UNIVERSITY OF WISCONSIN-LA CROSSE

Graduate Studies

THE EFFECTS OF HIGH INTENSITY INTERVAL TRAINING VERSUS STEADY STATE TRAINING ON AEROBIC CAPACITY

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

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EFFECTS OF HIGH INTENSITY INTERVAL TRAINING VERSUS STEADY-STATE TRAINING ON AEROBIC CAPACITY

By Courtney Farland

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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ABSTRACT

Farland, C.V. The effects of high intensity interval training versus steady state training on aerobic capacity. MS in Clinical Exercise Physiology, May 2014, 38pp. (J. Porcari)

Introduction: High intensity interval training (HIIT) has become an increasingly popular exercise phenomenon due to its cardiovascular effect and short duration. The purpose of this study was to compare the effects of two HIIT protocols and a steady-state protocol on aerobic capacity following an 8-week training period. Methods: Fifty-five untrained college-aged subjects (17 male, 38 female) were randomly assigned to one of the three training groups (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% VO_2max, with 10 seconds rest in between each bout. The Meyer group (n=15) completed 13 sets of 30 seconds at 100% of the PPO at VO_2max, with 60 seconds of active rest, yielding an output average of 90% of ventilatory threshold. Each subject completed 24 training sessions. Results: Significant increases in VO_2max and Peak Power Output for each training group, with no significant differences between groups. There were no significant changes in maximal HR for any training group over the course of the study. The results of this study suggest that steady-state, Tabata, and Meyer protocols elicit similar increases in aerobic capacity.

ACKNOWLEDGEMENTS

So many individuals contributed to the creation of this thesis. I would like to extend sincere gratitude towards John Porcari and Carl Foster for teaching me the amazing nature of science. I will use the skills acquired from these two incredibly respectable men on a daily basis. Thank you for your time, patience, and encouragement. Also, thank you to Scott Doberstein for his role within the thesis committee.

Chris Dodge deserves acknowledgement for answering countless questions over the duration of the three-month study. His expertise and patience are greatly appreciated. Thank you to the subjects who dedicated their fall semester to our study. I cannot thank these individuals enough for putting in the hours in order to make this experiment a reality. Thank you to my family, friends, and stellar classmates for helping me through the long days in the fall, and for always providing support and laughter.

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INTRODUCTION

The American College of Sports Medicine (ACSM) recommends that individuals accumulate at least 30 minutes of moderate-intensity exercise, 5 or more days per week, in order to attain health benefits and a reduced risk of chronic disease (ACSM's Guidelines for Exercise Testing and Prescription, 2014). More recently, ACSM adjusted its guidelines to include high intensity exercise, claiming similar benefits to those who perform at least 20 minutes of high-intensity exercise, 3 or more days per week. Such changes are applicable to the population, as lack of time has been shown to be the most common barrier to physical activity (Whyte, Gill, and Cathcart, 2010). As research within this area of study expands, evidence suggests that higher-intensity exercise, particularly exercise in which intervals are used, may offer greater aerobic benefits compared to conventional moderate-intensity exercise programs.

High intensity interval training (HIIT) historically has been used to train athletes (Guiraud et al., 2012). Due to its cardiovascular effect, recent studies suggest HIIT may also be suited for those with significant exercise intolerance, including clinical populations (Meyer and Foster, 2004) and relatively-sedentary individuals (Whyte, 2010).

Although there is no universal definition, HIIT generally refers to periods of brief intermittent exercise, usually performed with an "all out" effort or at an intensity near VO_{2peak}, alternated with an active recovery session (Gibala and McGee, 2008). The total length of HIIT sessions can last from 4-40 minutes (Buchheit and Laursen, 2013). Such exercise can be used with aerobic, anaerobic, and resitance modes of training. There is a wide range of HIIT training protocols due to the number of variables that can be manipulated. HIIT prescriptions can manipulate up to nine variables: work interval intensity and duration, relief interval intensity and duration, exercise modality, number of repetitions, number of series, and between-series recovery and duration (Buchheit and Laursen, 2013).

