Heart Rate versus %$\dot{V}O_{2max}$: Age, Sex, Race, Initial Fitness, and Training Response—HERITAGE

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ABSTRACT

SKINNER, J. S., S. E. GASKILL, T. RANKINEN, A. S. LEON, D. C. RAO, J. H. WILMORE, and C. BOUCHARD. Heart Rate versus %$\dot{V}O_{2max}$: Age, Sex, Race, Initial Fitness, and Training Response—HERITAGE. *Med. Sci. Sports Exerc.*, Vol. 35, No. 11, pp. 1908–1913, 2003. **Purpose:** In the HERITAGE Family Study, heart rate (HR) associated with various percentages of maximal oxygen intake ($\dot{V}O_{2max}$) was used to prescribe exercise intensity. When fitness improved, HR at the same power output (PO) decreased, and PO was increased to produce the prescribed HR. Although we assumed that subjects were again working at the same %$\dot{V}O_{2max}$, there were no studies with a large heterogeneous population to determine whether this was correct. **Methods:** Therefore, 653 subjects with complete data were classified by age, sex, race, initial $\dot{V}O_{2max}$, and $\dot{V}O_{2max}$ response after 20 wk of training. **Results:** All groups had a significant increase in $\dot{V}O_{2max}$ and a significant decrease in HR at the same absolute PO after training but no difference in HR at the same relative intensity. **Conclusions:** Training does not affect HR at a given %$\dot{V}O_{2max}$ in a heterogeneous population of men and women, blacks and whites aged 17–65 yr with different initial $\dot{V}O_{2max}$ values and different responses to training. **Key Words:** RELATIVE INTENSITY, ABSOLUTE INTENSITY

It is well known that heart rate (HR) and oxygen intake ($\dot{V}O_2$) increase linearly with exercise intensity and that they are linearly related to each other (1,7,12). This linear relationship was used to prescribe a standardized, 20-wk training program of progressively increasing duration and intensity for a large group of healthy, sedentary men and women aged 17–65 yr in the HERITAGE Family Study. This study was done by a consortium of five universities studying the role of the genotype in the cardiovascular and metabolic responses to aerobic exercise training and the contribution of inherited factors in the changes brought about by regular exercise on aerobic fitness and on multiple risk factors for cardiovascular disease and Type 2 diabetes.

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The HERITAGE Family Study has been described in detail in a previous publication (2).

When planning for this study began in the late 1980s, it was decided that all subjects should work at the same relative intensity (i.e., same percentage of maximal aerobic power or $\dot{V}O_{2max}$) to standardize the training program in order to investigate whether genetic factors influenced the response to training. Given that maximal exercise tests were to be given only at the beginning and end of the training program, a method was needed to prescribe and control exercise intensity during each training session over the 20-wk program. It was decided that exercise intensity would range from 55 to 75% $\dot{V}O_{2max}$ and that exercise prescription would be based on the HR associated with 55, 65, 70, and 75% of each subject's initial $\dot{V}O_{2max}$.

One of the most common changes with training is a reduction in HR at the same absolute power output (PO) (6,11). In the HERITAGE Family Study, a computer controlled the resistance of the cycle ergometer to maintain HR at the programmed level. Over the course of the 20-wk training program, it was assumed that the fitness level of the participants would improve. If there were improvements, then HR at the same PO would drop, and the computer would automatically increase PO to reach the prescribed

HR. It was also assumed that subjects would be working at the same $\%\dot{V}O_{2max}$ when working at the same HR. However, we found no study done on a large, heterogeneous population to determine whether this assumption was correct.

One cross-sectional study (3) evaluated hormonal and metabolic responses of seven untrained, seven moderately trained, and seven highly trained men to exercise at 50, 70, and 90% $\dot{V}O_{2max}$. Although not the main objective of the study, the investigators reported nonsignificant differences in HR at the three exercise intensities among the three groups. Due to the small sample size and the fact that there was no information on HR over time as fitness changed, results from this study suggested that our assumption was correct. However, it did not provide strong evidence that this was the case, i.e., that the same HR would be present at the same relative intensity throughout the 20-wk training program.

