Heart rate and blood pressure changes with endurance training: The HERITAGE Family Study

JACK H. WILMORE, PHILIP R. STANFORTH, JACQUES GAGNON, TREVA RICE, STEPHEN MANDEL, ARTHUR S. LEON, D. C. RAO, JAMES S. SKINNER, and CLAUDE BOUCHARD

Department of Health and Kinesiology, Texas A&M University, College Station, TX; Physical Activity Sciences Laboratory, Laval University, Quebec City, Quebec, CANADA; Division of Biostatistics, Washington University School of Medicine, St. Louis, MO; School of Kinesiology and Leisure Studies, University of Minnesota, Minneapolis, MN; Department of Kinesiology, Indiana University, Bloomington, IN; and Pennington Biomedical Research Center, Baton Rouge, LA

ABSTRACT

WILMORE, J. H., P. R. STANFORTH, J. GAGNON, T. RICE, S. MANDEL, A. S. LEON, D. C. RAO, J. S. SKINNER, and C. BOUCHARD. Heart rate and blood pressure changes with endurance training: The HERITAGE Family Study. *Med. Sci. Sports Exerc.*, Vol. 33, No. 1, 2001, pp. 107–116. **Purpose:** The purpose of this study was to determine the magnitude of change in resting and exercise heart rate (HR) and blood pressure (BP), by race, sex, and age, after a 20-wk endurance training program in 507 healthy and previously sedentary subjects from the HERITAGE Family Study. **Methods:** After baseline measurements, subjects exercised on cycle ergometers 3 d·wk^{-1} for a total of 60 exercise sessions starting at 55% of $\dot{V}O_{2max}$ for 30 min·session^{-1} and building to 75% of $\dot{V}O_{2max}$ for 50 min·session^{-1} for the last 6 wk. HR and BP at rest and during exercise (50 W, 60% of $\dot{V}O_{2max}$, maximal exercise) were each determined in duplicate on two different days both before and after training (resting values at 24-h and 72-h posttraining). **Results:** After the period of training, there was a small decrease in resting HR (−2.7 to −4.6 beats·min^{-1} across groups at 72-h posttraining), and small changes (i.e., < 3 mm Hg) in resting systolic (SBP), diastolic (DBP), and calculated mean BP (MBP), which varied by race, sex, and age. During exercise at the same absolute work rate (50 W), HR, SBP, DBP, and MBP were all significantly reduced, with greater reductions in HR in women compared with men, and greater reductions in BP in blacks and older subjects compared with whites and younger subjects, respectively. At the same relative work rate (60% $\dot{V}O_{2max}$), HR, DBP, and MBP were reduced, but SBP remained unchanged. Blacks had a greater reduction in DBP, but whites had a greater reduction in HR. Finally, at maximal exercise, there was a small decrease in HR, with men and whites decreasing more than women and blacks; an 8 mm Hg increase in SBP, with men increasing more than women; a 4 mm Hg decrease in DBP, with blacks decreasing more than whites; and no change in MBP. **Conclusion:** In conclusion, the reductions in resting HR and BP with training were generally small, but the reductions during exercise were substantial and clinically important, with the older and the black populations experiencing greater reductions. **Key Words:** RESTING AND EXERCISE, RACE, SEX, AGE

It has been clearly established that the prevalence of hypertension is substantially higher in blacks compared with whites, yet the mechanisms explaining this difference are largely unknown (3). In addition to a greater prevalence of hypertension, there is an earlier onset and greater severity. This is associated with a 30% greater rate of nonfatal stroke, a 80% greater rate of fatal stroke, a 50% greater rate of coronary artery disease deaths, and a rate of end-stage renal disease that is 5 times greater in blacks as compared with matched whites (2).

It is now clear that endurance exercise training can result in significant reductions in resting blood pressure (BP) in hypertensive patients and in individuals who are borderline hypertensive, i.e., systolic BP (SBP) < 160 mm Hg and diastolic BP (DBP) < 95 mm Hg (10,25). Further, endurance training reduces BP in normotensive individuals as well (13), but the changes are of smaller magnitude.

It is less clear whether the beneficial reductions in resting BP with endurance training extend to the higher risk black population. In the only longitudinal study we could find, black men with severe hypertension (DBP ≥ 100 mm Hg and/or SBP ≥ 180 mm Hg) underwent up to 32 wk of aerobic training while medicated, which led to a significant reduction in DBP (14). Two other studies, which used a cross-sectional design, investigated the association of regular physical activity with resting BP. Melby et al. (16) found SBP was approximately 8 mm Hg lower in regularly exercising compared with nonexercising black men and women. Ainsworth et al. (1) reported a lower prevalence of hypertension in active black women, but not in active black men, when compared with their sedentary counterparts. To the best of our knowledge, no study has attempted to systematically investigate the effects of exercise training on resting and exercise BP in a large population of both black and

0195-9131/01/3301-0107/$3.00/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

Received for publication April 2000.
Accepted for publication April 2000.

white normotensive and mildly hypertensive subjects by using a longitudinal research design.

Therefore, the purpose of this study was to determine the effects of a highly controlled, 20-wk exercise training program on resting and exercise BP in a previously sedentary population of black and white participants in the HERITAGE Family Study. Heart rate (HR) responses at rest and during exercise were also of interest. The HERITAGE Family Study is a large multicenter clinical trial investigating the possible genetic basis for the large variability in the responses of physiological measures, as well as risk factors for cardiovascular disease and type 2 diabetes mellitus, to endurance exercise training. This study includes four Clinical Centers [Indiana University (formerly at Arizona State University), The Pennington Biomedical Research Center, Baton Rouge, LA (formerly at Laval University, Québec, Canada), the University of Minnesota, and Texas A&M University (formerly at The University of Texas at Austin)] and a Data Coordinating Center (Washington University School of Medicine, St. Louis, MO). Details of the HERITAGE Family Study aims, experimental design, and measurement protocols have been presented in detail in a previous publication (6).

METHODS

Participants. The HERITAGE Family Study subject population consisted of families, including the natural father and mother ($\leq$ 65 yr of age) and generally three offspring 17 yr of age or older for white families, or at least two first-degree relatives for black families. Inclusion and exclusion criteria were summarized in detail in a prior publication (6). Specific criteria of importance to this paper included the fact that participants were sedentary at baseline, normotensive or mildly hypertensive (<160/100) without antihypertension medication, and BMI was < 40.0$\cdot$kg^{-2}. Several participants were included in the study with BMIs slightly in excess of this value because they were considered by a supervising physician at one of the Clinical Centers to be "healthy" and able to perform the required exercise prescription. A total of 744 participants finished all HERITAGE testing and training protocols. Of this total, 507 had complete resting and exercise HR and BP data, and constitute the sample for this study. Their characteristics are presented in Table 1. Each Clinical Center's Institutional Review Board had previously approved the study protocol, and informed consent was obtained from each participant.

Experimental design. Participants were screened by the Clinical Center's supervising physician and staff. Only those who were previously sedentary, free of preexisting disease, and not taking any medications that would affect any of the outcome variables were allowed to enter the study (6). A comprehensive battery of tests was administered before starting the training program, which included the following: health, medical, and nutrition questionnaires; maximal and submaximal exercise tests; blood tests for lipids, lipoproteins, and sex steroids; intravenous glucose tolerance test; resting BP; and body composition tests. After the initial test battery, subjects completed a 20-wk endurance training program (3 d$\cdot$wk^{-1} for a total of 60 exercise sessions) on cycle ergometers that were computer-controlled to maintain the participants' HRs at levels associated with fixed percentages of their aerobic capacity ($\dot{V}O_{2max}$). The training program started at 55% of $\dot{V}O_{2max}$ for 30 min$\cdot$session^{-1} and gradually increased to 75% of $\dot{V}O_{2max}$ for 50 min$\cdot$session^{-1} during the last 6 wk of training. The full test battery was administered again at the conclusion of the training program.

