Changes in Ventilatory Threshold with Exercise Training in a Sedentary Population: The Heritage Family Study

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The purpose of this study was to evaluate the effect of exercise training intensity relative to the ventilatory threshold (VT) on changes in work (watts) and $\dot{V}O_2$ at the ventilatory threshold and at maximal exercise in previously sedentary participants in the HERITAGE Family Study. We hypothesized that those who exercised below their VT would improve less in $\dot{V}O_2$ at the ventilatory threshold ($\dot{V}O_2$vt) and $\dot{V}O_2$max than those who tained at an intensity greater than their VT. Supervised cycle ergometer training was performed at the 4 participating clinical centers, 3 times a week for 20 weeks. Exercise training progressed from the HR corresponding to 55% $\dot{V}O_2$max for 30 minutes to the HR associated with 75% $\dot{V}O_2$max for 50 minutes for the final 6 weeks. VT was determined at baseline and after exercise training using standardized methods. 432 sedentary white and black men (n = 224) and women (n = 208), aged 17 to 65 years, were retrospectively divided into groups based on whether exercise training was initiated below, at, or above VT. Results: 1) Training intensity (relative to VT) accounting for about 26% of the improvement in $\dot{V}O_2$vt ($R^2 = 0.26$, $p < 0.0001$). 2) The absolute intensity of training in watts (W) accounted for approximately 56% of the training effect at VT ($R^2 = 0.56$, $p < 0.0001$) with post-training watts at VT (VT_{watts}) being not significantly different than W during training ($p > 0.70$). 3) Training intensity (relative to VT) had no effect on $\Delta\dot{V}O_2$max. These data clearly show that as a result of aerobic training both the $\dot{V}O_2$ and W associated with VT respond and become similar to the absolute intensity of sustained (3×/week for 50 min) aerobic exercise training. Higher intensities of exercise, relative to VT, result in larger gains in $\dot{V}O_2$vt but not in $\dot{V}O_2$max.

Key Words: Submaximal exercise, submaximal fitness, $\dot{V}O_2$, race, sex.

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Introduction

Maximum oxygen uptake ($\dot{V}O_2$max) or aerobic power has evolved as the "Gold Standard" for the evaluation of cardiorespiratory endurance or aerobic fitness [13,16,23]. However, some researchers argue that the lactate threshold (LT), and the associated $\dot{V}O_2$ at the ventilatory threshold ($\dot{V}O_2$vt), provide a more accurate index of general aerobic fitness than does $\dot{V}O_2$max [5–7,12,19,21].

Farrell et al. [8] were the first to report that the treadmill velocity associated with the onset of plasma lactate accumulation was closely related to performance in distance runners ($r \geq 0.91$). Other researchers confirmed that LT was a consistent predictor of endurance performance while also tracking changes in performance following endurance training [4,11,14,15,20,24].

The American College of Sport Medicine (ACSM) exercise guidelines recommend starting an aerobic training program at an intensity of 50% $\dot{V}O_2$max (or at 40% $\dot{V}O_2$max for those individuals with very low aerobic fitness) and as fitness improves to gradually increase exercise intensity up to 85% $\dot{V}O_2$max [10]. This range of exercise intensity corresponds well with the mean ratio of $\dot{V}O_2$vt/$\dot{V}O_2$max (VT%$\dot{V}O_2$max) which ranges from 52% in sedentary individuals to 85% in well-conditioned endurance athletes [4,12,14,20]. However, the ACSM guidelines fail to take into consideration the wide variance in VT%$\dot{V}O_2$max [12]. The mean VT%$\dot{V}O_2$max of the sedentary HERITAGE Family Study (HERITAGE) population was 55% with a range of 34% to 83%. If this large variance in baseline VT%$\dot{V}O_2$max is not considered during the design of exercise training protocols, the result will be individuals training at greatly different intensities relative to their ventilatory threshold (VT). Thus, the perceived exertion of individuals exercising at similar percentages of $\dot{V}O_2$max will vary greatly and the relative contributions of aerobic and anaerobic metabolism during exercise will cover a broad spectrum. In HERITAGE all individuals initiated training at the same %$\dot{V}O_2$max representing a broad distribution of training intensity relative to VT.

The purposes of this paper are to describe: 1) the effect of exercise training intensity relative to VT, on exercise training-induced changes in $\dot{V}O_2$ and watts at both VT and maximal exertion intensities, and 2) to describe the relationships between absolute training intensity and post-training both watts and

$\dot{V}O_2$ at VT. These analyses were performed retrospectively, since the HERITAGE exercise training protocol was designed based on percentages of $\dot{V}O_2$max. The initial training intensity for all participants was set at each individual's heart rate (HR) corresponding to 55% of baseline $\dot{V}O_2$max [3,18]. Within this population the baseline range of VT%$\dot{V}O_2$max was subsequently found to vary from 33.7% to 82.9%, with a mean ± SD of 54.9 ± 9.2%. As a result of the study design it was possible to retrospectively separate the participants into three groups, those who initiated exercise training at an intensity below, near, or above their baseline VT.