Two other studies examined the hormonal, metabolic, and hemodynamic changes that occurred with training. Hagberg et al. (5) studied 12 adolescents with essential hypertension and found that blood pressure and HR did not change at the same relative work rate. Winder et al. (13) trained six healthy men for 9 wk and evaluated the time course of changes. They also reported no change in HR at the same relative intensity. Because of the small sample size and limited age range in these two studies, it was still not clear whether HR would remain unchanged at the same relative intensity in the HERITAGE Family Study.

Because there was such a wide range in age and initial fitness level in both men and women (white and black) and because there was such a large variation in the training response (8), a large data set was available for a secondary, *post hoc* analysis to investigate whether HR at a given $\%\dot{V}O_{2max}$ was altered with training.

METHODS

Sample. The HERITAGE subjects came from families that included the natural mother and father (age 65 or less) and their natural children, 17–40 yr of age. The white families had at least three offspring, whereas the black families were smaller. Complete data on all variables of interest were available from 653 subjects tested and trained at the four Clinical Centers (Arizona State University [Indiana University since January 1996], Laval University, University of Minnesota, and The University of Texas at Austin). The fifth center was the Data Coordinating Center at Washington University in St. Louis. Subjects were healthy and sedentary (no regular physical activity over the previous 6 months) and met a number of inclusion and exclusion criteria. They also underwent a medical exam with a physician that included a 12-lead ECG obtained at rest and during a maximal exercise test. Please see Bouchard et al. (2) for more details on the various tests and criteria for including and excluding subjects. No subject was taking a medication that affected HR at rest or in response to exercise. The study protocol was previously approved by the Human Subjects Committee at each of the four Clinical Centers. Written informed consent was obtained from each subject.

$\dot{V}O_{2max}$ tests. Two maximal and one submaximal exercise tests were performed on separate days before and after the 20-wk training program using a cycle ergometer (model 800S, SensorMedics, Yorba Linda, CA) connected to a metabolic measurement cart (model 2900, SensorMedics). The ECG was used to monitor HR. During each exercise stage, gas exchange variables ($\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}E$, and RER) were recorded as a rolling average of three 20-s intervals. The criteria for $\dot{V}O_{2max}$ were RER >1.1, plateau in $\dot{V}O_2$ (change of <100 mL$\cdot$min^{-1} in the last three consecutive 20-s averages), and a HR within 10 beats$\cdot$min^{-1} of the maximal level predicted by age. All subjects achieved $\dot{V}O_{2max}$ by at least one of these criteria in the duplicate tests before and after training; most subjects met two or more criteria. When the reproducibility of the maximal tests was determined, an intraclass correlation coefficient of 0.97 and a coefficient of variation of 5% were found (9).

To accommodate subjects of different body size and fitness level, the initial PO for the first maximal test was 40–50 W for 3 min, followed by increases of 10–25 W each 2 min until volitional exhaustion. Results of this test were used to select PO for subsequent tests. For the submaximal test, subjects exercised for 10–12 min at an absolute PO of 50 W and for 10–12 min at the same relative intensity of 60% $\dot{V}O_{2max}$. The first two stages of the second maximal test were the same as those of the submaximal test, followed by 3 min at 80% $\dot{V}O_{2max}$. 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 exhaustion.

