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The Effect of Intensity of Aerobic VO2max Resting Heart Rate and Blood Pressure

Shannan Elizabeth Gormley

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THE EFFECT OF INTENSITY OF AEROBIC TRAINING ON

$V\text{O}_\text{2}\text{MAX}$, RESTING HEART RATE AND BLOOD PRESSURE

by

Shannan Elizabeth Gormley
B.S. May 2002, James Madison University

A Thesis Submitted to the Faculty of
Old Dominion University in Partial Fulfillment of the
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Approved by:

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ABSTRACT

THE EFFECT OF INTENSITY OF AEROBIC TRAINING ON VO2MAX, RESTING HEART RATE AND BLOOD PRESSURE

Shannan Elizabeth Gormley
Old Dominion University, 2007
Director: Dr. David Swain

The ACSM recommends 20 to 60 minutes of continuous or intermittent activity 3 to 5 times per week to maintain cardiorespiratory fitness (Pollock et al., 1998). The 1996 Surgeon General’s Report on Physical Activity and Health indicates that Americans are not meeting these physical activity recommendations (DHHS). Several clear consequences of physical inactivity are the appearance of cardiovascular disease risk factors, such as hypertension, hyperlipidemia and obesity. Two recent review articles suggested that higher intensity exercise will elicit a greater reduction in cardiovascular disease risk factors (Swain and Franklin, 2002; Swain and Franklin, 2006). In order to determine whether various exercise intensities differentially affect resting heart rate, resting blood pressure and aerobic capacity, college-aged males and females were recruited for this study. Sixty-one healthy subjects were matched for age, gender, and VO2max and randomly assigned to a moderate-intensity, vigorous-intensity, maximal-intensity or a non-exercising control group. The weekly duration of training varied in opposition to the intensity to ensure there was equivalent energy expenditure across all groups. Subjects completed a six-week training protocol on a stationary bicycle ergometer. After training, VO2max significantly increased across all exercising groups (P...
< 0.05). The maximal-intensity group had the greatest increase of 7.2 ml·min⁻¹·kg⁻¹, followed by an increase of 4.8 ml·min⁻¹·kg⁻¹ in the vigorous-intensity group and an increase of 3.4 ml·min⁻¹·kg⁻¹ in the moderate-intensity group. Percent increases in the moderate (10.0%), vigorous (14.3%) and maximal-intensity (20.6%) groups were all significantly different from each other. There were no significant changes in resting heart rate or resting blood pressure following training. The results indicate that when energy expenditure is controlled, higher intensities of exercise are more effective for improving VO₂max than lower intensities of exercise in healthy, young, college-aged students.
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CHAPTER 1
INTRODUCTION

Problem Description

The 1996 Surgeon General’s Report on Physical Activity and Health suggests that more than 60% of Americans do not actively engage in regular physical activity (DHHS). Furthermore, almost 25% of Americans are not physically active at all. The Surgeon General’s Report also suggests that Americans should get at least 30 minutes of daily moderate intensity physical activity to maintain cardiovascular well-being. Similarly, the American College of Sports Medicine (ACSM) recommends 20-60 minutes of continuous or intermittent physical activity 3 to 5 times per week to develop and maintain cardiorespiratory fitness (Pollock et al., 1998).

These statistics on the sedentary lifestyle of most Americans clearly indicate that the physical activity recommendations are not being met. A crucial consequence of physical inactivity is the development of cardiovascular risk factors such as hypertension, obesity and hyperlipidemia. The Surgeon General’s recommendations, in conjunction with the ACSM’s recommendations, clearly demonstrate the importance of physical activity for maintaining cardiovascular health as well as potentially decreasing the incidence of cardiovascular disease risk factors.

Determining the appropriate level of exercise intensity could potentially affect the extent to which exercise is effective in preventing the occurrence of cardiovascular disease risk factors. The ACSM states that the mode of exercise should be one that engages large muscle groups, and is continuous and rhythmical in nature. The intensity of exercise should be performed at 40/50 to 85% oxygen consumption reserve (VO₂R) or
heart rate reserve (HRR), or at 55/65 to 90% maximum heart rate (HRmax). If individuals are unfit, ACSM recommends that exercise intensity should be initiated at 40 to 49% VO₂R or HRR until the individual can maintain a higher intensity.

In order to achieve cardiovascular benefits, exercise must at least be performed at a moderate intensity. Research suggests that vigorous intensity exercise results in greater increases in aerobic capacity when energy expenditure is controlled (Duscha et al., 2005, Pollock et al., 1998). A study including both cycling and walking/jogging at vigorous intensities resulted in greater increases in aerobic capacity (Asikainen et al., 2003). In this study, the higher intensity exercise was performed for a shorter period of time in order to provide the same energy expenditure as moderate exercise. Of particular interest is that a majority of studies examined the difference between moderate and vigorous-intensity exercise, but not maximal-intensity exercise. There is limited data on the potentially greater effects of interval training at maximal or near-maximal intensities for increasing aerobic capacity.

Although there appears to be a positive linear trend between exercise intensity and aerobic fitness, a similar relationship has not been demonstrated between exercise intensity and resting blood pressure or resting heart rate. In a recent review article (Swain and Franklin, 2006), three out of four studies examined found that higher intensity exercise resulted in greater reduction in resting diastolic blood pressure than did the lower intensity (Asikainen et al., 2003, Kang et al., 2002, and Tashiro et al., 1993). Other studies also demonstrated that higher exercise intensity had a greater effect on resting diastolic blood pressure than systolic blood pressure (Miyai et al., 2002). However, there have been a couple of studies that did not demonstrate a significant
difference between lower versus higher intensity exercise training on resting blood pressure in a normotensive population (Tashiro et al., 1993, Braith et al., 1994). There is inconclusive evidence to state that more vigorous training will result in decreased systolic and diastolic blood pressure.

A consistent trend has also been seen with exercise intensity and resting heart rate. There has been evidence to suggest that exercise performed at a vigorous intensity, >70% VO_{2max}, will result in significantly lower resting heart rate than moderate intensity exercise, >60% VO_{2max} (Jennings et al., 1986, Miayi et al., 2002). One of these studies compared moderate and vigorous exercise, and a significant decrease in heart rate was observed in both groups; however, there was no significant difference between the moderate and vigorous exercise intensities (Braith et al., 1994). Further research is warranted to fully examine the question of whether higher intensity exercise is more effective in lowering resting blood pressure and heart rate.

**Statement of Purpose**

The purpose of this study is to determine whether or not various intensities of aerobic training differentially affect resting heart rate, resting blood pressure and aerobic capacity. This study will attempt to determine that exercise at higher intensities will elicit a greater decrease in resting heart rate and blood pressure as well as a greater increase in aerobic capacity.

Subjects will participate in a six-week training program on a stationary bicycle ergometer. Initial testing will include an incremental exercise test on a bicycle ergometer to measure maximal oxygen uptake (VO_{2max}). Other measurements to be obtained during initial testing include height, mass, skinfolds, resting heart rate and blood pressure. After
initial testing, subjects will be matched by gender and VO$_{2\text{max}}$, and then randomly assigned into one of four groups, 1) Moderate Intensity, 2) Vigorous Intensity, 3) Maximal Intensity (Interval Training), and 4) Non-Exercising Control. Upon completion of training, i.e., at the end of the six-week period, subjects will repeat initial testing.