For the resting BP measurements, participants reported to the laboratory before 11:00 a.m., having refrained from tobacco and caffeine products for at least 2 h, and having performed no formal exercise in the previous 12 h. A series of four to eight HR and BP measurements were obtained on each of two separate days, both pre- and post-training. Identical controls were applied for the exercise BP measurements, with the exception that testing was not limited to the early morning hours. The exercise BP measurements were also obtained on two separate days, both pre- and post-training, but only two measurements were obtained at each power output. Identical measurement protocols were used

TABLE 1. Physical characteristics of the participants.

Participants	Age (yr)	Height (cm)	Weight (kg)	BMI (kg$\cdot$m^{-2})
All participants (N = 507)	34.9 ± 13.2	169.4 ± 9.4	75.8 ± 17.0	26.3 ± 5.1
By sex and age				
Men (N = 215)	36.1 ± 14.0	177.5 ± 6.4	84.1 ± 16.3	26.7 ± 4.8
17–29 yr (N = 95)	23.1 ± 3.9	178.6 ± 6.2	79.6 ± 15.8	24.9 ± 4.5
30–49 yr (N = 70)	39.8 ± 6.8	177.7 ± 6.6	90.2 ± 15.8	28.5 ± 4.7
50–65 yr (N = 50)	55.7 ± 4.2	175.0 ± 6.0	84.3 ± 15.5	27.5 ± 4.2
Women (N = 292)	34.1 ± 12.6	163.5 ± 6.4	69.7 ± 14.7	26.1 ± 5.4
17–29 yr (N = 134)	22.7 ± 3.7	163.7 ± 5.8	64.0 ± 12.8	23.9 ± 4.5
30–49 yr (N = 116)	39.5 ± 5.9	163.5 ± 6.9	73.6 ± 14.2	27.6 ± 5.5
50–65 yr (N = 42)	55.3 ± 4.1	163.1 ± 7.0	77.2 ± 15.2	29.0 ± 5.0
By race				
Blacks - total (N = 166)	33.4 ± 10.5	167.7 ± 9.4	77.3 ± 16.2	27.5 ± 5.4
Men (N = 57)	34.2 ± 11.2	176.8 ± 7.1	84.0 ± 16.3	26.8 ± 4.7
Women (N = 109)	33.0 ± 10.1	162.9 ± 6.5	73.9 ± 15.1	27.9 ± 5.8
Whites - total (N = 341)	35.7 ± 14.3	170.3 ± 9.3	75.1 ± 17.3	25.8 ± 4.9
Men (N = 158)	36.8 ± 14.8	177.7 ± 6.2	84.2 ± 16.4	26.6 ± 4.8
Women (N = 183)	34.7 ± 13.8	163.9 ± 6.4	67.2 ± 13.9	25.0 ± 4.9

* Data are expressed as mean ± SD.

pre- and post-training, with the exception that posttraining measurements were obtained at 24-h and 72-h after the last training bout.

Blood pressure and exercise test methodology. BP and HR measures were taken using the Colin STBP-780 automated BP unit (San Antonio, TX). This system employs two electrocondenser microphones embedded in the cuff. The sound signal is synchronized to the electrocardiograph (ECG) R wave, and a detection algorithm is used to determine both SBP and DBP. Earphones worn by the technician allowed for a manual confirmation of the algorithm-determined BP values. In addition, the instrument's printer function enabled the technician to visually confirm the accuracy of the reading with its graphic representation of the Korotkoff sounds (K-sounds).

Proper cuff size (child, regular adult, or large adult) was determined using the guidelines from the 1993 Report of the Joint National Committee on Detection, Evaluation, and Treatment of High Blood Pressure (3), and the size was recorded in the subject's file. The subject was seated in a reclining chair in a semirecumbent position (legs supported parallel to the floor and the back support reclined at a 45° angle from the floor), with the arms relaxed and supported. The laboratory was quiet, with little or no light and a room temperature between 23°C and 26°C. A sheet or blanket was available if the subject requested it. The BP equipment and technician were to the side or behind the subject so that the subject could not see the BP monitor or the technician.

After a rest period of at least 5 min, four HR and BP readings were taken at 2-min intervals (2 min from the start of one to the start of the next BP measurement.) The first reading was always deleted. If the next three measurements were considered "reliable," no more measurements were taken. If one or more of these measurements were considered "unreliable," additional measurements were taken until there were at least three reliable measurements or until eight measurements had been taken. The reported BP was the mean of the three or more reliable measurements. Subjects reported to the laboratory on a second day, within ± 2 h of the first day, and the same procedures were repeated.

Unreliable measurements were those considered to be invalid because of subject movement, machine malfunction, technician error, or where by checking the graphic representation of the K-sounds it was obvious that the Colin STBP-780 had chosen the wrong SBP or DBP. For each BP measurement, two separate readings were manually recorded; the automated value determined by the Colin STBP-780 and the manual reading value determined by the technician listening through headphones. The technician first recorded the manual reading without looking at the automated reading and then recorded the automated reading from the printout from the Colin STBP-780. The manual BP was never used; however, when there was a significant discrepancy between the automated and manual reading, the technician examined the graph of the K-sounds to determine whether the Colin STBP-780 reading was valid.

HR was measured by the STBP-780 as a moving average of six beats. The HR measured during each BP measurement was printed out by the STBP-780 and recorded. HR values reported were those on the STBP printout corresponding to the BP measurement used.

SBP was defined as the first sound (appearance of K-sounds) and DBP was defined as the fifth sound (disappearance of K-sounds). Mean BP (MBP) was derived as follows: MBP = DBP + [0.333 × (SBP-DBP)]. The Colin STBP-780 was calibrated using a mercury manometer at the beginning of most testing days. Colin STBP-780 values were recorded at mercury manometer pressures of 200, 150, 100, 50, and 0 mm Hg. The Colin STBP-780 was considered calibrated if its values were within ± 2 mm Hg of the mercury manometer values. If the Colin STBP-780 failed calibration, it was recalibrated.

Subjects completed a total of three exercise tests, each on different days, both pre- and post-training: a maximal test (Max), a submaximal test (Sub_{max}), and a submaximal to maximal test (Sub_{max}/Max). All exercise tests were conducted on a cycle ergometer (SensorMedics Ergo-Metrics 800S, Yorba Linda, CA). Subjects completed the initial maximal exercise test using a graded exercise test protocol, starting at 50 W for 3 min. The power output was then increased by 25 W every 2 min thereafter to the point of exhaustion. For older, smaller, or less fit subjects, the test was started at 40 W and increased by 10- to 20-W increments. Using the results of this initial maximal test, subjects then performed the Sub_{max} exercise test on a second day at 50 W and at 60% of their initial $\dot{V}O_{2max}$. The Sub_{max}/Max exercise test was then performed on a third day, starting with the Sub_{max} protocol, i.e., 50 W and 60% of the initial $\dot{V}O_{2max}$, and progressing to a maximal level of exertion. The results of the three exercise tests were used to establish the endurance training program work rates and to quantify the magnitude of the training response (6).

For the Sub_{max} and Sub_{max}/Max tests, the two HR and BP values were obtained and averaged both at 50 W and at 60% of the initial $\dot{V}O_{2max}$. Subjects exercised for approximately 12–15 min at each power output, with a 4-min period of seated rest between power outputs. Maximal BP and HR were obtained at the very end of the Max and the Sub_{max}/Max tests. The values presented in this paper represent the mean of the responses for the two submaximal tests (i.e., Sub_{max} and Sub_{max}/Max) and for the two maximal tests (i.e., Max and Sub_{max}/Max), both before and after training.