Methods

Study population

The HERITAGE Family Study population consists of 744 initially sedentary, healthy participants, including 484 whites from 99 two-generational families and 260 blacks from 102 families. Sedentary was defined as no regular strenuous physical activity over the previous 6 months [3,18]. Exclusion and inclusion criteria for this study were previously described [3,18].

Of the 744 participants successfully completing the study, VT was adequately identified, retrospectively from both pre- and post-training exercise testing data, in 432 individuals (217 males and 215 females).

Participants with adequate VT data were then subdivided into tertiles (n = 144 each) based on their baseline VT%$\dot{V}O_2$max levels. The "Above VT Group" consisted of those individuals whose baseline VT%$\dot{V}0_2$max was less than 50.4% (mean ± SD = 45.0 ± 4.0%). Thus the initial prescribed exercise intensity was above their VT. The 'Near VT Group' consisted of those individuals whose baseline VT%$\dot{V}O_2$max was between 50.5% to 58% (mean ± SD 54.2 ± 2.5%), and thus began training at or close to their baseline VT. The "Below VT Group" were individuals whose baseline VT%$\dot{V}O_2$max was greater than 58.4% (mean ± SD = 65.1 ± 5.1%) and the initial exercise training intensity was lower than their VT. Baseline characteristics of participants included in this study are summarized in Table **1**.

Approval was obtained from the institutional review boards (IRB) at each of the 4 participating clinical centers and written informed consent was obtained from each participant.

Exercise testing

Participants completed a battery of laboratory procedures and exercise tests at baseline and following 20 weeks of training [18]. The present study includes only mean $\dot{V}O_2$max, $\dot{V}O_2$vt, and cardiorespiratory measurements at VT obtained from the baseline and post-training maximal exercise tests.

Exercise testing was performed on a Sensormedics 800S Cycle Ergometer (Yorba Linda, CA) at the 4 clinical centers. Prior to exercise testing, participants familiarized themselves with the cycle ergometer via short practice sessions when test procedures were explained and questions answered. Measurements during exercise testing included metabolic measurements via expired air analysis using a Sensormedics 2900 Metabolic cart (Yorba Linda, CA).

Participants generally began the exercise test at a power output (PO) of 50 W for the first 3 min stage, which was followed by increases in PO of 25 W increments per each 2 min stage until volitional exhaustion was achieved. Accommodations were made for smaller or less fit individuals by starting the test at a PO of less than 50 W with subsequent 10 – 20 W incremental increases in PO per stage. The goal was to achieve $\dot{V}O_2$max within approximately 10 – 12 minutes of testing. Criteria for achieving $\dot{V}O_2$max in HERITAGE have been previously described [3,18].

Respiratory gas exchange measurements during testing including rates of ventilation (Ve), utilization of oxygen ($\dot{V}O_2$), production of carbon dioxide ($\dot{V}CO_2$), and the respiratory exchange ratio (RER), were recorded continuously. Data were analyzed using rolling averages of the most recent consecutive 20 second averages. Participants repeated the same testing procedures after 20 weeks of exercise training.

Exercise training program

Participants trained under supervision 3 times a week for 20 weeks (60 sessions) on Universal Aerobicycle Cycle Ergometers (Cedar Rapids, IA) at each of the 4 clinical centers. Cycle ergometers were calibrated approximately every four months over the three years of exercise training using a dynamometer that was shipped between the four clinical centers. Cycle ergometer crank torque was measured at 25 watt increments between 75 to 275 watts and appropriate adjustments were made to each ergometer to maintain accurate resistance. In addition, participants were required to rotate the use of cycles during each visit.

The exercise training intensity was controlled and monitored by a computer-controlled Mednet System (Universal, Inc. Cedar Rapids, IA) hooked up to each cycle ergometer. The Mednet system receives telemetered HR sent via Polar HR Monitor transmitters (Polar Electro, OY, Finland) and Vacumetrics Receiving Units (Vacumetrics, Inc., Ventura, CA). In addition, a back-up ear clip HR-monitoring system was also employed. Ergometer resistance was adjusted constantly by the Mednet system to maintain HR within ±5 beats/minute of the target HR corresponding to the relative exercise intensity prescribed for the individual. HRs associated with 55%, 65%, 70% and 75% of $\dot{V}O_2$max were determined from baseline exercise testing data for each individual and used throughout the training period to control the intensity of exercise. Exercise training progressed from the HR corresponding to 55% $\dot{V}O_2$max for 30 minutes at the beginning of the exercise training, increasing to the HR associated with 75% baseline $\dot{V}O_2$max for 50 minutes for the final 18 sessions (final 6 weeks). Further details of the HERITAGE exercise-training program are described elsewhere [3,18].