**Hypotheses**

1. There will be significantly greater increases in VO$_{2\text{max}}$ in the higher intensity groups: maximal > vigorous > moderate > control.
2. There will be significantly greater reductions in resting systolic blood pressure in the higher intensity groups: maximal > vigorous > moderate > control.
3. There will be significantly greater reductions in resting diastolic blood pressure in the higher intensity groups: maximal > vigorous > moderate > control.
4. There will be significantly greater reductions in resting heart rate in the higher intensity groups: maximal > vigorous > moderate > control.

**Limitations**

There are two principle limitations in this study. While a majority of training studies of a similar nature are often 12 or more weeks in duration (Pollock et al., 1998), this study was 6 weeks in duration. Therefore, a limitation is that training adaptations may not occur due to the 6-week duration. Secondly, the subjects in this study were relatively young and of low risk for heart disease, thus limiting the findings to such a group, rather than to the general population.
Operational Definitions

\( \text{VO}_2\text{max} \): The highest \( \text{VO}_2 \) recorded over a 60-second period during an incremental exercise test, provided RER is \( \geq 1.10 \) or a plateau in oxygen consumption is observed (i.e., the increase in \( \text{VO}_2 \) from the penultimate stage to the last completed stage is less than 50% of the expected increase).

RER (Respiratory Exchange Ratio): The ratio of \( \text{CO}_2 \) production to \( \text{O}_2 \) consumption measured at the mouth.

Resting Heart Rate (HR): Subject’s HR collected during the last two minutes of a 15-minute rest period lying in a supine position.

Resting Blood Pressure (BP): Subject’s systolic and diastolic BP collected during the last two minutes of a 15-minute rest period lying in a supine position.

Moderate Intensity Exercise: Exercise performed at 50% HRR.

Vigorous Intensity Exercise: Exercise performed at 75% HRR.

Maximal Intensity Exercise (Interval): Exercise performed at 90-100% HRR for 5 minutes, followed by 5 minutes at 50% HRR, to be repeated for a total of five intervals.

HRR (Heart Rate Reserve): Percentage of the difference between resting and maximal HR.
CHAPTER II
LITERATURE REVIEW

Exercise and Cardiovascular Risk Factors

Physical activity and cardiovascular health have been shown to be positively correlated. Epidemiological evidence suggests that exercise performed at a vigorous intensity (> 6 METs, 1 MET = 3.5 ml·min⁻¹·kg⁻¹) has a greater effect on reducing cardiovascular risk factors than moderate intensity (< 6 METs) exercise (Swain and Franklin, 2006; Cox, 2006; Pollock et al., 1998). It has been debated, however, whether exercise should be performed at a higher intensity in order to lower cardiovascular risk factors. One of the pioneering studies in determining a threshold for improving cardiorespiratory fitness was conducted by Karvonen et al. (1957). This training study demonstrated that exercise needed to be performed at an intensity of at least 70% HRR to elicit improvements in cardiovascular fitness. However, the subjects in this study were all relatively fit young men. The ACSM currently recommends 20 to 60 minutes of exercise performed at 40/50-85% HRR or VO₂R for most adults, where 40% is considered a threshold level for improvements for deconditioned individuals and 50% is a threshold for average adults (ACSM, 2006). More recently, evidence suggests that an exercise intensity of 45% VO₂R is the minimal level of intensity needed to improve cardiovascular fitness for moderately fit individuals (with a VO₂max ≥ 40 ml·min⁻¹·kg⁻¹) and 30% VO₂R for low fit individuals (Swain and Franklin, 2002). Karvonen et al. set a foundation upon which other studies have expanded the understanding of the cardiovascular benefits of exercise.
The purpose of this literature review is to critically examine the varying effects of exercise intensity on the reduction of cardiovascular disease risk factors. Given the objectives of this study, the discussion of cardiovascular disease risk factors will be limited to resting heart rate, resting blood pressure and aerobic capacity. Several confounding factors, such as mode of exercise, duration of training and prescribed exercise intensity will be considered upon examining research. Intensity of exercise will be defined in accordance with the ACSM guidelines (Pollock et al., 1998) for moderate (40-60% HRR or VO$_2$R), vigorous (60-85% HRR or VO$_2$R) and maximal intensity (> 90% HRR or VO$_2$R).

**Epidemiologic Evidence**

Epidemiological studies have demonstrated an inverse relationship between exercise intensity and incidence of cardiovascular disease risk factors. One clear limitation in this type of research is that the assessment of physical activity is typically through questionnaires and self-reporting. Upon analysis of many of these studies, it was noted that the categorizing of workloads into moderate-, vigorous-, or high-intensity exercise was not consistent (Swain and Franklin, 2006).

In a recent comprehensive review, it was proposed that exercise performed at a vigorous intensity will result in greater reduction in cardiovascular risk factors than moderate intensity exercise, when total energy expenditure is kept constant (Swain and Franklin, 2006). This was based on findings from studies such as Tanesescu et al. (2002), who examined reported physical activity and incidence of coronary heart disease (CHD) in over 44,000 men, and Manson et al. (2002), who similarly studied over 72,000 women. Independent of total volume of physical activity, the men in Tanesescu et al.'s
study who engaged in vigorous physical activity (> 6 METs) had a 17% lower incidence of CHD than those who engaged only in light physical activity (< 4 METs), while those who engaged in moderate physical activity (4-6 METs) had a non-significant 6% reduction compared to the light activity subjects. When looking only at walking, Tanesescu et al. found that, with total amount of walking per week controlled, there was an inverse relationship between walking speed and risk of CHD. Similarly, Manson et al. found in women that walking speed was inversely related to incidence of CHD after controlling for total volume of walking. Manson et al. also reported that vigorous physical activity was associated with a reduction in CHD risk, but did not compare it with moderate and light physical activity.

A cross-sectional study of 12,000 men and women investigated the role of exercise intensity and duration in relation to incidence of cardiovascular disease risk factors (Mensink et al., 1997). Each 100 kcal·kg⁻¹·wk⁻¹ spent on vigorous (7.5-9.0 MET) physical activity was associated with a 3 mmHg decrease in diastolic BP and a 10 bpm decrease in resting HR in men, and a 7 mmHg decrease in systolic BP and 6 bpm decrease in resting HR in women. The same amount of energy expenditure done at moderate (5-7 METs) and low (3.5-4.5 METs) intensities resulted in significantly lesser changes.

Williams (1998) examined cardiovascular risk factors in nearly 9,000 recreational runners. He found that, independent of weekly running distance, there was a significant inverse relationship between 10-K race speed and both systolic and diastolic BP, in both men and women. Assuming that those who race faster also train at a higher intensity than
those who race slower, this study concluded that resting blood pressure is more affected by the intensity of physical activity than the total volume performed.

