THE ACUTE PHYSIOLOGICAL EFFECTS OF INTERVAL VERSUS STEADY-STATE EXERCISE

A Manuscript Style Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

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College of Science and Health
Clinical Exercise Physiology

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THE ACUTE PHYSIOLOGICAL EFFECTS OF INTERVAL VERSUS STEADY-STATE EXERCISE

By Sarah E. Horlitz

We recommend acceptance of this thesis in partial fulfillment of the candidate's requirements for the degree of Master of Science in Clinical Exercise Physiology

The candidate has completed the oral defense of the thesis.

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ABSTRACT

Horlitz, S.E. The acute physiological effects of interval versus steady-state exercise. MS in Clinical Exercise Physiology, December 2010, 47pp. (J. Porcari)

This study was designed to evaluate the exercise intensity and energy expenditure of interval exercise compared to steady-state exercise on a cycle ergometer. Fourteen subjects completed a VO2max test on a cycle ergometer to determine their aerobic capacity. Subjects then completed an interval ride and a steady-state ride. The interval ride alternated one minute of high-intensity cycling at 90% of maximal power output followed by one minute of active rest for 20 minutes. The steady-state ride consisted of 20 minutes of exercise at 90% of the subject’s ventilatory threshold (VT). Total work was matched between conditions. Oxygen consumption (VO2), heart rate (HR), lactate, and RPE values were measured. After completion of both trials, a post-exercise questionnaire was administered. No significant difference (p<.05) was found in HR between the rides (142 ± 14.9 vs. 145 ± 13.7). There were significant differences between the interval ride vs. steady-state ride for VO2 (31.2 ± 6.05 vs. 29.9 ± 5.97), lactate (4.8 ± 2.19 vs. 2.1 ± 1.64), and RPE (5.6 ± 1.3 vs. 3.8 ± .83). Interval exercise elicits 9% higher energy expenditure than steady-state exercise and may be an effective way to obtain cardiovascular benefits for individuals with limited time.
ACKNOWLEDGEMENTS

I would like to take this opportunity to say how grateful I am for being able to attend one of the best programs for Clinical Exercise Physiology in the United States. I know this program has helped shape who I am as a person and who I will become as a professional Exercise Physiologist. This past year has been an amazing experience and the memories from UWL will last a lifetime.

There are many people I would like to thank for assisting me with this project. First, I would like to thank my thesis chair Dr. John Porcari for guiding me through this long process of finishing my graduate thesis; your countless hours of assistance are enormously appreciated!

I would also like to thank Dr. Carl Foster and Dr. Jeff Steffen, my other committee members, for making this project possible. Special thanks to Chris Dodge for fixing any problems I encountered in the lab and Glenn Wright for being a great resource throughout my research.

Thank you to my parents for all your encouragement throughout the past few years. Without all your support, I wouldn’t be who I am today.

To my classmates, whom all can relate to the stress of finishing a thesis and completing a Master’s degree in one year, thanks for all the support and memories over the past 12 months, you all will do great in the professional world!
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INTRODUCTION

Interval training is a technique used in a variety of health and fitness settings. It can be seen at the gym as part of a cycling class, on the track where athletes are running sprints, or even in a rehabilitation center as patients perform a bike workout alternating pedaling fast and slow. High-intensity interval training (HIT) is a term commonly used to describe intervals. HIT refers to repeated sessions of relatively brief intermittent exercise, often performed at an intensity close to VO₂max (5). These intervals may last from a few seconds to a few minutes. Evidence suggests using HIT can cause increases in muscular endurance, VO₂max, and anaerobic metabolism (2, 3, 5, 7, 8, 11, 13, 14).

Many studies have found an increase in cardiovascular endurance following an interval training program (3, 5, 11). A group in Japan performed an experiment using interval training in rats (11). One group swam continuously for 6 hours and the other group completed high-intensity intervals for a total of 4 ½ minutes. Both groups showed comparable molecular changes in the muscle, which illustrate increased endurance. Similar molecular changes were also observed in human subjects following a cycling program (5). One group biked at a sustained rate for 90 to 120 minutes and the other group completed high intensity intervals for a total of 2-3 minutes of exercise. Another study found that an increase in endurance can be detected in as few as six interval sessions (3). Burgomaster et al. (3) found that after as few as 2 weeks of high-intensity intervals, subjects were able to more than double their endurance compared to a control group.
In addition to increasing cardiovascular endurance, HIT has been shown to improve VO$_2$max (2, 3, 5, 7, 8, 10-12). Gorostiaga et al. (7) conducted a study in 1991 which found an 11-16% increase in VO$_2$max following 8 weeks of interval cycling. A continuous training group did not improve VO$_2$max despite the fact that both groups completed the same amount of total work. A study by Helegrud et al. (8) also studied the effect of different training intensities on VO$_2$max. They tested four different exercise groups, including long slow distance running, lactate threshold running, and two different types of intervals, over a 6-week training program. They found that both modes of interval training resulted in a significantly greater increase in VO$_2$max compared to the other two groups.

