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Graduate Studies

ANAEROBIC BENEFITS OF HIGH INTENSITY INTERVAL TRAINING VERSUS  
CONTINUOUS STEADY-STATE TRAINING

A Manuscript Style Thesis Submitted in Partial Fulfillment of the Requirements for the  
Degree of Master of Science, Clinical Exercise Physiology

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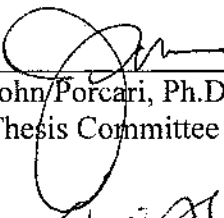
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By Jeff Schuette

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

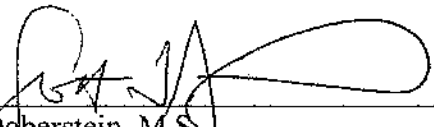
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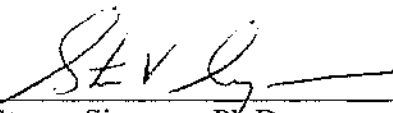
  
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## ABSTRACT

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The purpose of this study was to compare the effects of two high intensity interval training (HIIT) protocols and a steady-state protocol on anaerobic capacity after 8 weeks of training. Fifty-five untrained college-aged subjects (17 male, 38 female) completed this 8-week training study. The subjects were randomly assigned to one of three training protocols (steady-state, Tabata, or Meyer). The steady-state group (n=19) completed 20 minutes of exercise at 90% of ventilatory threshold. The Tabata group (n=21) completed eight intervals of 20 seconds at 170%  $\text{VO}_2\text{max}$ , with 10 seconds rest in between each bout. The Meyer group (n=15) completed 30 seconds at 100% of the PPO at  $\text{VO}_2\text{max}$ , with 60 seconds of active rest at an output that made the average of the intervals equal to 90% of ventilatory threshold. This was repeated 13 times for a total of 20 minutes of exercise. Each subject completed 24 sessions of their respective training protocol. Pre and post-test Wingate anaerobic tests (WAnT) were used to assess the changes in peak power output (PPO), mean power output (MPO), and rate to fatigue. There were significant improvements in PPO (steady-state=+6.7%, Tabata=+9.1%, Meyer=+4.4%), PPO/kg (steady-state=+7.8%, Tabata=+8.5%, Meyer=+5.1%), MPO (steady-state=+3.4%, Tabata=+8.1%, Meyer=+9.8%), and MPO/kg (steady-state=+4.3%, Tabata=+6.8%, Meyer=+6.1%) in all three training groups ( $p<.05$ ). Rate to fatigue significantly digressed in all three groups ( $p<.05$ , steady-state=-3.7%, Tabata=-9.2%, Meyer=-3.0%). There were no significant differences between the three groups. The results of this study indicate that untrained individuals can improve their anaerobic capacity regardless of the training protocol utilized.

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## INTRODUCTION

High intensity interval training (HIIT) has increased greatly in popularity over the past several decades. Studies have shown that HIIT can induce multiple benefits in a variety of individuals. Benefits such as an increase in aerobic capacity ( $VO_2\text{max}$ ) in individuals ranging from cardiac patients (Meyer and Foster 2004; Meyer et al., 1996), cyclists (Seiler, Joranson, Olesen, and Hetlelid, 2013), sedentary adults (Nybo et al., 2010), obese children (De Araujo et al., 2012), college-aged students (Tabata et al., 1996), female soccer players (Rowan, Kueffner, and Stavrianeas, 2012), and healthy men (Helgerud et al., 2007). However, many of these studies also show that continuous steady-state training can also increase  $VO_2\text{max}$ , although usually to a lesser degree compared to HIIT.

So why is HIIT important if continuous steady-state training can induce similar aerobic benefits? One significant reason HIIT is important is because HIIT can induce anaerobic benefits that continuous steady-state training cannot produce. Increasing anaerobic power is important because it allows an individual to move faster, jump higher, and lift more weight. This is important for a variety of individuals ranging from athletes to the elderly. Tabata et al. (1996) conducted a 6-week training study comparing 60 minutes of continuous steady-state training to a HIIT protocol involving 20 second work periods separated by 10 second rest periods (20s:10s) for a total of 4 minutes. They found that anaerobic capacity increased by 28% following HIIT, while steady-state training caused no significant increases.

An effective way to measure anaerobic capacity is by using the 30-second Wingate Anaerobic Test (WAnT) (Beneke, Pollmann, Bleif, Leithauser and Hutler 2002). This 30-second test effectively measures peak power output (PPO), mean power output (MPO), and rate to fatigue, which are all important anaerobic capacity measures. Peak power output is a measurement that can be used to assess an individual's ATP creatine phosphate system (ATP/PC), while MPO is an effective way to assess the glycolytic system (Maud et al., 1995). Beneke et al. (2002) conducted a study to determine the contributions of each energy system during the WAnT. Their research found that the aerobic oxidative system contributed 18.6% of total energy expenditure, with the glycolytic system contributing 50.3%, and the ATP/PC system contributing 31.1% respectively, during the WAnT. This shows that the WAnT is 81.4% anaerobic, with the oxidative system contributing the most at the very end of the 30-second period.

Many studies have shown that various HIIT training protocols are effective at improving the anaerobic systems, thus improving performance on the WAnT. Astorino, Allen, Roberson, and Juranich (2012) found that PPO and MPO improved by 10.1% and 10.6%, respectively, after only 2 weeks of HIIT, compared to a non-training control group. However, they found no significant change in rate to fatigue. Another study that replicated the training protocol of Astorino et al. (2012) found significant changes in MPO (+3.6%), but no significant changes were found for PPO (Whyte, Gill, and Cathcart, 2010). Ziemann et al. (2011) compared a HIIT protocol with a work-to-rest ratio of 1:2 to a non-training group and found a significant increase in MPO (+3.4%) in the HIIT group. They also found a similar increase in PPO (+3.5%) in the HIIT group, but it was not significant when compared to the control group.

