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Age, sex, race, initial fitness, and response to training: the HERITAGE Family Study

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Skinner, James S., Artur Jaskólski, Anna Jaskólska, Joanne Krasnoff, Jacques Gagnon, Arthur S. Leon, D. C. Rao, Jack H. Wilmore, and Claude Bouchard. Age, sex, race, initial fitness, and response to training: the HERITAGE Family Study. *J Appl Physiol* 90: 1770–1776, 2001.—Effects of age, sex, race, and initial fitness on training responses of maximal O_2 uptake ($\dot{V}O_{2\,max}$) are unclear. Data were available on 435 whites and 198 blacks (287 men and 346 women), aged 17–65 yr, before and after standardized cycle ergometer training. Individual responses varied widely, but $\dot{V}O_{2\,max}$ increased significantly for all groups. Responses by men and women and by blacks and whites of all ages varied widely. There was no sex difference for change (Δ) in $\dot{V}O_{2\,max}$ (ml·kg^{-1}·min^{-1}); women had lower initial values and greater relative (%) increases. Blacks began with lower values but had similar responses. Older subjects had a lower Δ but a similar percent change. Baseline $\dot{V}O_{2\,max}$ correlated nonsignificantly with $\Delta\dot{V}O_{2\,max}$ but significantly with percent change. There were high, medium, and low responders in all age groups, both sexes, both races, and all levels of initial fitness. Age, sex, race, and initial fitness have little influence on $\dot{V}O_{2\,max}$ response to standardized training in a large heterogeneous sample of sedentary black and white men and women.

trainability; maximal oxygen uptake

IT IS NOT CLEAR WHETHER and how much age, sex, race, and initial fitness affect trainability (i.e., improvement in cardiorespiratory endurance after training), as measured by increases in maximal O_2 uptake ($\dot{V}O_{2\,max}$). A review of the literature suggests that there is either no difference (1, 11, 13) or a reduction (17, 18, 23) in trainability with increasing age. A few studies (2, 16) suggest that women are less trainable than men, but recent evidence (1, 9) suggests little or no difference between the sexes in trainability of $\dot{V}O_{2\,max}$. There appears to be little difference between blacks and whites in $\dot{V}O_{2\,max}$ before training (5), but we failed to find any published studies directly comparing their responses to the same training program. Relative to initial fitness, results from earlier studies (6, 15) showed that subjects with initially lower levels of $\dot{V}O_{2\,max}$ had larger increases in $\dot{V}O_{2\,max}$ after training than did those with higher levels at baseline. Later studies on older black and white men and women (9) and on a large sample of whites (3) failed to confirm these observations.

In most of the previously cited studies, the numbers of subjects who may have completed training programs that differed in intensity, duration, and/or frequency were small; this was true for individual training sessions, as well as for the total program. In addition, most of these studies focused on the contribution of only one or two of the variables under consideration in the present report, i.e., age, sex, race, and initial fitness, on the response of $\dot{V}O_{2\,max}$ to training. None have looked at all four factors simultaneously. To investigate the contribution of all four factors, it is necessary to have a large number of sedentary black and white men and women of different ages complete a prolonged exercise training program with the same frequency, duration, and relative intensity of exercise and then compare the response of $\dot{V}O_{2\,max}$; this was possible using data from the HERITAGE Family Study.

The HERITAGE Family Study is a consortium of five laboratories that has studied the role of the genotype in the cardiovascular and metabolic responses to aerobic exercise training and the contribution of inherited factors to the changes brought about by regular exercise on aerobic fitness and on several risk factors for cardiovascular disease and type 2 diabetes. The design of this study has been described in detail elsewhere (4). Although it was primarily designed to be a genetic study, the large number of subjects who performed the

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same standardized training program allowed us to investigate a number of nongenetic aspects. Thus the purpose of the present ancillary study was to determine the contributions of sex, race, age, and initial fitness on the response of $\dot{V}O_{2\,max}$ to a standardized exercise training program.

METHODS

Sample. The HERITAGE subjects came from families that included the natural mother and father (≤65 yr of age) and their natural children (17–40 yr of age). The white families had at least three offspring; the black families were smaller. Complete data were available from 633 subjects studied at the four clinical centers [Arizona State University (Indiana University since January 1996), Laval University, the University of Minnesota, and the University of Texas at Austin]. The number of participants in subgroups based on age, sex, and race is shown in Table 1. Subjects were healthy, sedentary, and met a number of inclusion and exclusion criteria (4). They also passed a medical examination by a physician that included a 12-lead electrocardiogram obtained at rest, during submaximal exercise, and during a maximal exercise test. The study protocol was previously approved by the committee to protect human subjects in research studies at each of the four clinical centers. Written informed consent was obtained from each subject.