These studies showed a consistent trend in the inverse relationship between intensity of exercise and both the incidence of CHD and the strength of certain CHD risk factors. However, a more thorough examination of pertinent clinical trials is warranted to determine the training effects of varying exercise intensities on resting HR, resting BP and aerobic capacity.

**Clinical Trials**

*Training and VO$_{2\text{max}}$*

In order to determine a true training effect of exercise intensity on improving VO$_{2\text{max}}$, studies that compare varying exercise intensities of equal energy expenditure must be examined. Numerous such studies have been previously reviewed (Swain and Franklin, 2002; Swain and Franklin, 2006); and a majority of them found either a significantly greater increase or a numerically greater in VO$_{2\text{max}}$ in groups that performed vigorous- as compared to moderate-intensity exercise, while no studies found a significantly greater increase in moderate- versus vigorous-intensity groups. The preponderance of evidence is that higher intensities elicit greater increases in VO$_{2\text{max}}$. Two examples of these previously reviewed studies are included below, plus three that were not included in the previous reviews.

A walking trial studied the effects of various exercise interventions on coronary risk factors in postmenopausal women (Asikainen et al., 2003). Among groups that expended a total of 1,500 kcal per week, one group exercised at 65% VO$_{2\text{max}}$, another at 55% VO$_{2\text{max}}$ and a third at 45% VO$_{2\text{max}}$. All groups increased VO$_{2\text{max}}$ as a result of
training, but there were no significant differences between groups. As discussed later, there were significant differences between groups in their BP response.

Another study measured the effects of moderate- versus high-intensity exercise on lowering blood pressure, this time in sedentary, normotensive, older adults (Braith et al., 1994). Subjects included males and females, ages 60-79 years (N = 44). Based on initial VO_{2}\text{max}, subjects were stratified and randomly assigned to one of 3 groups, including a control group, moderate-intensity group and a high-intensity training group. Both training groups completed 3 walking (treadmill) sessions per week over 26 weeks. Each subject completed a 2-week ramp period until he/she could walk continuously for 40 minutes at an intensity of 70% HRR. Moderate-intensity exercise included 45 minutes of walking at 70% HRR. High-intensity exercise included 35 minutes of walking at 85% HRR. The exercise duration was modified for the high-intensity group to ensure the caloric expenditure would be equivalent to moderate-intensity exercise. Both groups experienced an increase in VO_{2}\text{max}, compared to control, with high-intensity exercise resulting in a significantly greater increase. One finding of interest in this study is the fact that moderate-intensity exercise was 70% HRR, which is often considered a more vigorous intensity. Promising data from this study support the benefits of both vigorous- and high-intensity exercise for reducing cardiovascular risk factors in older adults.

A study by Duscha et al. compared the effects of varying exercise intensities on peak oxygen uptake in overweight, normotensive, middle-age men and women (2005). Subjects (N = 133) were randomly assigned to one of 4 exercise groups 1) high amount/high intensity, HAHI, 2) low amount/high intensity, LAHI, 3) low amount/moderate intensity, LAMI, or a 4) non-exercising control group. The HAHI
training group expended 2,000 kcal/wk at 65 to 80% VO_{2max}. The LAHI and LAMI groups expended 1,200 kcal/wk at an intensity of 65 to 80% VO_{2max} and 40 to 55% VO_{2max}, respectively. There were significant improvements seen in VO_{2max} versus baseline in all three groups: 6% for LAMI, 11% for LAHI and 18% for HAHI. The increase for the LAMI group was significantly less than that of the HAHI group, while the increase for the LAHI group was not significantly different from either of the other groups. The authors felt that this lack of significance was only due to sample size, and concluded that high-intensity exercise was more effective at raising VO_{2max} than moderate-intensity exercise, even when the same total number of calories was expended.

In a recent study, O'Donovan et al. (2005) examined the effects of 24 weeks of moderate- and high-intensity exercise, of equal energy cost, on improvements in cardiovascular fitness. Subjects included adult, sedentary men (N = 42), who were randomly assigned to either a moderate-intensity, high-intensity or control group. The moderate-intensity group performed three 400-kcal cycling sessions per week at 60% VO_{2max}, while the high-intensity group performed three calorically equivalent sessions at 80% VO_{2max}. There was an increase in the moderate (4.9 ± 2.1 ml·min^{-1}·kg^{-1}) and high-intensity (7.1 ± 3.7 ml·min^{-1}·kg^{-1}) groups for VO_{2max} compared to baseline values and to the control group. However, although the high intensity group had a numerically greater increase than the moderate intensity group, this difference was not significant.

Okura et al. conducted a study on obese women (N = 90) to determine if moderate-intensity walking and vigorous-intensity aerobic dance, in combination with a weight loss diet, would elicit similar responses in the reduction of cardiovascular disease risk factors (2003). Subjects were randomly assigned to either moderate-intensity
exercise plus diet, vigorous-intensity exercise plus diet, or a diet-only control group. The subjects in the vigorous-intensity group performed a bench-stepping exercise 3 days per week for 45 minutes at 70 to 85% VO\(_2\text{max}\). Subjects in the moderate-intensity group were instructed to walk every day for 30 minutes at 40-50% VO\(_2\text{max}\). Subjects were required to attend the majority of the 40 prescribed training sessions. Increases in VO\(_2\text{max}\) were 11% for diet-only, 17% for diet plus moderate intensity exercise, and 25% for diet plus vigorous intensity exercise. Only the vigorous group's increase was significantly greater than the diet-only group's increase.

The results of these studies suggest that when energy expenditure is kept constant, a more vigorous-intensity exercise results in a greater increase in VO\(_2\text{max}\). Some studies suggest that intervals performed at an intensity of maximal or near-maximal VO\(_2\) produce even larger increases in VO\(_2\text{max}\) (Swain, 2005). For example, Hickson et al. (1977) had subjects perform six 5-min intervals at VO\(_2\text{max}\), 3 days per week for 10 weeks, as part of a high intensity training program, and reported a 44% increase in VO\(_2\text{max}\). There was no comparison group in the Hickson study using a different training program. The only study to examine maximal intensity interval training in comparison to continuous training with equivalent energy expenditure was by Warburton et al. (2005). Subjects were 14 male cardiac patients who were placed in either a 16-week traditional cardiac rehabilitation program or an interval training program. The traditional program consisted of exercising for 30 min at 65% HRR, five days per week, while the interval group performed the same exercise three days per week and performed intervals two days per week. The intervals consisted of 2 min at 90% HRR followed by 2 min at 40% HRR for a total of 30 min. Following training, VO\(_2\text{max}\) increased 18% in the interval group and 13%
in the traditional group; both increases were significant, but not different from each other. However, the interval group did have a significantly greater improvement than the traditional group in both ventilatory threshold and time to exhaustion. Perhaps if the interval training group had done a greater amount of interval training (instead of doing 40% of their training with intervals and 60% with the same intensity as the traditional group), or if there were more than 7 subjects per group, the responses in VO\textsubscript{2max} may have been significantly different. Further studies could clarify the role of exercise intensity for improving aerobic fitness when energy expenditure is equal among groups.