So which type of high-intensity protocol is best? And how does that protocol compare to traditional endurance training? Astrand and Rodahl posed this question decades ago, writing "It is an important but unsolved question which type of training is most effective: to maintain a level representing 90 percent of the maximal oxygen uptake for 40 minutes, or to tax 100 percent of the oxygen uptake capacity for 16 min" (Seiler, Joranson, Olesen, and Hetlelid, 2013). This question remains unanswered, although current research is suggests that HIIT is a more effective and efficient method to train the cardiovascular system. In order to assess the aerobic enhancements of any training protocol, an incremental maximal oxygen uptake (VO_{2max}) test is used in which the subject continues exercising until the point of maximal fatigue.

Burgomaster, Hughes, Heigenhauser, Bradwell, and Gibala (2005) found that only six bouts of sprint interval training performed over 2 weeks doubled endurance time (26 to 51 min) to fatigue during cycling at a fixed workload of ~80% VO_{2peak} in recreationally-active subjects. The control group was tested without a training intervention and showed no change in endurance time to fatigue over the 2 weeks. In subjects with coronary artery disease, a 17.9% improvement was found in VO_2max in the high intensity group compared to an increase of only 7.9% in the moderate intensity group (Rognmo, Hetland, Helgerud, Hoff, and Slordahl, 2004). These two studies illustrate the strong training stimulus involved in high intensity intervals and the efficacy of high intensity over moderate intensity training.

Tabata training has become an increasingly popular method of HIIT training. Named after its founder Izumi Tabata, this type of training involves eight 20 second bouts of exercise carried out at 170% of the subject's VO_2max, interspersed with 10 second recovery bouts. Tabata et al. (1996) found that similar protocols not only improve the anaerobic energy system, but also enhance a subject's aerobic capacity by ~13%. This could be explained by Guiraud et al. (2012) who found that in healthy subjects, the improvement in VO_{2peak} with exercise training appeared to correlate with the amount of time spent at a high level of oxygen uptake. Therefore, it is common to use this parameter to determine the acute physiological requirements of different interval training protocols (Billat et al., 2001).

Meyer intervals are another HIIT protocol. This type of training involves 30 second exercise bouts paired with 60 second recovery bouts. This type of training protocol was first used in cardiac patients at an intensity of 50% exercise capacity for work phases and a very low watt intensity for recovery patients. Such HIIT protocols are now being used by healthier populations by increasing the percent VO_2 at which to work and the intensity of the 60 second recovery phase (Meyer and Foster, 2004).

Many studies have assessed the aerobic benefits of HIIT, but few have compared the benefits of HIIT protocols to traditional steady-state training benefits. The purpose of this study was to compare Tabata and Meyer HIIT protocols with a traditional steady-state protocol. Assessed outcomes include maximal heart rate (HR), VO_2max, and peak power output (PPO) following an 8-week training program.

METHODS

Subjects

Sixty-five (23 male, 42 female) relatively-sedentary subjects volunteered for the study. Their ages ranged from 18 to 28 years. The protocol, purpose, and risks of the study were explained to all interested participants. In order to rule out any contraindications to exercise, a Physical Activity and Readiness Questionnaire (PAR-Q) was administered to subjects prior to participation (Appendix A). Additionally, all subjects completed an exercise questionnaire (Appendix B). In order to be eligible for the study, subjects could not be exercising more than twice/week at a low to moderate intensity. Qualified subjects completed a written informed consent before undergoing any testing or training procedures. The study was approved by the University of Wisconsin-La Crosse Institutional Review Board for the Protection of Human Subjects.

Testing

This study was part of a larger study that included research on post-exercise hypotension, exercise enjoyment, anaerobic benefits of HIIT training versus steady-state (PPO, mean power output, and rate to fatigue), and acute responses to exercise (heart rate, blood lactate, and rating of perceived exertion). For this aspect of the study, an incremental VO_2max test was used to assess the effects of these 8-week training programs on aerobic capacity. The VO_2max test was performed on a Lode Excalibur sport cycle ergometer (Groningen, Netherlands).

The test began with a 3 minute warm up at 25 watts. After 3 minutes, the load was increased by 25 watts every minute. Subjects were encouraged to maintain a cadence of 80-100 at 80 revolutions per minute (RPM). The test was terminated when subjects were too fatigued to continue, or when the cadence fell below 70 RPM. Maximal HR was measured using a Polar heart rate monitor (Kempele, Finland). Rating of perceived exertion was measured during the test using the 1-10 scale. A Parvo Medics gas analyzer was used to determine oxygen consumption (VO2max) during the test (Sandy, Utah).