$\dot{V}O_{2\,max}$ tests. Two maximal exercise tests on separate days before and after the 20-wk training program were performed using a cycle ergometer (model 800S, SensorMedics, Yorba Linda, CA) connected to a metabolic measurement cart (model 2900, SensorMedics). An electrocardiogram machine was used to monitor heart rate (HR). During each exercise stage, gas exchange variables (O_2 uptake, CO_2 output, minute ventilation, and respiratory exchange ratio) were recorded as a rolling average of three 20-s intervals. The criteria for $\dot{V}O_{2\,max}$ were as follows: respiratory exchange ratio >1.1, plateau in O_2 uptake (change of <100 ml/min in the last 3 consecutive 20-s averages), and an HR within 10 beats/min of the maximal level predicted by age. All subjects achieved a $\dot{V}O_{2\,max}$ by at least one of these criteria before and after training. The majority of the exercise tests were conducted at the same time of day, with ≥48 h between tests.

To accommodate subjects of different body size and fitness level, the initial power output (PO) for the first maximal test was 40–50 W for 3 min followed by increases of 10–25 W at 2-min intervals until volitional exhaustion; this was done to increase the number of stages the subjects could perform before reaching their maximum, inasmuch as results of this test were used to select the POs for the subsequent tests. During the second maximal test, subjects exercised for 8–12 min at 50 W, 8–12 min at 60% $\dot{V}O_{2\,max}$, and 3 min at 80% $\dot{V}O_{2\,max}$. In those cases where 50 W was >60% $\dot{V}O_{2\,max}$, the PO associated with 60% was done first followed by that associated with 50 W. The resistance was then increased to the highest PO attained in the first maximal test. If subjects were able to pedal after 2 min, PO was increased each 2 min thereafter until they reached volitional fatigue.

Table 1. *Number of participants in the HERITAGE Family Study with complete data on all variables being studied and classified by age, sex, and race*

	Younger (17–29 yr)	Middle (30–49 yr)	Older (50–65 yr)	Total
Black men	37	33	8	78
Black women	64	49	7	120
Blacks	101	82	15	198
White men	101	49	59	209
White women	113	69	44	226
Whites	214	118	103	435
Men	138	82	67	287
Women	177	118	51	346
Total	315	200	118	633

The reproducibility of the maximal tests was determined, and an intraclass correlation coefficient of 0.97 and a coefficient of variation of 5% were found. There were no differences in reproducibility among the four clinical centers (19).

Exercise training program. The training program was done on cycle ergometers (Universal Aerobicycle, Cedar Rapids, IA) that were interfaced with a computer system (Universal Gym Mednet, Cedar Rapids, IA) to maintain a constant programmed training HR by modifying PO. Participants exercised three times per week for 20 wk, beginning at 30 min/session and progressing to 50 min/session during the last 6 wk. Exercise intensity increased from the HR associated with 55% $\dot{V}O_{2\,max}$ measured at baseline to that associated with 75% $\dot{V}O_{2\,max}$ during the last 8 wk of training. All training sessions were supervised on-site. More detailed descriptions can be found elsewhere (20).

Compliance to training. From a total of 855 eligible participants, 742 were considered to have complied with the study, because they had finished the training program and had complete or nearly complete data on all tests before and after training. These 742 participants finished ≥95% of the 60 required training sessions (i.e., ≥57 sessions). The 633 participants in the present study were taken from these 742 because they had complete data on all variables being studied. One hundred thirteen participants did not complete the study for a variety of reasons: 6 had an injury or illness, 7 became pregnant, 1 relocated, 22 voluntarily refused to continue, 10 were dropped because 1 or more members of the family dropped out or were dropped, rendering the rest of the family ineligible by our criteria, 18 missed too many training sessions, 33 were not able to complete all the tests, and 16 did not complete the study for “other” reasons.

Body composition measurements. Body density was determined by underwater weighing (24). Reproducibility of the body density, fat mass, and pulmonary residual volume measurements was high, with intraclass correlation coefficients between 0.97 and 1.00. There were no differences in reproducibility among the four clinical centers (24).

$\dot{V}O_{2\,max}$ and changes in $\dot{V}O_{2\,max}$. $\dot{V}O_{2\,max}$ measured in ml/min is a good indicator of the capacity of the cardiorespiratory system to transport O_2 and of the muscle system to utilize it. As such, it is a good indicator of the power of the system. However, there can be a problem with use of ml/min in subjects who vary markedly in body mass. In the present study, individual values for body mass ranged from 40 to 138 kg, and values for $\dot{V}O_{2\,max}$ ranged from 1,166 to 4,434 ml/min. A better comparison would be the relative change (%) in $\dot{V}O_{2\,max}$, which was the method used in most of the studies reviewed in this report. To partially compensate for the large variation in body mass, $\dot{V}O_{2\,max}$ can be expressed as $ml \cdot kg^{-1} \cdot min^{-1}$; this is usually used as an index of aerobic fitness and is useful for comparing different groups of subjects that vary in body mass. The main tissue in the body that uses O_2 during exercise is muscle, and an estimate of muscle can be obtained from the fat-free mass (FFM). Because men and women have differences in body mass, as well as in the composition of that mass, another way to compensate for these differences is to express $\dot{V}O_{2\,max}$ as $ml \cdot kg\ FFM^{-1} \cdot min^{-1}$. A problem with both of these ways to express $\dot{V}O_{2\,max}$