**Training and Resting Blood Pressure**

The fact that endurance exercise lowers resting BP is well established (Pescatello et al., 2004). However, only a few studies have compared the relative effects of moderate and vigorous intensity exercise of equal energy expenditure, and their results, while suggestive, are not conclusive.

One trial included women, who walked at either 45% VO\textsubscript{2max}, 55% VO\textsubscript{2max} or 65% VO\textsubscript{2max}, 5 days per week, expending either 200 or 300 kcal/session (Asikainen et al., 2003). Groups were separated according to exercise intensity or energy expenditure. Researchers combined groups according to intensity and energy expenditure (300 kcal/session) and determined that vigorous intensity exercise resulted in a significant decrease in DBP of 3 mmHg, but not SBP. Furthermore, no significant changes were observed in resting BP for either the combined 200 kcal- or 300 kcal/session moderate intensity groups. Thus, only the vigorous intensity group demonstrated any improvement in resting BP.
A crossover study was conducted on adult males and females examining the potential depressor effects of exercise (Tashiro et al., 1993). Each subject had mild hypertension (> 140/90 mmHg), but did not possess any other cardiovascular risk factors. Subjects (N = 10) were randomly assigned to 2 groups, each group participated in a low work rate trial, followed by a 10-week washout period and then a high work rate trial. Low work rate exercise consisted of 10 weeks of cycling at 50% VO2max for 60 minutes, including a 5-minute warm-up and cool-down. High work rate training included 10 weeks of cycling at 75% VO2max for 30 to 40 minutes. The duration of exercise for the high work rate was modified so that energy expenditure would be equivalent to the low work rate trial. Following the lower-intensity training, there was a significant 6 mmHg decrease in SBP, but not for DBP. There was a significant decrease in SBP of 7 mmHg and DBP of 9 mmHg following high-intensity training. As with the previous study, only the vigorous intensity training produced a decrease in resting DBP.

Kang et al. (2002) performed an 8-month study on obese adolescents using training intensities of either 57% or 77% VO2max. As with the two previous studies, the vigorous intensity group demonstrated a significant decrease in DBP, while the moderate intensity group did not. Neither group experienced a change in SBP.

In a study conducted on sedentary older adults, subjects performed either vigorous, 70% HRR, or higher-intensity exercise, 85% HRR, to determine the effects on cardiovascular disease risk factors over a 26-week period (Braith et al., 1994). Results showed a similar decrease in SBP in both the vigorous- and higher-intensity groups at the 3- and 6-month periods. DBP decreased significantly in both groups after 3 months of
training, but there was no further change in DBP at 6 months. Thus, this study did not show a differential effect of training intensity on resting BP.

A more recent study by Okura et al. compared “high-intensity” dance plus a weight loss diet versus “low-intensity” walking plus a weight loss diet in obese females in a 14-week intervention (2003). Although there was a decrease of nearly 12 mmHg in SBP and a decrease of 6 mmHg in DBP in each exercise group, these improvements were not significantly greater than those in the diet-only group.

There is convincing evidence for the effectiveness of both moderate- and vigorous-intensity exercise for lowering resting BP. While there is some evidence that vigorous intensity exercise is more effective than moderate intensity exercise at lowering diastolic BP, more research is needed to examine the relationship between exercise intensity and resting BP.

Training and Resting Heart Rate

A reduction in resting HR is a hallmark of aerobic training that is caused by an increase in parasympathetic tone and decrease in sympathetic tone (McArdle et al., 2007). However, there is a limited amount of data specifically examining the effect of exercise intensity on resting HR. Of the previously examined training studies, only two measured resting heart rate. In the Tashiro et al. study (1993), two groups were cycling at either 50% VO₂max or 75% VO₂max over a 10-week period, and neither group experienced a significant decrease in resting HR. In the Braith et al. study, two groups were exercising at either 70% VO₂max or 85% VO₂max over a period of 26 weeks. Subjects in both groups experienced a significant decrease in resting HR at the end of the study period, but there was no difference between the groups.
Conclusion

To date, evidence suggests that aerobic training will improve VO₂max and lower SBP, DBP and HR in a sedentary, normotensive population. Vigorous intensity exercise is clearly more effective than moderate intensity exercise at increasing VO₂max. Furthermore, most training studies support a greater effect for vigorous intensity in lowering diastolic BP, while epidemiological studies support a greater effect for vigorous intensity in lowering SBP, DBP and HR. However, there is insufficient evidence to determine conclusively whether a significantly greater effect occurs with vigorous-intensity exercise in lowering SBP, DBP and resting HR. Furthermore, only one of the studies in this review compared an interval training regimen at a near-maximal VO₂ intensity to either moderate- or vigorous-intensity exercise. The role of such interval training in improving VO₂max and potentially lowering BP and HR needs further examination. Therefore, a further understanding of the varying effects of exercise intensity, comparing moderate-, vigorous-, and maximal-intensity exercise on resting BP, resting HR and aerobic fitness is warranted.
CHAPTER III
METHODOLOGY

Subjects

Male and female adults between the ages of 18 and 44 years old were recruited for this study. All subjects were at a low risk for cardiovascular disease, according to ACSM’s Guidelines for Exercise Testing and Prescription (2006), i.e. they did not have any signs or symptoms of cardiovascular disease and did not have known cardiovascular, pulmonary or metabolic disease. Exclusionary criteria included any subject classified at moderate or high risk for cardiovascular disease, according to the ACSM, anyone taking medications that influence heart rate (such as beta-blockers), anyone who was pregnant, and anyone with recent, significant bicycle training, i.e., a competitive cyclist or one who has engaged in at least three hours of cycling per week over the past 3 months. Each subject, prior to testing, was screened using a questionnaire (App A).

Upon the date of initial testing, subjects were informed of the nature, purposes, risks and potential benefits of the study, and signed a consent form in accordance with the institutional guidelines for research with human subjects. To increase the validity of testing results, subjects were instructed to refrain from caffeine, heavy meals or heavy exercise 3 hours prior to testing.

Instrumentation

Cycle Ergometry

Initial maximal exercise testing was performed on a cycle ergometer (Monark cycle 828 E, Varberg, Sweden). Calibration of the cycle ergometer was completed prior
to initiation of the study, and at one-month intervals. The seat height was adjusted to allow a small amount of bend (approx. 5 degrees) in the knee when the leg is at full extension and the foot was held parallel to the floor. The Monark cycle ergometer was used for all training sessions during the study.

Measurement of Metabolic Data

A SensorMedics Vmax 29c metabolic cart (Yorba Linda, CA) was used during pre- and post-testing sessions to measure VO2max and RER. The flow sensor was calibrated against a 3.0 L syringe, and CO2 and O2 sensors were calibrated against known gases prior to each test. The mouthpiece and flow sensor were attached to a headpiece to collect expired air.