Several studies have also observed increases in fat metabolism when using HIT (3, 9, 13). Research by Burgomaster et al. (3) found that interval training results in an increase in muscle oxidative potential and mitochondrial activity, which both contribute to overall metabolism (3). Similar results were shown by Talanian et al. (13) who also detected an increased fat oxidation and mitochondrial enzyme activity during interval training compared to steady-state exercise. They found that women were able to burn 36% more fat when performing cycling intervals compared to exercise at a moderate pace for 1 hour (4, 13).

Interval training may be a valuable training tool for the health and fitness world. Since obesity rates are on the rise and cardiovascular disease continues to be one of the top causes of death in the U.S., weight loss and exercise are becoming more and more important. There are many reasons people do not exercise on a regular basis. Lack of time is listed as the major reason that many people do not participate in an exercise
program (6). HIT may be a beneficial alternative to endurance training because similar benefits may be gained in a fraction of the time. In addition, many Americans look for the quickest and easiest way to lose weight. With scientific data supporting that interval training burns more fat than endurance exercise, this may make interval training more desirable than continuous exercise (3, 10, 13). Along with increased metabolism and time efficiency, people tend to struggle with adherence; it is important to find a fitness plan they can stick with. Some data suggest that there is a higher level of adherence to interval training than steady-state (9).

For the most part, research on this topic has focused on the benefits of intervals over a relatively long period of time. The aim of this study is to examine the acute physiological effects of interval training versus a steady-state exercise, including total calorie expenditure, ratings of perceived exertion (RPE), and overall enjoyment.

**METHODS**

**Subjects.** The subjects in this study were 14 apparently healthy individuals (eight males and six females). All subjects were regular exercisers who met the American College of Sports Medicine (ACSM) recommendations for physical activity. ACSM recommends that individuals participate in at least 30 minutes of moderate physical activity 5 days each week or 20 minutes of vigorous activity 3 days per week (1).

**Protocol.** Prior to the study, approval from the Institution Review Board for the Protection of Human Subjects at the University of Wisconsin La Crosse was obtained. Each subject provided written informed consent prior to testing (Appendix A). Initially, each subject performed a maximal cycle ergometer test to determine their maximal heart
rate and maximum oxygen uptake (VO_{2max}). Following a warm-up, subjects began pedaling at 25 W. Every 2 minutes the workload increased by 25 W until the subject reached volitional exhaustion. During the VO_{2max} test, the subjects' ventilatory threshold (VT) and maximum power output (PO) were obtained. VT was determined using the V-slope method. This data assisted in calculating appropriate work levels for the subjects' during their subsequent rides.

Following the preliminary VO_{2max} test, each subject completed two trials on a cycle ergometer in random order. One ride was a steady-state ride and the other an interval ride. The steady-state ride began with a 5-minute warm-up. Each subject then completed 20 minutes of exercise at a work load corresponding to approximately 90% of their VT. The trial ended with a 5-minute cool-down.

The interval trial began with a 5-minute warm-up, followed by 20 minutes of intervals. The intervals were at a ratio of 1:1. This ratio refers to 1 minute of high-intensity exercise and 1 minute of active rest. The high intensity segment was at a power output corresponding to 90% of the subject's maximal power output. The active rest segment was set at a power output which allowed the summated total PO (watts) to be equal to the PO of the steady-state ride. Half of the subjects completed the steady-state ride first and the other half completed the interval ride first. A minimum rest period of 72 hours was set between trials to ensure subjects had completely recovered from their previous test.

For all testing VO_{2} was continuously monitored using an AEI metabolic cart (Pittsburg, PA). Heart rate was acquired every minute using a Polar heart rate monitor.
Lactate levels were obtained every 5 minutes using a finger prick method and a Nova Biomedical Lactate Plus blood lactate analyzer (Waltham, MA). Ratings of perceived exertion (RPE) were collected every 5 minutes using the 1-10 Borg scale.

Energy expenditure was calculated from the metabolic and blood lactate data. Aerobic energy expenditure (kcals) were calculated by converting VO₂ (ml/kg/min) to absolute oxygen consumption (L/O₂) multiplied by 5 to equal kcals. The anaerobic energy expenditure was determined by converting the change in lactate levels to an oxygen equivalent value of 3 ml/kg, which was also converted to kcals (14). The aerobic and anaerobic values were added together to set total calorie expenditure per minute and for the total 20-minute workout.

Upon completion of both trials, each subject completed a post-exercise questionnaire. This questionnaire asked subjects about which exercise they preferred, which they would more likely adhere to, and which would be the most effective in influencing the length of their workouts.

**Statistical Analysis.** Descriptive statistics were used to calculate the means and standard deviations for the data collected. Paired samples t-tests were used to compare HR, VO₂, RPE, lactate, and energy expenditure for the interval ride and steady-state ride. Alpha was set at .05 to achieve statistical significance.

**RESULTS**

The descriptive characteristics of the subjects are displayed in Table 1. There was no significant difference in age between males and females. However, as expected,
males were significantly taller and weighed more than females. Males also had a higher maximal heart rate, oxygen consumption, and power output than females.

Table 1. Descriptive characteristics of the subject population (N=14).