is that changes in body mass or FFM make it difficult to make comparisons within the same person; i.e., whereas training may influence the ability of the body to transport and utilize O_2 (numerator), there also may be changes in body mass or FFM that affect the denominator. Although there are advantages and disadvantages of each method, $\dot{V}O_{2\,max}$ will be expressed in all three ways for a more complete picture of the changes.

Statistics. Descriptive statistics (means ± SD) of all dependent variables were calculated for all subjects and by sex, race, age group, sex × race, and sex × race × age group. A repeated-measures ANOVA was used to compare the changes in $\dot{V}O_{2\,max}$ with training. A one-way ANOVA was used to examine differences in group means. A Scheffé post hoc test was used to identify significant differences among the three age groups. A 2 × 2 × 3 (sex × race × age group) factorial ANOVA was used to identify significant interactions; no significant interactions were found. For the purposes of this study, trainability was defined as the absolute (Δ) and relative (%) change in $\dot{V}O_{2\,max}$ after the training program. Because there were individual changes in body mass (22) and in FFM, the means for $\dot{V}O_{2\,max}$ (ml·kg^{-1}·min^{-1} and ml·kg FFM^{-1}·min^{-1}, respectively) were adjusted by an analysis of covariance, with the Δbody mass or ΔFFM as the covariate. A correlational analysis was used to assess relationships between baseline $\dot{V}O_{2\,max}$ (ml·kg^{-1}·min^{-1}) and changes in $\dot{V}O_{2\,max}$ (ml·kg^{-1}·min^{-1}) after training. All family members were included in the analyses, which brings up the issue of nonindependence of the observations. Although nonindependence of members within families is generally considered to inflate the effective sample size and thus increase type I error (more false positives), extensive simulations have shown that ignoring the within-family dependencies does not invalidate the results (M. A. Province, personal communication). The level of statistical significance for all tests was set at $P < 0.01$.

RESULTS

Descriptive characteristics. Age, physical characteristics, and maximal HR of the 633 subjects with complete data can be found in Table 2 for the total group and for subgroups sorted by age, sex, and race. As expected, women were shorter, weighed less, and had more body fat than men ($P < 0.01$). Black women weighed more and had more body fat than white women ($P < 0.01$). After training, body mass was significantly reduced in men (0.4 kg) and in subjects aged 30–49 yr (0.6 kg). There were no significant mean FFM changes in any group.

Before and after training, maximal HR was higher ($P < 0.01$) in the youngest than in the middle age group and higher ($P < 0.01$) in the middle than in the oldest age group. After training, there was a small (2.8 beats/min) but statistically significant reduction in maximal HR in white men ($P < 0.01$). Probably as a result, men (2.1 beats/min) and whites (1.1 beats/min) also had small but significant decreases ($P < 0.01$). Men in the youngest age group also had a small (1.3 beats/min) but significant ($P < 0.01$) drop after training. There were no changes in maximal HR after training in blacks, women, or the two older age groups. The physiological significance of these small reductions in maximal HR is unclear, but the differences probably reached statistical significance only because of the large number of subjects in the various subgroups.

$\dot{V}O_{2\,max}$. When expressed as ml/min, ml·kg^{-1}·min^{-1}, and ml·kg FFM^{-1}·min^{-1}, $\dot{V}O_{2\,max}$ was lower in black men and women than in white men and women before and after training ($P < 0.01$; Table 3). As expected,

Table 2. *Age, characteristics, and maximal heart rate from subjects in the HERITAGE Family Study sorted by race, sex, and age*