Measurement of Blood Pressure and Heart Rate

A Polar heart rate monitor was used to collect resting heart rate measurements. An Omron automated blood pressure cuff (HEM-422CR) was used to measure blood pressure. An automated cuff served to remove observer bias. This cuff was compared to auscultated values using a mercury manometer on 14 pilot subjects not associated with the study whose resting systolic BP values ranged from 105 to 148 mmHg and resting diastolic BP values ranged from 60 to 90 mmHg. Mean (± SE) systolic values were 128 ± 3.2 mmHg manual and 127 ± 3.4 mmHg automated, with Pearson R = 0.93 and with no significant difference between the means by paired Student t-test (p = 0.40). Mean diastolic values were 74 ± 2.2 mmHg manual and 73 ± 2.5 mmHg automated, with Pearson R = 0.93 and with no significant difference between the means by paired Student t-test (p = 0.25).
**Anthropometric Data**

Investigators utilized calipers (Lange, Cambridge, Maryland) to perform skinfold measurements. Percentage of body fat were estimated by the Jackson-Pollock 3-site method (Jackson and Pollock, 1985) and used to characterize the subjects. Height and mass were measured on a Detecto balance scale.

**Procedures**

**Pre-Testing**

Upon arrival to the Human Performance Laboratory, investigators obtained informed consent from each subject. Height, mass and skinfold measurements were taken, and BMI and percent body fat calculated.

Subjects were fitted with a chest strap for heart rate measurement and a brachial cuff for BP measurement and laid supine on an examination table. Initial blood pressure and heart rate were then measured. Subjects were instructed to lie quietly for 15 minutes, i.e. refrain from speaking or moving. Heart rate and blood pressure were measured at minutes 14 and 15, and averaged to report resting values.

Following the rest period, each subject completed a maximal incremental exercise test on a cycle ergometer. The subject continued to wear the heart rate 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 W and 30 W, respectively. Resistance was increased every 3 minutes by 0.75 kg for males and 0.5 kg for females. Heart rate was recorded during the last 10 seconds 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.

\( \text{VO}_{2\text{max}} \) was calculated as the average of the 3 highest, continuous 20-second interval \( \text{VO}_2 \) measurements. If the subject was unable to obtain an \( \text{RQ} \geq 1.10 \), or failed to exhibit a plateau in \( \text{VO}_2 \), the test would be rescheduled, as the subject would not have met criteria for \( \text{VO}_{2\text{max}} \).

Training Protocol

Subjects were matched according to gender and \( \text{VO}_{2\text{max}} \) and randomly assigned to one of four exercise groups: 1) Moderate Intensity, 2) Vigorous Intensity, 3) Maximal Intensity (Interval) and 4) Non-Exercising Control Group. Table 1 presents the training protocol. The training protocol varied in duration and intensity of exercise to ensure that each training group achieved equivalent energy expenditure.

All subjects were informed that they must complete at least 90% of all training sessions in order to fulfill the requirements of the study. Training during the 6-week experimental period was performed on the cycle ergometers in either the Human Performance Laboratory or Wellness Institute under supervision. For week 1, each group performed moderate intensity cycling at 50% HRR for 30 minutes on 3 non-consecutive days. Each cycling session was performed at a cadence of 60 rpm and contained 5-minute warm-up and cool-down periods not included in the 30 minutes. Heart rate was recorded every 5 minutes 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. 6-week training program

<table>
<thead>
<tr>
<th></th>
<th>MOD group</th>
<th>VIG group</th>
<th>MAX group</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Week 1</strong></td>
<td>50% HRR</td>
<td>50% HRR</td>
<td>50% HRR</td>
</tr>
<tr>
<td></td>
<td>30 min</td>
<td>30 min</td>
<td>30 min</td>
</tr>
<tr>
<td></td>
<td>3 days</td>
<td>3 days</td>
<td>3 days</td>
</tr>
<tr>
<td><strong>Week 2</strong></td>
<td>50% HRR</td>
<td>75% HRR</td>
<td>75% HRR</td>
</tr>
<tr>
<td></td>
<td>45 min</td>
<td>40 min</td>
<td>40 min</td>
</tr>
<tr>
<td></td>
<td>4 days</td>
<td>3 days</td>
<td>3 days</td>
</tr>
<tr>
<td><strong>Weeks 3 - 6</strong></td>
<td>50% HRR</td>
<td>75% HRR</td>
<td>5 min 75% HRR</td>
</tr>
<tr>
<td></td>
<td>60 min</td>
<td>40 min</td>
<td>5 x (5 min 90-100%;</td>
</tr>
<tr>
<td></td>
<td>4 days</td>
<td>4 days</td>
<td>5 min 50%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 days</td>
</tr>
</tbody>
</table>

During week 2, the moderate intensity group increased the exercise duration to 45 minutes and frequency to 4 days of exercise, while maintaining 50% HRR. The vigorous intensity group increased the exercise duration to 40 minutes, frequency to 4 days and intensity to 75% HRR. The maximal intensity group exercised with the same prescription as the vigorous intensity group during week 2.

For the remaining 4 weeks of exercise, subjects were exercising at their final levels of duration, frequency and intensity. The moderate intensity group exercised at 50% HRR for 60 minutes, 4 days per week. The vigorous intensity group exercised at 75% HRR for 40 minutes, 4 days per week. The maximal intensity group pedaled at 75% HRR for 5 minutes and then completed 5 intervals of pedaling at 95% HRR, followed by

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5 minutes at 50% HRR, 3 days per week. All three groups performed a 5-min warm-up and 5-min cool-down with each exercise session throughout the 6 weeks.

**Activity Tracking**

To account for potential effects of exercise performed outside of the experimental trials, subjects were asked to keep a detailed activity log. Information included in the log was the mode of exercise, duration and perceived intensity of exercise (light: able to speak in complete sentences easily; moderate: aware of increased breathing, but still able to speak in complete sentences; vigorous: breathing is labored, unable to speak in complete sentences). Subjects in each of the 4 groups kept this activity journal and turned in journals at the end of the 6 weeks.

**Post-Testing**

In order to eliminate possibly confounding factors, post-testing was conducted at a similar time of day as the pre-tests for each subject. Subjects were again asked to refrain from caffeine, heavy meals or heavy exercise for 3 hours prior to testing. The testing protocol matched the procedures of the pre-test. Post-testing occurred the week immediately following the completion of the 6-week experimental period.

**Statistical Analysis**

Data analyzed included only that of subjects who completed the minimum requirement of 90% of total training sessions. Descriptive statistics were compared using analysis of variance. Differences in training variables among groups were analyzed using a 2 x 4 (two time periods and 4 groups) analysis of variance with repeated measures on one factor (time). For significant F ratios, a post hoc Tukey's test was used to determine which group means differed from each other, with statistical significance set at a level of
95% confidence (P < 0.05). Data are presented as mean values + SD, unless otherwise specified.
Initially, 61 participants were recruited for the study, matched for gender and VO\textsubscript{2max} and randomly placed into one of the four exercise or control groups. Fifty-five participants (36 female, 19 male) completed the study protocol, while 6 participants withdrew, citing schedule conflicts. The remaining 55 participants completed at least 90% of the required training sessions for each group, moderate (93.8% ± 2.8), vigorous (93.3% ± 2.3) and maximal (94.4% ± 4.5). There was no significant difference in the exercise session compliance across groups. Table 2 depicts the percent compliance with the training sessions as well as the actual intensity achieved for each group. Participants in each group achieved a mean HRR roughly equivalent to the prescribed exercise intensity. The moderate-intensity group achieved a mean HRR of 50.3%; the vigorous-intensity group achieved a mean HRR of 74.4%. The maximal-intensity group achieved a mean HRR of 92.1% during the maximal interval and 51.5% during the recovery interval.