Burgomaster et al. (2008) conducted a 6-week study comparing multiple bouts of Wingate HIIT and 40-60 minutes of continuous cycling at 65% of  $VO_{2max}$ . They found that PPO increased by 17% for HIIT versus 7% for continuous cycling, but there was no significant difference found between groups. However, MPO improved significantly only in the HIIT group (+7%). Bayati, Farzard, Gharakhanlou, and Agha-Alinejad (2011) conducted an 8-week study that compared two different HIIT protocols. Both protocols used 30-second work bouts, but utilized different rest intervals. Group 1 completed 30-second all-out efforts interspersed with 4 minutes of recovery, while group 2 alternated 30-second bouts at 125% of peak power with 2 minutes of recovery. The control group did not complete any training. Peak power output increased 10.3% and 7.3% for groups 1 and 2, respectively, which was significant when compared to the control group. Only group 1 increased their MPO significantly when compared to the control group (+17%). However, group 2 had a non-significant increase in MPO of 11%.

Exploring the anaerobic benefits of HIIT is important because only a handful of studies have focused on the anaerobic benefits of HIIT versus steady-state training. Additionally, very few of those studies compared multiple HIIT protocols versus a steady-state control group, and those that have evaluated the anaerobic benefits of HIIT using the WAnT have shown variable results. Also, with the rising popularity of the Tabata et al. (1996) 20s:10s protocol in many fitness settings, it is important to explore the possible benefits this protocol can induce, especially in relation to anaerobic power. Another popular HIIT protocol is Meyer et al. (1996) 30s:60s intervals. These intervals have been used effectively with a wide variety of cardiac rehabilitation patients, resulting in significant increases in  $VO_{2max}$  (Freyssin et al., 2012; Meyer et al., 1996).

The purpose of this study was to compare the effects of two HIIT protocols (Tabata and Meyer) and a steady-state protocol on anaerobic capacity. The outcomes that were assessed were PPO, MPO, and rate to fatigue consequent to the 8-week training program.

## **METHODS**

### **Subjects**

Potential subjects were recruited from the University of Wisconsin-La Crosse community by speaking in classes, handing out fliers, and through word of mouth. Potential subjects were screened using the Physical Activity Readiness Questionnaire (PAR-Q) to rule out any subjects that might have cardiovascular or orthopedic contraindications to exercise (Appendix A). Potential subjects also completed an exercise questionnaire (Appendix B). In order to qualify for the study, potential subjects had to be apparently healthy and untrained. Potential subjects were deemed untrained if they worked out 2 or fewer times per week at a low to moderate level. After screening, 65 subjects (23 male, 42 female), between the ages of 18-28 years qualified to be in the study. These subjects were randomized into three groups with 20 subjects being placed in the steady-state group, 24 in the Tabata interval group, and 21 in the Meyer interval group. After having the study testing and training protocols explained, along with the risks and benefits of participating in the study, subjects provided written informed consent (Appendix C). The study was approved by the University of Wisconsin-La Crosse Institutional Review Board for the Protection of Human Subjects.

### **Testing**

This study was a part of a larger study that assessed the potential benefits of HIIT versus steady-state on post-exercise hypotension, exercise enjoyment, and aerobic capacity. For this aspect of the study we used the WAnT to determine the effects of an 8-

week training protocol on anaerobic power. This test was performed on a Lode Excalibur sport cycle ergometer (Groningen, Netherlands). The subject spent 5 minutes warming up on a Monark cycle ergometer (Vansbro, Sweden). They warmed up for 2 minutes at 25 watts, and then warmed up for 1-minute at each successive workload of 50, 75 and 25 watts. The subject was then transferred from the Monark cycle ergometer and to the Lode cycle ergometer for the actual test.

The WAnT test began with a 1-minute countdown in which the subject would pedal at 90-100 rotations per minute against no resistance. When the countdown reached five, we encouraged the subject to pedal as rapidly as possible, because when the countdown hit zero, resistance equal to .075 kpm/kg of bodyweight was added. The subjects were then encouraged to pedal as hard and fast as they could against that resistance for the next 30 seconds. Peak power output (PPO), mean power output (MPO), and rate to fatigue were measured during the test. Peak power output was the highest absolute power output detected during the test. Mean power output was the average power the subject was able to maintain during the entire 30-second test. Rate to fatigue was the average amount of power lost each second. Relative PPO and MPO measurements were also derived by dividing these measurements by bodyweight (kg).

### **Training**

The subjects had at least 48 hours of rest after testing and before the start of their training program. Each subject trained three times a week for 8 weeks, with each training program done on a Monark cycle ergometer. The steady-state group completed 20 continuous minutes of exercise at 90% of ventilatory threshold (VT). The Tabata interval group completed 20 seconds at 170% of  $VO_2$ max, followed by 10 seconds rest. This was repeated for a total of eight times. The Meyer interval group completed 30 seconds at

100% of the PPO at  $\text{VO}_2\text{max}$ , with 60 seconds of active rest at an output that made the average of the intervals equal to 90% of ventilatory threshold. This was repeated 13 times for a total of 20 minutes of exercise. Each group performed the same 5-minute warm-up and cool-down, which were both identical to the warm-up utilized for the WAnT. At the end of each week, ratings of perceived exertions (RPE) were assessed. When RPE dropped by 2 units or greater on the 1-10 RPE scale, the workload was increased by 10% for that subject.

### **Statistical Analysis**

Standard descriptive statistics were used to characterize the subject population. A one-way analysis of variance (ANOVA) was performed across pre-training scores to determine if the groups were equal at the start of the study. A three-way ANOVA with repeated measures was then performed (pre/post x group x gender) to determine if there were any between group changes as a result of training. When there was a significant F-ratio, Tukey's post-hocs test were used to determine pairwise differences. Alpha was set at .05 to achieve statistical significance.