Group	*n*	Age, yr	Height, cm	Body Mass, kg Pre	Body Mass, kg Post	Fat-Free Mass, kg Pre	Fat-Free Mass, kg Post	Body Fat, %	Maximum Heart Rate, beats/min Pre	Maximum Heart Rate, beats/min Post
Race and sex										
Black men	78	33.9 ± 11.7	176.4 ± 6.6	83.6 ± 15.9	83.0 ± 15.5	63.7 ± 8.4	64.0 ± 8.3	22.9 ± 7.2	182.1 ± 14.1	181.9 ± 13.3
White men	209	36.4 ± 15.0	177.9 ± 6.4	83.6 ± 15.7	83.3 ± 15.4	63.5 ± 7.8	64.0 ± 7.9	22.8 ± 9.1	186.6 ± 14.2*	183.8 ± 13.4
Black women	120	32.1 ± 10.7	162.5 ± 6.4	73.7 ± 15.8†	73.5 ± 15.6†	46.2 ± 5.5	46.2 ± 5.5	35.8 ± 8.8†	183.3 ± 14.4	184.5 ± 12.2
White women	226	34.5 ± 13.7	163.8 ± 6.5	66.3 ± 13.2	66.1 ± 12.9	45.5 ± 5.1	45.9 ± 5.2	29.9 ± 9.7	185.2 ± 13.2	185.6 ± 12.2
Race										
Blacks	198	32.8 ± 11.1	167.9 ± 9.4	77.6 ± 16.5	77.3 ± 16.2	53.1 ± 10.9	53.4 ± 10.8	30.7 ± 10.3†	182.8 ± 14.3	183.5 ± 12.6
Whites	435	35.4 ± 14.4	170.6 ± 9.5	74.6 ± 16.8	74.4 ± 16.5	54.1 ± 11.2	54.6 ± 11.2	26.5 ± 10.0	185.8 ± 13.7*	184.7 ± 12.8
Sex										
Men	287	35.7 ± 14.2	177.5 ± 6.4	83.6 ± 15.7*†	83.2 ± 15.4†	63.6 ± 8.0†	64.0 ± 8.0†	22.8 ± 8.6†	185.4 ± 14.3*	183.3 ± 13.3
Women	346	33.7 ± 12.8	163.4 ± 6.5	68.9 ± 14.6	68.7 ± 14.3	45.7 ± 5.3	46.1 ± 5.3	31.9 ± 9.8	184.5 ± 13.6	185.2 ± 12.2
Age										
17–29 yr	315	23.1 ± 4.0	170.2 ± 9.6	71.4 ± 16.6	71.3 ± 16.4	53.6 ± 11.1	54.2 ± 11.1	23.8 ± 10.3	192.5 ± 9.3*	191.2 ± 8.8
30–49 yr	200	40.3 ± 6.0	168.9 ± 9.6	79.5 ± 16.4*	78.9 ± 16.0	54.0 ± 11.4	54.3 ± 11.4	31.5 ± 8.5	180.5 ± 12.7	180.7 ± 11.2
50–65 yr	118	55.7 ± 4.1‡	170.1 ± 9.3	80.2 ± 15.0§	79.8 ± 14.7§	54.0 ± 10.7	54.3 ± 10.7	32.3 ± 8.8§	172.1 ± 13.7‡	172.0 ± 12.2‡
All subjects	633	34.6 ± 13.5	169.8 ± 9.6	75.6 ± 16.8	75.3 ± 15.6	53.8 ± 11.1	54.2 ± 11.1	27.8 ± 10.3	184.9 ± 13.9	184.3 ± 12.8

Values are means ± SD. Pre and Post, before and after training. *Different from Post ($P < 0.01$). †Difference between race and/or sex groups ($P < 0.01$). ‡All age groups different from each other ($P < 0.01$, by ANOVA). §17–29 yr different from older groups ($P < 0.01$, by ANOVA), but no difference between 2 older groups.