<table>
<thead>
<tr>
<th>Intensity Group</th>
<th>Prescribed % HRR</th>
<th>Actual % HRR</th>
<th>% Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate</td>
<td>50%</td>
<td>50.3% ± 0.50</td>
<td>93.8 ± 2.8</td>
</tr>
<tr>
<td>Vigorous</td>
<td>75%</td>
<td>74.4% ± 0.96</td>
<td>93.3 ± 2.9</td>
</tr>
<tr>
<td>Interval</td>
<td></td>
<td></td>
<td>94.4 ± 4.5</td>
</tr>
<tr>
<td>Max Interval</td>
<td>95%</td>
<td>92.1% ± 4.01</td>
<td></td>
</tr>
<tr>
<td>Recovery Interval</td>
<td>50%</td>
<td>51.5% ± 1.52</td>
<td></td>
</tr>
</tbody>
</table>

All values are reported as Mean ± SD.
Anthropometric Variables

The baseline descriptive characteristics of the subjects are presented in Table 3. Each group contained both male and female subjects, Control (8 female, 5 male), Moderate (9 female, 5 male), Vigorous (10 female, 5 male) and Interval (9 female, 4 male). The groups were evenly distributed according to anthropometric characteristics. There were no significant differences observed at baseline between any of the groups for age, height, mass, BMI or body fat percentage. Further, there were no significant changes for any of the anthropometric variables following training.

Table 3. Subject Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Age (yr)</th>
<th>Height (cm)</th>
<th>Mass (kg)</th>
<th>BMI (kg/m²)</th>
<th>Body Fat (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre (N=13)</td>
<td>22 ± 2.8</td>
<td>167.8 ± 8.4</td>
<td>67.7 ± 13.1</td>
<td>23.9 ± 3.9</td>
<td>16.5 ± 8.5</td>
</tr>
<tr>
<td>Post (N=13)</td>
<td></td>
<td>167.7 ± 9.4</td>
<td>67.4 ± 12.7</td>
<td>23.9 ± 3.8</td>
<td>15.9 ± 8.0</td>
</tr>
<tr>
<td>Moderate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre (N=14)</td>
<td>22.5 ± 3.7</td>
<td>166.8 ± 8.1</td>
<td>67.4 ± 11.7</td>
<td>24.0 ± 3.3</td>
<td>21.5 ± 5.5</td>
</tr>
<tr>
<td>Post (N=14)</td>
<td></td>
<td>166.8 ± 8.2</td>
<td>67.8 ± 11.3</td>
<td>24.0 ± 2.9</td>
<td>20.6 ± 7.0</td>
</tr>
<tr>
<td>Vigorous</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre (N=15)</td>
<td>21.8 ± 3.6</td>
<td>168.4 ± 5.8</td>
<td>71.9 ± 14.7</td>
<td>25.4 ± 5.1</td>
<td>20.9 ± 10.5</td>
</tr>
<tr>
<td>Post (N=15)</td>
<td></td>
<td>167.7 ± 8.8</td>
<td>71.7 ± 15.2</td>
<td>25.4 ± 5.4</td>
<td>19.1 ± 10.4</td>
</tr>
<tr>
<td>Interval</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre (N=13)</td>
<td>20.7 ± 1.4</td>
<td>167.8 ± 7.9</td>
<td>67.6 ± 13.9</td>
<td>23.8 ± 3.4</td>
<td>16.7 ± 5.7</td>
</tr>
<tr>
<td>Post (N=13)</td>
<td></td>
<td>167.8 ± 8.3</td>
<td>66.4 ± 14.9</td>
<td>23.4 ± 3.8</td>
<td>16.0 ± 7.0</td>
</tr>
</tbody>
</table>

Values are presented as Mean ± SD. BMI = Body Mass Index.
Aerobic Fitness

VO$_{2\text{max}}$ significantly increased in all three exercise groups, as seen in Table 4. The greatest improvement in aerobic capacity was seen in the maximal-intensity group, with an increase of 7.2 ml·min$^{-1}$·kg$^{-1}$, followed by an increase of 4.8 ml·min$^{-1}$·kg$^{-1}$ in the vigorous-intensity group and an increase of 3.4 ml·min$^{-1}$·kg$^{-1}$ in the moderate-intensity group. The control group experienced no significant change.

### Table 4. Changes in VO$_{2\text{max}}$ (ml·min$^{-1}$·kg$^{-1}$) following 6-week training protocol.

<table>
<thead>
<tr>
<th>Intensity Group</th>
<th>Initial VO$_{2\text{max}}$</th>
<th>Final VO$_{2\text{max}}$</th>
<th>Net Change in VO$_{2\text{max}}$</th>
<th>Initial RERmax</th>
<th>Final RERmax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate</td>
<td>35.3 ± 7.9</td>
<td>38.7 ± 9.1</td>
<td>+3.4 ± 3.9$^*$</td>
<td>1.20 ± 0.09</td>
<td>1.17 ± 0.04</td>
</tr>
<tr>
<td>Vigorous</td>
<td>33.6 ± 9.0$^*$</td>
<td>38.4 ± 10.7</td>
<td>+4.8 ± 3.2$^{ab}$</td>
<td>1.20 ± 0.07</td>
<td>1.17 ± 0.05</td>
</tr>
<tr>
<td>Maximal</td>
<td>35.7 ± 6.2</td>
<td>42.9 ± 7.3</td>
<td>+7.2 ± 4.3$^{b}$</td>
<td>1.17 ± 0.05</td>
<td>1.18 ± 0.04</td>
</tr>
<tr>
<td>Control</td>
<td>37.7 ± 8.7</td>
<td>38.4 ± 10.7</td>
<td>+0.7 ± 3.8</td>
<td>1.18 ± 0.03</td>
<td>1.19 ± 0.05</td>
</tr>
</tbody>
</table>

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).

The initial VO$_{2\text{max}}$ values for the vigorous-intensity group were significantly lower than the control group (P < 0.05). In order to normalize for baseline values, a post-hoc analysis was performed on the mean percent changes in VO$_{2\text{max}}$. Using a one-way ANOVA, there were significant percent increases (P < 0.001) in the moderate (10.0%), vigorous (14.3%) and maximal-intensity (20.6%) groups versus baseline. There was also
a significantly greater percent increase in VO$_{2\text{max}}$ for each intensity group above the next lower intensity group. Results are displayed in Figure 1.

**Figure 1.** Percent increase in VO$_{2\text{max}}$ for each intensity group.

![Bar chart showing percent increase in VO$_{2\text{max}}$ for each intensity group.]