Training program. To determine each person's training intensity, HR, PO, and $\dot{V}O_2$ obtained during the three baseline cycle ergometer tests were plotted to determine the average HR and PO associated with 55, 65, 70, and 75% of his/her $\dot{V}O_{2max}$ before training. These HR values were used throughout the training program. Training sessions lasted 30 min during the first 2 wk, and subjects exercised at the HR associated with 55% of their $\dot{V}O_{2max}$. Either intensity or duration was then increased each 2 wk until the 14th wk of training when subjects exercised at the HR associated with 75% of their initial $\dot{V}O_{2max}$ for 50 min. This intensity and duration were then maintained for the next 6 wk. Training was controlled by HR using the Universal Gym Mednet® (Cedar Rapids, IA) computerized system. The computer received a HR signal from either a Polar chest strap transmitter (Polar U.S., Inc., Montvale, NJ) or from an ear-clip sensor. Subjects trained for the programmed duration at a HR that was maintained within $\pm$ 5 beats$\cdot$min^{-1} of the programmed HR by manipulating PO. A more detailed description of the training program can be found elsewhere (10).

Data analysis. Regression equations for HR to PO (W) were calculated for each subject. PO and HR at 30%, 40%, 50%, etc., up to 100% $\dot{V}O_{2max}$ were estimated from each regression equation. The HR and PO for the entire cohort

TABLE 1. Characteristics at baseline of participants in the HERITAGE Family Study with complete data on all variables being studied and classified by age, sex, andrace.

Groups	Age (yr)	Height (cm)	Weight (kg)	BMI ($kg \cdot m^{-2}$)	$\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)
All (N = 653)					
Mean	35.3	169.3	76.4	26.6	31.0
SD	13.7	9.6	17.4	5.4	8.8
Minimum	16.9	144.1	39.6	17.0	13.8
Maximum	65.9	196.8	140.2	47.5	57.0
Sex					
Men (N = 293)					
Mean	36.1	177.4	84.5	26.9	35.9
SD	14.3	6.5	16.5	4.9	8.6
Women (N = 360)					
Mean	34.6	163.0	70.2	26.4	27.3
SD	13.1	6.5	15.5	5.8	7.0
Race					
Blacks (N = 221)					
Mean	34.2	166.9	77.9	28.0	27.1
SD	11.7	9.5	17.4	5.9	7.3
Whites (N = 432)					
Mean	35.9	170.5	75.6	25.9	33.1
SD	14.6	9.5	17.4	5.0	8.9
Age (yr)					
17–29 (N = 295)					
Mean	22.7	169.8	70.9	24.5	36.0
SD	3.7	9.8	17.0	5.1	8.7
30–49 (N = 229)					
Mean	39.8	168.7	80.3	28.2	28.0
SD	6.3	9.5	16.8	5.2	6.8
50–65 (N = 129)					
Mean	55.8	169.3	81.3	28.4	25.3
SD	4.3	9.4	15.8	4.8	6.3

and for several subgroups (age, sex, race, and response to training) were then averaged. Because subjects were compared with themselves, mean HR at each PO and at each %$\dot{V}O_{2max}$ before and after training were compared using a paired t-test, with significance set at 0.01. For the comparison across the three age groups, an analysis of variance was used, with significance set at 0.01.

RESULTS

Descriptive Characteristics

Age, physical characteristics, and $\dot{V}O_{2max}$ of the subjects with complete data can be found in Table 1 for the entire group of 653 and for subgroups sorted by age, sex, and race.

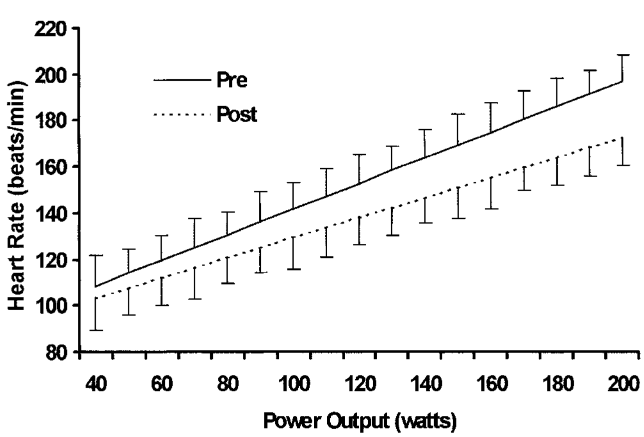

FIGURE 1—Heart rates at fixed power outputs (W) for 653 subjects with complete data before and after training.