<table>
<thead>
<tr>
<th>Gender</th>
<th>Females (8)</th>
<th>Males (6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>23.1 ± .84</td>
<td>24.2 ± 1.60</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>65.9 ± 2.10</td>
<td>70.8 ± 2.14*</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>66.0 ± 6.98</td>
<td>86.8 ± 15.59*</td>
</tr>
<tr>
<td>Heart Rate Max (bpm)</td>
<td>168 ± 12.8</td>
<td>182 ± 12.6*</td>
</tr>
<tr>
<td>VO₂max (ml/kg/min)</td>
<td>39.3 ± 8.82</td>
<td>52.1 ± 8.60*</td>
</tr>
<tr>
<td>Power Output (watts)</td>
<td>218.8 ± 53.03</td>
<td>327.5 ± 19.69*</td>
</tr>
</tbody>
</table>

*Indicates a significant difference between females and males (p<0.05).

The physiological responses to the steady-state and interval rides on the cycle ergometer are summarized in Table 2 and graphically presented in Figures 1-4. Overall, there were no differences found between the interval and steady-state rides for absolute heart rate, % of HRmax, or resting lactate values. The interval ride did elicit higher average VO₂ levels, RPE, and lactate levels compared to the steady-state bout. Total calorie expenditure was 9% higher during the interval ride but, this was not statistically significant (p=.06).
Table 2. Exercise responses to the steady-state and interval trials on the cycle ergometer.

<table>
<thead>
<tr>
<th>Category</th>
<th>Steady-State X ± SD</th>
<th>Interval X ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart Rate (bpm)</td>
<td>142 ± 14.9</td>
<td>145 ± 13.7</td>
</tr>
<tr>
<td>% HRmax</td>
<td>82 ± 7.4</td>
<td>83 ± 6.9</td>
</tr>
<tr>
<td>VO₂ (ml/kg/min)</td>
<td>29.9 ± 5.97</td>
<td>31.2 ± 6.05*</td>
</tr>
<tr>
<td>% VO₂ max</td>
<td>68 ± 12.0</td>
<td>71 ± 13.0*</td>
</tr>
<tr>
<td>RPE</td>
<td>3.8 ± .83</td>
<td>5.6 ± 1.3*</td>
</tr>
<tr>
<td>Resting Lactate (mmoles)</td>
<td>1.5 ± .76</td>
<td>1.6 ± .45</td>
</tr>
<tr>
<td>Exercise Lactate (mmoles)</td>
<td>2.1 ± 1.64</td>
<td>4.8 ± 2.19*</td>
</tr>
<tr>
<td>Recovery Lactate (mmoles)</td>
<td>2.7 ± 1.32</td>
<td>5.8 ± 2.86*</td>
</tr>
<tr>
<td>Total Kcals</td>
<td>292 ± 29.4</td>
<td>310 ± 25.1</td>
</tr>
</tbody>
</table>

*Indicates a significant difference between steady-state and interval ride (p <0.05).

The heart rate response of the subjects for both the interval and steady-state rides are presented in Figure 1. The interval ride elicited pronounced rises and falls in heart rate each minute as the power output changed. There was no significant difference in the warm-up and cool-down heart rates between the two rides.
Figure 1. Heart rate responses during the interval and steady-state rides.

Figure 2 displays oxygen consumption (VO$_2$) throughout both 30-minute workouts. Similarly to the heart rate response, the interval VO$_2$ displays pronounced rises and falls each minute, with a change in power output (watts). There was no significant difference in the VO$_2$ values during the warm-up or cool-down between conditions.
The lactate levels during the steady-state and interval rides are presented in Figure 3. Lactate levels were taken at rest, after the warm-up, every 4 minutes during the workout, and after the cool-down. No differences were found in the resting lactate values between conditions. A larger rise in lactate levels in the interval ride was evident as early as 4 minutes into the workout. The interval had significantly higher lactate values throughout the duration of the ride and the cool-down compared to the steady-state ride.
Figure 3. Blood lactate levels during interval and steady-state rides.

Throughout each ride, subjects were asked to rate the level of difficulty using the Borg's 1-10 scale. Subjects reported their RPE after the 5 minute warm-up, every 4 minutes in the workout, and after the cool-down. Figure 4 displays RPE values during both the interval and steady-state rides. RPEs after the warm-up were the same, however during the workouts, the interval ride showed significantly higher ratings than during the steady-state condition.
Figure 4. Ratings of perceived exertion (RPE) during the interval and steady-state rides.

Upon completion of both trials, subjects filled out a post-exercise questionnaire. Question 1 asked, “Which exercise did you prefer?” Subjects were then asked to circle the interval ride or steady-state ride. Nine out of 14 (64%) subjects preferred the interval ride over the steady-state ride. Questions 2 through 5 were answered using a Likert scale with a rating of “1” being “not at all enjoyable/effective” and a rating of “10” being “highly enjoyable/effective.” Questions 2 and 3 asked “How enjoyable was your steady-state ride/interval ride.” No difference was found in the overall enjoyment of each ride expressed in average rankings of 5.8±2.05 and 5.7±1.64 for the steady-state and interval ride, respectively. Questions 4 and 5 asked, “How effective would the interval ride/steady-state ride be in influencing how often or how frequently you exercise.”
 Neither ride was found to influence the frequency of exercise more than the other ride, with average ranking of 6.0±1.84 and 5.4±1.95 for the interval and steady-state rides, respectively. The last question asked "Which exercise would be more likely to extend the length of your workout." Ten out of 14 (71%) subjects said that the steady-state ride would be more likely to extend the length of their workout.