**Exercise Group**

*Significant % increase in VO$_{2\text{max}}$ versus baseline (P < 0.001)

**Significant difference between groups (P < 0.001)

**Resting Heart Rate**

There were no significant differences in the baseline RHR values between groups.

There were no significant changes in RHR following training (Table 5).
Table 5. Changes in RHR (beats/min) following 6-week training period.

<table>
<thead>
<tr>
<th>Intensity Group</th>
<th>Initial RHR</th>
<th>Final RHR</th>
<th>Net Change in RHR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate</td>
<td>66.8 ± 6.3</td>
<td>66.6 ± 9.7</td>
<td>-0.2 ± 9.0</td>
</tr>
<tr>
<td>Vigorous</td>
<td>66.2 ± 9.6</td>
<td>66.2 ± 10.6</td>
<td>0.0 ± 7.9</td>
</tr>
<tr>
<td>Maximal</td>
<td>63.5 ± 7.6</td>
<td>65.1 ± 9.9</td>
<td>+1.6 ± 9.5</td>
</tr>
<tr>
<td>Control</td>
<td>66.8 ± 12.3</td>
<td>66.5 ± 8.8</td>
<td>-0.3 ± 9.2</td>
</tr>
</tbody>
</table>

Resting Blood Pressure

There were no significant differences in the baseline BP values between groups.

There were no significant changes in systolic BP (Table 6) or diastolic BP (Table 7) following training.

Table 6. Changes in SBP (mmHg) following 6-week training period.

<table>
<thead>
<tr>
<th>Intensity Group</th>
<th>Initial SBP</th>
<th>Final SBP</th>
<th>Net Change in SBP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate</td>
<td>106.8 ± 13.4</td>
<td>107.9 ± 12.7</td>
<td>+1.1 ± 5.3</td>
</tr>
<tr>
<td>Vigorous</td>
<td>111.1 ± 12.3</td>
<td>111.8 ± 9.8</td>
<td>+0.7 ± 8.9</td>
</tr>
<tr>
<td>Maximal</td>
<td>106.4 ± 12.3</td>
<td>107.5 ± 12.8</td>
<td>+1.1 ± 5.7</td>
</tr>
<tr>
<td>Control</td>
<td>108.8 ± 13.7</td>
<td>106.1 ± 12.2</td>
<td>-2.7 ± 7.5</td>
</tr>
</tbody>
</table>
Table 7. Changes in DBP (mmHg) following 6-week training period.

<table>
<thead>
<tr>
<th>Intensity Group</th>
<th>Initial DBP</th>
<th>Final DBP</th>
<th>Net Change in DBP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate</td>
<td>64.3 ± 6.1</td>
<td>65.7 ± 6.1</td>
<td>+1.4 ± 5.9</td>
</tr>
<tr>
<td>Vigorous</td>
<td>70.4 ± 8.7</td>
<td>69.2 ± 5.5</td>
<td>-1.2 ± 6.3</td>
</tr>
<tr>
<td>Maximal</td>
<td>63.9 ± 6.6</td>
<td>62.3 ± 6.2</td>
<td>-1.6 ± 6.0</td>
</tr>
<tr>
<td>Control</td>
<td>62.7 ± 5.2</td>
<td>63.3 ± 6.2</td>
<td>+0.6 ± 4.1</td>
</tr>
</tbody>
</table>
CHAPTER V
DISCUSSION

The purpose of this study was to determine whether or not various intensities of aerobic training differentially affect resting heart rate, resting blood pressure and aerobic capacity. The results demonstrate that higher intensities of exercise elicit greater improvements in VO$_{2\text{max}}$ than lower intensities of exercise over a 4 to 6-week training period. These findings are consistent with the original hypothesis. Unlike the change in VO$_{2\text{max}}$, there were no changes observed in resting heart rate and resting blood pressure following training.

VO$_{2\text{max}}$

The ACSM currently recommends 20 to 60 minutes of exercise performed at 40/50-85% HRR or VO$_{2\text{R}}$ for most adults, where 40% is considered a threshold level for improvements for deconditioned individuals and 50% is a threshold for average adults (ACSM, 2006). There has been previous evidence suggesting that exercise of a higher intensity will result in greater gains in cardiovascular fitness (Swain and Franklin, 2002; Swain and Franklin, 2006). However, only a few reports included a sufficient number of subjects to confirm that groups training at higher intensities experienced significantly greater increases in VO$_{2\text{max}}$ 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 VO$_{2\text{max}}$ versus baseline values, and the absolute increase in the maximal intensity group was significantly greater than that in the moderate intensity group. Moreover, when the increases in VO$_{2\text{max}}$ 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 VO$_{2\text{max}}$. Such intervals have been included in training programs as early as 1977, when Hickson et al. reported a 44% increase in VO$_{2\text{max}}$ after 10 weeks of training that consisted of six 5-min intervals of bicycling at VO$_{2\text{max}}$ on 3 days per week plus 40 min of vigorous running on 3 days per week. However, Hickson did not compare this training program with any other. Two recent studies have compared interval training with lower intensity continuous training. Warburton et al.'s study (2005) of male cardiac patients did not fully separate the interval and continuous training, as the interval group performed intervals at 90% HRR on 2 days per week and continuous training at 65% HRR on 3 other days per week. The interval group had a numerically larger increase (18%) in VO$_{2\text{max}}$ than the group that did only continuous training (13%), but the difference was not statistically significant.

A study just published by Helgerud et al. (2007) examined the effects of 8 weeks of aerobic endurance training at various exercise intensities in healthy, male, college-aged students. Groups performed running at a moderate-intensity (70% HRmax for 45 min each session), vigorous-intensity (85% HRmax for ~24 min per session) and two maximal-intensity interval training regimens that both alternated 90-95% HRmax with 70% HRmax, one using 15 second intervals and one using four 4-min intervals. Both interval training groups significantly increased VO$_{2\text{max}}$, while neither continuous training group did. Using a formula published by Swain and Franklin (2002), Helgerud's moderate-intensity and vigorous-intensity groups were exercising at ~47% and ~72%.
HRR, respectively, which are comparable to the current study. The failure of Helgerud's continuous training groups to increase VO$_{2\text{max}}$ was probably due to their high baseline fitness, which averaged 58 ml min$^{-1}$ kg$^{-1}$, as compared to only 34 ml min$^{-1}$ kg$^{-1}$ in the current study.

Helgerud et al.'s findings were somewhat similar to those of the current study in demonstrating the effectiveness of interval training at a near-maximal intensity, but differed from the current study in the population (only males versus both males and females) and the mode of exercise (running versus cycling).

Interval training has been used previously with female subjects (Talanian et al., 2007), but the current study appears to be the first to compare the effectiveness of interval training and continuous training with females. Accordingly, a post-hoc analysis was performed to determine the results in the female subjects alone. VO$_{2\text{max}}$ increased 15.5% among females in the maximal intensity interval group, by 13.6% in the vigorous-intensity group and by 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 VO$_{2\text{max}}$ among men in the higher intensity groups was observed, but it did not reach significance ($P = 0.13$ for one-way ANOVA on % changes) due to the relatively low number of men (4-5 per group, versus 8-10 women per group).