Determination of ventilatory threshold

Three validated methods were used concurrently to determine VT from pre- and post-training exercise test data: 1) Ventilatory equivalent method (VEQ method) [17]; 2) Excess carbon dioxide method ($ExCO_2$) [1,22], and 3) Modified V-slope method using 20 second averaged data [2]. Visual evaluation was performed using these methods. In addition computer algorithm was developed to determine VT from the V-slope method. These methods are discussed in more detail elsewhere [9] and discussed briefly below.

A detailed protocol was devised to maintain tight quality control over the retrospective determinations of VT from the exercise test reports. These controls included: 1) Values for the ventilatory equivalence of oxygen $Ve/\dot{V}O_2$ and $ExCO_2$ had to be stable prior to VT for the data to be considered usable. Data were considered stable when measurements for either $Ve/\dot{V}O_2$ or $ExCO_2$ in the minute prior to VT did not vary by more than 8%. 2) Two trained reviewers at the Minnesota HERITAGE clinical center independently determined time when VT was achieved (VT Time) and values for $\dot{V}O_2$vt ($ml \times min^{-1}$) using each of the visual methods. The intra-evaluator VT times determined for each test were then compared with one another and with the computer algorithm data. The VEQ and $ExCO_2$ methods then were used as the primary determinants to identify VT. The visual and computer algorithm V-slope methods were used to assist in identifying VT but were not used as a final determinant of VT. If VT time, as determined by the VEQ and $ExCO_2$ methods, occurred within the same minute of exercise, then the $\dot{V}O_2$vt value and the VT time for the 2 methods were averaged. When the VT times determined by the VEQ and $ExCO_2$ methods did not occur within the same minute, the data were excluded from this study. (3) The inter-evaluator VT times that were independently determined were then compared. If either evaluator had rejected the data, then the data for that participant were rejected. If the independently determined VT times were within the same minute, then the $\dot{V}O_2$vt values and VT times were averaged. 4) When the independent determinations of VT did not occur within the same minute, a third trained observer independently analyzed the exercise test reports to adjudicate the determination of VT prior to inclusion or exclusion of the data. VT determination by the third observer needed to be within the same minute as one of the two original evaluators, otherwise the data for that participant were rejected.

In addition, the following conditions had to be met before data were included in this study: (A) Respiratory compensation (2^{nd} non-linear break in the V-slope and $ExCO_2$ plots and the concurrent rise in both $Ve/\dot{V}O_2$ and $Ve/\dot{V}CO_2$) needed to be identified in two of the three methods for VT determination. (B) Adjudicated VT determination needed to be within the 95% confidence interval for the variance in $\dot{V}$EQ and $ExCO_2$ in the minute prior to achieving VT (within 8% of absolute values) and the appearance time of VT needed to be at < 4 minutes into the exercise test.

Table 1 Mean (± SD) baseline participant characteristics

Group	N	Age	Mass (kg)	% Body Fat (UWW)[2]	BMI[1]	$\dot{V}O_2$max ($ml \times kg^{-1} \times min^{-1}$)	$\dot{V}O_2$vt ($ml \times kg^{-1} \times min^{-1}$)	VT%$\dot{V}O_2$max[3]	PO[4] at VT
Above VT[5]	144	29.5 ± 10.7***	79.8 ± 16.6***	25.9 ± 4.7	22.2 ± 9.0***	38.2 ± 7.0***	17.2 ± 3.1***	45.0 ± 4.0	85.5 ± 22.5***
Near VT[6]	144	35.0 ± 13.4***	80.1 ± 19.0***	26.9 ± 5.5	27.8 ± 9.7***	32.3 ± 7.8***	17.5 ± 4.4***	54.2 ± 2.5	86.6 ± 27.5***
Below VT[7]	144	37.5 ± 13.7	75.6 ± 16.7	27.3 ± 5.6	31.6 ± 10.6	28.0 ± 6.7	18.2 ± 4.5	65.0 ± 5.1	84.0 ± 29.6
Overall[8]	432	34.0 ± 13.8	78.5 ± 17.6	26.7 ± 5.3	27.1 ± 10.4	32.9 ± 8.3	17.6 ± 4.1	54.8 ± 9.1	85.4 ± 26.7

1 BMI = Body Mass Index = mass (kg)/height^2 (m)
2 UWW = Underwater (Hydrostatic) Weighing
3 VT%$\dot{V}O_2$max = $\dot{V}O_2$vt/$\dot{V}O_2$max×100
4 PO = Power output (W), VT = Ventilatory Threshold
5 Above VT Group = VT%$\dot{V}O_2$max < 50.4% (Exercise training started at an intensity greater than VT)
6 Near VT Group = VT%$\dot{V}O_2$max > 50.4% and 58.4% (Exercise training started at an intensity near VT)
7 Below VT Group = VT%$\dot{V}O_2$max > 58.4% (Exercise training started at an intensity less than VT)
8 Overall = VT Cohort of 432 HERTIAGE participants with adequately identified VT
*** Significant difference between training intensity groups ($p < 0.001$)