For all exercise tests, $\dot{V}O_2$, $\dot{V}CO_2$, expiratory minute ventilation ($\dot{V}_E$) and the respiratory exchange ratio (RER) were determined every 20 s and reported as a rolling average of the three most recent 20-s values, using a SensorMedics 2900 metabolic measurement cart (MMC). $\dot{V}O_{2max}$ was defined as the peak value obtained during the test. HR was determined by ECG and the Colin STBP-780 instrument, and values were recorded during the last 15 s of each stage of the maximal test, and once steady state had been achieved at each of the submaximal work rates during the Sub_{max} and Sub_{max}/Max tests.

Quality assurance, quality control, and statistical methodology. Important quality assurance and quality control procedures were instituted across all four Clinical

Centers, as described by Gagnon et al. (11). Staff from all Clinical Centers were trained centrally on several occasions, and all staff from each Clinical Center had to attain certification on each technique for which they were responsible. Further, one or two staff members at each Clinical Center were responsible for all BP measurements. A detailed Manual of Procedures (MOP) was developed, and staff were required to review those sections of the MOP for which they were responsible every 6 months. Each year for the first 2 years of the study, a traveling crew of four participants, two men and two women, went to each of the Clinical Centers over a 3- to 4-wk period and were tested according to the HERITAGE Family Study protocol at each Clinical Center, allowing comparisons to be made across the four Clinical Centers on these same four participants (11).

The reproducibility of measurements in this study was very high (24,31). At rest, intraclass correlations ranged from 0.79 to 0.85, technical errors were less than 5.1 mm Hg, and coefficients of variation were less than 7% for SBP, DBP, and MBP (24). At 50 W and 60% of $\dot{V}O_{2max}$, the intraclass correlations were between 0.77 and 0.82, technical errors were below 10.0 mm Hg, and coefficients of variation were less than 9.0% (31). Similar reproducibilities were obtained for SBP at maximal exercise, with an intraclass correlation coefficient of 0.75, a coefficient of variation of 6.9%, and a technical error of 13.2 mm Hg. As expected, DBP was less reliable at maximal exercise, with an intraclass correlation coefficient of 0.54, a coefficient of variation of 11.6%, and a technical error of 9.6 mm Hg (23).

All data were analyzed using the SAS statistical package (version 6.12; SAS Institute Inc. Cary, NC). Data are expressed as mean ± SD except where noted. A matched-pair t-test was used to determine significant differences between pre- and post-training data. A multiple testing analysis of variance (ANOVA) was implemented by using the general linear models procedure to determine the influence of race, sex, and age on the magnitude of change in any given variable. Statistical significance was established at the 0.05 level.

RESULTS

The exercise training program substantially increased $\dot{V}O_{2max}$ (mean ± SD) 17.4% ± 9.8%, with individual variation among subjects of from 0% to 51% increase. The decreases in exercise HR at each power output posttraining compared to pretraining further confirmed a substantial training effect.

The pre- and post-training data for resting HR and BP are presented in Table 2. There was a small, but statistically significant, decrease in resting HR for the total sample and all subgroups at both 24-h and 72-h posttraining. Further, there were some significant, but small, changes in resting SBP, DBP, and MBP, but this differed by subgroup with black men having the largest decrease in SBP and older men having the largest decrease in DBP and MBP. Further, the BP results differed by the timing of the posttraining measurement, with all significant decreases within subgroups occurring at 24 h, followed by a subsequent increase at 72 h.

The pre- and post-training data for submaximal exercise HR and BP are contained in Table 3 (50 W) and Table 4 (60% of $\dot{V}O_{2max}$). At the same absolute power output (50 W), there were decreases in both HR and BP for the total sample and for all subgroups. The decreases in HR were greater in women than men. The decreases in SBP, DBP, and MBP were greater in blacks than whites, and the decreases in SBP and MBP were greater in older than in younger subjects. At the same relative power output (60% $\dot{V}O_{2max}$), which represented a higher power output posttraining compared with pretraining, mean HR decreased for the total sample and across all subgroups with whites decreasing more than blacks and older women decreasing more than younger women. SBP did not decrease for the total sample but did decrease in the older men. DBP and MBP, however, did decrease for the total sample and for all subgroups, with black women decreasing DBP more than white women and older men decreasing MBP more than younger men.

The HR and BP data at maximal exercise are presented in Table 5. Maximal HR decreased for the total sample, men, and whites, with significant differences in response by sex and race. Maximal SBP increased in the total sample and in all but one subgroup (older women), with men having a greater increase than women. Conversely, maximal DBP decreased in the total sample and in all but two subgroups (middle-aged men and older women), with the magnitude of response being greater in blacks than whites. Maximal MBP remained unchanged in the total sample and in all but the younger (increased MBP) and middle-aged (decreased MBP) women.

DISCUSSION

When investigating changes in resting HR and BP consequent to any intervention, it is critical to be able to document that a true resting state was obtained both before and after the intervention. A substudy of the HERITAGE Family Study was undertaken to determine the magnitude of change in resting metabolic rate (RMR) consequent to the HERITAGE Family Study endurance training intervention (30). In this substudy, it was absolutely critical for the subjects to be in a true resting state. To assure this, subjects wore HR monitors (Polar U.S., Inc., Montvale, NJ) with a memory transfer system for a period of from 8 to 10 h before the measurement of RMR early the next morning. The resulting data substantiated that the HR obtained during the RMR measurement period was identical to the lowest HR obtained during the previous night's sleep. Further, both of these resting HRs were identical to the HR obtained during the 2 days when resting BP was measured (28). Therefore, we feel confident that the data presented in this paper represent true resting values.

The decrease in resting HR with endurance training in this study was small (< 5 beats·min^{-1}) for the total sample and

TABLE 2. Changes in resting heart rate and blood pressure pre- to posttraining ($N = 507$).

