Effect of Intensity of Aerobic Training on $\dot{V}O_{2max}$

SHANNAN E. GORMLEY, DAVID P. SWAIN, RENEE HIGH, ROBERT J. SPINA, ELIZABETH A. DOWLING, USHASRI S. KOTIPALLI, and RAMYA GANDRAKOTA

The Wellness Institute and Research Center, Department of Exercise Science, Sport, Physical Education, and Recreation, Old Dominion University, Norfolk, VA

ABSTRACT

GORMLEY, S. E., D. P. SWAIN, R. HIGH, R. J. SPINA, E. A. DOWLING, U. S. KOTIPALLI, and R. GANDRAKOTA. Effect of Intensity of Aerobic Training on $\dot{V}O_{2max}$. *Med. Sci. Sports Exerc.*, Vol. 40, No. 7, pp. 1336–1343, 2008. **Purpose:** To determine whether various intensities of aerobic training differentially affect aerobic capacity as well as resting HR and resting blood pressure (BP). **Methods:** Sixty-one health young adult subjects were matched for sex and $\dot{V}O_{2max}$ and were randomly assigned to a moderate- (50% $\dot{V}O_2$ reserve ($\dot{V}O_2R$), vigorous (75% $\dot{V}O_2R$), near-maximal-intensity (95% $\dot{V}O_2R$), or a nonexercising control group. Intensity during exercise was controlled by having the subjects maintain target HR based on HR reserve. Exercise volume (and thus energy expenditure) was controlled across the three training groups by varying duration and frequency. Fifty-five subjects completed a 6-wk training protocol on a stationary bicycle ergometer and pre- and posttesting. During the final 4 wk, the moderate-intensity group exercised for 60 min, 4 d·wk^{-1} the vigorous-intensity group exercised for 40 min, 4 d·wk^{-1} and the near-maximal–intensity group exercised 3 d·wk^{-1} performing 5 min at 75% $\dot{V}O_2R$ followed by five intervals of 5 min at 95% $\dot{V}O_2R$ and 5 min at 50% $\dot{V}O_2R$. **Results:** $\dot{V}O_{2max}$ significantly increased in all exercising groups by 7.2, 4.8, and 3.4 mL·min^{-1}·kg^{-1} in the near-maximal–, the vigorous-, and the moderate-intensity groups, respectively. Percent increases in the near-maximal– (20.6%), the vigorous- (14.3%), and the moderate-intensity (10.0%) groups were all significantly different from each other ($P < 0.05$). There were no significant changes in resting HR and BP in any group. **Conclusion:** When volume of exercise is controlled, higher intensities of exercise are more effective for improving $\dot{V}O_{2max}$ than lower intensities of exercise in healthy, young adults. **Key Words:** EXERCISE, MAXIMUM OXYGEN CONSUMPTION, BLOOD PRESSURE, HR

The 1996 Surgeon General's Report recommended that Americans obtain at least 30 min of moderate-intensity physical activity, most days of the week, to maintain cardiovascular well-being (36). The report also stated that a greater amount or a greater intensity of exercise confers greater benefits, but specifics for intensity were not provided. Recently, the American College of Sports Medicine and the American Heart Association recommended a minimum of 30 min of moderate-intensity physical activity 5 d·wk^{-1}, 20 min of vigorous-intensity physical activity 3 d·wk^{-1}, or a combination of the two (15).

Address for correspondence: David P. Swain, Ph.D., FACSM, Department of Exercise Science, Sport, Physical Education, and Recreation, Old Dominion University, Norfolk, VA 23529; E-mail: dswain@odu.edu.
Submitted for publication November 2007.
Accepted for publication February 2008.

0195-9131/08/4007-1336/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/MSS.0b013e316c4839

Research suggests that vigorous-intensity exercise (60–84% oxygen consumption reserve ($\dot{V}O_2R$)) results in greater increases in aerobic capacity than moderate-intensity exercise (40–59% $\dot{V}O_2R$) (32). Specifically, some training studies that have compared more than one intensity of continuous aerobic exercise while controlling the total volume or energy expenditure of exercise have found significantly greater increases in aerobic capacity in the higher-intensity group (5,7,8,10,13,14,19,25,28). However, several similar studies found no difference between groups performing continuous exercise at different intensities (3,4,6,9,12,16, 20–22,30,31). Moreover, only a few studies have compared the effects of near-maximal–intensity exercise, which can only be performed using intervals, with continuous exercise of either moderate or vigorous intensities. Three studies found that such intervals were more effective than lower-intensity continuous training in cardiac patients (27,37,38). Only two studies have compared near-maximal intervals with lower-intensity continuous training in healthy adults, and both studies included only highly fit males as subjects (11,16). Both studies found significant increases in $\dot{V}O_{2max}$ in the interval group and no increase in the lower-intensity continuous training groups, but it is not known if individuals of average fitness, and especially women, will respond similarly. Therefore, the current study aimed to confirm whether continuous exercise at a vigorous intensity is more effective than continuous exercise at a moderate intensity for improving aerobic capacity and also to determine whether interval training at a near-maximal intensity in a mixed-gender population of average fitness is more effective than continuous exercise of a lower intensity.