**DISCUSSION**

The purpose of this study was to investigate the acute effects of interval training versus steady-state exercise on energy expenditure, RPE, and overall enjoyment. The study was designed so that the same total amount of work was completed during each workout. It was found that interval training resulted in 4% higher levels of oxygen consumption compared to the steady-state exercise (31.2 vs. 29.9 ml/kg/min, respectively). In addition, lactate levels measured during the interval ride were more than double those during the steady-state ride, signifying an increased role of the anaerobic energy systems. To calculate energy expenditure, a VO₂ equivalent of lactate was added to the VO₂ values recorded during exercise to account for the anaerobic energy expenditure (14). Total caloric expenditure was then calculated from the VO₂ data. When this was done, total caloric expenditure for the 20-minute interval workout was 9% higher than the steady-state workout (310 vs. 292 kcals).

The concept of adding in the anaerobic energy expenditure comes from the work of Margaraia et al. (11) and Di Prampero et al. (4), who found that high intensity exercise leads to a higher production of lactic acid. They determined that using only aerobic metabolic data can significantly underestimate total energy expenditure during high
intensity exercise (i.e. interval training), thus the VO₂ equivalent of anaerobic exercise must be added in. Scott et al. (14) determined the VO₂ equivalent to be 3 ml/kg/min per each millimole of lactate produced during exercise, which was the value used in the current study.

ACSM (1) guidelines recommend that individuals should expend at least 300 kcals per session of exercise. Because interval training burned 9% more calories during only a 20-minute workout, individuals can meet this criteria more rapidly than during steady-state exercise. Since time has always been a factor affecting the likelihood of participating in exercise for many individuals, the use of interval exercise is a favorable option for those with time constraints.

Exercise adherence is also an obstacle for many individuals. The present study surveyed the overall enjoyment of exercise by administering a post-exercise questionnaire to subjects. Although, neither the steady-state nor the interval ride was found to be more enjoyable than the other, 64% of subjects preferred the interval ride to the steady-state ride. Thus, adding variety to an exercise regime may contribute to adherence.

Conversely, when completing a longer workout, subjects indicated steady-state exercise would be preferred. Seventy-one percent of subjects said that steady-state exercise would be more likely to extend the length of their workout. This may be a result of the higher intensity of interval exercise. The session RPE values were markedly higher during the interval workout (5.6) compared to the steady-state bout (3.8). A rating of 3.8 for the steady-state ride corresponds to a “somewhat hard” intensity and a rating of
5.6 for the interval ride corresponds with a “hard” intensity when looking at the verbal anchor points on the 1-10 Borg scale. Thus, for a shorter workout, a harder intensity may be satisfactory, but for individuals who have time for a longer workout, exercising at the lower intensity at a constant pace may be a better way to go.

Previous studies have shown that interval training offers results in greater increases in VO₂max in a short period of time compared to continuous training (7, 8). The key factor in determining increases in VO₂max appears to be exercise intensity; the higher the exercise intensity, the greater the increase in aerobic capacity. In the current study, the average HR for the interval ride and steady-state ride were similar (145 vs. 142 bpm). However, during the 1-minute high intensity intervals, HR averaged 89% of HRmax. Similarly, oxygen consumption during the high-intensity portion of the interval ride was 78% of VO₂max. Both of these indicate that subjects were well above their anaerobic thresholds during the high-intensity portions of the ride. Thus, this could serve to explain why high-intensity interval training results in greater increases in aerobic capacity compared to traditional aerobic training at a constant pace, which is typically conducted at an intensity below the anaerobic threshold.
CONCLUSION

This study found that interval training burned 9% more calories per session compared to steady-state exercise, despite an identical total work output. Additionally, it was preferred over steady-state exercise in a majority of individuals, even though it elicited higher RPE values. Because of the many time constraints individuals encounter on a daily basis, interval training may be a favorable option for individuals who want to achieve ACSM’s recommendations for exercise.
REFERENCES


APPENDIX A

INFORMED CONSENT
Protocol Title: Acute Physiological Effects of Interval Versus Steady-State Exercise

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Emergency Contact: Dr. John Porcari  
133 Mitchell Hall  
608-785-8684

Purpose and Procedures

- The purpose of this study is to determine the calories burned, perceived intensity of exercise, and overall enjoyment during interval training compared to continuous exercise.
- My participation will involve three cycle tests. The first will involve cycling at increasing speeds to maximal effort. The second will involve 30 minutes of moderate intensity cycling, including a 5 minute warm-up and 5 minute cool-down. The third will involve cycling at a high-intensity alternated with low-intensity for 20 minutes, at the same average workload, also including 5 minute warm-up and cool-down.
- My participation will require approximately 3 hours over a course of 2-3 weeks.
- During the tests, I will wear a snorkel-like device to analyze my breathing and a heart-rate monitor around my chest.
- Throughout the three tests, I will have my finger pricked by a lancet, and the blood will be examined by a blood lactate analyzer every 4 minutes.
- Testing will take place in Mitchell Hall room 225, UWL.