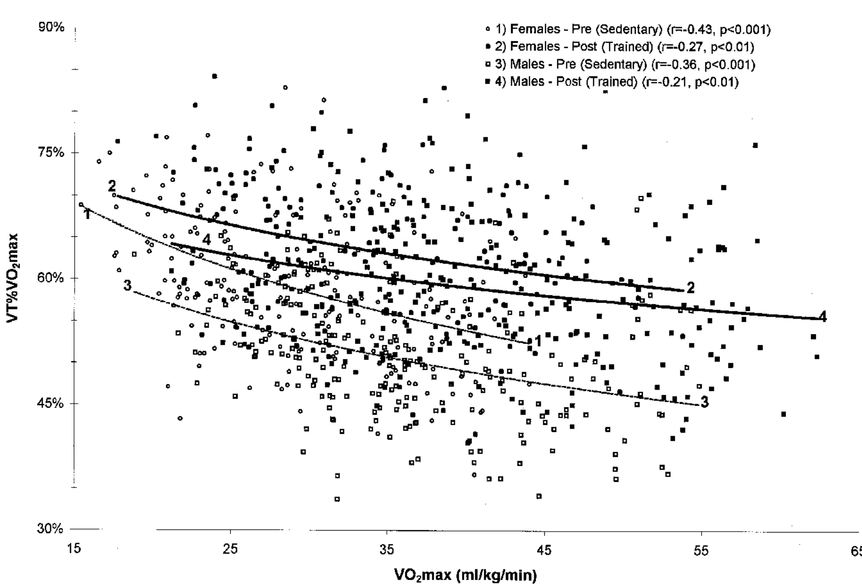

Fig. 1 Relationship of $\dot{V}O_2$max to VT%$\dot{V}O_2$max. Circles represent females and squares designate males. Open figures are baseline values and filled figures are post-training. The logarithmic lines of best fit are noted for males and females, pre and post-training. Note that females utilize a significantly ($p < 0.01$) greater % of $\dot{V}O_2$max at VT (VT%$\dot{V}O_2$max) than do males both at baseline and post-training. Also note that the relationships between $\dot{V}O_2$max and VT%$\dot{V}O_2$max are significant for each group. As $\dot{V}O_2$max increases in this sedentary population, VT%$\dot{V}O_2$max decreases showing that individuals with lower $\dot{V}O_2$max values use a greater percentage of $\dot{V}O_2$max at VT. Pearson Product Moment Correlation values (r) represent the 2nd order relationship between $\dot{V}O_2$max and $\dot{V}O_2$vt/max. Significance of each relationship is shown.

All of the above conditions had to be met on the baseline test for the participant's data to be included. If no adequate baseline VT was available, post-training VT was not determined and the participant's data were not used in this study. The same process was used to evaluate the post-training data. To be included in the current study, participants needed to have valid VT measurements determined for both pre- and post-testing exercise tests. Further details of the methodology, along with their validity and reliability are reported elsewhere [9]. The above exclusion criteria during the evaluation of VT eliminated 312 potential participants from this study. Based on the validity and reliability studies that were conducted on the VT methodology used in HERITAGE [9], only 2 % of 432 participants with good VT data would be expected to fall outside the 95 % confidence interval comparing VT with LT. The test-retest reliability for the VT determination method was very robust ($r = 0.93$) and the mean values of repeated determinations were not different ($p > 0.05$).

Statistics

Between subject's ANOVAs and Scheffe's post hoc procedures were used to determine significant differences among exercise training intensity groups at baseline and for percent change values. Statistical significance was set at $p < 0.01$ unless otherwise noted in the text or tables. A multiple stepwise correlation was used to evaluate relationships between training intensity and post-training values of $\dot{V}O_2$max and watts at VT. Further, differences in $\dot{V}O_2$max and $\dot{V}O_2$vt of less than $2\ ml \times kg^{-1} \times min^{-1}$ were not considered biologically meaningful, even if statistically significant, since there is an expected test-retest error of this magnitude in the $\dot{V}O_2$ measurements. Means and standard deviations of the means are reported.