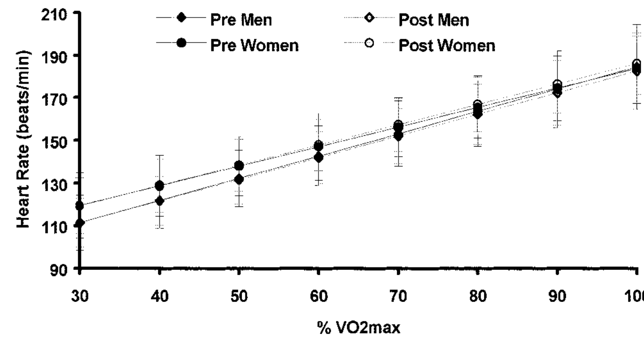

FIGURE 2—Heart rates at fixed relative intensities (%$\dot{V}O_{2max}$) for 293 men and 360 women pre- and posttraining.

Data are presented as means and standard deviations for the entire group and subgroups. In addition, the minimal and maximal values are given for the entire group to show the wide range of values in this heterogeneous group. Because the objective of the present study was to determine how HR at a given PO changes and how this affects the HR at a given %$\dot{V}O_{2max}$, no analysis of differences among the subgroups is presented in this table. Readers who are interested in the comparison of values before and after training in these subgroups can refer to the article by Skinner et al. (8) for more details.

Effect of Training on Maximal HR

There was no change in maximal HR in the total group (184.9 ± 13.9 $beats \cdot min^{-1}$ before and 184.3 ± 12.8 $beats \cdot min^{-1}$ after training) or for most of the subgroups after training. Some small reductions of 1–2 $beats \cdot min^{-1}$ in several subgroups were statistically significant ($P < 0.01$), primarily because of the large number of subjects (data not shown).

Effect of training on HR at the same absolute PO

As can be seen in Figure 1, there was a significant decrease in HR at the same absolute PO ($P < 0.01$) for the total group, indicating that there was a training effect; this is in agreement with the significant mean rise in $\dot{V}O_{2max}$ of 17% for the entire group ($P < 0.01$).

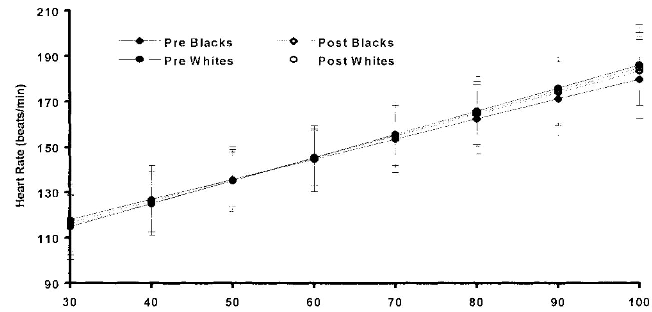

FIGURE 3—Heart rates at fixed relative intensities (%$\dot{V}O_{2max}$) for 221 black and 432 white subjects pre- and posttraining.

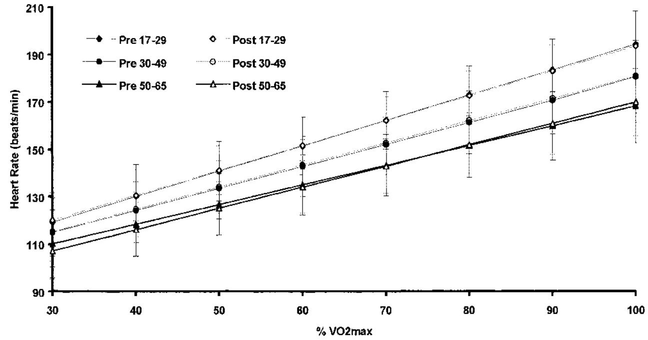

FIGURE 4—Heart rates at fixed relative intensities (%$\dot{V}O_{2max}$) for 295 young (17–29 yr), 229 middle-aged (30–49 yr) and 129 older (50–65 yr) subjects pre- and posttraining.