Potential Risks

- I may experience respiratory and muscular fatigue during each trial
- Muscle soreness may occur after each trial.
- First aid and individuals trained in CPR will be present during each trial. If any complications occur, the test will be terminated.
- The risks of serious or life-threatening complications are very rare for an active and healthy individual, like me.

Rights and Confidentiality

- Participation is voluntary.
- I am able to withdraw at anytime, with no penalty.
• All personal performance information is kept confidential. Data collected will be used anonymously.
• Results of this study may be published in a scientific journal. Only grouped data will be used.

Possible Benefits

• My participation may help determine the acute effects of interval training and steady-state exercise. These results may help researchers, athletes, and health professionals understand more about various training methods.

Questions regarding these procedures may be directed towards the principal investigator, Sarah Horlitz, or study advisor, John Porcari. Questions about the protection of human subjects may be addressed to the UWL Institutional Review Board for the Protection of Human Subjects (608-785-8124 or irb@uw lax.edu).

Participant: __________________________ Date: ________________

Researcher: __________________________ Date: ________________
APPENDIX B

POST-EXERCISE QUESTIONNAIRE
POST-EXERCISE QUESTIONNAIRE

Circle the answer that most accurately describes your interval ride and steady-state ride on the cycle ergometer.

1. Which exercise did you prefer (circle one)?
   
   Steady-state ride   Interval Ride

2. How enjoyable was your steady-state ride?
   
   Not at all enjoyable   Enjoyable   Highly Enjoyable
   
   1  2  3  4  5  6  7  8  9  10

3. How enjoyable was your interval ride?
   
   Not at all enjoyable   Enjoyable   Highly Enjoyable
   
   1  2  3  4  5  6  7  8  9  10

4. How effective would the interval ride be in influencing how often or how frequently you exercise?
   
   Not at all effective   Effective   Very Effective
   
   1  2  3  4  5  6  7  8  9  10

5. How effective would the steady-state ride be in influencing how often or how frequently you exercise?
   
   Not at all effective   Effective   Very Effective
   
   1  2  3  4  5  6  7  8  9  10

6. Which exercise would be more likely to extend the length of your workout time?
   
   Steady-state ride   Interval Ride
APPENDIX C

RATING OF PERCEIVED EXERTION (RPE)
### Rating of Perceived Exertion

<table>
<thead>
<tr>
<th>RPE</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Complete rest</td>
</tr>
<tr>
<td>1</td>
<td>Very, very easy</td>
</tr>
<tr>
<td>2</td>
<td>Easy</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
</tr>
<tr>
<td>4</td>
<td>Somewhat hard</td>
</tr>
<tr>
<td>5</td>
<td>Hard</td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Very hard</td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Extremely hard (almost maximal)</td>
</tr>
<tr>
<td>--</td>
<td>Exhaustion</td>
</tr>
</tbody>
</table>

REVIEW OF LITERATURE

Physical fitness is an important asset to overall health. It is a well-known fact that exercise contributes to cardiovascular health, weight management, and mental wellness. The American College of Sports Medicine (ACSM) recommends that individuals participate in regular physical activity for at least 30 minutes a day, 5 days a week at moderate intensity or 20 minutes, 3 days a week at a vigorous intensity (3).

For many years, steady-state endurance training has been the recommended way to achieve the most benefits from exercise. However, recently research has been looking at the use of interval training to elicit similar benefits to endurance training. Interval training (IT) has been described as the combination of high-intensity and low-intensity work used in a successive pattern. Lately, several research studies have focused on the effects of high-intensity interval training (HIT). HIT refers to repeated sessions of brief intermittent exercise often performed with an “all out” intensity close to that of \( VO_2 \text{max} \) (7). These intervals may last anywhere from a few seconds to several minutes with periods of rest in between. Many different physiological factors have been monitored during interval training including \( VO_2 \text{max} \), endurance, and metabolism (5, 7-11, 19, 21, 24-26).

**Endurance and \( VO_2 \text{max} \).** Maximal oxygen consumption, or \( VO_2 \text{max} \), is one of the best determinants of a person’s overall fitness. This is defined as the maximum capacity of the body to transport and utilize oxygen for energy production (23). \( VO_2 \text{max} \) is measured by an incremental exercise test to the point of exhaustion. \( VO_2 \text{max} \) is the
point in which the oxygen consumption plateaus, despite an increase in workload (3).

When studying the effects of exercise training, many researchers will administer a VO₂max test to provide preliminary information prior to beginning training. Information provided by a VO₂max test may include: maximum power output (POmax), maximum heart rate (HRmax), ventilatory threshold (VT), maximal METs, and lactate threshold (LT).

Gorstiaga et al. (9) studied the effects of interval training (IT) and continuous training (CT) on overall fitness over a period of 8 weeks. Twelve subjects were used in the study; six in each training group. Both groups participated in cycling for 30 minutes a day, 3 days per week, for 8 weeks. The CT group cycled at 50% of their maximal workload continuously and the IT group completed intervals of 30 seconds of work alternated by 30 seconds of rest at 100% of maximal workload. The researchers found that the IT group showed much higher increases in VO₂max, power output, and exercising work rates compared to the CT group.