Variable	Pretraining (Mean ± SD)	24 h Post-training (Mean ± SD)	72 h Posttraining (Mean ± SD)	Absolute Difference (24 h - pre)	Absolute Difference (72 h - pre)	Significant Difference* ($P < 0.05$)
Heart rate, beats/·min⁻¹						
Total	65.4 ± 8.9	62.8 ± 9.4	62.2 ± 9.1	−2.6	−3.2	a, b
Men	61.8 ± 8.2	58.8 ± 8.1	58.4 ± 8.1	−3.0	−3.4	a, b
17–29 yr	60.0 ± 8.7	56.7 ± 8.2	57.2 ± 8.7	−3.3	−2.8	a, b
30–49 yr	63.2 ± 7.9	61.0 ± 7.6	59.8 ± 8.2	−2.2	−3.4	a, b
50–65 yr	63.1 ± 7.2	59.6 ± 7.7	58.5 ± 6.4	−3.5	−4.6	a, b
Women	68.2 ± 8.4	65.8 ± 9.2	65.0 ± 8.8	−2.4	−3.2	a, b
17–29 yr	67.6 ± 8.9	65.9 ± 9.6	64.6 ± 9.2	−1.7	−3.0	a, b
30–49 yr	69.3 ± 7.8	66.1 ± 9.0	65.8 ± 8.6	−3.2	−3.5	a, b
50–65 yr	66.9 ± 7.9	64.5 ± 8.3	64.2 ± 7.9	−2.4	−2.7	a, b
Blacks-total	67.0 ± 8.4	64.7 ± 9.7	63.9 ± 9.0	−2.3	−3.1	a, b
Men	62.4 ± 8.1	59.6 ± 8.0	58.8 ± 8.1	−2.8	−3.6	a, b
Women	69.4 ± 7.6	67.4 ± 9.5	66.5 ± 8.4	−2.0	−2.9	a, b
Whites-total	64.7 ± 9.0	61.9 ± 9.1	61.4 ± 9.0	−2.8	−3.3	a, b
Men	61.5 ± 8.3	58.5 ± 8.1	58.2 ± 8.1	−3.0	−3.3	a, b
Women	67.4 ± 8.8	64.9 ± 8.9	64.2 ± 8.9	−2.5	−3.2	a, b
Systolic BP (mm Hg)						
Total	118.5 ± 11.7	117.7 ± 12.0	118.7 ± 12.3	−0.8	+0.2	a
Men	121.5 ± 10.7	120.1 ± 10.9	121.5 ± 11.3	−1.4	0.0	a
17–29 yr	120.9 ± 9.6	119.5 ± 9.8	120.4 ± 9.7	−1.5	−0.5	—
30–49 yr	121.9 ± 10.3	120.9 ± 10.2	122.1 ± 11.1	−1.0	+0.2	—
50–65 yr	122.1 ± 13.1	120.2 ± 13.5	122.5 ± 14.1	−1.9	+0.4	—
Women	116.2 ± 11.9	115.9 ± 12.5	116.7 ± 12.6	−0.3	+0.5	—
17–29 yr	113.2 ± 9.6	112.4 ± 9.3	112.9 ± 8.6	−0.8	−0.3	—
30–49 yr	117.5 ± 11.7	117.6 ± 13.4	118.6 ± 13.5	+0.1	+1.1	—
50–65 yr	122.4 ± 15.8	122.4 ± 15.4	123.7 ± 16.3	0.0	+1.3	—
Blacks - total	123.0 ± 11.5	121.7 ± 12.2	121.8 ± 13.0	−1.3	−1.2	a, d
Men	125.1 ± 10.1	122.9 ± 10.3	123.6 ± 13.1	−2.2	−1.5	a
Women	121.9 ± 12.1	121.0 ± 13.1	120.9 ± 12.9	−0.9	−1.0	e
Whites - total	116.3 ± 11.2	115.8 ± 11.4	117.2 ± 11.6	−0.5	+0.9	b, d
Men	120.2 ± 10.7	119.1 ± 10.9	120.7 ± 10.5	−1.1	+0.5	a
Women	112.9 ± 10.5	112.9 ± 11.1	114.3 ± 11.7	0.0	+1.4	b, e
Diastolic BP (mm Hg)						
Total	68.2 ± 8.6	67.8 ± 9.1	68.8 ± 9.1	−0.4	+0.6	b
Men	69.6 ± 8.6	68.9 ± 8.8	70.3 ± 9.5	−0.7	+0.7	—
17–29 yr	66.4 ± 8.2	66.1 ± 8.4	66.8 ± 8.5	−0.3	+0.4	—
30–49 yr	72.0 ± 7.9	71.8 ± 8.4	73.7 ± 9.5	−0.2	+1.7	b
50–65 yr	72.3 ± 8.2	70.4 ± 8.7	72.1 ± 9.0	−1.9	−0.2	a
Women	67.2 ± 8.6	67.0 ± 9.2	67.7 ± 8.7	−0.2	+0.5	—
17–29 yr	64.5 ± 7.8	63.9 ± 7.8	64.8 ± 7.5	−0.6	+0.3	—
30–49 yr	69.4 ± 8.9	69.6 ± 9.9	70.2 ± 9.2	+0.2	+0.8	—
50–65 yr	70.0 ± 7.8	69.5 ± 8.7	70.0 ± 8.2	−0.5	0.0	—
Black - total	72.6 ± 8.2	72.1 ± 8.8	72.6 ± 9.3	−0.5	0.0	—
Men	73.6 ± 6.6	72.5 ± 8.2	73.7 ± 8.8	−1.1	+0.1	—
Women	72.0 ± 8.9	72.0 ± 9.1	72.0 ± 9.5	0.0	0.0	—
Whites - total	66.1 ± 8.1	65.7 ± 8.5	66.9 ± 8.5	−0.4	+0.8	b
Men	68.1 ± 8.7	67.7 ± 8.7	69.0 ± 9.4	−0.4	+0.9	—
Women	64.4 ± 7.0	64.1 ± 8.0	65.1 ± 7.1	−0.3	+0.7	—
Mean BP (mm Hg)						
Total	84.9 ± 9.0	84.4 ± 9.3	85.4 ± 9.4	−0.5	+0.5	a
Men	86.9 ± 8.4	86.0 ± 8.5	87.3 ± 9.1	−0.9	+0.4	a
17–29 yr	84.6 ± 7.7	83.9 ± 7.8	84.7 ± 7.8	−0.7	+0.1	—
30–49 yr	88.6 ± 8.2	88.1 ± 8.3	89.8 ± 9.3	−0.5	+1.2	—
50–65 yr	88.9 ± 8.8	87.0 ± 9.4	88.9 ± 10.0	−1.9	0.0	a
Women	83.6 ± 9.3	83.3 ± 9.6	84.1 ± 9.4	−0.3	+0.5	—
17–29 yr	80.7 ± 7.7	80.1 ± 7.5	80.8 ± 7.3	−0.6	+0.1	—
30–49 yr	85.5 ± 9.3	85.7 ± 10.5	86.4 ± 10.2	+0.2	+0.9	—
50–65 yr	87.5 ± 9.7	87.1 ± 10.2	87.9 ± 10.0	−0.4	+0.4	—
Blacks - total	89.3 ± 8.6	88.6 ± 9.2	89.0 ± 9.9	−0.7	−0.3	d
Men	90.8 ± 7.0	89.3 ± 7.9	90.3 ± 9.3	−1.5	−0.5	—
Women	88.6 ± 9.3	88.3 ± 9.8	88.3 ± 10.1	−0.3	−0.3	—
Whites - total	82.8 ± 8.3	82.4 ± 8.6	83.7 ± 8.7	−0.4	+0.9	b, d
Men	85.5 ± 8.4	84.8 ± 8.5	86.3 ± 8.8	−0.7	+0.8	—
Women	80.5 ± 7.5	80.3 ± 8.2	81.5 ± 7.9	−0.2	+1.0	b

* a, significant difference pretraining to 24-h posttraining; b, significant difference pretraining to 72-h posttraining; c, significant difference between men and women; d, significant difference between blacks and whites; e, significant differences between black women and white women.

all subgroups. Although some studies have demonstrated more substantial reductions (e.g., 7-13 beats·min^{-1}) in resting HR (5,19,22,27), others have reported little or no change with endurance training (7,17,18,21,28). From these studies, it appears that the magnitude of change in resting HR is unrelated to the magnitude of change in $\dot{V}O_{2max}$.

TABLE 3. Changes in exercise heart rate and blood pressure at 50 Watts (N = 507).