## RESULTS

Fifty-five of the original 65 subjects completed the study (17 male, 38 female). The steady-state group lost one male due to loss of interest. The Tabata group lost two females due to loss of interest and one female due to an unrelated injury. The Meyer group lost one female due to loss of interest, four males due to unrelated injury/illness, and one female due to unrelated injury. Descriptive statistics of the subjects who completed the study are presented in Table 1. The results of the training are presented in Table 2 and Figures 1 and 2, respectively. There were no significant differences between groups for any variable pre-training. Because the analysis found no gender effect, only group data collapsed across gender is presented. Peak power output, MPO, PPO/kg, MPO/kg, and rate to fatigue increased significantly for all three groups from pre to post-training. However, there were no significant differences found in the magnitude of the improvement between the three groups. The Tabata group showed the largest percentage increase in PPO (+9.1%), PPO/kg (+8.5%), and MPO/kg (+6.8%), whereas the Meyer group had the largest percentage increase in MPO (+9.8%), and the smallest decrease in rate to fatigue (+3%).

Table 1. Descriptive characteristics of the subjects.

|                    | <b>Steady-State (19)</b> | <b>Tabata (21)</b> | <b>Meyer (15)</b> |
|--------------------|--------------------------|--------------------|-------------------|
| <b>Age (yrs)</b>   |                          |                    |                   |
| Males              | 19.5 ± 1.38              | 20.3 ± 2.14        | 19.3 ± 1.26       |
| Females            | 19.6 ± 2.94              | 19.5 ± 1.16        | 19.9 ± 2.77       |
| <b>Height (cm)</b> |                          |                    |                   |
| Males              | 181.5 ± 8.94             | 174.6 ± 6.08       | 179.3 ± 10.69     |
| Females            | 164.8 ± 4.87             | 168.6 ± 3.93       | 164.9 ± 4.85      |
| <b>Weight (kg)</b> |                          |                    |                   |
| Males              | 94.3 ± 7.22              | 81.0 ± 13.85       | 76.4 ± 12.47      |
| Females            | 68.6 ± 15.12             | 68.2 ± 14.04       | 71.9 ± 18.55      |

Table 2. Responses of the three training groups from pre to post-training.

|                                    | <b>Pre</b>   | <b>Post</b>  | <b>Change (%)</b> |
|------------------------------------|--------------|--------------|-------------------|
| <b>Peak (Watts)</b>                |              |              |                   |
| Steady-State                       | 894 ± 293.2  | 954 ± 270.0  | 60 (6.7%)*        |
| Tabata                             | 861 ± 238.8  | 939 ± 258.6  | 78 (9.1%)*        |
| Meyer                              | 867 ± 235.6  | 905 ± 242.3  | 38 (4.4%)*        |
| <b>Peak (Watts/kg)</b>             |              |              |                   |
| Steady-State                       | 11.5 ± 1.62  | 12.4 ± 1.36  | 0.9 (7.8%)*       |
| Tabata                             | 11.7 ± 1.49  | 12.7 ± 1.48  | 1.0 (8.5%)*       |
| Meyer                              | 11.8 ± 1.52  | 12.4 ± 1.72  | 0.6 (5.1%)*       |
| <b>Mean (Watts)</b>                |              |              |                   |
| Steady-State                       | 470 ± 154.7  | 486 ± 148.4  | 16 (3.4%)*        |
| Tabata                             | 467 ± 126.5  | 505 ± 139.0  | 38 (8.1%)*        |
| Meyer                              | 430 ± 89.8   | 472 ± 101.1  | 42 (9.8%)*        |
| <b>Mean (Watts/kg)</b>             |              |              |                   |
| Steady-State                       | 6.08 ± 1.001 | 6.34 ± 0.962 | 0.26 (4.3%)*      |
| Tabata                             | 6.44 ± 1.008 | 6.88 ± 1.076 | 0.44 (6.8%)*      |
| Meyer                              | 6.23 ± 1.261 | 6.61 ± 1.044 | 0.38 (6.1%)*      |
| <b>Rate to Fatigue (Watts/sec)</b> |              |              |                   |
| Steady-State                       | 21.6 ± 8.54  | 22.4 ± 7.72  | 0.8 (3.7%)*       |
| Tabata                             | 19.6 ± 6.42  | 21.4 ± 7.60  | 1.8 (9.2%)*       |
| Meyer                              | 20.0 ± 7.61  | 20.6 ± 7.50  | 0.6 (3.0%)*       |

\*Significant change from pre-testing (p<.05).