Vigorous-intensity exercise confers greater cardioprotective health benefits than moderate-intensity exercise, including a lower incidence of coronary heart disease that may be related to lower risk factors (33). Clinical trials have found that higher-intensity exercise resulted in greater reductions in resting blood pressure (BP) than lower intensity (3,19,24,35), although not all studies have found an intensity effect (5).

A hallmark of endurance training is resting bradycardia (29). However, few studies have evaluated the potential role of exercise intensity in reducing resting HR. One study that did not control the volume of exercise found that training at 72% of $\dot{V}O_2R$ resulted in a significant decrease in resting HR, whereas training at 50% $\dot{V}O_2R$ did not (23). This finding is suggestive of an intensity effect, but because volume was not controlled, it is not conclusive. Only five studies that have controlled exercise volume between two groups exercising at different intensities measured resting HR (5,13,22,24,35). Of these, only one found an intensity effect, in that women training at 64% $\dot{V}O_2R$ decreased resting HR, whereas those training at 41% $\dot{V}O_2R$ did not (24). Men in neither intensity group decreased resting HR; however, there were few men in the study. Further research is warranted to fully examine the question of whether higher-intensity exercise is more effective at lowering resting BP and HR than lower-intensity exercise.

The primary purpose of this study was to determine whether various intensities of aerobic training differentially affect aerobic capacity in healthy adults. Some studies that have compared vigorous and moderate intensities of continuous exercise found that vigorous-intensity is more effective, but other studies have not. Moreover, research comparing near-maximal–intensity intervals with lower-intensity continuous training is limited to either cardiac patients or highly fit men. A secondary purpose of the study was to examine the effects of training intensity on resting HR and resting BP. It was hypothesized that there would be significantly greater increases in $\dot{V}O_{2max}$ in the higher-intensity groups: near-maximal > vigorous > moderate > control. It was also hypothesized that there would be significantly greater reductions in resting systolic BP, diastolic BP, and HR in the higher-intensity groups: near-maximal > vigorous > moderate > control.

METHODS

Subjects. Sixty-one male and female young adults were recruited from the students and staff of Old Dominion University for this study. All subjects were at a low risk for cardiovascular disease according to *ACSM's Guidelines for Exercise Testing and Prescription*, that is, they were between 18 and 44 yr, they had no more than one risk factor for coronary heart disease, they had no signs or symptoms of cardiovascular disease, and they did not have known cardiovascular, pulmonary, or metabolic disease (2). Exclusionary criteria included anyone classified higher than low risk, anyone taking medications that influence HR (such as beta-blockers), anyone who was pregnant, and anyone with recent, significant bicycle training, that is, a competitive cyclist or one who had engaged in at least 3 h of cycling per week over the past 3 months.

The study was reviewed and approved by the university's institutional review board. Upon the date of initial testing, subjects were informed of the nature, the risks, and the potential benefits of the study orally and in writing, and then subjects provided written, informed consent.

Testing procedures. Subjects were instructed to refrain from caffeine, heavy meals, or heavy exercise 3 h before testing. Upon arrival to the laboratory, investigators obtained informed consent from each subject. Height, mass, and three-site skinfolds were measured (18), and body mass index (BMI) and percent body fat were calculated. Skinfolds were measured by a single, experienced investigator.

Subjects were fitted with a chest strap monitor (Polar, Kempe, Finland) for HR measurement and an automated brachial BP device (HEM-422CR; Omron, Vernon Hills, IL) and lay supine quietly for 15 min. HR and BP were measured at 14 and 15 min and averaged to report resting values.

After the rest period, each subject completed a maximal incremental exercise test on a cycle ergometer (Cycle 828 E; Monark, Varberg, Sweden). Calibration of the cycle ergometer was completed before initiation of the study and at 1-month intervals. The seat height was adjusted to allow a slight bend in the knee with the leg at full extension and the foot held parallel to the floor. The subject continued to wear the HR monitor and was fitted with a mouthpiece and head gear for the collection of expired gases. For the exercise testing protocol, the subject pedaled at a cadence of 60 rpm at an initial resistance of 0.75 kg for males and 0.5 kg for females to produce workloads of 45 and 30 W, respectively. Resistance was increased every 3 min by 0.75 kg for males and 0.5 kg for females. HR was recorded during the last 10 s of each minute of exercise. Testing was terminated when the subject was no longer able to continue or could not maintain a cadence of 60 rpm despite encouragement.

A metabolic cart (Vmax 29c; SensorMedics, Yorba Linda, CA) was used during pre- and posttesting sessions to measure $\dot{V}O_{2max}$ and RER. The flow sensor was calibrated against a 3.0-L syringe, and CO_2 and O_2 sensors were calibrated against known gases before each test. $\dot{V}O_{2max}$ was calculated as the average of the three highest, continuous 20-s intervals (typically, but not necessarily, the last three 20-s intervals of the test). Criteria for attainment of $\dot{V}O_{2max}$ were an RER ≥1.10 or a plateau in $\dot{V}O_2$ (an increase in $\dot{V}O_2$

APPLIED SCIENCES

from the penultimate stage to the last completed stage that was less than one half the expected increase).

To reduce potential sources of variability, the pretests and the posttests were administered at the same time of day for each subject. The testing procedures of the posttest matched those of the pretest. Posttesting occurred the week immediately after the completion of the 6-wk experimental period.