Variable	Pretraining (Mean ± SD)	Posttraining (Mean ± SD)	Absolute Difference (post-pre)	Significant Difference* (P < 0.05)
Heart rate (beats·min^{-1})				
Total	120.2 ± 18.6	108.9 ± 14.2	−11.3	a
Men	106.7 ± 12.1	98.4 ± 9.6	−8.3	a, b
17–29 yr	105.7 ± 10.7	98.5 ± 9.1	−7.2	a
30–49 yr	108.2 ± 12.1	99.3 ± 9.5	−8.9	a
50–65 yr	106.6 ± 14.4	96.8 ± 10.4	−9.8	a
Women	130.1 ± 16.3	116.6 ± 11.9	−13.5	a, b
17–29 yr	130.5 ± 15.7	117.9 ± 11.1	−12.6	a
30–49 yr	128.8 ± 17.2	115.7 ± 12.6	−13.1	a
50–65 yr	132.3 ± 15.3	115.0 ± 12.2	−17.3	a
Blacks - total	124.8 ± 19.4	112.9 ± 13.7	−11.9	a
Men	108.5 ± 12.7	100.6 ± 8.9	−7.9	a
Women	133.3 ± 16.7	119.3 ± 11.2	−14.0	a
Whites - total	117.9 ± 17.8	106.9 ± 14.0	−11.0	a
Men	106.1 ± 11.8	97.6 ± 9.7	−8.5	a
Women	128.1 ± 15.7	115.0 ± 12.1	−13.1	a
Systolic BP (mm Hg)				
Total	148.0 ± 20.6	139.9 ± 16.7	−8.1	a
Men	149.7 ± 18.6	142.6 ± 14.1	−7.1	a
17–29 yr	142.5 ± 12.5	139.1 ± 11.3	−3.4	a, g, h
30–49 yr	152.9 ± 18.2	143.9 ± 13.9	−9.0	a, f
50–65 yr	158.9 ± 23.2	147.6 ± 17.4	−11.3	a, f
Women	146.8 ± 21.9	137.9 ± 18.1	−8.9	a
17–29 yr	136.4 ± 13.4	130.6 ± 12.3	−5.8	a, h
30–49 yr	149.2 ± 19.5	140.0 ± 16.8	−9.2	a, h
50–65 yr	173.0 ± 26.2	155.2 ± 23.6	−17.8	a, f, g
Blacks - total	154.4 ± 21.0	143.8 ± 16.4	−10.6	a, c
Men	156.4 ± 19.0	146.7 ± 12.9	−9.7	a, d
Women	153.3 ± 22.0	142.3 ± 17.8	−11.0	a, e
Whites - total	144.9 ± 19.7	138.0 ± 16.5	−6.9	a, c
Men	147.2 ± 17.9	141.2 ± 14.3	−6.0	a, d
Women	142.9 ± 20.9	135.2 ± 17.9	−7.7	a, e
Diastolic BP (mm Hg)				
Total	73.9 ± 11.6	69.7 ± 10.4	−4.2	a
Men	75.1 ± 11.3	71.3 ± 9.6	−3.8	a
17–29 yr	69.7 ± 9.5	67.3 ± 7.9	−2.4	a
30–49 yr	78.9 ± 10.1	73.9 ± 9.0	−5.0	a
50–65 yr	79.8 ± 12.2	75.1 ± 10.5	−4.7	a
Women	73.1 ± 11.8	68.5 ± 10.8	−4.6	a
17–29 yr	67.1 ± 9.4	63.8 ± 9.1	−3.3	a
30–49 yr	76.8 ± 11.1	71.3 ± 10.3	−5.5	a
50–65 yr	82.0 ± 10.7	75.9 ± 10.5	−6.1	a
Blacks - total	79.2 ± 11.0	73.1 ± 10.8	−6.1	a, c
Men	81.1 ± 10.1	75.0 ± 9.0	−6.1	a, d
Women	78.2 ± 11.4	72.0 ± 11.5	−6.2	a, e
Whites - total	71.4 ± 11.0	68.0 ± 9.8	−3.4	a, c
Men	72.9 ± 11.0	69.9 ± 9.4	−3.0	a, d
Women	70.1 ± 10.9	66.4 ± 9.9	−3.7	a, e
Mean BP (mm Hg)				
Total	98.7 ± 13.4	93.1 ± 11.4	−5.6	a
Men	100.0 ± 12.6	95.1 ± 9.9	−4.9	a
17–29 yr	93.9 ± 9.1	91.2 ± 7.6	−2.7	a, g, h
30–49 yr	103.8 ± 11.6	97.4 ± 9.8	−6.4	a, f
50–65 yr	106.2 ± 14.4	99.3 ± 11.1	−6.9	a, f
Women	97.7 ± 13.9	91.7 ± 12.3	−6.0	a
17–29 yr	90.3 ± 9.7	86.1 ± 9.1	−4.2	a, h
30–49 yr	100.9 ± 12.7	94.2 ± 11.6	−6.7	a
50–65 yr	112.3 ± 13.5	102.5 ± 13.7	−9.8	a, f
Blacks - total	104.3 ± 12.8	96.7 ± 11.5	−7.6	a, c
Men	106.3 ± 11.7	99.0 ± 9.1	−7.3	a, d
Women	103.3 ± 13.3	95.5 ± 12.4	−7.8	a, e
Whites - total	95.9 ± 12.8	91.4 ± 11.0	−4.5	a, c
Men	97.7 ± 12.1	93.7 ± 9.8	−4.0	a, d
Women	94.4 ± 13.1	89.4 ± 11.7	−5.0	a, e

* a, significant difference pre- to posttraining; b, significant difference between men and women; c, significant difference between blacks and whites; d, significant difference between black men and white men; e, significant difference between black women and white women; f, significant difference compared with 17 to 29 year-old group; g, significant difference compared with 30 to 49 year-old group; h, significant difference compared with 50 to 65 year-old group.

The lack of substantial decreases in resting SBP, DBP, and MBP after endurance training was unexpected. In six reviews over the past 8 yr, it has been clearly documented that endurance exercise training results in decreases in both SBP and DBP at rest in normotensives, borderline hypertensives, and hypertensives (4,9,10,12,20,25). Fagard and Tipton in their review (10) summarized that the weighted net change in BP (SBP/DBP) with endurance training av-

TABLE 4. Changes in exercise heart rate and blood pressure at 60% of $\dot{V}O_{2max}$.