Training

Following the pre-testing, subjects were ranked based on an average of three scores: 1) PPO/kg from the VO_2max test, 2) PPO/kg from the anaerobic Wingate test and 3) MPO/kg from the anaerobic Wingate test. Males and females were ranked separately. From these rankings, subjects were randomly assigned to the steady-state, Tabata, or Meyer training group.

Steady-state training consisted of 20 minutes of continuous exercise at 90% of ventillatory threshold (VT), which was determined using pre-test VO_2max data. Meyer interval training consisted of 20 minutes (13 sets) of 30 second work intervals (@ 100% PPO at VO_2max) paired with 60 seconds of active recovery (at an effort to yield a mean PO @ 90% VT). Tabata training consisted of 20 seconds of work (@ 170% VO_2max) paired with 10 seconds of rest (or active recovery) for a total of 8 sets, or 4 minutes. Steady-state and Meyer subjects cycled at a cadence of 80 RPM, while Tabata subjects were encouraged to cycle as fast as possible. Five-minute warm-up and cool-down protocols were identical for all three training groups (2 minutes @ 25 watts, 1 minute @ 50 watts, 1 minute @ 75 watts, 1 minute @ 25 watts). At the end of each week, RPE was assessed using the 1-10 scale. When RPE dropped by

2 units or greater, the workload was increased by approximately 10% for that subject. All subjects completed 24 exercise sessions over the 8-week training period.

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 similar at the beginning 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, a Tukey post-hoc test was 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 three female subjects, two due to loss of interest and the other an unrelated foot injury. The Meyer group lost a total of six subjects. One female was lost due to loss of interest, four males due to unrelated injury/illness, and one female due to unrelated injury. Descriptive characteristics of subjects who completed the study are presented in Table 1. No significant differences existed between the three training groups with regards to age, height, and weight at the start of the study.

Table 1. Descriptive characteristics of the subjects who completed the study

	Steady-State (19)	**Tabata (21)**	**Meyer (15)**
Age (yrs)			
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
Height (cm)			
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
Weight (kg)			
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

Changes over the course of the study are presented in Table 2 and Figures 1 and 2, respectively. There were no significant differences between groups for any variable pre-training. There were no significant differences in responses of males vs. females over the course of the study, thus only group data collapsed across gender is presented.

Table 2. Changes in maximal heart rate, oxygen consumption, and peak power over the course of the study.

	Pre	Post	Change (%)
Maximal HR (bpm)			
Steady-State	191 ± 11.9	191 ± 9.0	0 (0)
Tabata	190 ± 9.0	193 ± 9.3	3 (2)
Meyer	191 ± 12.6	191 ± 8.9	0 (0)
VO_2max (mL/kg/min)			
Steady-State	33.6 ± 5.41	40.1 ± 6.25	6.5 (19)*
Tabata	34.0 ± 6.52	40.1 ± 6.82	6.1 (18)*
Meyer	34.3 ± 9.12	40.6 ± 8.72	6.3 (18)*
VO_2 max (L/min)			
Steady-State	2.57 ± .712	3.06 ± .886	.49 (19)*
Tabata	2.45 ± .676	2.86 ± .793	.41 (17)*
Meyer	2.50 ± .708	2.89 ± .670	.39 (16)*
Peak Power Output (Watts)			
Steady-State	216 ± 49.3	251 ± 62.5	35 (16)*
Tabata	204 ± 57.3	251 ± 54.9	47 (23)*
Meyer	209 ± 52.3	239 ± 51.3	30 (14)*

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

There were no significant changes in maximal HR for any training group over the course of the study. All three groups experienced significant improvements in PPO over the course of the study, however, there was no significant difference in the amount of improvement between groups. The steady-state group had an increase of 35 watts (16%).The Tabata group had an increase of 47 watts (23%), and the Meyer group had an increase of 30 watts (14%).

All three groups also had significant increases in aerobic capacity over the course of the study. However, there were no significant differences between the three training groups. The steady-state group had an increase of 6.5 mL/kg/min (19%), the Tabata group had an increase of 6.1 mL/kg/min (18%), and the Meyer group had an increase of 6.3 mL/kg/min (18%). Changes in VO_2 (L/min) followed a similar pattern, as the steady-state group improved by 19%, the Tabata group improved by 17%, and the Meyer group improved by (16%).