Training protocol. Subjects were matched according to sex and $\dot{V}O_{2max}$ and were randomly assigned to one of four groups: 1) moderate intensity (50% $\dot{V}O_2R$), 2) vigorous intensity (75% $\dot{V}O_2R$), 3) near-maximal intensity (intervals at 95% $\dot{V}O_2R$), and 4) nonexercising control. Age was not used in the assignment process, because the age range of the subjects was relatively narrow. Table 1 presents the training protocol. The training protocol varied in duration and frequency to ensure that each intensity group performed the same volume of exercise, defined in aerobic training units (ATU) based on $\dot{V}O_2R$, that is, volume = intensity (%$\dot{V}O_2R$) × duration (minutes per session) × frequency (sessions per week). During exercise, intensity was controlled by establishing target HR at the equivalent percentages of HR reserve (HRR) based on the resting and the maximum HR values measured during testing (34).

Although intensity was controlled via HR and total volume of exercise was based on ATU, the external work that was performed in each exercise session was recorded to determine whether energy expenditure was similar across the three training groups. Cadence on the bike ergometer was maintained at 60 rpm, and resistance (*R*, in kilograms) was recorded every 5 min, not including the warm-up and cool-down. The average *R* across all training sessions in a given week was determined for each subject, and external work (in joules) was calculated as

$$\text{Work} = (R)\ (9.81\ \text{m}\cdot\text{s}^{-2})(6\ \text{m})(60\ \text{rpm})(t)$$

where t is the total duration (not including warm-up and cool-down) in minutes of the exercise sessions in the given week.

Subjects were informed that they must complete at least 90% of all training sessions to fulfill the requirements of the study. Training during the 6-wk experimental period was performed on the same model of cycle ergometer as used in testing. Each training session was supervised to ensure that the target HR was maintained and to ensure that cadence was maintained at 60 rpm. A visual display of cadence was available for the subject and the investigator to monitor. For week 1, each group performed moderate-intensity cycling at 50% HRR for 30 min on three nonconsecutive days. Each cycling session contained 5-min warm-up and cool-down periods not included in the 30 min. HR and resistance were recorded every 5 min during each exercise session. The resistance against which subjects pedaled was adjusted if needed at the start of the next 5-min period to keep the subjects' HR close to the target value.

TABLE 1. Six-week training program.

	Moderate Group	Vigorous Group	Near-Maximal Group
Week 1	50% HRR	50% HRR	50% HRR
	30 min	30 min	30 min
	3 d	3 d	3 d
	45 ATU	45 ATU	45 ATU
Week 2	50% HRR	75% HRR	75% HRR
	45 min	40 min	40 min
	4 d	3 d	3 d
	90 ATU	90 ATU	90 ATU
Weeks 3–6	50% HRR	75% HRR	5 min 75% HRR
	60 min	40 min	5 × (5 min 90–100%; 5 min 50%)
	4 d	4 d	3 d
	120 ATU	120 ATU	120 ATU

ATU = intensity (%HRR or %$\dot{V}O_2R$) × duration × frequency; equivalent to energy expenditure of *X* number of minutes per week spent at $\dot{V}O_{2max}$.

During week 2, the moderate-intensity group increased the exercise duration to 45 min and frequency to 4 d of exercise while maintaining 50% HRR. The vigorous-intensity group increased the duration to 40 min and the intensity to 75% HRR, while maintaining a frequency of 3 d. The near-maximal–intensity group exercised with the same prescription as the vigorous-intensity group during week 2.

For the remaining 4 wk of exercise, subjects were exercising at their final levels of duration, frequency, and intensity. The moderate-intensity group exercised at 50% HRR for 60 min, 4 d·wk^{-1}. The vigorous-intensity group exercised at 75% HRR for 40 min, 4 d·wk^{-1}. The near-maximal–intensity group exercised at 75% HRR for 5 min followed by five intervals of 5 min at 95% HRR (the work phase) and 5 min at 50% HRR (the recovery phase), 3 d·wk^{-1}. All three groups performed a 5-min warm-up and a 5-min cool-down with each exercise session throughout the 6 wk. From the HR values recorded every 5 min during each training session, an average HR for each subject was calculated (separately for the work and recovery phases of the intervals for the near-maximal–intensity group) and expressed in %HRR units. For the final 4 wk of training, the mean %HRR for all sessions completed by all subjects within each group was determined.

Subjects were asked to not vary their usual physical activity patterns during the study and were asked to maintain a log of all physical activity performed outside of the supervised training. Volume of physical activity was estimated using the compendium of physical activity (1). Each activity was assigned an approximate intensity in METs from the compendium; 1 MET was subtracted from the value in the compendium to express the net rather than gross intensity. The MET value was multiplied by the duration of the activity to obtain MET-hours of activity, and these values were summed for each subject for any given week.

Statistical analysis. Six participants withdrew from the study due to scheduling conflicts, and only the remaining 55 were included in the analysis. Descriptive statistics are presented as mean and SD. Effects of training on the principal dependent variables ($\dot{V}O_{2max}$, resting HR, resting systolic BP, and resting diastolic BP) were analyzed using two-way ANOVA, one factor being time (with two levels: before and after) and the other being treatment (with

TABLE 2. Subject characteristics.