Variable	Pretraining (Mean ± SD)	Posttraining (Mean ± SD)	Absolute Difference (post - pre)	Significant Difference* ($P < 0.05$)
Heart rate (beats·min^{-1})				
Total	140.0 ± 16.3	135.7 ± 15.1	−4.3	a
Men	137.6 ± 15.4	132.8 ± 13.6	−4.8	a
17–29 yr	144.0 ± 12.4	139.6 ± 10.5	−4.4	a
30–49 yr	136.4 ± 13.7	131.8 ± 11.1	−4.6	a
50–65 yr	127.2 ± 16.7	121.0 ± 13.8	−6.2	a
Women	141.8 ± 16.7	137.9 ± 15.8	−3.9	a
17–29 yr	151.0 ± 14.1	147.1 ± 13.0	−3.9	a
30–49 yr	136.2 ± 14.6	133.7 ± 12.7	−2.5	a, h
50–65 yr	128.0 ± 13.0	120.3 ± 11.7	−7.7	a, g
Blacks - total	136.8 ± 14.5	134.0 ± 12.9	−2.8	a, c
Men	134.0 ± 13.3	131.5 ± 11.5	−2.5	d
Women	138.2 ± 14.9	135.3 ± 13.5	−2.9	a
Whites - total	141.6 ± 16.9	136.5 ± 16.1	−5.1	a, c
Men	138.9 ± 15.9	133.2 ± 14.3	−5.7	a, d
Women	144.0 ± 17.3	139.4 ± 16.9	−4.6	a
Systolic BP (mm Hg)				
Total	164.2 ± 21.5	163.4 ± 21.1	−0.8	—
Men	177.5 ± 18.7	175.7 ± 18.0	−1.8	—
17–29 yr	174.2 ± 16.8	175.4 ± 17.0	+1.2	—
30–49 yr	181.1 ± 20.2	177.4 ± 19.1	−3.7	—
50–65 yr	178.7 ± 18.9	173.9 ± 18.3	−4.8	a
Women	154.5 ± 17.9	154.3 ± 18.6	−0.2	—
17–29 yr	149.4 ± 14.6	150.3 ± 15.8	+0.9	—
30–49 yr	155.5 ± 16.0	155.4 ± 16.1	−0.1	—
50–65 yr	167.8 ± 24.1	164.0 ± 27.4	−3.8	—
Blacks - total	165.3 ± 22.3	164.8 ± 22.5	−0.5	—
Men	181.9 ± 21.3	180.2 ± 20.0	−1.7	—
Women	156.7 ± 17.4	156.8 ± 19.3	+0.1	—
Whites - total	163.7 ± 21.1	162.7 ± 20.4	−1.0	—
Men	175.9 ± 17.4	174.1 ± 16.9	−1.8	—
Women	153.1 ± 18.1	152.8 ± 18.0	−0.3	—
Diastolic BP (mm Hg)				
Total	75.2 ± 11.7	70.1 ± 10.5	−5.1	a
Men	76.5 ± 11.7	71.5 ± 9.8	−5.0	a
17–29 yr	70.5 ± 9.9	67.0 ± 8.3	−3.5	a
30–49 yr	80.6 ± 10.2	74.4 ± 8.3	−6.2	a
50–65 yr	82.1 ± 11.8	76.2 ± 10.8	−5.9	a
Women	74.4 ± 11.5	69.0 ± 10.9	−5.4	a
17–29 yr	69.2 ± 10.1	64.5 ± 9.8	−4.7	a
30–49 yr	77.5 ± 11.1	71.8 ± 10.2	−5.7	a
50–65 yr	82.1 ± 9.5	75.7 ± 10.8	−6.4	a
Blacks - total	80.3 ± 10.6	73.7 ± 10.8	−6.6	a, c
Men	82.3 ± 10.8	75.9 ± 8.6	−6.4	a
Women	79.3 ± 10.4	72.5 ± 11.7	−6.8	a, e
Whites - total	72.8 ± 11.3	68.3 ± 10.0	−4.5	a, c
Men	74.4 ± 11.3	69.9 ± 9.8	−4.5	a
Women	71.4 ± 11.2	66.9 ± 9.9	−4.5	a, e
Mean BP (mm Hg)				
Total	104.9 ± 12.7	101.2 ± 11.9	−3.7	a
Men	110.1 ± 11.9	106.2 ± 10.2	−3.9	a
17–29 yr	105.0 ± 9.9	103.1 ± 9.3	−1.9	a, h
30–49 yr	114.0 ± 11.2	108.7 ± 9.9	−5.3	a
50–65 yr	114.3 ± 12.6	108.7 ± 10.7	−5.6	a, f
Women	101.0 ± 12.0	97.4 ± 11.7	−3.6	a
17–29 yr	95.9 ± 9.9	93.1 ± 10.0	−2.8	a
30–49 yr	103.5 ± 11.0	99.6 ± 10.5	−3.9	a
50–65 yr	110.9 ± 12.5	105.2 ± 14.4	−5.7	a
Blacks - total	108.6 ± 12.5	104.0 ± 12.7	−4.6	a
Men	115.5 ± 12.0	110.7 ± 10.2	−4.8	a
Women	105.0 ± 11.2	100.6 ± 12.5	−4.4	a
Whites - total	103.1 ± 12.5	99.8 ± 11.3	−3.3	a
Men	108.2 ± 11.3	104.6 ± 9.7	−3.6	a
Women	98.7 ± 11.8	95.6 ± 10.9	−3.1	a

* a, significant difference pre- to posttraining; b, significant difference between men and women; c, significant difference between blacks and whites; d, significant difference between black men and white men; e, significant difference between black women and white women; f, significant difference compared with 17 to 29 year-old group; g, significant difference compared with 30-yr-old to 49-year-old group; h, significant difference compared with 50 to 65 year-old group.

eraged −3/−3 mm Hg in normotensive subjects, −6/−7 mm Hg in borderline hypertensive subjects, and −10/−8 mm Hg in hypertensive subjects. Further, Kelley and Tran (13) conducted a meta-analysis of studies examining aerobic exercise training and resting BP reduction in normotensive individuals and reported that there was a mean decrease of

TABLE 5. Changes in exercise heart rate and blood pressure at maximal exercise.

Variable	Pretraining (Mean ± SD)	Posttraining (Mean ± SD)	Absolute Difference (post - pure)	Significant Difference* ($P < 0.05$)
Heart rate (beats·min^{-1})				
Total	184.5 ± 14.0	183.9 ± 12.8	−0.6	a
Men	184.7 ± 14.5	182.8 ± 13.7	−1.9	a, b
17–29 yr	193.3 ± 9.2	190.8 ± 9.3	−2.5	a
30–49 yr	182.0 ± 12.1	180.5 ± 10.5	−1.5	—
50–65 yr	172.3 ± 15.3	171.0 ± 13.3	−1.3	—
Women	184.3 ± 13.7	184.7 ± 12.4	+0.4	b
17–29 yr	191.7 ± 9.3	191.7 ± 8.7	0.0	—
30–49 yr	181.2 ± 12.0	181.5 ± 10.6	+0.3	—
50–65 yr	169.3 ± 14.7	171.1 ± 12.3	+1.8	—
Blacks - total	182.6 ± 14.0	183.3 ± 12.1	+0.7	c
Men	182.5 ± 14.1	182.7 ± 12.1	+0.2	d
Women	182.6 ± 14.0	183.6 ± 12.2	+1.0	—
Whites - total	185.4 ± 14.0	184.2 ± 13.1	−1.2	a, c
Men	185.6 ± 14.6	182.9 ± 13.8	−2.7	a, d
Women	185.3 ± 13.5	185.4 ± 12.5	+0.1	—
Systolic BP (mm Hg)				
Total	194.7 ± 26.2	203.0 ± 27.8	+8.3	a
Men	209.1 ± 21.5	219.4 ± 23.7	+10.3	a, b
17–29 yr	203.1 ± 20.3	213.6 ± 21.8	+10.5	a
30–49 yr	214.0 ± 21.6	226.8 ± 25.2	+12.8	a
50–65 yr	213.5 ± 21.0	220.1 ± 22.6	+6.6	a
Women	184.1 ± 24.3	191.0 ± 24.2	+6.9	a, b
17–29 yr	172.6 ± 17.4	181.6 ± 18.6	+9.0	a
30–49 yr	190.4 ± 22.9	195.9 ± 23.1	+5.5	a
50–65 yr	203.8 ± 28.3	207.3 ± 30.3	+3.5	—
Blacks - total	199.8 ± 26.2	206.9 ± 28.5	+7.1	a
Men	215.2 ± 23.5	225.7 ± 26.5	+10.5	a
Women	191.8 ± 24.0	197.1 ± 24.3	+5.3	a
Whites - total	192.2 ± 25.9	201.1 ± 27.3	+8.9	a
Men	206.9 ± 20.4	217.1 ± 22.3	+10.2	a
Women .	179.6 ± 23.4	187.4 ± 23.5	+7.8	a
Diastolic BP (mm Hg)				
Total	83.8 ± 12.9	80.1 ± 12.3	−3.7	a
Men	84.6 ± 13.0	81.0 ± 12.6	−3.6	a
17–29 yr	80.6 ± 13.0	76.1 ± 11.7	−4.5	a
30–49 yr	86.9 ± 11.7	84.6 ± 11.4	−2.3	—
50–65 yr	88.9 ± 12.9	85.3 ± 12.8	−3.6	a
Women	83.2 ± 12.9	79.4 ± 12.0	−3.8	a
17–29 yr	78.7 ± 12.4	77.4 ± 11.2	−1.3	g
30–49 yr	87.5 ± 12.5	80.0 ± 12.9	−7.5	a, f
56–65 yr	85.9 ± 10.8	83.7 ± 11.1	−2.2	—
Blacks - total	88.9 ± 12.7	83.4 ± 12.8	−5.5	a, c
Men	90.1 ± 12.4	84.3 ± 11.9	−5.8	a
Women	88.3 ± 12.9	83.0 ± 13.2	−5.3	a
Whites - total	81.3 ± 12.3	78.4 ± 11.8	−2.9	a, c
Men	82.6 ± 12.7	79.8 ± 12.7	−2.8	a
Women	80.1 ± 11.9	77.2 ± 10.8	−2.9	a
Mean BP (mm Hg)				
Total	120.7 ± 14.6	121.0 ± 14.4	+0.3	—
Men	126.1 ± 13.2	127.1 ± 13.3	+1.0	—
17–29 yr	121.5 ± 12.6	121.9 ± 12.2	+0.4	—
30–49 yr	129.3 ± 12.3	132.0 ± 12.3	+2.7	—
50–65 yr	130.4 ± 12.9	130.3 ± 13.3	−0.1	—
Women	116.8 ± 14.4	116.6 ± 13.5	−0.2	—
17–29 yr	109.9 ± 12.2	112.1 ± 11.7	+2.2	a, g
30–49 yr	121.8 ± 13.8	118.7 ± 13.2	−3.1	a, f
50–65 yr	125.2 ± 12.5	124.9 ± 14.4	−0.3	—
Blacks - total	125.9 ± 14.6	124.6 ± 14.1	−1.3	c
Men	131.8 ± 13.6	131.4 ± 12.1	−0.4	—
Women	122.8 ± 14.2	121.0 ± 13.8	−1.8	e
Whites - total	118.2 ± 14.0	119.3 ± 14.2	+1.1	c
Men	124.0 ± 12.4	125.6 ± 13.4	+1.6	—
Women	113.2 ± 13.4	113.9 ± 12.6	+0.7	e