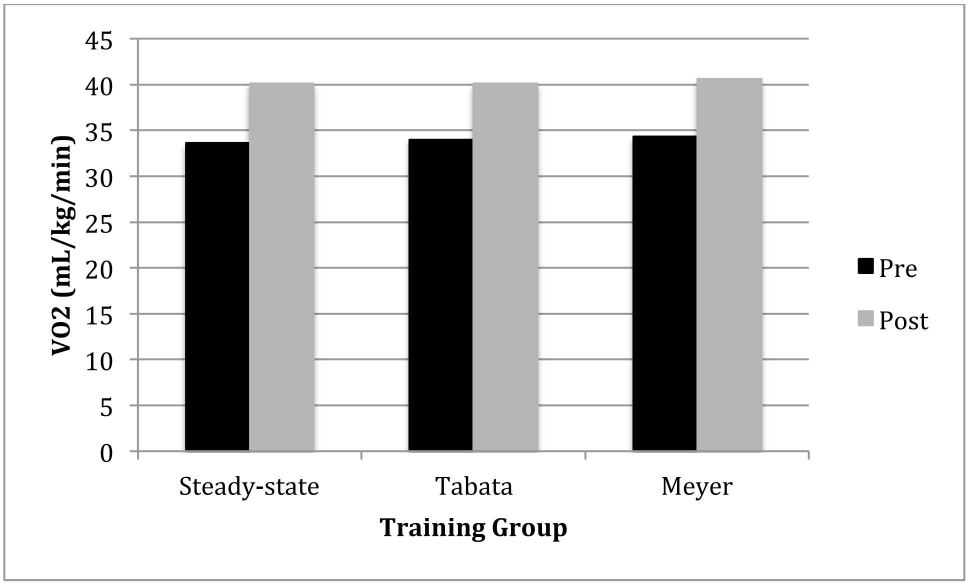

Figure 1. Changes in VO_2max over the course of the training study.

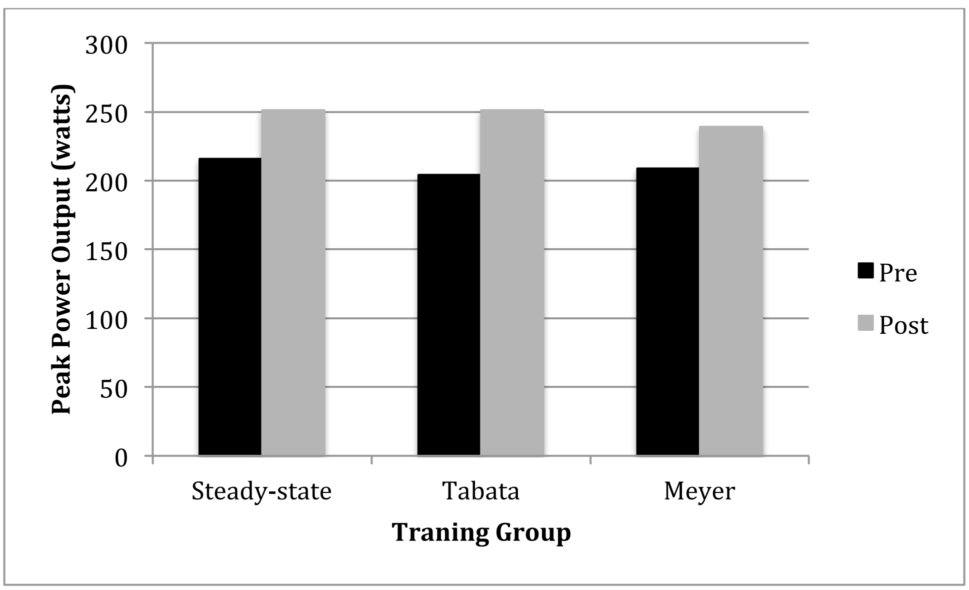

Figure 2. Changes in peak power output over the course of the study.

DISCUSSION

The purpose of this study was to evaluate changes in aerobic capacity following 8 weeks of HIIT compared to steady-state training. This study found no significant difference in the amount of change between groups. All three groups had significant increases in PPO and VO_2max. This indicates that there was a positive adaptation for all three training groups in regards to aerobic capacity. There were no significant differences for maximal HR. This indicates that training did not influence the highest heart rate achieved by subjects.

Improvements in VO_2max may occur through increases in oxygen delivery and utilization by the active muscles (Bayati, Farzad, Gharakhanlou, and Agha-Alinejad, 2011). Given that the maximal HR did not significantly change as a response to training, such improvements must be attributed to increases in stroke volume. Several authors (Barnett et al., 2004, Gibala et al., 2006) have reported that VO_2 increases as a result of the subject's capacity to produce energy through oxidative metabolism.