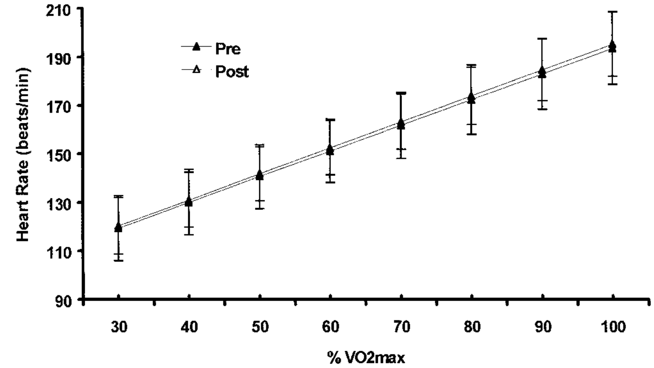

FIGURE 6—Heart rates at fixed relative intensities (%$\dot{V}O_{2max}$) pre- and posttraining for 163 subjects who had low initial $\dot{V}O_{2max}$ levels (13.7–24.2 mL·kg^{-1}·min^{-1}).

Effect of Training on HR at the Same %$\dot{V}O_{2max}$

Men and women. As expected, women had higher HR at the same absolute PO. At the same %$\dot{V}O_{2max}$, women had a slightly higher HR than men at the lower intensities but no differences at the higher intensities (Fig. 2). There was no difference in HR at the same %$\dot{V}O_{2max}$ after training in either sex.

Blacks and whites. Because there were more women in the black subgroup, blacks had higher HR at the same absolute PO; both races had a significant ($P < 0.01$) reduction in HR with training (data not shown). There was no difference in HR at the same %$\dot{V}O_{2max}$ after training in either race (Fig. 3).

Age groups. Subjects in all three age groups had significantly lower HR ($P < 0.01$) at the same absolute PO after training (data not shown). As expected, the youngest subjects had a higher maximal HR ($P < 0.01$) and higher HR at any given %$\dot{V}O_{2max}$ ($P < 0.01$) compared with the other two age groups. The middle group also had a higher maximal HR ($P < 0.01$) and higher HR at any given %$\dot{V}O_{2max}$ ($P < 0.01$) compared with the oldest age group (Fig. 4). As was seen with the other subgroups, there was no difference in HR at the same %$\dot{V}O_{2max}$ after training in any age group.

Initial $\dot{V}O_{2max}$. Because there was a wide range in initial $\dot{V}O_{2max}$ levels in the present study, subjects were placed into quartiles. The mean HR of each quartile was significantly lower ($P < 0.01$) at the same absolute PO after training (data not shown). The least fit subjects in the first quartile (initial $\dot{V}O_{2max}$ of 13.7–24.2 mL·kg^{-1}·min^{-1}) showed no difference in HR at the same %$\dot{V}O_{2max}$ after training (Fig. 5). Similarly, the fittest subjects in the fourth quartile (initial $\dot{V}O_{2max}$ of 36.3 to 57.0 mL·kg^{-1}·min^{-1}) also had no difference in HR at the same %$\dot{V}O_{2max}$ after training (Fig. 6).

Total group. Even though there was a significant ($P < 0.01$) decrease in HR at the same absolute PO (Fig. 1), there was no difference in mean HR at the same %$\dot{V}O_{2max}$ after training in the total group of 653 subjects (Fig. 7).

Response to training. There was a large variation in the response to training in the present study. Although the average increase in $\dot{V}O_{2max}$ was 17–18% in the different subgroups, the response varied from essentially no change up to an increase of about 50% (8). Therefore, we also examined whether the HR response was different in those with varying levels of improvement in $\dot{V}O_{2max}$; this was done by placing subjects into quartiles of response.