	Age (yr)	Height (cm)	Mass (kg)	BMI (kg·m^{-2})	% Body Fat
Control					
Pretest (N = 13)	22 ± 3	168 ± 8	67.7 ± 13.1	23.9 ± 3.9	16.5 ± 8.5
Posttest (N = 13)		168 ± 9	67.4 ± 12.7	23.9 ± 3.8	15.9 ± 8.0
Moderate					
Pretest (N = 14)	23 ± 4	167 ± 8	67.4 ± 11.7	24.0 ± 3.3	21.5 ± 5.5
Posttest (N = 14)		167 ± 8	67.8 ± 11.3	24.0 ± 2.9	20.6 ± 7.0
Vigorous					
Pretest (N = 15)	22 ± 4	168 ± 6	71.9 ± 14.7	25.4 ± 5.1	20.9 ± 10.5
Posttest (N = 15)		168 ± 9	71.7 ± 15.2	25.4 ± 5.4	19.1 ± 10.4
Near-maximal					
Pretest (N = 13)	21 ± 1	168 ± 8	67.6 ± 13.9	23.8 ± 3.4	16.7 ± 5.7
Posttest (N = 13)		168 ± 8	66.4 ± 14.9	23.4 ± 3.8	16.0 ± 7.0

Values are presented as mean ± SD.

four levels corresponding to the four training groups); repeated measures were used on one factor (time). For significant F-ratios, a *post hoc* Turkey's test was used to determine which group means differed from each other. To evaluate percent changes in variables, a one-way ANOVA with *post hoc* Tukey's test was used. One-way ANOVA was also used to determine whether the work performed on the bike ergometers during any given week was different between the three training groups, and whether the physical activity performed outside of the study during any given week was different between the four subject groups. For all tests, statistical significance was set at an alpha level of 0.05.

RESULTS

Subjects. The baseline descriptive characteristics of the subjects are presented in Table 2. Although the inclusion criterion for age was 18–44 yr, the actual age range was 18–31 yr. Each group contained similar numbers of male and female subjects: control (8 females, 5 males), moderate (9 females, 5 males), vigorous (10 females, 5 males), and near-maximal (9 females, 4 males). There were no significant differences observed at baseline between any of the groups for age, height, mass, BMI, or percent body fat. Further, there were no significant changes for any of the anthropometric variables after training.

Of the 55 participants who completed the study, all attended at least 90% of the training sessions: moderate (93.8 ± 2.8%), vigorous (93.3 ± 2.3%), and near-maximal (94.4 ± 4.5%). There was no significant difference in adherence across groups. Participants in each group achieved the prescribed exercise intensity. The moderate-intensity group achieved a mean HRR of 50.3 ± 0.5%; the vigorous-intensity group, 74.4 ± 1.0%; the near-maximal–intensity group, 92.1 ± 4.0% during the work interval and 51.5 ± 1.5% during the recovery interval.

Within each week of training, there was no difference in the work performed on the ergometer by the three training groups. Results for weeks 1, 3, and 6 are as follows. Week 1: 346 ± 158 kJ, moderate-intensity group; 345 ± 199 kJ, vigorous-intensity group; 320 ± 145 kJ, near-maximal–intensity group (P = 0.90). Week 3: 972 ± 546 kJ, moderate-intensity group; 949 ± 404 kJ, vigorous-intensity group; 1008 ± 317 kJ, near-maximal–intensity group (P = 0.94). Week 6: 1034 ± 449 kJ, moderate-intensity group; 1017 ± 321 kJ, vigorous-intensity group; 1032 ± 385 kJ, near-maximal–intensity group (P = 0.99).

Complete logs of outside physical activity were available from 13 subjects in the control group and 10 subjects each in the three training groups. Data were analyzed for weeks 1, 3, and 6, and there were no differences between the four subject groups. Week 1: 15.3 ± 11.9 MET·h, control group; 10.6 ± 10.1 MET·h, moderate-intensity group; 11.6 ± 19.4 MET·h, vigorous-intensity group; 25.0 ± 23.7 MET·h, near-maximal–intensity group (P = 0.23). Week 3: 15.6 ± 12.9 MET·h, control group; 14.0 ± 10.6 MET·h, moderate-intensity group; 14.0 ± 15.1 MET·h, vigorous-intensity group; 23.4 ± 26.1 MET·h, near-maximal–intensity group (P = 0.55). Week 6: 7.1 ± 8.2 MET·h, control group; 11.2 ± 11.7 MET·h, moderate-intensity group; 6.0 ± 7.4 MET·h, vigorous-intensity group; 17.7 ± 20.8 MET·h, near-maximal–intensity group (P = 0.17). Although a very slight trend for greater physical activity by the near-maximal–intensity group was observed, this did not reach statistical significance due to the large variation between individuals, with some subjects in each group having no physical activity and others having high amounts.

Aerobic capacity. $\dot{V}O_{2max}$ significantly increased in all three exercise groups, as seen in Table 3. The initial

TABLE 3. Changes in $\dot{V}O_{2max}$ (mL·min^{-1}·kg^{-1}) after the 6-wk training protocol.