The steady-state and Meyer training groups spent 90 minutes on the bike per week (including warm-up and cool-down procedures) for 8-weeks, while the Tabata group spent less than half of that, accumulating only 42 minutes per week. Therefore, the Tabata group spent 53% less time on the bike and still showed improvements similar to the steady-state and Meyer groups. These results reinforce the time-efficient component of HIIT training regarding improvements in aerobic capacity. This is especially impressive considering the Tabata group only performed 4 minutes of hard work per training session, accounting for a total of 96 minutes of hard work over the entire course of the study.

Lack of time is one of the most common barriers keeping people from exercising (Whyte et al., 2010). HIIT protocols give these people the opportunity to gain benefits similar to exercise at a longer duration, if they are willing to work at an intensity level greater than 100% of VO_2max. There is a unique balance between duration and intensity and their correlation to aerobic capacity. If a person has more time, they may be able to work at lower intensity levels to reap similar gains as a person with less time working at a very high intensity level. According to the present study, significant improvements of similar magnitude were seen in all groups, so the specific type of training protocol is irrelevant. The subjects used in the study were all students with busy lives revolving around academia, involvement, and socializing. A shorter workout may seem most favorable for busy college kids, but it may be undesirable to push them to 170% of their VO_2max several times per week.

Prior to HIIT studies, it was most common for individuals looking for aerobic gains to train at a set workload for a long period of time in order to exhaust their aerobic energy system. We now know that training the anaerobic energy system can maximize the efficiency of the aerobic energy system. It is also known that aerobic contribution to sprint interval bouts increases during HIIT exercises when recovery periods are short (Bogdanis, Nevill, Boobis, Lakomy, 1996). Brief periods of recovery produce a higher demand on aerobic metabolism in order to produce adenosine tri-phosphate (ATP) during the latter portion of the exercise bout.

There are a few limitations within the present study. First, practice tests were not performed. A trial run at low workloads may have increased familiarity with the protocol more so than verbal cues prior to testing. Secondly, untrained subjects are likely to see rapid increases in VO_2max after initially starting an exercise program due to their relatively low baseline level of fitness (Whyte et al., 2010).

The present study found that regardless of the training protocol, untrained subjects experienced significant improvements in aerobic capacity after an 8-week training program. A

Tabata workout is only 4 minutes in duration, but is more demanding than 20 minute Meyer or Steady-state workouts. Ultimately, this study suggests that individuals find which training regimen is most sustainable, as benefits will become more pronounced over time. A combination of the three protocols may provide the greatest variety and therefore be easiest to continue in the future.

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APPENDIX A

PHYSICAL ACTIVITY READINESS QUESTIONAIRE

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? If yes, explain:
Yes or No	Do you have chest pain brought on by physical activity? If yes, explain:
Yes or No	Have you developed chest pain in the past month? If yes, explain:
Yes or No	Have you on one or more occasions lost consciousness or fallen over as a result of dizziness? If yes, explain:
Yes or No	Do you have a bone or joint problem that could be or has been aggravated by exercise? If yes, explain:
Yes or No	Has a doctor ever recommended medication for your blood pressure or a heart condition? 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? If yes, explain:

APPENDIX B

EXERCISE QUESTIONAIRE

Comparative Effectiveness of Interval and Continuous Exercise Training

Name:

Age:

Gender:

Birth Date:

Email:

Phone Number:

<u>Exercise History Questionnaire</u>

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 manuscript is to review the existing literature involving the effects of high-intensity interval training on aerobic capacity.

Inactivity

> The hazards of being inactive are clear. Physical inactivity is a serious, nationwide problem (Surgeon General Report: Center for Disease Control and Prevention, 1996).

Inactivity and its resulting, negative health implications has become a significant issue within our nation's society. Why is this? Why are Americans choosing to forgo the gym? Why is physical activity so difficult to obtain for so many people? Lack of time is one of the most common exercise barriers (Reichart, Barros, Dominigues, Hallal, 2007).