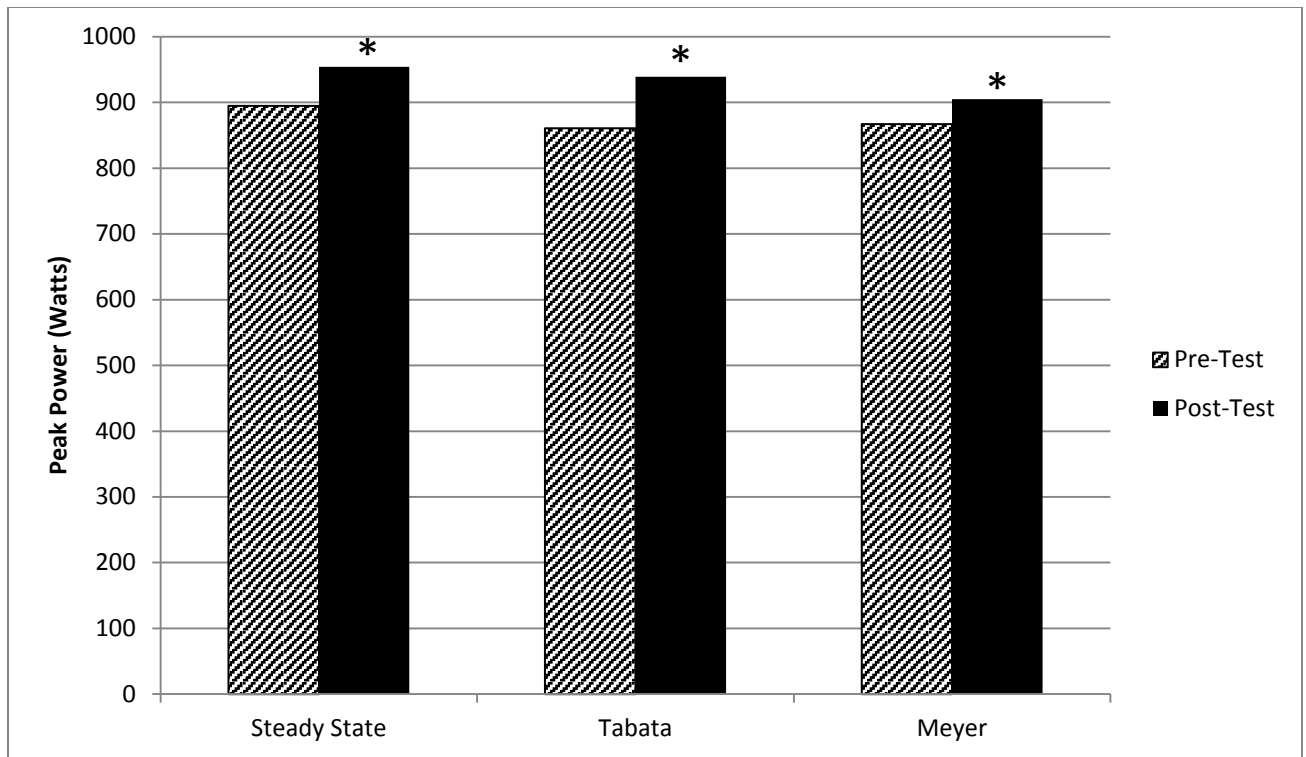


Figure 1. Change in peak power (watts) for the three training groups from pre-testing to post-testing.

\*Significant change from pre-testing ( $p < .05$ ).

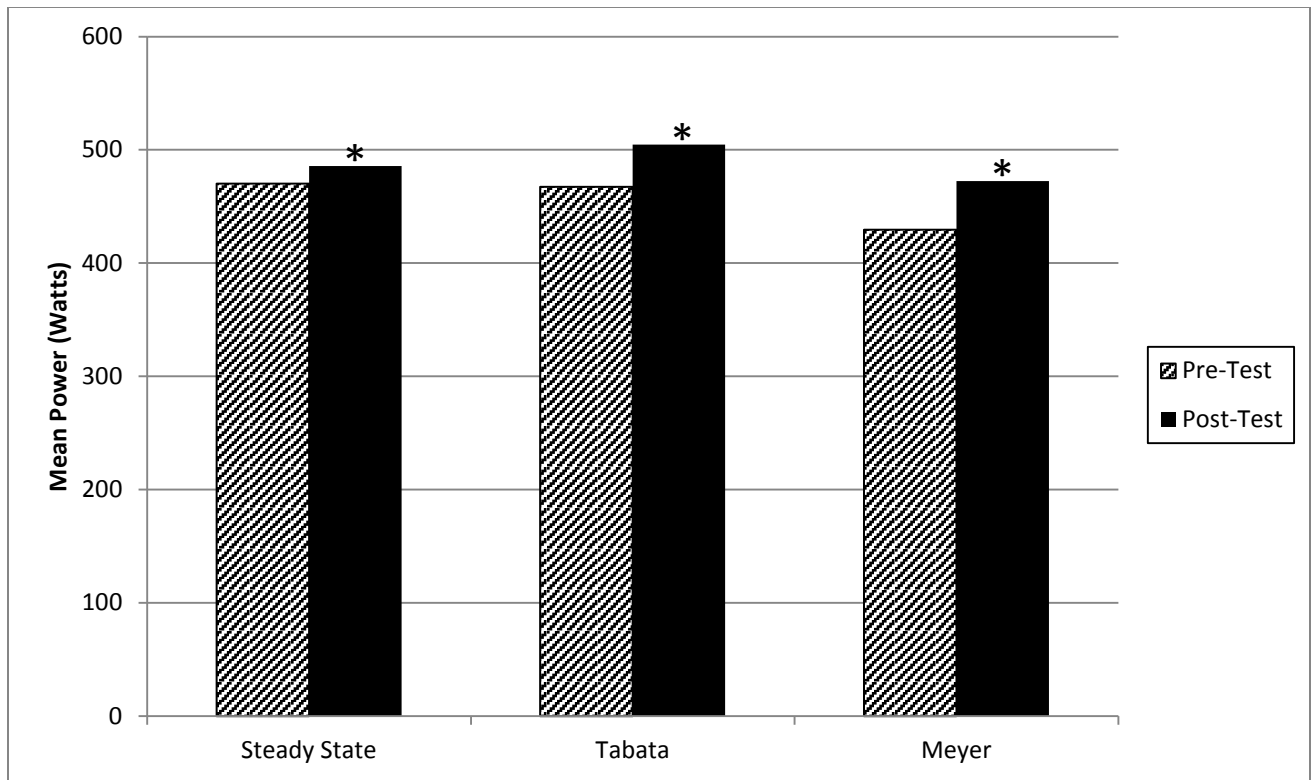


Figure 2. Change in mean power (watts) for the three training groups from pre-testing to post-testing.

\*Significant change from pre-testing ( $p < .05$ ).