Subjects in the first quartile had a low response to training (a change in $\dot{V}O_{2max}$ of −1.5 to +3.4 mL·kg^{-1}·min^{-1}). In spite of this small change in $\dot{V}O_{2max}$, there was a significant reduction ($P < 0.01$) in mean HR at the same absolute PO (data not shown). There was no difference in mean HR at the same %$\dot{V}O_{2max}$ after training in these low responders (Fig. 8).

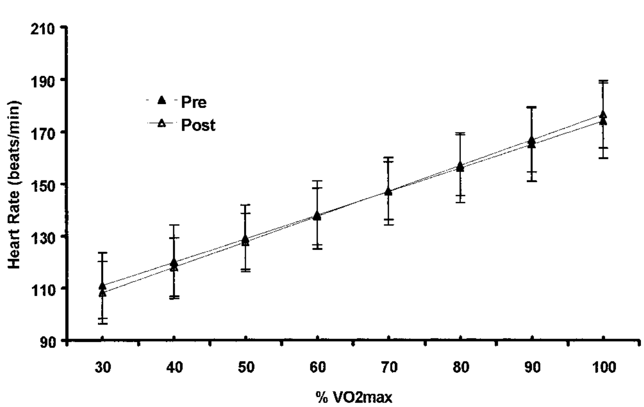

FIGURE 5—Heart rates at fixed relative intensities (%$\dot{V}O_{2max}$) for 653 subjects with complete data pre- and posttraining.

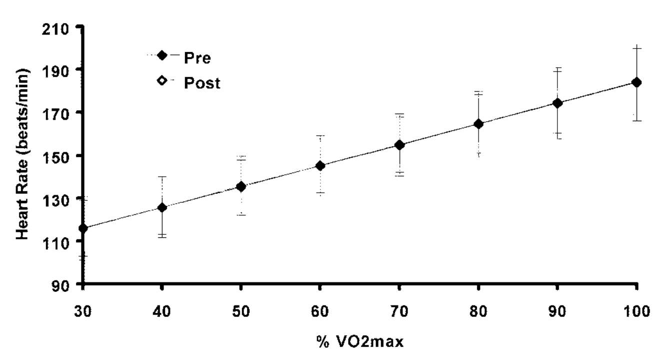

FIGURE 7—Heart rates at fixed relative intensities (%$\dot{V}O_{2max}$) pre- and posttraining for 163 subjects who had high initial $\dot{V}O_{2max}$ levels (36.3–57.0 mL·kg^{-1}·min^{-1}).

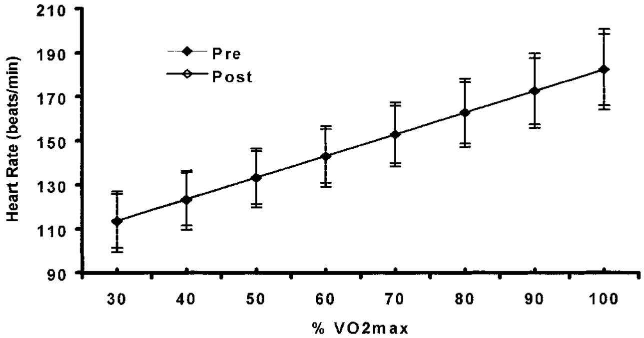

FIGURE 8—Heart rates at fixed relative intensities (%$\dot{V}O_{2max}$) pre- and posttraining for 163 subjects who had a low response in $\dot{V}O_{2max}$ to training (change of −1.5 to +3.4 mL·kg^{-1}·min^{-1}).