Intensity Group	Initial $\dot{V}O_{2max}$	Final $\dot{V}O_{2max}$	Net Change in $\dot{V}O_{2max}$	Initial RER_{max}	Final RER_{max}
Moderate	35.3 ± 7.9	38.7 ± 9.1	+3.4 ± 3.9†	1.20 ± 0.09	1.17 ± 0.04
Vigorous	33.6 ± 9.0*	38.4 ± 10.7	+4.8 ± 3.2[a],†	1.20 ± 0.07	1.17 ± 0.05
Near-maximal	35.7 ± 6.2	42.9 ± 7.3	+7.2 ± 4.3[a,b],†	1.17 ± 0.05	1.18 ± 0.04
Control	37.7 ± 8.7	38.4 ± 10.7	+0.7 ± 3.8	1.18 ± 0.03	1.19 ± 0.05

* Significantly lower than control at baseline using two-way ANOVA (P < 0.05).
†Significant increase versus baseline using two-way ANOVA (P < 0.05).
[a] Significantly greater increase than control group using two-way ANOVA (P < 0.05).
[b] Significantly greater increase than moderate group using two-way ANOVA (P < 0.05).

$\dot{V}O_{2max}$ for the vigorous-intensity group was significantly lower than the control group. To control for baseline values, percent changes in $\dot{V}O_{2max}$ were analyzed by one-way ANOVA. As shown in Figure 1, there were significant percent increases in the moderate- (10.0%), the vigorous- (14.3%), and the near-maximal–intensity (20.6%) groups versus baseline. Percent increases in $\dot{V}O_{2max}$ for each group were all significantly different from each other.

Resting HR and BP. There were no significant differences in the baseline resting HR between moderate (67 ± 6 bpm), vigorous (66 ± 10 bpm), near-maximal (64 ± 8 bpm), and control (67 ± 12 bpm) groups. There were no differences after training: moderate (67 ± 10 bpm), vigorous (66 ± 11 bpm), near-maximal (65 ± 10 bpm), and control (67 ± 9 bpm).

There were no significant differences in the baseline systolic BP between moderate (107 ± 13 mm Hg), vigorous (111 ± 12 mm Hg), near-maximal (106 ± 12 mm Hg), and control (109 ± 14 mm Hg) groups. There were no differences after training: moderate (108 ± 13 mm Hg), vigorous (112 ± 10 mm Hg), near-maximal (108 ± 13 mm Hg), and control (106 ± 12 mm Hg). Similarly, there were no significant differences in baseline diastolic BP between moderate (64 ± 6 mm Hg), vigorous (70 ± 9 mm Hg), near-maximal (64 ± 7 mm Hg), and control (63 ± 5 mm Hg) groups. There were no differences after training: moderate (66 ± 6 mm Hg), vigorous (69 ± 6 mm Hg), near-maximal (62 ± 6 mm Hg), and control (63 ± 6 mm Hg).

APPLIED SCIENCES

DISCUSSION

The main finding of the study was that higher intensities of exercise elicit greater improvements in $\dot{V}O_{2max}$ than lower intensities of exercise over a 4- to 6-wk training period in healthy, young adults. This finding is consistent with the original hypothesis. Unlike $\dot{V}O_{2max}$, there were no changes observed in resting HR and resting BP after training.

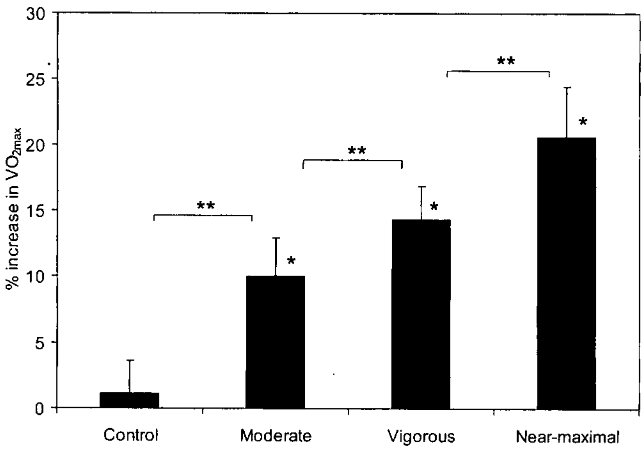

FIGURE 1—Percent changes (mean ± SE) in $\dot{V}O_{2max}$ after training. *Significantly different from baseline (P < 0.05). **Significant difference between groups (P < 0.05).

A major strength of this study was the control of total volume of exercise between training groups. Each group performed the same amount of exercise based on $\dot{V}O_2R$ or HRR, which was expressed as ATU. This is a better means of matching exercise volume than matching based on energy expenditure *per se* because each subject in this study performed the same amount of exercise relative to his or her aerobic capacity. On the other hand, if each subject had been asked to expend a set number of kilocalories per week, then this would have been a greater relative challenge for the lesser-fit subjects than the higher-fit subjects. Nonetheless, although exercise volume was matched using ATU, each group performed the same amount of external work per week, given that the mean $\dot{V}O_{2max}$ values at baseline were similar. The average external work in the sixth week of training, ~1000 kJ, translates to approximately 1000 kcal of energy expenditure, given 4.186 $kJ \cdot kcal^{-1}$ and assuming a human efficiency of ~24%. The actual caloric cost of the exercise would be somewhat higher than this value, given friction in the drive train of the ergometer and the energy cost of spinning the legs.