**Resting Heart Rate**

Although several studies propose that vigorous-intensity exercise, >70% VO$_{2\text{max}}$, will significantly lower resting heart rate, there was no consistent trend seen in the changes in resting heart rate for this subject population (Braith et al., 1994; Jennings et
al., 1986, Miayi et al., 2002). 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 healthy, young and at low risk for cardiovascular disease. Our results were similar to the findings of Tashiro et al. (1993), which despite 10 weeks of both moderate- and vigorous-intensity exercise, did not observe any significant changes in resting heart rate for a hypertensive adult population.

**Resting Blood Pressure**

Research by Kang et al. (2002) and Tashiro et al. (1993) suggest that exercise of a vigorous intensity, >70% VO\(_{2}\)\(_{\text{max}}\), results in a significantly greater decrease in diastolic blood pressure than exercise of a moderate intensity. A study by Braith et al. (2002) found a significant decrease in both systolic and diastolic blood pressure following 26 weeks of vigorous- (70% VO\(_{2}\)\(_{\text{max}}\)) and high-intensity (80-85% VO\(_{2}\)\(_{\text{max}}\)) training, however, there was not a significant difference between groups. In the ACSM’s Position Stand on exercise and hypertension, it was concluded that dynamic aerobic training results in a lower resting blood pressure, independent of exercise intensity, in individuals with normal blood pressure, as well as hypertension and that the reduction could be more pronounced in individuals with hypertension (2004). 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. Similar to the RHR data, the lack of effect was likely dependent on the fact that the subjects were healthy, young, normotensive individuals.

**Conclusion**

These results indicate that when energy expenditure is controlled, vigorous-intensity is more effective for improving VO\(_{2}\)\(_{\text{max}}\) 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 a near-maximal intensity. The subjects in this study did not experience a significant decrease in resting heart rate or blood pressure. One of the limitations identified in this study was that the participants were young and at a low cardiovascular risk. This could have contributed to the lack of response in resting heart rate and blood pressure following training.

An acknowledged limitation of this study was the duration of training. Various other studies examined had an average duration of 12 or more weeks (Pollock et al., 1998), while this study was 6 weeks in duration. Despite the short duration, there is a clear positive linear relationship between exercise intensity and improvements in aerobic fitness.

This study contributes to a growing amount of evidence proposing the beneficial effects of higher intensity exercise for improvements in VO$_{2 \text{max}}$. It has been consistently demonstrated that exercise performed at a vigorous intensity (> 60% of HRR or VO$_2$R in relative terms, or > 6 METs, 1 MET = 3.5 ml·min$^{-1}$·kg$^{-1}$, in absolute terms) has a greater effect on reducing cardiovascular risk factors than moderate intensity (< 60% HRR or VO$_2$R, or < 6 METs) exercise (Swain and Franklin, 2006; Cox, 2006; Pollock et al., 1998). A point to consider is that previous studies have had numerous variances in mode, intensity, duration and frequency in training. Studies of a common design could reinforce the cardiovascular benefits of higher intensity training.

One concern with higher intensity exercise is the possibility of poor adherence, or "burnout." Vigorous intensity training was performed for 5 weeks, and interval training was performed for only 4 weeks, in the current study, 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.

Related longitudinal studies could also reveal the long term health benefits of higher intensity training. This study illustrated short term improvements in aerobic fitness for all groups, but further experimentation is warranted. Additionally, increased duration of training could result in a greater training effect for decreasing resting heart rate and blood pressure. The findings of this research are limited in scope to healthy individuals. As suggested by the Position Stand of the ACSM, hypertensive population or individuals at a higher risk for cardiovascular disease may also benefit from the cardio-protective effects of higher intensity exercise.
REFERENCES


Swain, D.P. Moderate or vigorous intensity exercise: which is better for improving aerobic fitness? *Preventive Cardiology.* 55-58, 2005.


Appendix A. EXERCISE TEST SCREENING QUESTIONNAIRE

Name ___________________ Sex ____ Date ____________

I. Risk Factors (two or more places individual at “moderate risk”)
   ___ 1. Do you have a family history of heart disease? [heart attack, bypass surgery, angioplasty or sudden death prior to the age of 55 (father or brother) or 65 (mother or sister)]
   ___ 2. Have you smoked cigarettes in the past 6 months?
   ___ 3. What is your usual blood pressure (> 140/90)? Do you take blood pressure medication?
   ___ 4. What is your LDL cholesterol (>130)? If you don’t know your LDL, what is your total cholesterol (> 200)? ALSO, what is your HDL cholesterol (< 35)? [Either LDL (sub. total if LDL not known) OR HDL is a risk. (note: "negative risk factor" HDL > 60)]
   ___ 5. What is your fasting glucose (> 110)?
   ___ 6. What is your height and weight (BMI > 30)?
   ___ 7. Do you get at least 30 min of moderate physical activity most days of the week (or its equivalent)?

II. Symptoms (one or more places individual at “high risk”)
   ___ 1. Do you ever have pain or discomfort in your chest or surrounding areas? (i.e. ischemia)
   ___ 2. Do you ever feel faint or dizzy? (Other than when sitting up rapidly)
   ___ 3. Do you find it difficult to breathe when you are lying down or sleeping?
   ___ 4. Do your ankles ever become swollen? (Other than after a long period of standing)
   ___ 5. Do you ever have heart palpitations, or an unusual period of rapid heart rate?
   ___ 6. Do you ever experience pain in your legs? (i.e. intermittent claudication)
   ___ 7. Has a physician ever said you have a heart murmur? (Has he/she said it is OK, and safe for you to exercise?)
   ___ 8. Do you feel unusually fatigued or find it difficult to breathe with usual activities?

III. Other
   ___ 1. How old are you? (men > 45, women > 55 are at “moderate risk”) must be 18-44
   ___ 2. Do you have any of the following diseases? Heart disease, peripheral vascular disease, cerebrovascular disease, chronic obstructive pulmonary disease (emphysema or chronic bronchitis) asthma (chronic), interstitial lung disease, cystic fibrosis, diabetes mellitus, thyroid disorder, renal disease, or liver disease (yes to any places individual at “high risk”)
   ___ 3. Do you have any bone or joint problems such as arthritis or a past injury that might get worse with exercise? (exercise testing may need to be delayed, or modified)
   ___ 4. Do you have a cold or flu, or any other infection? (exercise testing must be delayed)
   ___ 5. Do you have any other problem that might make it difficult for you to do strenuous exercise?
   ___ 6. Is it possible that you may be pregnant? (exercise testing may need to be delayed, or modified)
   ___ 7. Are you taking any medications, such as blood pressure medication, that would affect your heart rate?

Interpretation
Low Risk (young, and no more than 1 risk factor): can do maximal testing or enter a vigorous exercise program
Moderate Risk (older, or 2 or more risk factors): can do submaximal testing or enter a moderate exercise program
High Risk (one or more symptoms, or disease): can do no testing without physician presence; can enter no program without physician clearance

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