Table 3. *$\dot{V}O_{2max}$ data from participants in the HERITAGE Family Study*

		$\dot{V}O_{2max}$											
		ml/min				ml·kg^{-1}·min^{-1}				ml·kg FFM^{-1}·min^{-1}			
Group	*n*	Pre	Post	Δ	%	Pre	Post[g]	Δ	%	Pre	Post[g]	Δ	%
Race and sex													
Black men	78	2,732±484[e,f]	3,150±502[f]	418±198	15.9±8.0	33.3±6.1[e,f]	38.7±6.5[f]	5.3±2.3	16.2±7.7	42.9±5.4[e,f]	49.4±5.7[f]	6.4±2.9	15.3±7.2
White men	209	3,037±591[e]	3,490±653	453±236	15.3±8.1	37.3±9.0[e]	43.0±9.7	5.6±3.1	15.7±8.8	47.9±7.5[e]	54.5±8.0	6.7±3.6	14.4±8.1
Black women	120	1,778±354[e,f]	2,110±344[f]	332±144	19.9±10.2	24.7±5.4[e,f]	29.5±5.5[f]	4.7±2.2	20.3±10.9	38.5±5.9[e,f]	45.4±5.6[f]	6.9±3.1	18.8±10.0
White women	226	1,921±354[e]	2,271±420	350±185	18.6±9.4	29.8±6.8[e]	35.3±7.7	5.5±3.0	19.1±10.4	42.2±6.2[e]	49.4±7.0	7.2±3.8	17.5±9.5
Race													
Blacks	198	2,154±621[e,f]	2,520±655[f]	366±172	18.3±9.6	28.1±7.1[e,f]	33.0±7.4[f]	4.9±2.3[e]	18.7±9.9	40.2±6.1[e,f]	46.9±5.9[f]	6.7±3.0	17.4±9.1
Whites	435	2,457±738[e]	2,856±817	399±217	17.0±9.0	33.5±8.8[e]	39.0±9.5	5.5±3.0	17.5±9.8	44.9±7.4[e]	51.9±7.9	6.9±3.7	16.0±9.0
Sex													
Men	287	2,954±580[e,f]	3,398±633[f]	444±226[f]	15.5±8.1[f]	36.2±8.5[e,f]	41.8±9.1[f]	5.5±2.9	15.9±8.5[e]	46.5±7.3[e,f]	53.1±7.8[f]	6.6±3.4	14.6±7.9[f]
Women	346	1,871±360[e]	2,215±402	344±172	19.0±9.7	28.1±6.8[e]	33.2±7.5	5.2±2.8	19.5±10.6	40.9±6.3[e]	48.0±6.8	7.1±3.6	17.9±9.7
Age													
17–29 yr	315	2,531±748[e]	2,928±819	397±216	16.5±8.9	35.9±8.7[e]	41.6±9.2	5.7±3.1	16.9±9.4	46.7±7.0[e]	53.6±7.2	6.9±3.7	15.3±8.7
30–49 yr	200	2,262±685[e]	2,664±752	402±189	18.8±9.1	28.5±6.2[e]	33.9±7.0	5.3±2.6	19.3±9.8	41.4±6.3[e]	48.7±6.8	7.3±3.3	18.1±9.0
50–65 yr	118	2,083±550[a,e]	2,427±604[a]	344±192[b]	17.5±9.7	26.2±6.2[c,e]	30.7±6.6[a]	4.5±2.3[b]	17.9±10.4	38.4±5.6[a,e]	44.6±5.9[a]	6.2±3.3	16.7±9.7[d]
All subjects	633	2,362±717[e]	2,751±785	389±204	17.4±9.2	31.8±8.6[e]	37.1±9.3	5.4±2.8	17.8±9.3	43.5±7.3[e]	50.3±7.7	6.9±3.5	16.5±9.1

Values are means ± SD. $\dot{V}O_{2max}$, maximal O_2 uptake. FFM, fat-free mass. [a] All age groups different from each other ($P < 0.01$ by ANOVA); [b] 50–65 yr different from younger groups ($P < 0.01$ by ANOVA); no difference between 2 younger groups; [c] 17–29 yr different from older groups ($P < 0.01$, by ANOVA); no difference between 2 older groups; [d] 31–49 yr different from youngest group ($P < 0.01$, by ANOVA), but not from the oldest group; no difference between youngest and oldest groups. [e] Different from POST ($P < 0.01$); [f] Difference between race and/or sex groups ($P < 0.01$); [g] means adjusted by analysis of covariance for changes in body mass or FFM.

women also had lower values than men before and after training ($P < 0.01$). In terms of $\dot{V}O_{2max}$ expressed as ml/min before and after training, the youngest age group had higher ($P < 0.01$) values than the middle age group, which had higher values ($P < 0.01$) than the oldest group. For $\dot{V}O_{2max}$ expressed as ml·kg^{-1}·min^{-1} before training, the youngest age group had higher values ($P < 0.01$) than the other two older age groups, but there was no difference between the two older groups. After training, the youngest group had higher values ($P < 0.01$) than the middle age group, which had higher values ($P < 0.01$) than the oldest group. Relative to $\dot{V}O_{2max}$ expressed as ml·kg FFM^{-1}·min^{-1} before and after training, the youngest group had higher ($P < 0.01$) values than the middle age group, which had higher values ($P < 0.01$) than the oldest group.

After training, mean values for $\dot{V}O_{2max}$ expressed as ml/min, ml·kg^{-1}·min^{-1}, and ml·kg FFM^{-1}·min^{-1} increased significantly ($P < 0.01$) in the total group, as well as in each subgroup classified by age, sex, or race. The mean $\Delta\dot{V}O_{2max}$ was 389 ml/min for the total group, ranging from means of 332 to 453 ml/min in the subgroups. The mean $\Delta\dot{V}O_{2max}$ was 5.4 ml·kg^{-1}·min^{-1} for the total group, varying from means of 4.5 to 5.7 ml·kg^{-1}·min^{-1} in the subgroups. The mean $\Delta\dot{V}O_{2max}$ was 6.9 ml·kg FFM^{-1}·min^{-1} for the total group, varying from means of 6.2 to 7.3 ml·kg FFM^{-1}·min^{-1} in the subgroups.

For the total group, the mean relative increase in $\dot{V}O_{2max}$ expressed in ml/min, ml·kg^{-1}·min^{-1}, and ml·kg FFM^{-1}·min^{-1} was 17.4, 17.8, and 16.5%, respectively. These relative increases ranged from 15.5 to 19.9% for $\dot{V}O_{2max}$ expressed as ml/min, from 15.9% to 20.3% for $\dot{V}O_{2max}$ expressed as ml·kg^{-1}·min^{-1}, and from 14.4 to 18.8% for $\dot{V}O_{2max}$ expressed as ml·kg FFM^{-1}·min^{-1} in the subgroups.