Aerobic capacity. The ACSM currently recommends 20 to 60 min of exercise performed at 40/50–85% HRR or $\dot{V}O_2R$ for most adults, where 40% is considered a threshold level for deconditioned individuals and 50% is a threshold for average adults (2). There has been previous evidence suggesting that exercise of a higher intensity will result in greater gains in cardiovascular fitness (32,33). However, only a few reports included a sufficient number of subjects to confirm that groups training at higher intensities experienced significantly greater increases in $\dot{V}O_{2max}$ than groups training at lower intensities when the total volume of exercise was controlled. In this study, each of the exercising groups experienced a significant absolute increase in $\dot{V}O_{2max}$ versus baseline values, and the absolute increase in the near-maximal–intensity group was significantly greater than that in the moderate-intensity group. Moreover, when the increases in $\dot{V}O_{2max}$ were expressed as percent changes, the response in each intensity group was significantly greater than that in the lower-intensity groups.

This study is unusual in including a group that exercised with intervals at an intensity that approached $\dot{V}O_{2max}$. Such intervals have been included in training programs as early as 1977, when Hickson et al. (17) reported a 44% increase in $\dot{V}O_{2max}$ after 10 wk of training that consisted of six 5-min intervals of bicycling at $\dot{V}O_{2max}$ on 3 $d \cdot wk^{-1}$ plus 40 min of vigorous running on 3 $d \cdot wk^{-1}$. However, Hickson et al. (17) did not compare this training program with any other. Three recent studies have compared high-intensity interval training with lower-intensity continuous training in cardiac patients with total work controlled (27,37,38). Significantly greater benefits were found in the interval group than the continuous group for $\dot{V}O_{2max}$ (27,38), ventilatory threshold and treadmill time to exhaustion (37), and left ventricular performance (38).

A study recently published by Helgerud et al. (16) examined the effects of 8 wk of aerobic endurance training at various exercise intensities in healthy, young-adult males. Groups performed running at a moderate-intensity (70% HR_{max} for 45 min each session), vigorous-intensity (85% HR_{max} for ~24 min per session), and two maximal-intensity interval training regimens that both alternated 90–95% HR_{max} with 70% HR_{max}, one using multiple 15-s intervals and one using four 4-min intervals. Both interval training groups significantly increased $\dot{V}O_{2max}$, whereas neither continuous training group did. Using a previously published formula (32), the moderate- and vigorous-intensity groups of Helgerud et al. (16) were exercising at ~47% and ~72% HRR, respectively, which are comparable to the current study. The failure of the continuous training groups of Helgerud et al. (16) to increase $\dot{V}O_{2max}$ was probably due to their high baseline fitness, which averaged 58 $mL \cdot min^{-1} \cdot kg^{-1}$. Esfarjani and Laursen (11) recently compared interval training at $\dot{V}O_{2max}$ with continuous training at 75% HRR in male runners. As in the study of Helgerud et al. (16), the subjects' baseline $\dot{V}O_{2max}$ was greater than 50 $mL \cdot min^{-1} \cdot kg^{-1}$, and only the interval group increased $\dot{V}O_{2max}$. Both of these studies differed from the current study in the population (only males vs both males and females; high vs average fitness) and the mode of exercise (running vs cycling).

It should be noted that although interval training groups spend some of their training time at a very high intensity, a similar amount of time is spent at a lower intensity, and therefore the mean intensity of training may not be any higher than that of a continuous training program. In the current study, the interval training group used 5 min each for the work and the recovery phases of the intervals and had an average intensity of 72% HRR, which is slightly less than the 75% HRR of the vigorous group. The work–recovery periods of Helgerud et al. (16) were 4 min at ~93% HR_{max} and 3 min at 70% HR_{max}, for a mean intensity of 83% HR_{max} in the interval group, whereas one of the continuous groups used 85% HR_{max}. Warburton et al. (37) used 2 min at 90% HRR and 2 min at 40% HRR for the work and the recovery phases, yielding a mean intensity of 65% HRR in the interval group, and had the continuous training group use 65% HRR. Wisloff et al. (38) used 4-min work phases at ~93% HR_{max} and 3-min recovery phases at 60% HR_{max}, for a mean intensity of 79% HR_{max} in the interval group, and used ~73% HR_{max} in the continuous training group. Despite the similarity of mean intensity between the interval and the continuous training groups, the interval groups in all of these studies experienced greater improvements in aerobic fitness after training. Therefore, although intensity is a key variable in cardiorespiratory training (as shown by comparing the two continuous training groups in this study), the mean intensity may not be as important as the highest intensity that is used for a significant portion of the training. A topic for future research is to determine what portion of training should be done at high intensities and using what work–recovery periods to obtain the greatest results.

Interval training has been used previously with elderly female cardiac patients (27,38), but the current study appears to be the first to compare the effectiveness of interval training and continuous training among healthy females. Accordingly, a *post hoc* analysis was performed to determine the results in the female subjects alone. $\dot{V}O_{2max}$ increased 15.5% among females in the near-maximal–intensity interval group, 13.6% in the vigorous-intensity group, and 8.0% in the moderate-intensity group. All increases were significant, and the interval group's increase was significantly greater than the moderate-intensity group's increase. A similar trend for greater increases in $\dot{V}O_{2max}$ among men in the higher-intensity groups was observed, but it did not reach significance ($P = 0.13$ for one-way ANOVA on percent changes) due to the relatively low number of men (4–5 per group vs 8–10 women per group).