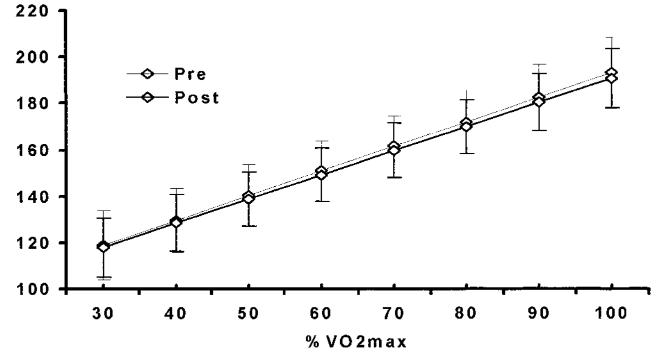

FIGURE 9—Heart rates at fixed relative intensities (%$\dot{V}O_{2max}$) pre- and posttraining for 163 subjects who had a high response in $\dot{V}O_{2max}$ to training (increase of 6.8 to 14.9 mL·kg^{-1}·min^{-1}).

Subjects in the fourth quartile had the highest response to training (a rise in $\dot{V}O_{2max}$ of 6.8 to 14.9 mL·kg^{-1}·min^{-1}). This group of high responders also had a significant decrease ($P < 0.01$) in mean HR at the same absolute PO (data not shown) but no difference in mean HR at the same %$\dot{V}O_{2max}$ after training (Fig. 9). Subjects in the second and third quartiles of response had similar results (data not shown).

DISCUSSION

After data collection in the HERITAGE Family Study was completed, we found only one published study that looked specifically at responses to exercise at the same relative intensity before and after training. Greiwe et al. (4) studied the catecholamine response to exercise of the same relative intensity by six women and three men before and after training. $\dot{V}O_{2max}$ increased 20% after 10 wk of training. The investigators found no significant difference in HR or plasma epinephrine taken during 15-min exercise bouts on the treadmill performed at 60, 65, 70, 75, 80, and 85% $\dot{V}O_{2max}$ before and after training; these findings confirm the HR results of the present study. On the other hand, plasma norepinephrine levels were significantly higher after training. They suggested that the similar HR found at higher levels of sympathetic nervous system activity is associated with a "decreased sensitivity to chronotropic stimulation."

The purpose of the secondary analysis of the data from the HERITAGE Family Study was to determine whether HR at the same relative intensity remained constant over time during a training program. The data were analyzed to compare HR versus %$\dot{V}O_{2max}$ before and after 20 wk of training for the total group and various subgroups. These analyses showed that for all subjects, for both sexes, for both races, for the three age groups, for the quartiles of initial $\dot{V}O_{2max}$, and for the quartiles of increase in $\dot{V}O_{2max}$ with training, there was a significant ($P < 0.01$) decrease in HR at the same absolute intensity (PO in watts) but no difference in HR at the same relative intensity (%$\dot{V}O_{2max}$) after training.

Results of a previous analysis of data from this large, heterogeneous, biracial, and sedentary population found that age, sex, race, and initial fitness level had little influence on the response of $\dot{V}O_{2max}$ to a standardized 20-wk exercise training program (8). Data from the present study extend these findings and demonstrate that although HR at the same absolute PO may vary among the subgroups, HR before and after training are not different at the same relative intensities within each subgroup studied (viz., age, sex, race, initial $\dot{V}O_{2max}$, and level of response to training).

Because HR is used so often to prescribe exercise intensity, the findings of the present study are important. These results demonstrate that once $\dot{V}O_{2max}$ and the relationships among HR, PO, and $\dot{V}O_2$ are known for each individual, then HR is a good estimate of relative exercise intensity. In addition, HR can be used to estimate relative exercise intensity over the course of an exercise-training program; this is important because it suggests that frequent testing is not necessary to adjust the exercise prescription.

In summary, HR at a given %$\dot{V}O_{2max}$ was not affected by training in a large heterogeneous group of men and women, blacks and whites, who varied widely in initial fitness, response to training, and age. We conclude that frequent testing is not necessary to adjust an exercise prescription once the relationship among HR, PO, and $\dot{V}O_2$ have been determined for a given individual relative to his/her $\dot{V}O_{2max}$.

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