Results

Baseline data

Table **1** lists baseline characteristics for individuals with adequate VT data (grouped by initial exercise training intensity relative to VT). The mean baseline $\dot{V}O_2$max value for the sample was $32.9 \pm 8.3\ ml \times kg^{-1} \times min^{-1}$ with values for male participants significantly greater than those for females (36.6 ± 8.2 vs $29.1 \pm 6.6\ ml \times kg^{-1} \times min^{-1}$, $p < 0.0001$). The mean baseline $\dot{V}O_2$vt for the cohort was $17.6 \pm 4.1\ ml \times kg^{-1} \times min^{-1}$ or 5.0 METs, with men and women showing similar values (18.2 ± 5.6 vs $17.1 \pm 4.6\ ml \times kg^{-1} \times min^{-1}$).

Fig. **1** shows the relationship of $\dot{V}O_2$max to VT%$\dot{V}O_2$max. On average, women had higher VT%$\dot{V}O_2$max values than men at baseline (59.4 ± 8.6% vs 50.7 ± 7.6% respectively, $p < 0.001$). Pre- and post-training second order lines of best fit are shown and r values (all significant at $p < 0.01$) are noted.

Absolute change in $\dot{V}O_2$vt and $\dot{V}O_2$max with training

Table **2** details the absolute pre- to post-training changes in $\dot{V}O_2$vt ($\Delta\dot{V}O_2$vt) and $\dot{V}O_2$max ($\Delta\dot{V}O_2$max). There were no significant differences in $\Delta\dot{V}O_2$max between VT intensity groups for the study population overall or by gender or race subgroups. Intensity of training relative to VT had a positive effect on $\Delta\dot{V}O_2$vt. Training above VT stimulated the largest increase in $\dot{V}O_2$vt and training, below VT resulted in a smaller improvement. A similar pattern was seen in both males and females and in blacks and whites (Table **2**).

Table 2 Absolute changes with training in $\dot{V}O_2$max ($\Delta\dot{V}O_2$max) and $\dot{V}O_2$vt ($\Delta\dot{V}O_2$vt). Data are shown overall for both $\Delta\dot{V}O_2$max and $\Delta\dot{V}O_2$vt. $\Delta\dot{V}O_2$vt data are shown by gender and race grouped by training. There were no significant differences in $\Delta\dot{V}O_2$max between training intensity tertiles within gender or race subgroups. Mean ± SD

Group	Overall			Males		Females		Blacks		Whites	
		$\Delta\dot{V}O_2$max	$\Delta\dot{V}O_2$vt		$\Delta\dot{V}O_2$vt		$\Delta\dot{V}O_2$vt		$\Delta\dot{V}O_2$vt		$\Delta\dot{V}O_2$vt
	n	ml/kg/min	ml/kg/min	n	ml/kg/min	n	ml/kg/min	n	ml/kg/min	n	ml/kg/min
Above VT	144	5.8 ± 3.4# ns	7.6 ± 4.1***	117	8.0 ± 4.0***	36	6.3 ± 3.4***	36	6.7 ± 3.5***	117	7.9 ± 4.2***
Near VT	144	5.2 ± 2.9 ns	4.9 ± 3.2***	77	4.9 ± 3.5***	68	5.8 ± 2.8***	47	4.3 ± 2.6***	96	5.3 ± 3.5***
Below VT	144	5.2 ± 2.4#	3.8 ± 3.2	34	3.9 ± 3.7	112	3.8 ± 3.0	54	3.3 ± 2.3	92	4.1 ± 3.5
All	432	5.4 ± 2.9	5.5 ± 3.8	228	6.4 ± 4.2	214	4.6 ± 3.1	127	4.5 ± 3.0	305	5.9 ± 4.1

ns No significant difference between group ($p > 0.05$)
*** Significant difference between intensity groups ($p < 0.001$)
# Significant difference between change in $\dot{V}O_2$max and $\dot{V}O_2$vt ($p < 0.001$)

Table 3 Absolute changes with training in power output at VT (ΔPO at VT), overall and for gender and race, grouped by training intensity relative to VT. Mean ± SD

Group	Overall		Males		Females		Blacks		Whites	
		ΔPO at VT		ΔPO at VT		ΔPO at VT		ΔPO at VT		ΔPO at VT
	n	watts	n	watts	n	watts	n	watts	n	watts
Above VT	144	54.7 ± 40.4***	117	59.6 ± 42.7***	36	38.5 ± 19.8***	36	46.4 ± 24.3***	117	57.2 ± 42.9***
Near VT	144	36.9 ± 23.7***	77	40.3 ± 26.3***	68	32.9 ± 19.7***	47	36.9 ± 22.0***	96	36.9 ± 24.7***
Below VT	144	26.9 ± 20.9	34	31.9 ± 28.2	112	25.4 ± 18.0	54	25.2 ± 20.7	92	28.0 ± 21.1
All	432	39.7 ± 31.6	228	48.9 ± 37.5	214	29.9 ± 19.4	127	34.7 ± 23.6	305	42.0 ± 34.4