## **DISCUSSION**

The purpose of this study was to evaluate changes in anaerobic capacity after 8 weeks of HIIT compared to steady-state training. This study found no significant difference in the amount of change between the three training groups. All three groups had significant increases in PPO, PPO/kg, MPO, MPO/kg, and rate to fatigue. An improvement in PPO, MPO, PPO/kg, and MPO/kg indicates a positive adaptation to training. The improvements in both PPO and MPO can be attributed to improvements in the ATP/PC and glycolytic systems considering those two systems are used for 81.3% of the WAnT (Beneke et al., 2002; Maud et al., 1995). However, all three groups also had an increase in rate to fatigue, meaning that the subjects lost power more quickly during the post-test WAnT. It is difficult to explain this result, since the subjects should have had better endurance. It is possible that because subjects had significantly higher PPO's during post-testing, this contributed to the greater drop off in power over the course of the WAnT.

The steady-state and Meyer groups spent 90 minutes per week on the bike for 8 weeks, while the Tabata group spent less than half of that, accumulating only 42 minutes of exercise per week. That means that the Tabata group spent 53% less time on the bike and still had similar improvements as the other two groups. This bodes well for HIIT, because it helps reiterate the fact that HIIT is a time efficient strategy to improve fitness levels, especially for Tabata intervals which involves only 4 minutes of hard work per session. However, it should be noted that immediate post-exercise recovery seemed to be

slower in the Tabata group, due to the level of intensity.

Past research on HIIT and anaerobic capacity, specifically with the WAnT, has found a wide variety of results. The majority of the studies have found that HIIT increases anaerobic capacity, however, most of these studies compared a HIIT group to a non-training control group. If the present study had compared any of the three groups to a non-training control group, it is easily assumed that the improvement between the three groups would be significantly different than the non-training group. For instance Ziemann et al. (2011) found that PPO improved significantly in two HIIT groups and that MPO improved significantly in one group when compared to a non-training group. It is likely that this study would have come to similar conclusions if a non-training group was utilized.

A problem with the previous studies using the WAnT is that they did not compare multiple HIIT protocols with a steady-state group, making it difficult to compare past research with the results of this study. Laursen, Shing, Peake, Coombes, and Jenkins (2005) compared three HIIT protocols with a low-intensity group and found that anaerobic capacity improved significantly in the HIIT groups versus the low-intensity group. However, they used accumulated oxygen deficit instead of the WAnT to determine anaerobic capacity, and it remains unclear how well these two anaerobic measurements compare.

Burgomaster et al. (2008) compared an endurance training protocol (1 hr at 65% of  $VO_{2peak}$ ) with a HIIT protocol (4-6 WAnT's with 4.5 minute recovery). Their results were comparable to the present study in the fact that PPO improved significantly, but there were no differences between the groups. However, they did find that MPO only

significantly improved in the HIIT protocol. The current study found no differences in MPO between HIIT and steady-state training.

Astorino et al. (2012) and Whyte et al. (2010) both utilized the same 2-week training protocol, which involved multiple bouts of the WAnT. Astorino et al. (2012) found significant increases in PPO (+10.1%) and MPO (+10.6%) with HIIT compared to a non-training group. Whyte et al. (2010) found no significant changes in PPO and a significant increase in MPO (+3.6%). The disparity between these two studies can most likely be attributed to the subjects used in each study. The study by Astorino et al. (2012) involved recreationally active individuals ( $\text{VO}_2\text{max}=43.6 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$ ), while Whyte used overweight/obese men ( $\text{VO}_2\text{max}=32.8 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$ ). Differing motivation levels between recreationally fit individuals versus untrained, overweight/obese individuals could have impacted how hard subjects pushed themselves during training. In this current study it was found that motivating untrained subjects to go as hard as possible for 24 sessions of Tabata intervals was not easy, due to the high level of intensity and fatigue.

There were a few limitations that could have affected the present study. During pre-testing, a practice WAnT wasn't performed. Completing a practice WAnT before the actual test would have helped minimize the learning affect, since none of the subjects had ever performed a WAnT. However, with 65 WAnT subjects to pre-test, it was not feasible for the present study. An alternative may have been to alter the warm-up. A warm-up that included several 3-5 second sprints against low resistance would have helped prepare the subjects for the acceleration phase of the WAnT.

Another limitation of the study involved the Monark cycle ergometer used during the Tabata training sessions. The cycle ergometer did not monitor rotations per minute

(RPM), therefore it was impossible to make sure if our subjects were performing the target workload, which was based upon maintaining a specific RPM.

The use of well-trained subjects instead of untrained subjects may have also altered the results. The original study by Tabata et al. (1996) involved moderately trained individuals ( $\text{VO}_2\text{max}=48.2 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$ ), whereas the present study used untrained individuals ( $\text{VO}_2\text{max}=33.9 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$ ). Untrained individuals may be more likely to improve regardless of the stimulus or protocol, while trained individuals may require specialization like HIIT.

Residual fatigue may also have played a role in the results of the present study. Minett and Duffield (2014) state that intermittent-sprint exercises create disturbances in both peripheral and central systems, reducing performance. These disturbances are increased when successive bouts of sprint exercises are performed (i.e., Tabata and Meyer intervals), due to a lack of recovery time. These disturbances have been shown to last for up to 96 hours, which is around the time frame in which post-testing was performed after completion of training in the present study. Results may have been different if more rest was allowed between the completion of training and post-testing, so that residual fatigue would not be a factor.

The present study found that regardless of training protocol, untrained subjects can show significant improvement in anaerobic capacity after an 8-week training program. Tabata et al. (1996) intervals were found to be the most time efficient, but require a lot of motivation to do them day in and day out. While steady-state and Meyer et al. (1996) intervals were found to be more tolerable, they also were more time consuming. For untrained individuals the best training protocol is one that they can stay

dedicated to, since the present study found improvements in anaerobic capacity regardless of the training protocol.