Helgerud (11) also studied the effects of training intensity on VO₂max. Forty healthy, male subjects were randomly assigned to one of four groups and completed an 8-week running program. The four different training groups were: long slow distance running (LSD), running at lactate threshold (LT), 15/15 intervals (47 repetitions of 15 seconds of intervals at 95% of HRmax and 15 seconds of active rest at 70% HRmax), and 4 x 4 interval group (four repetitions of 4 minutes at 90-95% HRmax and 3 minutes active rest at 70% HRmax). Each training load was calculated to equate total work completed. VO₂max increased by 5.5% and 7.2% in the 15/15 and 4 x 4 interval running groups. There were no increases seen in either the LSD or the LT running groups.
There are several contributors to VO$_2$max including: the respiratory system, the circulatory system, and oxidative enzymes of the muscles. Exercise training plays a role in improving VO$_2$max by improving all of these factors. Respiration becomes more efficient, stroke volume (SV) increases, and muscles adapt to better utilize oxygen when it is present (23).

In the previously mentioned study by Helgerud’s (11), significant increases in stroke volume of the heart occurred in both interval running groups. This shows that higher aerobic intensity leads to significant improvements in SV compared to lower intensity. The product of SV and heart rate equate to cardiac output (CO), or the volume of blood pumped by the heart each minute. The greater the SV, the more efficient the CO. The close link found between SV and VO$_2$max in this study reiterates the role of the circulatory system in determining VO$_2$max (11, 23).

In addition to VO$_2$max, endurance is considered an excellent measurement of fitness (7, 8, 10, 20). Endurance is measured by the length of time a particular aerobic activity can be maintained at a certain workload before reaching fatigue. Gibala and associates (7) found that HIT dramatically improves exercise performance and endurance in as little as 2 weeks. Subjects in this study participated in six sessions of high-intensity training over a 2-week period. At the end of the study, subjects were able to double the length of time they could exercise at a fixed workload of 80% of VO$_2$max. A control group, which completed no training, showed no increase in endurance.

Hawley and colleagues (10) found an increase in VO$_2$max and improved time-trial performance after interval training in cyclists. Twenty competitive cyclists
underwent a series of HIT. Prior to completing the training, they performed an incremental ride to exhaustion to determine their VO\textsubscript{2}max and maximal power output (PO\textsubscript{max}). Each subject performed 6 to 12 sessions of HIT over 7 weeks. Each training session included six to nine 5 minute bouts of cycling at 80% of PO\textsubscript{max}, alternated with 1 minute of rest. After four sessions, each subject underwent another incremental test to adjust their training intensity. It was found that after as few as four interval sessions, PO\textsubscript{max} increased an average of 15-20 watts and time-trial performance was improved by 90-120 seconds. When retested after 12 HIT sessions, no further increases in either PO\textsubscript{max} or time-trial performance were observed.

Endurance and fitness can also be measured on a cellular basis. Muscle biopsies allow researchers to examine enzyme activity and metabolic reactions in skeletal muscles. Scientists at the National Institute of Health and Nutrition in Japan studied molecular changes of skeletal muscle in two groups of rats after swimming (20). An endurance group of rats was placed in a pool of water to paddle for two sessions of 3 hours. The interval group was weighted with a ballast and placed in the water to swim furiously for 20 seconds interchanged, with 10 seconds of rest. This was repeated for 14 cycles. The endurance training group completed a total of 6 hours of swimming, while the interval group completed a total of 4 ½ minutes of exercise. Muscle biopsies from these rats showed comparable preliminary molecular changes, which implies similar endurance improvements in both groups.

Gibala et al. (8) found similar results when studying cellular changes in human muscles. One group of six male subjects completed short, intense, 30-second bouts of exercise at an “all out” intensity, followed by 30 seconds of rest. Another group
performed continuous exercise. The first group completed approximately 9 minutes of exercise per week, while the other group completed about 5 hours. Subjects showed almost identical increases in endurance as determined by time trial performance on a stationary bike. Muscle biopsies also showed almost identical improvements in the number and size of the mitochondria within the muscle. These characteristics of the mitochondria are associated with fitness and endurance (8, 20). These results signify that the benefits of endurance training may be achieved with interval training in a fraction of the time.

**Metabolism.** Metabolism is a term that is used to explain a number of chemical reactions that take place within cells to maintain life. A considerable amount of research has been conducted on fat metabolism during interval training (5, 19, 21, 23-25). Exercise intensity is found to be one of the main factors determining the rate of fat metabolism and oxidation during exercise (21).