*** Significant difference between intensity groups ($p < 0.001$)

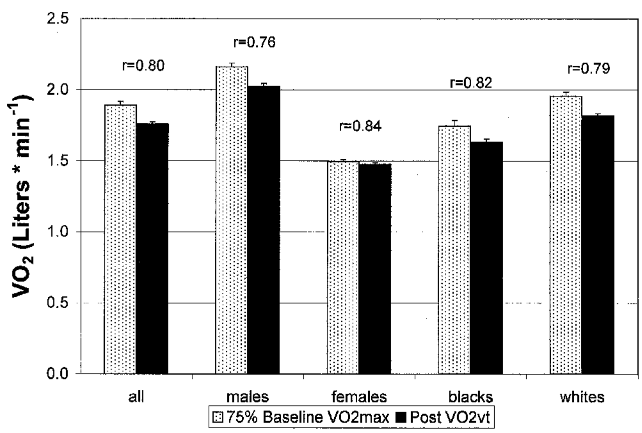

Fig. 2 Means and relationships of 75% baseline $\dot{V}O_2$max and post-training $\dot{V}O_2$vt. Exercise for the final 18 sessions was prescribed at the HR associated with 75% of baseline $\dot{V}O_2$max for 50 minutes each session. The stippled bar represents the prescribed training intensity, and the solid bar represents post-training $\dot{V}O_2$vt. Data are presented as $\dot{V}O_2$ (liters × min^{-1}). Data for the entire group (n = 432) is shown on the left, and by gender and race groups moving from left to right. Within group correlation values are indicated above the bars for each group (all significant, $p < 0.001$). There were no significant differences between the means of the prescribed training $\dot{V}O_2$ and post-training $\dot{V}O_2$vt overall or within subgroups.

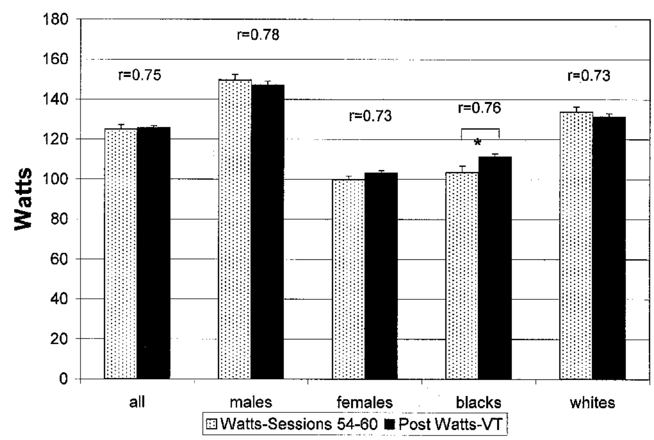

Fig. 3 Means and relationships of actual training intensity and post-training watts at VT. Exercise intensity (watts) for the final 18 sessions was averaged and is represented by the stippled bar. The solid bar represents post-training watts at VT determined during post-training exercise testing. Data are presented as mean watts ± sterr. Data for the entire group (n = 432) is shown on the left, and by gender and race groups moving from left to right. Within group correlation values are indicated above the bars for each group (all significant $p < 0.001$). There were no significant differences between the means of the prescribed training $\dot{V}O_2$ and post-training $\dot{V}O_2$vt overall, or within subgroups, except for the black subgroup where average training watts were significantly less than post-training watts at VT (103.5 ± 3.1 vs 111.1 ± 3.0 watts respectively, $p < 0.01$).

Table **3** lists the pre- to post-training changes in power output at VT_{watts}. Data are shown for the group overall and by gender and race by training intensity tertiles. Changes in VT_{watts} were greater for those who trained above VT than for those who trained near VT, who had larger improvements than for those who trained below VT. Male, female, black and white subgroups all responded in a similar manner (Table **3**).

Relationship of prescribed and actual training intensity with post-training $\dot{V}O_2$ and VT_{watts}

The final 6 weeks of training (18 sessions) were prescribed at the HR corresponding to 75% of baseline $\dot{V}O_2$max. Fig. **2** compares mean values for 75% baseline $\dot{V}O_2$max with post-training $\dot{V}O_2$vt overall and by gender and race. There were no significant differences between prescribed 75% baseline $\dot{V}O_2$max and post-training $\dot{V}O_2$vt overall or by gender or race. The within group correlations were robust ranging from r = 0.76 to 0.84 (Fig. **2**).

The average training intensity in watts (W) during the final 6 weeks of training was compared to post-training VT_{watts} determined during exercise testing. There was no significant difference between W during training and post-training VT_{watts} for the overall group. This relationship was maintained when analyses were done by gender or race, except for blacks (predominantly black females), where post-training VT_{watts} were 7.59 W higher during post-training exercise testing than during training. The within group correlations (overall, by gender and race) were strong ranging from r = 0.73 to 0.78.