Effect of age. There was a significant ($P < 0.01$) age group difference in response to training. When expressed as ml/min, ml·kg^{-1}·min^{-1}, and ml·kg FFM^{-1}·min^{-1}, $\Delta\dot{V}O_{2max}$ was smaller for subjects aged 50–65 yr than for the two younger groups. When expressed in ml/min and ml·kg^{-1}·min^{-1}, there was no significant difference in percent increase in $\dot{V}O_{2max}$ among the three age groups. However, when expressed in ml·kg FFM^{-1}·min^{-1}, the increase in $\dot{V}O_{2max}$ was larger in the 31- to 49-yr age group than in the youngest group but was not different from the oldest group; there was no difference between the oldest and youngest age groups. The correlation between age and change in $\dot{V}O_{2max}$ expressed in ml·kg^{-1}·min^{-1} was low ($r = -0.15$). Although this relationship was statistically significant ($P < 0.01$), age was associated with <1% of the rise in $\dot{V}O_{2max}$.

Effect of sex. In relative terms, women had a significantly greater mean percent rise in $\dot{V}O_{2max}$ ($P < 0.01$) than men when $\dot{V}O_{2max}$ was expressed as ml/min, ml·kg^{-1}·min^{-1}, or ml·kg FFM^{-1}·min^{-1}. When the mean increase was expressed as $\Delta\dot{V}O_{2max}$, there was no difference between the sexes for men in terms of ml·kg^{-1}·min^{-1} or ml·kg FFM^{-1}·min^{-1}, but men had a larger increase ($P < 0.01$) when $\Delta\dot{V}O_{2max}$ was expressed as ml/min.

Effect of race. There was no significant difference between blacks and whites in the mean increase in $\dot{V}O_{2\,max}$ with training, whether this was expressed in relative terms or when the mean $\Delta\dot{V}O_{2\,max}$ was expressed as ml/min or ml·kg FFM^{-1}·min^{-1}. However, when the mean $\Delta\dot{V}O_{2\,max}$ was expressed as ml·kg^{-1}·min^{-1}, blacks had a significantly lower rise ($P < 0.01$).

Effect of initial fitness. The correlation ($r = 0.08$) between baseline $\dot{V}O_{2\,max}$ expressed as ml·kg^{-1}·min^{-1} and $\Delta\dot{V}O_{2\,max}$ expressed as ml·kg^{-1}·min^{-1} was not statistically significant. There were high, medium, and low responders over a wide range of baseline values (Fig. 1). When the baseline values were correlated with relative (%) change in $\dot{V}O_{2\,max}$, there was a significant ($P < 0.01$) correlation coefficient of −0.37; i.e., similar Δs were associated with greater relative changes for those with lower initial values.

DISCUSSION

Effect of age. Aging has been characterized by an impaired ability to adapt to and recover from physiological stressors (18). Training, on the other hand, has been associated with an increased tolerance (adaptation) to the physiological stress of exercise. In a recent position stand, it was the conclusion of the American College of Sports Medicine (1) that trainability of $\dot{V}O_{2\,max}$ is not reduced with age. However, with the exception of the study by Kohrt et al. (9) on 110 men and women aged 60–71 yr, the other studies cited in the position stand had many fewer subjects. The present study is the largest exercise training study to date ($n = 633$) and encompasses individuals from 17 to 65 yr of age. Although the oldest group had a smaller $\Delta\dot{V}O_{2\,max}$, they also started with lower levels, and there was no difference in response in relative terms (i.e., percent increase). When Kohrt et al. assigned their subjects to three age groups (60–62, 63–66, and 67–71 yr), they also found no significant differences among the groups in the relative increase in $\dot{V}O_{2\,max}$ with training (21, 19, and 18%, respectively).

Kohrt et al. (9) looked at the relationship between age and change in $\dot{V}O_{2\,max}$ in their group of 110 older subjects and found a nonsignificant correlation coefficient of −0.13. This is similar to the coefficient of −0.15 found with 633 subjects in the present study. Even though the coefficient in the present study was significantly different from zero because of the large number of subjects, it would appear to have little practical significance, accounting for <1% of the variance in the training response of $\dot{V}O_{2\,max}$.

The training program used by Kohrt et al. (9) was similar in intensity and frequency to the program in the present study but lasted longer (9–12 mo vs. 20 wk). The average increase in $\dot{V}O_{2\,max}$ (ml/min) found by Kohrt et al. was 24%, but there was a wide variation in the amount of change (0–58%). This is similar to the average increase of 17% (range −5 to 56%) found in the present study. Because of the similarity of training programs and the results from these two large studies, data from the 110 subjects were obtained from the study of Kohrt et al., and the relationship between age and change in $\dot{V}O_{2\,max}$ was computed. The correlation coefficient for the combined 743 subjects ranging in age from 17 to 71 yr was −0.08; this was not significantly different from zero. Thus, when different age groups are compared, it appears that age has little or no significant effect on the response of $\dot{V}O_{2\,max}$ to training.

