlated significantly ($r = 0.28$; $P > 0.05$), thus indicating that the adaptations in these two parameters are not linked in a cause and effect relationship. Therefore, our data are consistent with the results in younger subjects (26), which demonstrated that the factors controlling the adaptation in the LT are, in part, different from those controlling the adaptation in $\dot{V}O_{2max}$. Mechanisms responsible for the improved $\dot{V}O_{2max}$ and LT in the elderly have not been clearly established, although central cardiovascular, peripheral circulatory, and local intramuscular adaptations have been documented and discussed previously (18,20,24,26,28).

The LI group trained at an intensity eliciting ~53% $\dot{V}O_{2max}$. Although this exercise training intensity was below their LT, 53% $\dot{V}O_{2max}$ is still above the minimum intensity recommended by the American College of Sports Medicine (1). Intensities as low as 42–45% $\dot{V}O_{2max}$ have been shown to elicit improvement in $\dot{V}O_{2max}$ in young (16) and middle-aged (17) males. However, in young untrained males the LT occurs at ~40–50% $\dot{V}O_{2max}$ (10,11,26). Thus, in young populations, the apparent minimum training intensity of 40–50% $\dot{V}O_{2max}$ may actually be at or above the LT. Whether in young subjects training below the LT elicits similar adaptations to training at or above the LT has not been firmly established; however, low-intensity training (~50% $\dot{V}O_{2max}$; roughly equal to LT) was found to be as effective as high-intensity training for improving the LT in young males (26). Because the LT occurs at a relatively high %$\dot{V}O_{2max}$ in the elderly, Cunningham et al. (8) suggested that use of $\dot{V}O_{2max}$ as a guide for exercise prescription (1) in the elderly may underestimate the necessary stimulus for inducing a training effect. The present results do not support this contention. Our data indicate that a training intensity at or above the LT is not necessary to induce a training response in the elderly. Indeed, the LI group demonstrated that, after 8 wk of exercise training, training below the LT (~72% of LT) was as effective as exercising above the LT (~121% of LT) for improving this index of aerobic function as well as increasing $\dot{V}O_{2max}$ and reducing the cardiorespiratory response to high-intensity exercise.

As a final note, we must emphasize that our subjects were specifically chosen to include only sedentary healthy individuals. For the elderly individual who is already engaged in aerobic activities, it is likely that higher intensities of exercise are necessary to induce further improvements in aerobic power (32). Nevertheless, for the previously sedentary individual, modest gains in aerobic power can be achieved with low-intensity, sub-LT exercise as described herein.