Discussion

The purposes of the present study were as follows: 1) To evaluate the effect of exercise training intensity relative to VT, on changes in $\dot{V}O_2$max and $\dot{V}O_2$vt and 2) to describe the relationships of exercise training intensity with post-training $\dot{V}O_2$ and VT_{watts}. The overall mean baseline $\dot{V}O_2$vt for this study is in close agreement with observations from other studies of sedentary populations as reported in a meta-analysis by Londeree [12]. That study, which included 29 groups of sedentary men and women, reported a mean $\dot{V}O_2$vt of 19.8 ± 4.2 ml × kg^{-1} × min^{-1} as compared with a mean of 17.6 ± 4.1 ml × kg^{-1} × min^{-1}in the HERITAGE cohort. The slight difference at VT of this study's results from those of previous studies may be due to several factors: VT determination methodology, definition of sedentary, population demographics or because Americans are becoming less physically active.

In the current study we found that training intensity, relative to VT, had a significant effect on $\Delta\dot{V}O_2$vt accounting for about 26% of the training effect ($r^2 = 0.26$, $p < 0.0001$) with higher relative intensities resulting in greater improvements in $\dot{V}O_2$vt than did lower intensities of training. However, we found the training intensity relative to VT to have no effect on $\Delta\dot{V}O_2$max. The relationship between intensity of training relative to VT and improvements in $\dot{V}O_2$vt were hypothesized, but the lack of effect of the training intensity relative to VT on changes in $\dot{V}O_2$max was surprising.

VT%$\dot{V}O_2$max is postulated as a marker to indicate potential for improving $\dot{V}O_2$ both submaximally and maximally. Individuals with high VT%$\dot{V}O_2$max values mimic trained endurance athletes and have only a small reserve above VT for improvements in submaximal VT and, like trained endurance athletes, may not substantially improve $\dot{V}O_2max$ with exercise training. The results of this study support that hypothesis. Participants in this study with higher baseline VT%$\dot{V}O_2max$ values increased $\dot{V}O_2vt$ less, both in percentage increase and in absolute values, than those individuals with lower baseline VT%$\dot{V}O_2max$ values.

Fig. **1** illustrates that VT%$\dot{V}O_2max$ increased with training, with males increasing more than females. Males and females had significantly different baseline VT%$\dot{V}O_2max$ values with males being lower than females. This difference persisted post-training. However, the post-training mean male-female difference was less than half the baseline difference. This reduced post-training difference in VT%$\dot{V}O_2max$ may be due to the standardized HERITAGE training program that required all participants to train at their HR associated with 75 % of $\dot{V}O_2max$ for the final 6 weeks of training.

A small group (n = 65) of individuals had baseline $\dot{V}O_2max$ values below 23.5 ml/kg/min (mean = 21.4 ± 2.4 ml × kg^{-1} × min^{-1}, range = 13.4 to 23.5 ml × kg^{-1} × min^{-1}). This group had low $\dot{V}O_2vt$ values (mean = 13.5 ± 2.1 ml × kg^{-1} × min^{-1}, range = 9.4 to 20.3 ml × kg^{-1} × min^{-1}) and high VT%$\dot{V}O_2max$ values (mean = 62.0 ± 8.4 %, range = 43.3 % to 78.3 %). These individuals showed very little improvement in $\dot{V}O_2max$ with training (1.2 ± 1.8 ml × kg^{-1} ×min^{-1}), and only modest gains in $\dot{V}O_2vt$ (2.8 ± 2.2 ml × kg^{-1} × min^{-1}), resulting in an increase in VT%$\dot{V}O_2max$ from 62.0 % to 76.2 %. These data support the concept that sedentary individuals with high baseline VT%VO_2max values have only a limited $\dot{V}O_2$ reserve above $\dot{V}O_2vt$ and thus have only limited possibility for improvements. For this group the prescribed training program may have not provided adequate intensity of training to increase $\dot{V}O_2max$ or $\dot{V}O_2vt$ as their training intensity often did not exceed VT until near the end of the training program.

Post-training, the mean male and female values for $\dot{V}O_2vt$ were equal to 74.2 % and 76.4 % of the baseline $\dot{V}O_2max$ values. This post-training $\dot{V}O_2vt$ was not different than, and strongly related to, the prescribed training $\dot{V}O_2$ (r = 0.84). In addition, the measured post-training power output at VT was not significantly different from the power output during the final 6 weeks of training (p > 0.15 and 3 = 0.79). These strong relationships, and non-significant differences, between intensity of training, measured either in W or $\dot{V}O_2$, suggeste that $\dot{V}O_2vt$ is responding and becoming similar to the intensity of sustained (50 min) aerobic training. Thus, regardless of the baseline values, it is possible that if individuals continued to train at equal % $\dot{V}O_2max$ intensities, eventually the post-training regression lines for males and females in Fig. **1** would coincide as horizontal space lines. Confirmation will require additional longitudinal research.