One comment made in the position stand by the American College of Sports Medicine (1) was that older participants may need more time to adapt to endurance training. Because the subjects in the present study were tested only at the beginning and end of the 20-wk training program, it is not possible to test this hypothesis. However, according to the present data, in subjects given ≥20 wk to adapt, the trainability of $\dot{V}O_{2\,max}$ in older subjects does not differ significantly from that in younger subjects.

Effect of sex. A position stand of the American College of Sports Medicine (1) concluded that, "Despite many biological differences, there appear to be no gender differences in the magnitude of improvement in $\dot{V}O_{2\,max}$ with endurance training." No sex-related differences in the response of $\dot{V}O_{2\,max}$ to training were seen whether these studies involved young (11), middle-aged (12), old (9), or very old (8) men and women. The findings of the present study support these conclusions. Before and after training, women in the present study had a significantly lower $\dot{V}O_{2\,max}$ (ml/min); this was related to the fact that they weighed ~15 kg less than the men. Thus, when a significantly smaller $\Delta\dot{V}O_{2\,max}$ (23% lower than that seen in men) was divided by an even greater difference in baseline $\dot{V}O_{2\,max}$ (40% lower than that seen in men), the resulting relative increase was significantly greater in women. Women in the present study had a similar $\Delta\dot{V}O_{2\,max}$ (ml·kg^{-1}·min^{-1} and ml·kg FFM^{-1}·min^{-1}) but began with significantly lower values, and the resulting relative increases were significantly higher. When the individual values for $\Delta\dot{V}O_{2\,max}$ (ml·kg^{-1}·min^{-1}) were plotted for men and women aged 17–65 yr (Fig. 2), there was no apparent difference between the sexes; i.e., there were high, medium, and low responders in

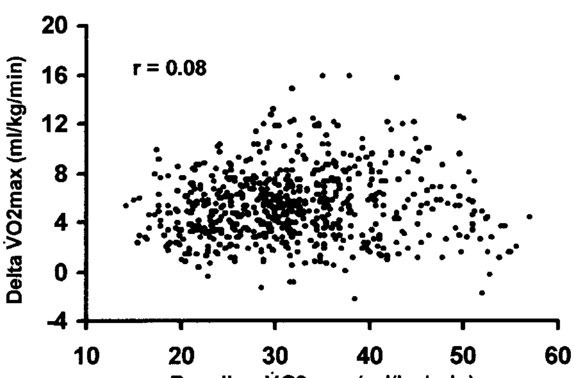

Fig. 1. Relationship between baseline maximal O_2 uptake ($\dot{V}O_{2max}$) and change (Δ) in $\dot{V}O_{2max}$ in 633 subjects in the HERITAGE Family Study.

both sexes at all ages. Thus it appears that sex has no significant effect on the response of $\dot{V}O_{2\,max}$ to endurance training.

Effect of race. When comparative studies have been done with various races, there tends to be little difference in $\dot{V}O_{2\,max}$ when such factors as age, sex, body size, and level of habitual activity are considered. For example, $\dot{V}O_{2\,max}$ (ml·kg^{-1}·min^{-1}) was not different between black and white men in the rural South in the United States (14), among male white subjects, Bantus, and Bushmen in South Africa (25), between white and Bantu male middle-distance athletes (10), among men from various Bantu tribes (26), or between male and female Tanzanian African and European white subjects (7). When subjects were matched for age, body mass index, and habitual activity, Ama (unpublished observations cited in Ref. 5) found that male African black subjects had a lower $\dot{V}O_{2\,max}$ than white French-Canadian subjects (41.6 vs. 46.0 ml·kg^{-1}·min^{-1}), but they also had a lower maximal HR, suggesting that the African men were not at their maximum. Even when racial differences are found, there is a considerable overlap in aerobic performance. As a result, Boulay et al. (5) concluded that there is no valid or reliable evidence of clear racial differences in $\dot{V}O_{2\,max}$. We have not found any studies comparing the trainability of $\dot{V}O_{2\,max}$ for blacks and whites.