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APPENDIX A  
PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

Physical Activity Readiness Questionnaire (PAR-Q)

|           |  |
|-----------|--|
| Yes or No | Has a doctor ever said that you have a heart condition and recommended only medically supervised activity?<br>If yes, explain:   |
| Yes or No | Do you have chest pain brought on by physical activity?<br>If yes, explain:  |
| Yes or No | Have you developed chest pain in the past month?<br>If yes, explain:   |
| Yes or No | Have you on one or more occasions lost consciousness or fallen over as a result of dizziness?<br>If yes, explain:  |
| Yes or No | Do you have a bone or joint problem that could be or has been aggravated by exercise?<br>If yes, explain:  |
| Yes or No | Has a doctor ever recommended medication for your blood pressure or a heart condition?<br>If yes, explain:   |
| Yes or No | Are you aware, through your own experience or a doctor's advice, of any other physical reason that would prohibit you from exercising without medical supervision?<br>If yes, explain: |

APPENDIX B  
EXERCISE QUESTIONNAIRE

# Comparative Effectiveness of Interval and Continuous Exercise Training

Name:

Age:

Gender:

Birth Date:

Email:

Phone Number:

## Exercise History Questionnaire

1. What type of exercise routine have you participated in over this past summer?
2. How often do you exercise routinely? (min/days/week)
3. On a scale of 1 to 10, rate the intensity of your workout with 10 being maximal effort.
4. Please list any medications (over the counter or prescribed) that you are currently taking.

APPENDIX C  
INFORMED CONSENT

## Informed Consent

### Purpose and Procedure

This study is designed to compare improvements in both aerobic and anaerobic exercise capacity resulting from exercise training using either steady state exercise or one of two types of widely used interval training methods.

My participation will involve 2 pre-tests (aerobic and anaerobic), 2 post-tests (same protocol, each requiring <60 min) and 3 exercise training sessions requiring ~30 min each week for 8 weeks. The testing and training may be very fatiguing.

Testing and training will take place in the Human Performance Laboratory, Mitchell Hall 225.

During the tests I will wear a snorkel-like device to analyze my breathing and a heart monitor, strapped around my chest, to monitor my heart rate. I may also have small blood samples taken from my finger tip. During training, I will also wear the heart rate monitor and have blood samples taken from my finger tip.

During both the tests and some training sessions, I will have to complete some questionnaires about how I feel about the training program and how I am feeling that day.

### Potential Risks

The exercise tests, particularly the anaerobic tests are very fatiguing, and I will become very out of breath and my legs will be very tired. This may also occur if I am assigned to one of the interval training groups.

Individuals trained in CPR, Advanced Cardiac Life Support, and first aid will be in the laboratory, and the test will be terminated if complications occur.

The risk of serious or life-threatening complications, for healthy individuals, like myself, is near zero.

### Rights and Confidentiality

My participation is voluntary. I can withdraw or refuse to answer any questions without any consequences at any time.

I can withdraw from the study at any time, for any reason, without penalty.

The results of this study may be published in the scientific literature or presented at professional meetings using group data only.

All information will be kept confidential through the use of number codes. My data will not be linked with personally identifiable information.

#### Possible Benefits

The primary benefit of this study is to the exercise community, and to the ability of exercise professionals to better serve their clients. Individually I should experience a 10-25% increase in my exercise capacity, which is generally associated with being healthier. By participating in a research project, I may find that my academic experience at UWL is richer.

Questions regarding study procedures may be directed to Professor Foster (608 785 8687 or cfoster@uwlax.edu), the principal investigator, or Chris Dodge, laboratory manager of the Human Performance Laboratory (608 785 8681 or cdodge@uwlax.edu). Questions regarding the protection of human subjects may be addressed to the UW-La Crosse Institutional Review Board for the Protection of Human Subjects, (608 785 8124 or irb@uwlax.edu).

Participant \_\_\_\_\_ Date \_\_\_\_\_

Researcher \_\_\_\_\_ Date \_\_\_\_\_

APPENDIX D  
REVIEW OF LITERATURE

## **REVIEW OF LITERATURE**

The purpose of this paper is to review the literature relative to the benefits of high intensity interval training (HIIT) versus steady-state training. I am specifically interested in the anaerobic benefits from HIIT, assessed using the Anaerobic Wingate Test (WAnT).

### **High Intensity Interval Training**

High intensity interval training (HIIT) has increased in popularity over the past couple of decades as one of the favorite ways to get in shape and lose weight in a quick and effective manner. The number of individuals HIIT can benefit is endless; it can benefit cardiac patients, sedentary, obese, athletes, and the elderly. Interval training is defined as performing intermittent bouts of work interspersed with bouts of rest. Interval training is also commonly referred to as repetition training or intermittent training (Daniels and Scardina, 1984). Some coaches believe there are differences between these types of training, but for the sake of simplicity all intermittent training presented in this review will be referred to as interval training.

Interval training is constantly researched because there are so many variables that can be manipulated. Buchneit and Laursen (2013) believe there are at least nine variables that can be changed to manipulate HIIT. They are (1) work interval intensity, (2) work duration, (3) rest period intensity, (4) rest period duration, (5) type of exercise, (6) number of repetitions, (7) number of sets, (8) between sets duration, and (9) between sets intensity. With so many variables that can be changed, it is clear why there is so

much debate between coaches, athletes, researchers, and writers about what is the most effective protocol to be used in different situations.

Research on HIIT took off in the 1960's with the work of Astrand, Astrand, Christiansen, and Hedman (1960). They used 1:1 work to rest ratios and found that using short work periods against large resistance was effective, while only putting a sub-maximal load on circulatory and respiratory systems. Lactic acid was 1/6th the level in the 30s:30s compared to the 3m:3m training bouts. Another study found that subjects running continuously at 20 km/hr could only sustain that speed for an average of 3.5 minutes and cover only 1.15 km. However, when running at 20 km/hr with intermittent rest periods, the subjects could cover an average of 5.83 km (Christensen, Hedman, and Saltin, 1960).