We believe that one of the most significant findings in this investigation was that post-training $\dot{V}O_2vt$ and power output at VT were not different than the prescribed and actual training intensities, respectively, and that the absolute intensity of training accounted for over 50 % of the changes in $\dot{V}O_2vt$ with aerobic exercise training. The comparison of actual training intensity (W) during the final 18 training sessions (final 6 weeks) with post-training VT_{watts} demonstrated no difference between the means (125.1 vs 125.5 W, p > 0.70). In addition, the training W and VT_{watts} were strongly correlated (r^2 = 0.56, p < 0.0001). Gender and race data showed some slight variations from the overall group means in the response of VT_{watts} to training intensity. Groups with initially higher baseline $\dot{V}O_2max$ and lower VT%$\dot{V}O_2max$ values (males and whites) tended to see greater mean absolute improvements in $\dot{V}O_2vt$ and VT_{watts} than groups with initially lower baseline $\dot{V}O_2max$ and higher VT%$\dot{V}O_2max$ values (females and blacks, respectively). However, in the male and white groups (high baseline $\dot{V}O_2max$ and low VT%$\dot{V}O_2max$) the post-training VT_{watts} was slightly lower (ns) than training W. These results may have been due to an inadequate length of the training period for $\dot{V}O_2vt$ and VT_{watts} to fully respond to the greater magnitude increases required of these groups. Those groups with lower average baseline $\dot{V}O_2max$ and higher VT%$\dot{V}O_2max$ values (females and blacks) tended to have smaller magnitude increases in training W and $\dot{V}O_2vt$ over the course of the study than did their counterparts. For these groups, post-training VT_{watts} tended to be slightly higher than training W and, in the case of blacks, the small 5.6 W difference was significant (p < 0.01). The reason for this greater response of $\dot{V}O_2vt$ in these groups is unknown and will require further research requiring a longer duration training study to determine the relationship between training intensity and post-training $\dot{V}O_2vt$.

A second major result demonstrated by these data is that the intensity of training relative to VT accounted for 26 % of the improvements in $\dot{V}O_2vt$. Since the HERITAGE protocol used a graduated intensity exercise program, based on %$\dot{V}O_2max$ at baseline, all participants trained at similar increasing intensities relative to $\dot{V}O_2max$ over the 20-week training period. Participants started at 55 % of $\dot{V}O_2max$ for 30 min and incrementally increased until they were exercising at 75 % of baseline $\dot{V}O_2max$ for 50 min during the final 6 weeks of training. Participants thus began training at different intensities relative to VT (VT ranged from 34 % – 83 % of $\dot{V}O_2max$), but by the end of the training period most participants were training at intensities near to or above their baseline $\dot{V}O_2vt$. Since the relative increases in training intensity were the same for all participants, the average training intensity relative to VT over the 20 weeks was the same for all participants. These results show that those participants who trained at lower intensities relative to VT improved less in submaximal fitness ($\dot{V}O_2vt$) than did those who trained at higher intensities relative to VT. Thus, the combination of the absolute training intensity (W) along with the intensity relative to VT, together account for over 80 % (r^2 = 0.82 from multiple regression) of the changes in $\dot{V}O_2vt$.

While it is obvious that VT cannot increase to match unsustainable anaerobic workloads, this study demonstrates that given a sensible aerobic training program with adequate duration and frequency of training, $\dot{V}O_2vt$ and VT_{watts} will respond to closely mirror the intensity of aerobic exercise training. It is likely that there is a minimum necessary training load to stimulate changes in VT, however, that threshold cannot be established from the data in this study, though participants who at baseline had high VT%$\dot{V}O_2max$ values >75 % demonstrated little or no change in $\dot{V}O_2vt$. Based on the strong relationships between training intensity and VT measurements found in these data it would suggest that 50 minutes of aerobic exercise, 3 times a week over 20 weeks, appears to be an adequate stimulus for $\dot{V}O_2vt$ to match training intensity within sedentary individuals with exercise intensity above VT more effectively increasing $\dot{V}O_2vt$ than lower intensity exercise. Further research may eventually determine the minimal individual aerobic exercise-training stimulus necessary to stimulate VT improvements.

In summary, the data from this study clearly show that if sedentary individuals exercise at intensities recommended by ACSM guidelines [10] for aerobic training, those individuals who initiate training above their VT will improve $\dot{V}O_2vt$ more than those training below their VT. However, the intensity of training relative to VT does not seem to affect the magnitude of changes in $\dot{V}O_2max$. Most interestingly, the data from this study show that when an individual is given adequate aerobic training stimulus (duration and frequency), $\dot{V}O_2vt$ responds by matching the intensity of the prescribed training in terms of $\dot{V}O_2$ and W.

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