Resting HR and BP. Endurance-trained subjects are known to have a significant resting bradycardia (29). However, only a few studies have examined the role of training intensity in lowering resting HR. In studies that have controlled total exercise volume in two groups training at different intensities, two found no change in resting HR in either group (13,35), two found similar decreases in both groups (5,22), and one found that women, but not men, in the higher-intensity group decreased resting HR, whereas neither women nor men did in the lower-intensity group (24). In the current study, there was no significant change for any of the exercising groups. This is likely attributed to the fact that the subjects were young, healthy, and had a low resting HR at baseline (~66 bpm). A greater duration of training may be needed to elicit the magnitude of bradycardia exhibited by athletes.

The ACSM's position stand on exercise and hypertension concluded that aerobic training reduces resting BP and that there is no intensity effect (26). However, clinical trials that have compared more than one intensity of training while controlling total volume generally support a greater decrease with higher intensities. Specifically, four of five such studies found a decrease in diastolic BP only in the higher-intensity group (3,19,24,35); one found a greater decrease in systolic BP in the higher-intensity group (24), and one found similar decreases in both systolic and diastolic BP in both groups (5). The current study found that none of the training groups, regardless of intensity, experienced a significant decrease in either systolic or diastolic BP at rest. This lack of effect was likely dependent on the fact that the subjects were young, healthy, and had a low resting BP at baseline (~108/65 mm Hg).

CONCLUSIONS

These results indicate that when exercise volume is controlled, vigorous-intensity exercise is more effective for improving $\dot{V}O_{2max}$ than moderate-intensity exercise in a healthy adult population at low risk for cardiovascular disease. Furthermore, the most effective training was interval exercise performed at near-maximal intensity. This study contributes to a growing body of evidence concerning the beneficial effects of higher-intensity exercise for improvements in $\dot{V}O_{2max}$, as well as potential benefits for cardiovascular health (33).

One concern with higher-intensity exercise is the possibility of poor adherence or "burnout." In the current study, vigorous-intensity training was performed for 5 wk, and interval training was performed for only 4 wk, with excellent compliance. Of course, subjects were supervised and received incentives for completing the study. Nonetheless, no problems were observed over the duration of the training program. Interval training is not traditionally used for extended periods of time, but further research should consider its benefits and potential deleterious effects. Additional clinical trials should investigate possible long-term health benefits of vigorous and higher-intensity training. This study illustrated short-term improvements in aerobic fitness for all groups, but further experimentation is warranted. A longer duration of training may result in a greater training effect on other variables, such as resting HR and BP.

The results of the present study do not constitute endorsement by ACSM.