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REFERENCES

1. American College of Sports Medicine. The recommended quantity and quality of exercise for developing and maintaining fitness in healthy adults. *Med. Sci. Sports* 10:vii–x, 1978.
2. Badenhop, D. T., P. A. Cleary, S. F. Schaal, E. L. Fox, and R. L. Bartels. Physiological adjustments to higher and lower intensity exercise in elders. *Med. Sci. Sports Exerc.* 15:496–502, 1983.
3. Beaver, W. L., K. Wasserman, and B. J. Whipp. Improved detection of lactate threshold during exercise using a log-log transformation. *J. Appl. Physiol.* 59:1936–1940, 1985.
4. Belman, M. J. and G. A. Gaesser. Ventilatory muscle training in the elderly. *J. Appl. Physiol.* 64:899–905, 1988.
5. Blumenthal, J. A., C. F. Emery, D. J. Madden, et al. Cardiovascular and behavioral effects of aerobic exercise training in healthy older men and women. *J. Gerontol.* 44:M147–M157, 1989.
6. Boone, T., K. L. Frentz, and H. R. Boyd. Carotid palpation at two exercise intensities. Med. Sci. Sports Exerc. 17:705–709, 1985.
7. Council on Scientific Affairs. Exercise programs for the elderly. *J.A.M.A.* 252:544–546, 1984.
8. Cunningham, D. A., E. A. Nancekievill, D. H. Paterson, A. P. Donner, and P. A. Rechnitzer. Ventilation threshold and aging. *J. Gerontol.* 40:703–709, 1985.
9. Cunningham, D. A., P. A. Rechnitzer, J. H. Howard, and A. P. Donner. Exercise training of men at retirement: a clinical trial. *J. Gerontol.* 42:17–23, 1987.
10. Davis, J. Anaerobic threshold. Review of the concept and directions for future research. *Med. Sci. Sports Exerc.* 17:6–18, 1985.
11. Davis, J., M. H. Frank, B. J. Whipp, and K. Wasserman. Anaerobic threshold alterations caused by endurance training in middle-aged men. *J. Appl. Physiol.* 46:1039–1046, 1979.
12. de Vries, H. A. Physiological effects of an exercise training regimen upon men aged 52 to 88. *J. Gerontol.* 25:325–336, 1970.
13. Dixon, W. J. (Ed.). *Statistics. BMDP Statistical Software.* Berkeley: University of California Press, 1981.
14. Dixon, W. J. and S. J. Massey. *Introduction to Statistical Analysis*, 4th Ed. New York: McGraw-Hill, 1983, p. 124.
15. Foster, V. L., G. J. E. Hume, W. C. Byrnes, A. L. Dickinson, and S. J. Chatfield. Endurance training for elderly women: moderate vs. low intensity. *J. Gerontol.* 44:M184–M188, 1989.
16. Gaesser, G. A. and R. G. Rich. Effects of high- and low-intensity exercise training on aerobic capacity and blood lipids. *Med. Sci. Sports Exerc.* 16:269–274, 1984.
17. Gossard, D., W. L. Haskell, C. B. Taylor, et al. Effects of low- and high-intensity home-based exercise training on functional capacity in healthy middle-aged men. *Am. J. Cardiol.* 57:446–449, 1986.
18. Hagberg, J. M., J. E. Graves, M. Limacher, et al. Cardiovascular responses of 70- to 79-yr-old men and women to exercise training. *J. Appl. Physiol.* 66:2589–2594, 1989.
19. Hohorst, H. L-(+)-Lactate: determination with lactic dehydrogenase and DPN. In: *Methods of Enzymatic Analysis*, H. V. Bergmeyer (Ed.). New York: Academic Press, 1963, pp. 266–270.
20. Holloszy, J. O. and E. F. Coyle. Adaptations of skeletal muscle to endurance exercise and their metabolic consequences. *J. Appl. Physiol.* 56:831–838, 1984.
21. Jones, N. L. and E. J. M. Campbell. *Clinical Exercise Testing.* Philadelphia: W. B. Saunders Co., 1982, pp. 231–243.
22. Larson, E. B. and R. A. Bruce. Exercise and aging. *Ann. Intern. Med.* 105:783–785, 1986.
23. Legge, B. J. and E. W. Banister. The Åstrand-Ryhming nomogram revisited. *J. Appl. Physiol.* 61:1203–1209, 1986.
24. Meredith, C. N., W. R. Frontera, E. C. Fisher, et al. Peripheral effects of endurance training in young and old subjects. *J. Appl. Physiol.* 66:2844–2849, 1989.
25. Niinimaa, V. and R. J. Shephard. Training and oxygen conductance in the elderly. I. The respiratory system. *J. Gerontol.* 33:354–361, 1978.
26. Poole, D. C. and G. A. Gaesser. Response of ventilatory and lactate thresholds to continuous and interval training. *J. Appl. Physiol.* 58:1115–1121, 1985.
27. Seals, D. R., J. M. Hagberg, B. F. Hurley, A. A. Ehsani, and J. O. Holloszy. Endurance training in older men and women. I. Cardiovascular responses to exercise. *J. Appl. Physiol.* 57:1024–1029, 1984.
28. Seals, D. R., B. F. Hurley, J. Schultz, and J. M. Hagberg. Endurance training in older men and women. II. Blood lactate response to submaximal exercise. *J. Appl. Physiol.* 57:1030–1033, 1984.
29. Sidney, K. H. and R. J. Shephard. Frequency and intensity of exercise training for elderly subjects. *Med. Sci. Sports* 10:125–131, 1978.
30. Stamford, B. A. Exercise and the elderly. In: *Exercise and Sport Sciences Reviews*, Vol. 16, K. B. Pandolf (Ed.). New York: Macmillan, 1988, pp. 341–379.
31. Suominen, H., E. Heikkinen, and T. Parkatti. Effects of 8 weeks' physical training on muscle and connective tissue of the M. vastus lateralis in 69-year-old men and women. *J. Gerontol.* 32:33–37, 1977.
32. Thomas, S. G., D. A. Cunningham, P. A. Rechnitzer, A. P. Donner, and J. H. Howard. Determinants of the training response in elderly men. *Med. Sci. Sports Exerc.* 17:667–672, 1985.
33. Thomas, S. G., D. A. Cunningham, J. Thompson, and P. A. Rechnitzer. Exercise training and "ventilation threshold" in elderly. *J. Appl. Physiol.* 59:1472–1476, 1985.