* a, significant difference pre- to posttraining; b, significant difference between men and women; c, significant difference between blacks and whites; d, significant difference between black men and white men; e, significant difference between black women and white women; f, significant difference compared with 17 to 29 year-old group; g, significant difference compared with 30 to 49 year-old group; h, significant difference compared with 50 to 65 year-old group.

−4.4 mm Hg in SBP and −3.2 mm Hg in DBP. The subjects in the present study were either in the normotensive or borderline hypertensive category, and the mean change for SBP/DBP for the total sample averaged only −0.8/−0.4 mm Hg at 24-h posttraining and +0.2/+0.6 mm Hg at 72-h posttraining.

There is no obvious explanation for the lack of substantial change in the present sample of subjects. There was no nonexercising control group in the HERITAGE Family Study, yet in almost all studies, the control groups remained unchanged over the intervention period. This was, in fact, the justification for not including a control group in the present study. Subjects were enrolled in the study throughout the year over a period of 5 years, so seasonal climatic changes should not have been a factor in these results. Neither the length of the training program, nor the intensity or duration of the individual exercise sessions, were factors, as the HERITAGE Family Study was of greater length (20 wk), intensity (75% of $\dot{V}O_{2max}$ for the last 6 wk), and exercise session duration (50 min·session^{-1} for the last 6 wk) when compared with the 35 studies included by Kelley and Tran in their meta-analysis (13).

The one difference between the present study and those included in the meta analysis of Kelley and Tran (13) was in the initial pretraining resting BP values. Their mean SBP and DBP values for all studies reviewed were 124.4 mm Hg and 77.5 mm Hg, respectively, compared with 118.5 mm Hg and 68.2 mm Hg in the present study. There is a point where further reductions in resting BP serve no useful purpose and can, in fact, be detrimental, i.e., hypotension. In support of this, simple correlational analyses were conducted between the initial pretraining resting HR, resting SBP, and resting DBP and the posttraining changes in each (i.e., pretraining − posttraining value). The resulting correlation coefficients were −0.39, −0.29, and −0.35, indicating that those with higher pretraining values tended to have greater reductions in resting values for HR, SBP, and DBP, respectively ($P < 0.0001$). The changes in resting values for HR and BP were unrelated to the percentage increase in $\dot{V}O_{2max}$, except for a weak correlation with resting HR ($r = 0.11$, $P < 0.01$).

During exercise at the same absolute power output (50 W), the reductions in HR, SBP, DBP, and MBP for the total group and all subgroups were expected (9). In the HERITAGE Family Study, $\dot{V}O_2$ and cardiac output at 50 W were decreased posttraining, whereas stroke volume and a-vO_2 diff were increased (29). This would explain the mechanisms behind the decrease in both HR and BP. The greater reductions in HR in women and BP in both the black and older subgroups are likely related to their higher pretraining levels as discussed above.

At 60% of $\dot{V}O_{2max}$, the decreases were much smaller than those seen at 50 W, and only the decreases in HR, DBP, and MBP achieved statistical significance. The literature is less clear when making comparisons pre- to post-training at the same relative power output; however, others have reported decreases in SBP at the same absolute power output (e.g., 50 W), but not at the same relative power output (e.g., 60% $\dot{V}O_{2max}$) (26). Because the absolute power output at 60% $\dot{V}O_{2max}$ was higher posttraining, the $\dot{V}O_2$ at 60% $\dot{V}O_{2max}$ was higher. The cardiac output was also higher, increasing from 13.7 to 14.7 L·min^{-1} (29). Yet, despite this increase in cardiac output, there were decreases in HR, DBP, and MBP, and no change in SBP. There were greater reductions in HR in whites and older women, and DBP in blacks, the latter likely related to the higher pretraining DBP values in blacks.

At maximal exercise, there were small reductions in HR in some subgroups and DBP in all but two subgroups, and moderate increases in SBP, with no change in MBP. Few studies have attempted to determine BP at maximal levels of exercise. Ekblom et al. (8) catheterized their subjects in order to measure direct arterial BP during exercise in eight young men, before and after a 16-wk endurance training program. They reported an increase in $\dot{V}O_{2max}$ of 16.8%, similar to the 17.4% increase in the present study. They found increases in both SBP and MBP posttraining, with no change in DBP. On the other hand, Martin et al. (15), used indirect techniques and found no increase in maximal SBP during upright cycle ergometry in middle-aged men and women who had undergone 12-wk of intense swim training. However, peak SBP during supine exercise increased from 204 mm Hg to 221 mm Hg consequent to training. $\dot{V}O_{2max}$ increased by 16% during upright cycling and by 10% during supine cycling. The increase in maximal SBP seen in the present study suggests an enhanced cardiac pump capacity after training (15). Men had a greater increase in maximal SBP than women, and blacks had a greater reduction in DBP than whites.

In summary, the HERITAGE Family Study 20-wk endurance exercise training program resulted in only small changes in resting HR and resting BP, which, with the exception of HR and DBP, varied by race. During exercise at the same absolute power output (50 W), HR, SBP, DBP, and MBP were all significantly reduced, with greater reductions in HR in women compared with men, and greater reductions in BP in blacks and older subjects compared with whites and younger subjects. At the same relative power output (60% $\dot{V}O_{2max}$), HR, DBP, and MBP were reduced, but SBP remained unchanged. Blacks had a greater reduction in DBP, whereas whites and older women had greater reductions in HR. Finally, at maximal exercise there was a small decrease in HR, with men and whites decreasing more than women and blacks; an 8 mm Hg increase in SBP, with men increasing more than women; a 4 mm Hg decrease in DBP, with blacks decreasing more than whites; and no change in MBP. In conclusion, the reductions in resting HR and BP with training were generally small and, with few exceptions, similar across race, sex, and age. The reductions in exercise HR and BP, however, were much more substantial. Further, and of clinical significance, the reductions were generally greater in the older and the black populations, populations at increased risk for hypertension and its consequences.

The HERITAGE Family Study is supported by the National Heart, Lung and Blood Institute through the following grants: HL45670 (C. Bouchard, PI); HL47323 (A. S. Leon, PI); HL47317 (D. C. Rao, PI); HL47327 (J. S. Skinner, PI); and HL47321 (J. H. Wilmore, PI). Claude Bouchard is partially supported by the George A. Bray Chair in Nutrition. Credit is also given to the University of Minnesota Clinical Research Center, NIH Grant MO1-RR000400. Further, Art Leon is partially supported by the Henry L. Taylor Professorship in Exercise Science and Health Enhancement.