Metabolic oxidation is important because it aids in the bio-chemical reactions within cells. Oxygen is used to extract energy from carbohydrates, fat, and protein within the body and transforms it into ATP, the body's main fuel. When performing aerobic activity, metabolic oxidation is the optimal mode of energy production and is sustained during steady-state exercise, as long as there is adequate oxygen delivered to the body's tissues. Once anaerobic or high-intensity exercise occurs, oxygen demand increases and energy produced via oxidation cannot match energy demand of the tissues. In this case, the body transitions to anaerobic metabolism to produce adequate ATP, through processes such as glycolysis (23).
Romijn (21) discovered that the rate of oxidating fat varies depending upon exercise intensity. His study observed that fat oxidation is low at low intensity exercise, is higher at moderate exercise intensity, and low again at high intensity exercise. The decrease in fat oxidation at high intensities occurs due to the transition from oxidation to anaerobic metabolism as means of producing ATP. Achten (1, 2) further examined this phenomenon and conducted a study to determine the intensity at which fat oxidation (Fatmax) is at its greatest and the point at which it regresses (1, 2). Fatmax was calculated to be 56% VO$_{2}$max. Fat oxidation was constant within the ranges of 51.3 and 69.4 % of VO$_{2}$max, but decreased at higher intensities. From these results, the researchers drew the conclusion that a positive correlation exists between the maximal rate of fat oxidation and the intensity of exercise. These researchers also determined that at Fatmax, 32 % of total energy expended was produced via fat oxidation (21). Other researchers have identified Fatmax at levels of 65% (23) and 57% (26) of VO$_{2}$max.

Talanian and associates (24) studied the effects of high-intensity intervals on fat oxidation in women. Eight female subjects completed two 60-minute rides before and after 7 sessions of HIT on a cycle at 90% VO$_{2}$max. A 13% increase in VO$_{2}$max and a 36% increase in fat oxidation was found after HIT.

Burgomaster et al. (5) studied the effects of 2 weeks of daily sprint training on muscle oxidative potential, VO$_{2}$max and endurance time to fatigue. Sixteen healthy individuals underwent pre-training muscle biopsies and then completed 6 sessions of sprints over the next 2 weeks. These sessions consisted of repeated 30 seconds of an “all out” sprint on a cycle ergometer, followed by 4 minutes of recovery. After 2 weeks, subjects in both the training and control group underwent a second muscle biopsy. The
study found that in the training group, citrate synthase (CS) activity increased by 38% from the pre muscle biopsy to the post muscle biopsy. Citrate synthase (CS) activity is the most commonly used marker of muscle oxidative potential. They found no increase in CS activity in the control group. In addition to CS activity, the average increase in cycle endurance time to fatigue in the interval group doubled compared to the control, which showed no detectable increase.

Perry (19) demonstrated that interval training for 6 weeks can significantly increase the muscles capacity to oxidize fat and carbohydrates in previously untrained individuals. Subjects completed a set of 10, 4 minute intervals at 90% of VO$_2$max followed by 2 minutes of rest. Muscle chemistries showed a 26% increase in CS activity and a 29% increase in β-HAD, another metabolic enzyme. Both enzymes contribute to fat oxidation. Additional increases in other enzymes were detected, signifying increased carbohydrate metabolism as well.

**Benefits of Interval Training in Cardiac Patients.** In addition to the using interval training with healthy subjects, it has also been integrated into exercise programs for cardiac patients. Numerous studies have been performed regarding interval training in patients with heart conditions (13-18).

Patients with chronic heart failure have an overall reduction in exercise capacity, aerobic power, and muscular strength. These effects are mostly due to poor cardiac output, which in turn, causes a decreased flow of blood to the periphery, specifically to the skeletal muscles (16). Exercise training is said to reverse some of these detrimental effects. Numerous studies have found that exercise at a higher intensity is more
beneficial than a higher volume of exercise at a lower intensity (13-18). For that reason, interval training has been found to be a useful method of exercise training in patients with heart failure and cardiovascular disease.

Safety of exercise has always been a concern for cardiac patients. Recent studies have found that interval exercise training is safe and beneficial to patients with heart failure (13, 16). Left ventricle (LV) function was observed between two groups of patients with CHF who underwent interval exercise training (IET) and steady-state exercise training (SSET). During exercise, minimal cardiac stress occurred and LV function was stable in both groups. Exercise induced changes in LV ejection fraction, heart rate, stroke volume, cardiac output, systolic blood pressure, ratings of leg fatigue and dyspnea (shortness of breath) were not statistically different between groups. All in all, IET was found to be as safe as SSET in LV function.

Meyer and colleagues (17) studied the physiological effects of short-term interval training and activity restriction in patients with severe heart failure. Eighteen male patients with HF completed 3 weeks of interval training, followed by 3 weeks of activity restriction. Baseline data was collected to determine lung function, ejection fraction, cardiac index, and aerobic capacity. The training period consisted of 30-second intervals, followed by 60 seconds of recovery, for 15 minutes, five times per week. Patients also completed 10 minutes of interval walking on the treadmill 2 times per week, in addition to the cycling. The results showed that after training patients increased their maximal work load by 57%, oxygen consumption at VT by 24%, and VO$_{2}$max by 23.7%. Patients also decreased their heart rate, lactate, leg fatigue, and dyspnea during submaximal exercise. After 3 weeks of activity restriction, data did not differ significantly from
baseline, implying that training must be continuous to get benefits. In short, an interval training program is shown to be very beneficial to patients when it is long-term and continuous.