Smodlaka (1963) found that another benefit of HIIT was the fact that short bouts of intense exercise with intermittent rest periods was a great way to keep the heart rate (HR) from reaching a critical pulse rate of 160 beats per minute (BPM). He found that long bouts of intense continuous exercise for 5 minutes with 2.5 minutes of rest, would raise HRs close to 160 BPM, while shorter work periods of 30 seconds with 45 seconds of rest would help keep the HR around 100 BPM. The extra rest allows for recuperation of the heart, which is why HIIT can be effective.

High intensity interval training has been shown to be an effective tool for a variety of diverse populations. A study on cardiac patients found that a 4-four week interval

training program resulted in a 20% greater increase in aerobic capacity compared to a steady-state program (Meyer and Foster 2004). Meyer et al. (1996) conducted a study on cardiac patients and compared 3 weeks of HIIT to an activity restricted control group. The HIIT group trained for 15 minutes a day, 5 days a week using 30s:60s of work to rest (Meyer Intervals). They found significant improvements in work rate, oxygen uptake, ventilation, HR, lactate, and leg fatigue in the HIIT group. The improvements they found in oxygen uptake in just 3 weeks of this HIIT protocol were similar to improvements seen in 8 to 24 week studies using conventional moderate intensity steady-state training.

Most modern research has utilized the protocol of hard intervals followed by rest or light intervals. However, recent research performed by Gunnarsson and Bangsbo (2012) used a different protocol entirely. They used 10-20-30 intervals, which included three intervals of low, moderate, and high running speeds. Moderately trained subjects would run 30 seconds at <30%, 20 seconds at <60%, and 10 seconds at >90% of maximal aerobic speed. Maximal aerobic speed was found by performing an incremental treadmill test to exhaustion and training intensities were adhered to through the use of GPS data. These intervals were performed for 5 minutes, with a 2-minute rest, and then repeated 2-3 more times for 5 minutes each. They found that with a 54% reduction in training volume the experimental group improved their 1500 meter and 5-k times by 21s and 48s respectively, while the control group did not change. The 10-20-30 group also saw a 4% increase in  $VO_2max$ . This study indicates that there is still a lot of research still to be done on HIIT, but that a variety of protocols can induce positive changes.

HIIT is so often researched because of the benefits that it can provide for a variety of populations. HIIT has proven effective for cardiac patients (Meyer et al. 1996; Meyer

and Foster 2004), cyclists (Seiler, Joranson, Olesen, and Hetlelid, 2013), sedentary adults (Nybo et al., 2010), obese children (De Araujo et al., 2012), college-aged students (Tabata et al., 1996), female soccer players (Rowan, Kueffner, and Stavrianeas, 2012), and males (Helgerud et al., 2007).

### **HIIT and Anaerobic Capacity**

Tabata et al. (1996) conducted a study using HIIT with a 20s:10s work to rest ratio at 170%  $\text{VO}_2\text{max}$ . Subjects completed eight total reps, 4 times a week and a fifth day of 20s:10s\*4 reps plus 30 minutes of steady state at 70% of  $\text{VO}_2\text{max}$ . They found that this protocol increased  $\text{VO}_2\text{max}$  significantly, and the increases were actually greater in the HIIT group ( $+7 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) compared to the group that completed 60 minutes of steady-state exercise five times a week ( $+5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ). However, one interesting thing of note is that anaerobic capacity increased by 28% using the 20s:10s protocol, while steady-state training showed no significant increases in anaerobic capacity. This is a huge benefit of HIIT, since it can induce the same benefits in aerobic capacity as steady-state training and can also induce positive anaerobic changes that steady-state training cannot.

Tabata et al. (1997) conducted a study comparing two HIIT protocols: 20s:10s work to rest ratio for 6-7 bouts at 170% of  $\text{VO}_2\text{max}$  and 4-5 30-second bouts at 200% of  $\text{VO}_2\text{max}$  with 2-minutes rest between bouts. They found that during the 20s:10s protocol, accumulated oxygen deficit equaled the individual's maximal anaerobic capacity ( $69 \pm 8 \text{ ml}\cdot\text{kg}^{-1}$ ), while during the 30-second protocol accumulated oxygen deficit was significantly less than maximal anaerobic capacity ( $46 \pm 12 \text{ ml}\cdot\text{kg}^{-1}$ ). This led them to

believe that the 20s:10s protocol would be more effective at increasing anaerobic capacity because of the maximal stress put on the anaerobic systems.

Patton and Hopkins (2005) studied well-trained cyclists and divided them into a control group and an explosive jumping plus HIIT group. The control group continued with their normal training, while the experimental group completed 20 explosive step-ups with each leg, followed by a 2-minute rest, and then 5x30 second maximal efforts on a cycle ergometer with a 30 second between each bout, This was followed by 2-minutes of rest, and then repeated two more times. They found that the experimental group increased 1-km mean power (+8.7%), 4-km mean power (+8.4%), and peak power (+6.7%), while the control group saw no significant changes.

Ziemann et al. (2011) compared a HIIT group (six 90s:180s) bouts versus a non-training control group. They did an analysis of the energy systems and found that the creatine phosphate system did not improve, but the nonphospagenic systems (glycolytic and/or oxidative) improved significantly. This indicates that this HIIT protocol is more effective at targeting nonphospagenic systems.

Laursen, Shing, Peake, Coombes, and Jenkins (2005) conducted a study using accumulated oxygen deficit to measure the increases in anaerobic capacity following three different HIIT protocols and a low-intensity control group. The three protocols they used were (1) 8 intervals at 60% of time to exhaustion, with a 1:2 recovery rate, (2) same as (1), except recovery time was based upon (HR return to 65% of HRmax), and (3) completed 12, 30-second bouts at 175% PPO, with 4.5 minutes of recovery. Each group trained twice a week for 4-weeks. They found that anaerobic capacity increased significantly for the three HIIT training groups. Group 1 improved accumulated oxygen

deficit by 104%, group 2 improved by 54%, group 3 improved by 75%, and the control only improved by 9%. However, the researchers noted that the certain maximal exercise test they utilized may have skewed the results, by showing too much improvement in the 4 groups.