APPLIED SCIENCES

REFERENCES

1. Ainsworth BE, Haskell WL, Whitt MC, et al. Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc.* 2000;32(9 Suppl):S498–516.
2. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription.* 7th ed. Philadelphia (PA): Lippincott Williams and Wilkins; 2006. p. 21–8, 141.
3. Asikainen TM, Miilunpalo S, Kukkonen-Harjula K, et al. Walking trials in postmenopausal women: effect of low doses of exercise and exercise fractionization on coronary risk factors. *Scand J Med Sci Sports.* 2003;13:284–92.
4. Blair SN, Chandler JV, Ellisor DB, Langley T. Improving physical fitness by exercise training programs. *South Med J.* 1980;73:1594–6.
5. Braith RW, Pollock ML, Lowenthal DT, Graves JE, Limacher MC. Moderate- and high-intensity exercise lowers blood pressure in normotensive subjects 60 to 79 years of age. *Am J Cardiol.* 1994;73:1124–8.
6. Branch JD, Pate RR, Bourque SP. Moderate intensity exercise training improves cardiorespiratory fitness in women. *J Womens Health Gend Based Med.* 2000;9:65–73.
7. Burke EJ, Franks BD. Changes in $\dot{V}O_{2max}$ resulting from bicycle training at different intensities holding total mechanical work constant. *Res.* 1975;46:31–7.
8. Crouse SF, O'Brien BC, Grandjean PW, et al. Training intensity, blood lipids, and apolipoproteins in men with high cholesterol. *J Appl Physiol.* 1997;82:270–7.
9. DiPietro L, Dziura J, Yeckel CW, Neufer PD. Exercise and improved insulin sensitivity in older women: evidence of the enduring benefits of higher intensity training. *J Appl Physiol.* 2006;100:142–9.
10. Duncan JJ, Gordon NF, Scott CB. Women walking for health and fitness. How much is enough? *JAMA.* 1991;266:3295–9.
11. Esfarjani F, Laursen PB. Manipulating high-intensity interval training: effects on $\dot{V}O_{2max}$, the lactate threshold and 3000 m running performance in moderately trained males. *J Sci Med Sport.* 2007;10:27–35.
12. Gaesser GA, Rich RG. Effects of high- and low-intensity exercise training on aerobic capacity and blood lipids. *Med Sci Sports Exerc.* 1984;16(3):269–74.
13. Gossard D, Haskell WL, Taylor CB, et al. Effects of low- and high-intensity home-based exercise training on functional capacity in healthy middle-aged men. *Am J Cardiol.* 1986;57:446–9.
14. Gutin B, Barbeau P, Owens S, et al. Effects of exercise intensity on cardiovascular fitness, total body composition, and visceral adiposity of obese adolescents. *Am J Clin Nutr.* 2002;75:818–26.
15. Haskell WL, Lee I-M, Pate RR, et al. Physical activity and public health: updated recommendations from the American College of Sports Medicine and the American Heart Association. *Med Sci Sports Exerc.* 2007;39(8):1423–34.
16. Helgerud J, Hoydal K, Wang E, et al. Aerobic high-intensity intervals improve $\dot{V}O_{2max}$ more than moderate training. *Med Sci Sports Exerc.* 2007;39(4):665–71.
17. Hickson RC, Bomze HA, Holloszy JO. Linear increase in aerobic power induced by a strenuous program of endurance exercise. *J Appl Physiol.* 1977;42:372–6.
18. Jackson AS, Pollock ML. Practical assessment of body composition. *Phys Sportsmed.* 1985;13:76–90.
19. Kang HS, Gutin B, Barbeau P, et al. Physical training improves insulin resistance syndrome markers in obese adolescents. *Med Sci Sports Exerc.* 2002;34(12):1920–7.
20. Kearney JT, Stull GA, Ewing JL, Strein JW. Cardiorespiratory responses of sedentary college women as a function of training intensity. *J Appl Physiol.* 1976;41:822–5.
21. King AC, Haskell WL, Young DR, Oka RK, Stefanick ML. Long-term effects of varying intensities and formats of physical activity on participation rates, fitness, and lipoproteins in men and women aged 50 to 65 years. *Circulation.* 1995;91:2596–604.
22. Leutholtz BC, Keyser RE, Heusner WW, Wendt VE, Rosen L. Exercise training and severe caloric restriction: effect on lean body mass in the obese. *Arch Phys Med Rehabil.* 1995;76:65–70.
23. Loimaala A, Huikuri H, Oja P, Pasanen M, Vuori I. Controlled 5-mo aerobic training improves heart rate but not heart rate variability or baroreflex sensitivity. *J Appl Physiol.* 2000;89:1825–9.
24. Nemoto K, Gen-No H, Masuki S, Okazaki K, Nose H. Effects of high-intensity interval walking training on physical fitness and blood pressure in middle-aged and older people. *Mayo Clin Proc.* 2007;82:803–11.
25. O'Donovan G, Owen A, Bird SR, et al. Changes in cardiorespiratory fitness and coronary heart disease risk factors following 24 wk of moderate- or high-intensity exercise of equal energy cost. *J Appl Physiol.* 2005;98:1619–25.
26. Pescatello LS, Franklin BA, Fagard R, Farquhar WB, Kelly GA, Ray CA. American College of Sports Medicine position stand. Exercise and hypertension. *Med Sci Sports Exerc.* 2004;36(3):533–53.
27. Rognmo O, Hetland E, Helgerud J, Hoff J, Slordahl SA. High intensity aerobic interval exercise is superior to moderate intensity exercise for increasing aerobic capacity in patients with coronary artery disease. *Eur J Cardiovasc Prev Rehabil.* 2004;11:216–22.
28. Savage MP, Petratis MM, Thomson WH, Berg K, Smith JL, Sady SP. Exercise training effects on serum lipids of prepubescent boys and adult men. *Med Sci Sports Exerc.* 1986;18(2):197–204.

29. Smith ML, Hudson DL, Hraitzer HM, Raven PB. Exercise training bradycardia: the role of autonomic balance. *Med Sci Sports Exerc.* 1989;21(1):40–4.
30. Spate-Douglas T, Keyser RE. Exercise intensity: its effect on the high-density lipoprotein profile. *Arch Phys Med Rehabil.* 1999;80:691–5.
31. Suter E, Marti B, Gutzwiller F. Jogging or walking: comparison of health effects. *Ann Epidemiol.* 1994;4:375–81.
32. Swain DP, Franklin BA. $\dot{V}O_2$ reserve and the minimal intensity for improving cardiovascular fitness. *Med Sci Sports Exerc.* 2002;34(1):152–7.
33. Swain DP, Franklin BA. Comparison of cardioprotective benefits of vigorous versus moderate intensity aerobic exercise. *Am J Cardiol.* 2006;97:141–7.
34. Swain DP, Leutholtz BC. Heart rate reserve is equivalent to $\%\dot{V}O_2$ reserve, not to $\%\dot{V}O_{2max}$. *Med Sci Sports Exerc.* 1997;29(3):410–4.
35. Tashiro E, Miura S, Koga M, et al. Crossover comparison between the depressor effects of low and high work-rate exercise in mild hypertension. *Clin Exp Pharmacol Physiol.* 1993;20:689–96.
36. US Department of Health and Human Services, editor. *Physical Activity and Health: A Report of the Surgeon General.* Washington (DC): US Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion; 1996.
37. Warburton DER, McKenzie DC, Haykowsky MJ, et al. Effectiveness of high-intensity interval training for the rehabilitation of patients with coronary artery disease. *Am J Cardiol.* 2005;95:1080–4.
38. Wisloff U, Stoylen A, Loennechen JP, et al. Superior cardiovascular effect of aerobic interval training versus moderate continuous training in heart failure patients. *Circulation.* 2007;115:3086–94.