Further studies by Meyer et al. (14) monitored the effects of interval versus continuous training in patients after coronary bypass surgery. Eighteen male subjects completed 3 weeks of either continuous or interval training. Overall, the continuous training group completed a higher total work load than the interval group, $3750 \pm 298$ Watts versus $3163 \pm 337$ Watts respectively. No significant changes were found in catecholamine or glucose levels at rest in either group after training. Both groups showed significant decreases in resting heart rates and had similar ratings of perceived exertion. However, the interval training group showed higher lactate levels during exercise than the continuous training group. Benefits of 3 weeks of training were only observed in the interval training group, which had a decreased heart rate at submaximal exercise levels, a lower blood pressure at rest, and increased physical performance.

The accumulation of Meyer’s studies of patients with heart patients’ support the use of interval training in a cardiac population. Interval training, in short bouts, allows patients to tolerate higher power outputs than in steady-state exercise, without significant increases in perceived exertion. Furthermore, interval training was shown to be as safe as steady-state in terms of blood pressure, heart rate, and left ventricular function.

**High-Intensity Intervals and Insulin Action.** Babraj et al. (4) studied the effects of HIT on insulin action and glycemic control. It is known that regular aerobic exercise reduces the risk of metabolic disorders, but there was little known about the
effect of interval training on factors such as glucose and insulin levels. Sixteen young
men, who were previously sedentary or recreationally active, underwent 6 weeks of HIT. The intervals were equated to approximately 15 minutes of total exercise on a cycle
ergometer. HIT was found to substantially improve insulin action and glucose
homeostasis in these individuals.

**Lactate Conversions.** The fuel of choice for muscles is adenosine triphosphate
(ATP). It is made in a variety of ways depending on the environment in the body.
During aerobic exercise, when oxygen is present, most of the ATP is made through
oxidation via the krebs cycle and electron transport system. Oxidation is a slow process
and at the onset of exercise may take up to a minute to become fully activated. At the
beginning of exercise, most ATP is created via anaerobic (without oxygen) mechanisms.
When ATP is created anaerobically, a metabolic waste product called lactate is formed.
When high intensity exercise is performed, such as in interval training, there is not
enough oxygen present to create the ATP needed to maintain the higher workload;
therefore ATP is formed anaerobically, in turn, producing lactate. During high intensity
exercise, ATP generation as measured by oxygen consumption is disproportional to the
energy demand, therefore VO₂ alone cannot adequately determine energy expenditure of
anaerobic activities. This is why a method to convert lactate to oxygen consumption has
been developed.

Margaria et al. (12) conducted a study on the energy utilization of supramaximal
intensity and came up with the earliest conversion of lactic acid to oxygen equivalent.
The study involved three subjects, who were asked to run at 18 km/hr at a 15% grade for
10 second intervals, followed by 10, 20, or 30 seconds of rest. Subjects repeated these
intervals until a steady-state was reached or until they could no longer continue. Resting lactic acid levels were measured prior to running, and at 3 and 5 minutes after completion of the run. This study showed that lactic acid concentration increased very rapidly in the first few runs and reached a steady-state after the fifth run. In addition, they observed the longer the period of rest between runs, the smaller the increase in lactic acid concentration. In fact, when a subject was given 30 seconds between runs, lactic acid concentration does not significantly increase. From this research study, they were able to formulate a conversion where 1 gram of lactic acid is equivalent to 44 milliliters of oxygen.

Di Prampero and Ferretti (6) did a thorough analysis of the concepts of anaerobic muscle metabolism. They found that anaerobic energy sources contribute greatly to total energy expenditure, especially in the early phases of exercise, and exercise at high intensities. They discussed that increasing lactic acid concentrations in the blood during exercise does indicate energy expenditure through anaerobic systems, and supported Margaria’s discovery of the conversion of lactic acid into oxygen consumption. This conversion was changed into more applicable units where a 1 mmole increase in blood lactate concentration is equivalent to a 3.3 ml/kg/min increase in oxygen consumption (Di Prampero).

Scott (22) performed a study which investigated the contribution of lactate to the energy expenditure of weight training. Eleven subjects completed three weight-training exercises at two different intensities—one at 60% of 1 repetition maximum (1RM) and the other at 80% 1RM. Gas exchange measurements were collected and lactate levels were taken before weight training and 2 minutes after. They stated that the change in
lactate (mmoles) was equivalent to 3 ml/kg/min of oxygen consumption. Scott found that adding in the energy from the conversion of lactate resulted in a significant increase in the total energy expenditure of weight training compared to that calculated from the aerobic-only energy expenditure. Therefore, the calculation of aerobic-only energy expenditure underestimates actual energy expenditure of anaerobic activities such as weight lifting (22).

CONCLUSION

Exercise has numerous benefits that support a healthy life. Until recently, research has looked to endurance training as the method to achieve the most benefits. Recent studies have found that interval training can increase VO_{2}\text{max}, exercise endurance, metabolism, and fitness. In addition, interval training is being implemented into cardiac rehabilitation programs since it has been found to be safe and well-tolerated. Interval training also has the potential to expend higher levels of energy than steady-state exercise, because of the additional contribution of anaerobic energy utilization. This could have important implications for the use of interval training in controlling body weight. Additional research should be performed to examine the potential benefits of a single bout of interval training compared to continuous exercise.
REFERENCES