### **Wingate Test**

The WAnT is a popular test that is used to measure anaerobic power; specifically it measures peak power output (PPO), mean power output (MPO), and fatigue index.

The WAnT is a maximal effort anaerobic test performed on a cycle ergometer. A subject warms up, and then is instructed to pedal as fast as possible against no resistance. A load is applied (.075 kp/kg), and the subject is told to pedal as hard and fast as they can for 30 seconds. The results of the WAnT show good insight into the capacity of the two anaerobic systems, because PPO is associated with the adenosine triphosphate/creatine phosphate system (ATP/PC), while MPO is associated with the glycolytic system (Maud et al., 1995).

Beneke, Pollmann, Bleif, Leithauser and Hutler (2002) conducted a study to determine the contributions of each energy system during the WAnT. They were able to calculate aerobic energy by measuring the  $VO_2$  above resting values during the WAnT. They were able to estimate the ATP/PC contribution by using the fast component (high  $O_2$  consumption) of the post-WAnT  $VO_2$  and the metabolic equivalent of  $O_2$ . The energy from the lactic acid system was estimated by net lactate accumulation, body mass, and a  $O_2$  lactate equivalent. They found that the aerobic system contributed 18.6%, glycolytic system 50.3%, and ATP/PC 31.1% of total energy expenditure.

Another study using an upper body WAnT also studied the contributions of the three energy systems. Using the same methods as Beneke et al. (2002), they found that the upper body WAnT was 11.4% aerobic, 60.3% glycolytic, and 28.3% ATP/PC. The slight differences in percentages can be attributed to the fact that the upper body has more type II fibers, and is less aerobic in nature (Lovell et al., 2012). Another study analyzing the energy systems used during the WAnT found that the aerobic system contributes 16% of ATP regeneration during the test, but that number increases to 35% during the last 5 seconds due to the fact that the ATP/PC and glycolytic peak in the first 5 and 15 seconds, respectively. However, they believe that the WAnT is too short of a test to fully exhaust a person's glycolytic anaerobic capacity and that it will most likely be underestimated (Smith and Hill 1991).

#### **Use of the WAnT to Evaluate HIIT**

Astorino, Allen, Roberson, and Jurancich (2012) used 4-6 bouts of the WAnT over a 2-week period as their HIIT and compared PPO, MPO, and fatigue index to a non-training control group. They found significant increases in PPO (+10.1%) and MPO (+10.6%) in the experimental group versus the control group, but they found no changes in fatigue index. Whyte, Gill and Cathcart (2010) did a study similar to that of Astorino et al. (2012) using the same 2-week training protocol, however they used sedentary obese men as subjects. They found no significant changes in PPO, but they did find a significant improvement in MPO (+3.6%). Another study using multiple bouts of WAnT HIIT compared to 40-60 minutes of continuous cycling at 65% of  $VO_2$ max found that after 6 weeks that PPO increased by 17% for HIIT versus 7% for continuous cycling, but

there was no significant difference found between groups. However, MPO was only improved in the HIIT group (+7%) (Burgomaster et al., 2008).

A study done by Inoue, Sa Filho, Mello, and Santos (2012) found there was no relationship between high power outputs on the WAnT and mountain bike cross-country performance. However, they did find that there was a strong relationship between performance during five WAnTs with 30 seconds between bouts and mountain bike cross-country performance. They were able to conclude that since blood lactate levels were so high after testing ( $16.0 \pm 2.3 \text{ mmol} \cdot \text{L}^{-1}$ ), that the anaerobic systems were heavily involved.

Delahunt, Callan, Donohoe, Melican and Holden (2013) conducted a training study using a unique type of interval training called the Yo-Yo intermittent recovery test. The Yo-Yo intermittent recovery test consisted of 40 meter shuttle runs (20 meter track down and back), with increasing speed of completion, that was controlled by auditory beeps played on a CD player. There was 10 seconds of rest between each bout, and when the subject could not complete the run before the beep sounded the test was over. The subjects completed this test two times a week, while a control group continued their normal physical activity. They found that PPO and MPO increased significantly for the Yo-Yo group, with 18% and 10% increases respectively.

Ziemann et al. (2011) compared HIIT to a non-training group and found a significant increase in MPO (+3.4%) in the HIIT group. They also found a similar increase in PPO (+3.5%) in the HIIT group, but it was not significant when compared to the control group. Bayati, Farzard, Gharakhanlou, and Agha-Alinejad (2011) conducted a study that compared two different HIIT protocols. Both protocols used 30-second work

bouts, but utilized different rest interval intensities. Group 1 completed 30-second all-out efforts with 4 minutes of recovery, while group 2 completed 30 second bouts with 125% of peak power with 2 minutes of recovery. The control group did not participate in training. The subjects trained 3 times a week for 4 weeks. Group 1 performed 3 intervals during weeks 1 and 2, 5 intervals in week 3, and 4 intervals in week 4. Group 2 performed 6 intervals during weeks 1 and 2, 10 intervals in week 3, and 8 intervals in week 4. Peak power output increased 10.3% and 7.3% for groups 1 and 2, respectively, with no significant differences between groups. Only group 1 increased their MPO significantly when compared to the control (17%). However, group 2 had an 11% increase, which is still good improvement

### **Conclusion**

There is great interest in the benefits of HIIT for athletes and a wide variety of patient populations. However, there is still much research that needs to be done, since there are so many different variables involved. Additionally, because of the different populations that may benefit from HIIT, different protocols may need to be tailored to specific needs. During this study we hope to determine the anaerobic benefits of two different models of HIIT training compared to steady-state training.

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