Thanks are expressed to all of the co-principal investigators, investigators, co-investigators, local project coordinators, research assistants, laboratory technicians, and secretaries who have contributed to this study [see Bouchard et al. (6)]. Finally, the HERITAGE consortium is very thankful to those hard-working families whose participation has made these data possible.

Address for correspondence: Jack H. Wilmore, Department of Health and Kinesiology, TAMU 4243-158 Read Building, Texas A&M University, College Station, TX 77843-4243; E-mail: jwilmore@tamu.edu.

REFERENCES

1. AINSWORTH, B. E., N. L. KEENAN, D. S. STROGATZ, J. M. GARRETT, and S. A. JAMES. Physical activity and hypertension in black adults: the Pitt County Study. *Am. J. Public Health* 81:1477–1479, 1991.
2. ANONYMOUS. Heart and Stroke Statistical Update. Dallas, TX: American Heart Association, 1998.
3. ANONYMOUS. The Fifth Report of the Joint National Committee on Detection, Evaluation, and Treatment of High Blood Pressure. National Institutes of Health: NHLBI NIH Publication No. 93-1088:1–49, 1993.
4. ARROLL, B., and R. BEAGLEHOLE. Does physical activity lower blood pressure: a critical review of the clinical trials. *J. Clin. Epidemiol.* 45:439–447, 1992.
5. BLUMENTHAL, J. A., M. FREDRIKSON, C. M. KUHN, R. L. ULMER, M. WALSH-RIDDLE, and M. APPELBAUM. Aerobic exercise reduces levels of cardiovascular and sympathoadrenal responses to mental stress in subjects without prior evidence of myocardial ischemia. *Am. J. Cardiol.* 65:93–98, 1990.
6. BOUCHARD, C., A. S. LEON, D. C. RAO, J. S. SKINNER, J. H. WILMORE, and J GAGNON. The HERITAGE Family Study: aims, design, and measurement protocol. *Med. Sci. Sports Exerc.* 27: 721–729, 1995.
7. EDWARDS, M. A. The effects of training at predetermined heart rate levels for sedentary college women. *Med. Sci. Sports Exerc.* 6:14–19, 1974.
8. EKBLOM, B., P.-O. ASTRAND, B. SALTIN, J. STENBERG, and B. WALLSTROM. Effect of training on circulatory response to exercise. *J. Appl. Physiol.* 24:518–528, 1968.
9. FAGARD, R., E. BIELEN, P. HESPEL, et al. Physical exercise in hypertension. In: *Hypertension: Pathophysiology, Diagnosis and Management*, J. H. Laragh and B. M. Brenner (Eds.). New York: Raven Press, 1990, pp. 1985–1998.
10. FAGARD, R. H., and C. M. TIPTON. Physical activity, fitness, and hypertension. In: *Physical Activity, Fitness, and Health*, C. Bouchard, R. J. Shephard, and T. Stephens (Eds.). Champaign, IL: Human Kinetics, 1994, pp. 633–655.
11. GAGNON, J., M. A. PROVINCE, C. BOUCHARD, et al. The HERITAGE Family Study: quality assurance and quality control. *Ann. Epidemiol.* 6:520–529, 1996.
12. HAGBERG, J. M., S. N. BLAIR, A. A. EHSANI, et al. American College of Sports Medicine Position Stand: physical activity, physical fitness, and hypertension. *Med. Sci. Sports Exerc.* 25:i–x, 1993.
13. KELLEY, G., and Z. V. TRAN. Aerobic exercise and normotensive adults: a meta-analysis. *Med. Sci. Sports Exerc.* 27:1371–1377, 1995.
14. KOKKINOS, P. F., P. NARAYAN, J. A. COLLERAN, et al. Effects of regular exercise on blood pressure and left ventricular hypertrophy in African-American men with severe hypertension. *N. Engl. J. Med.* 333:1462–1467, 1995.
15. MARTIN, W. H., III, J. MONTGOMERY, P. G. SNELL, et al. Cardiovascular adaptations to intense swim training in sedentary middle-aged men and women. *Circulation* 75:323–330, 1987.
16. MELBY, C. L., D. G. GOLDFLIES, and G. C. HYNER. Blood pressure and anthropometric differences in regularly exercising and nonexercising black adults. *Clin. Exp. Hypertens. Theory Pract.* A13: 1233–1248, 1991.
17. 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.
18. O'CONNOR, P. J., M. A. CROWLEY, A. W. GARDNER, and J. S. SKINNER. Influence of training on sleeping heart rate following daytime exercise. *Eur. J. Appl. Physiol. Occup. Physiol.* 67:37–42, 1993.
19. POLLOCK, M. L. The quantification of endurance training programs. *Exerc. Sport Sci. Rev.* 1:155–188, 1973.
20. SCHWARTZ, R. S., and V. A. HIRTH. The effect of endurance and resistance training on blood pressure. *Int. J. Obesity* 19:S52–S57, 1995.
21. SEDGWICK, A. W., R. J. CRAIG, R. CROUCH, and B. DOWLING. The effects of physical training on the day and night long-term heartrates of middle-aged men. *Eur. J. Appl. Physiol.* 33:307–314, 1974.
22. SHI, X., G. H. J. STEVENS, B. H. FORESMAN, S. A. STERN, and P. B. RAVEN. Autonomic nervous system control of the heart: endurance exercise training. *Med. Sci. Sports Exerc.* 27:1406–1413, 1995.
23. SKINNER, J. S., K. M. WILMORE, A. JASKÓLSKA, et al. Reproducibility of maximal exercise test data in the HERITAGE Family Study. *Med. Sci. Sports Exerc.* 31:1623–1628, 1999.
24. STANFORTH, P. R., J. GAGNON, T. RICE, et al. Reproducibility of resting blood pressure and heart rate measurements: The HERITAGE Family Study. *Ann. Epidemiol.* 10:271–277, 2000.
25. TIPTON, C. M. EXERCISE, training and hypertension: an update. *Exerc. Sport Sci. Rev.* 19:447–505, 1991.
26. VAN HOOF, R., P. HESPEL, R. FAGARD, P. LIJNEN, J. STAESSEN, and A. AMERY. Effect of endurance training on blood pressure at rest, during exercise and during 24 hours in sedentary men. *Am. J. Cardiol.* 63:945–949, 1989.
27. WILMORE, J. H., J. ROYCE, R. N. GIRANDOLA, F. I. KATCH, and V. L. KATCH. Physiological alterations resulting from a 10-week program of jogging. *Med. Sci. Sports Exerc.* 2:7–14, 1970.
28. WILMORE, J. H., P. R. STANFORTH, J. GAGNON, et al. Endurance exercise training has a minimal effect on resting heart rate: the HERITAGE study. *Med. Sci. Sports Exerc.* 28:829–835, 1996.
29. WILMORE, J. H., P. R. STANFORTH, J. GAGNON, et al. Cardiac output and stroke volume changes with endurance training: the Heritage Family Study. *Med. Sci. Sports Exerc.* 33:– –, 2000.
30. WILMORE, J. H., P. R. STANFORTH, L. A. HUDSPETH, et al. Alterations in resting metabolic rate as a consequence of 20 wk of endurance training: the HERITAGE Family Study. *Am. J. Clin. Nutr.* 68:66–71, 1998.
31. WILMORE, J. H., P. R. STANFORTH, K. R. TURLEY, et al. Reproducibility of cardiovascular, respiratory and metabolic responses to submaximal exercise: the HERITAGE Family Study. *Med. Sci. Sports Exerc.* 30:259–265, 1998.