In the present study, our sample of sedentary black men and women had lower baseline values of $\dot{V}O_{2\,max}$ (ml/min, ml·kg^{-1}·min^{-1}, and ml·kg FFM^{-1}·min^{-1}) than the sedentary white men and women; the reasons for these initial differences are not clear. Although there was no difference in $\Delta\dot{V}O_{2\,max}$ (ml/min or ml·kg FFM^{-1}·min^{-1}) after training, blacks had a significantly lower $\Delta\dot{V}O_{2\,max}$ (ml·kg^{-1}·min^{-1}). When expressed as the percent increase in $\dot{V}O_{2\,max}$, there were no significant differences between races in terms of ml/min, ml·kg^{-1}·min^{-1}, or ml·kg FFM^{-1}·min^{-1}. This was also apparent when individual $\Delta\dot{V}O_{2\,max}$ (ml·kg^{-1}·min^{-1}) values were plotted for 17- to 65-yr-old blacks and whites (Fig. 3). As was seen with men and women, there were high, medium, and low responders in both races at all ages. Thus our data appear to confirm previous observations that race has no significant effect on the response of $\dot{V}O_{2\,max}$ to endurance training.

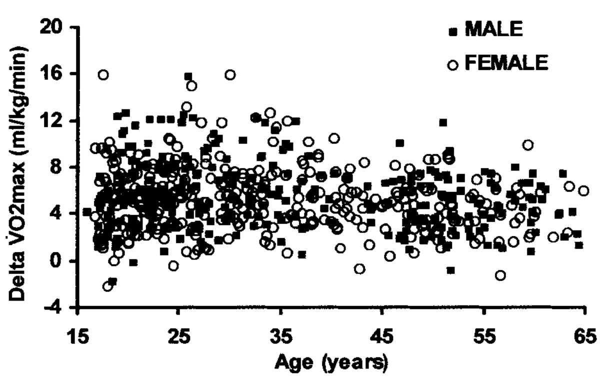

Fig. 2. Change in $\dot{V}O_{2max}$ at various ages in 287 men and 346 women in the HERITAGE Family Study.

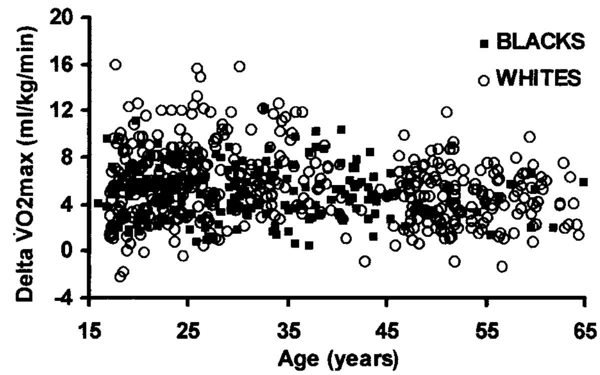

Fig. 3. Change in $\dot{V}O_{2max}$ at various ages in 198 blacks and 435 whites in the HERITAGE Family Study.

Effect of initial fitness. Although a few studies (6, 15) have suggested that initial fitness level can affect the response to training, other studies (3, 9, 21) have not reached the same conclusion. Thomas et al. (21) found a nonsignificant correlation (r = 0.20) between initial $\dot{V}O_{2\,max}$ and the change in $\dot{V}O_{2\,max}$ in older men after a 12-mo training program of moderate intensity. Kohrt et al. (9) found nonsignificant correlations in their older men (r = 0.04) and women (r = −0.23). They also found no significant difference in improvement in $\dot{V}O_{2\,max}$ between those men whose initial $\dot{V}O_{2\,max}$ was in the lowest quartile (20%) and those in the highest quartile (19%). For women, the respective values for the lowest and highest quartiles of initial $\dot{V}O_{2\,max}$ was 19 and 14% ($P < 0.09$). On the basis of data on 481 sedentary whites from the HERITAGE Family Study, Bouchard et al. (3) reported nonsignificant correlation coefficients ranging from 0.03 to −0.16 computed separately for fathers, mothers, sons, and daughters. The present study, which includes data from blacks in the HERITAGE Family Study, also found a nonsignificant correlation coefficient (r = 0.08) between initial $\dot{V}O_{2\,max}$ (ml·kg^{-1}·min^{-1}) and $\Delta\dot{V}O_{2\,max}$ (ml·kg^{-1}·min^{-1}) for all sedentary subjects. However, when the relative (%) changes in $\dot{V}O_{2\,max}$ were correlated with initial levels, the relationship was significant (r = −0.38). From the data in Fig. 1, it is apparent that there are high, medium, and low responders to training at all levels of initial $\dot{V}O_{2\,max}$. Thus it appears that initial fitness level has no significant effect on $\Delta\dot{V}O_{2\,max}$ after training but that similar $\Delta\dot{V}O_{2\,max}$ values represent a higher percentage of the lower initial values.

In summary, we have shown in a large heterogeneous, biracial, sedentary population that age, sex, race, and initial fitness level have little or no effect on the response of $\dot{V}O_{2\,max}$ to a standardized 20-wk endurance exercise training program. There appear to be high, medium, and low responders to training at all ages, in both sexes, in both races, and at all levels of initial fitness studied. Genetics (13) may help explain the large variation in training response in these subjects.

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