The American College of Sports Medicine (ACSM) has advocated for adults to accumulate at least 30 minutes of moderate-intensity exercise, most days of the week in order to attain health benefits (Pate, Pratt, Blair, Haskell, Macera, Bouchard et al, 1995).
However, more recently, ACSM has established an alternative routine that is less time consuming: at least 20 minutes of high-intensity exercise, at least 3 days per week (Haskell, Lee, Pate, Powell, Blair, Franklin, et al, 2007). Such exercise includes more vigorous work for a shorter period of time, with similar benefits. In fact, evidence suggests that higher-intensity exercise may offer a more time-efficient strategy for improving metabolic health than conventional moderate-intensity exercise programs (Whyte, Gill, Cathcart, 2010).

HIIT Principles

Though there is no universal definition, HIIT generally refers to several periods of brief intermittent exercise, usually performed with an "all out" effort or at an intensity near VO_{2peak} and an active recovery session (Gibala and McGee, 2008). Based on the training intensity, a single exercise bout may last as long as a few seconds or up to several minutes, with multiple bouts separated by up to a few minutes of rest or active, low-intensity recovery exercise. The total length of HIIT sessions last ~5-40 minutes (Buchheit and Laursen, 2013). Such exercise is usually associated with modes of activity such as running or cycling (Gibala et al, 2008).

A wide array of adaptations have been revealed following this particular type of training including increased resting glycogen content, skeletal muscle oxidative capacity, improved cardiovascular fitness, increased activity of various glycolytic and oxidative enzymes, H^+ buffering capacity, and time to exhaustion (Bayati, Farzad, Gharakhanlou et al, 2011).

High intensity interval training (HIIT) is used frequently within the sports training business (Guiraud, Nigam, Gremeaux et al, 2012). Endurance athletes have been utilizing such training modes for years to cut down on training time and maximize aerobic capacity past the bounds of continuous steady-state training. With HIIT, high-intensity effort may be sustained for longer periods of time, eliciting a greater training stimulus and VO_{2max} value (Guiraud et al, 2012). This response might be attributed to a higher ventillatory threshold (VT) which can occur as soon as 3 weeks after initiating HIIT programming (Meyer, Schwaibold, Westbrook et al, 1996).

<u>HIIT and VO_2</u>

VO_{2max} is arguably the single most important factor determining success within aerobic endurance sports (Helgerud, Hoydal, Wang et al, 2007). Steady-state training (even of high intensity) may seem most beneficial for athletes working to enhance the cardiorespiratory system. It is interesting that short but very intense exercise training may induce similar improvements within cardiorespiratory fitness and skeletal muscle oxidative capacity as prolonged training (Nybo, Sundstrup, Jakobsen et al, 2010).

Typically, the contribution of the aerobic energy system to the total energy requirement within a short exercise bout (i.e. 10 seconds) is only ~13% (Bogdanis, Nevill, Lakomy et al, 1998). However, when short sprints are repeated with short recovery or when sprint exercise lasts for up to 30 seconds, anaerobic energy production decreases and a significant amount of energy is consequently acquired from the aerobic energy system (Gaitanos, Williams, Boobis et al, 1993; Bogdanis et al, 1998; Boganis, Nevill, Boobis et al, 1996; McCartney, Spiret, Heigenhauser et al, 1986). Thus, HIIT allows the body to tap into the oxidative system in a much shorter amount of time compared to steady-state, continuous training.

Kessler, Sisson and Short (2012) published a review article which examined 17 studies examining the impact of HIIT on VO_{2max}. Three of these involved sprint interval training (SIT) lasting 2-6 weeks, and 14 studies observing 4-24 weeks of aerobic interval training (AIT) which is performed at a slightly lesser intensity but sustained for a longer period of time. All but one treatment group of a single study demonstrated an increase in VO_{2max} after the programs.

Due to variability in regard to interval length, total exercise session length, and work intensity, there is minimal repetition within scientific studies concerning HIIT. Four Norwegian researchers set out to investigate the potential interaction between work intensity and total work duration in prompting adaptations to aerobic interval training (, Joranson, Olesen et al, 2013). Thirty-five recreational cyclists adhered to one of four training programs over 7 weeks: 1) low/moderate continuous training, 4-6 sessions/wk, 2) 4 x 16 min, 2 sessions/wk, 3) 4 x 8 min, 2 sessions/wk, 4) 4 x 4 min, 2 sessions/wk. Though interval work periods varied in duration, all were matched for effort at maximum sustainable intensity. The main finding of this research shows that an interval training program in which subjects accumulated 32 min of work at ~90% HR_{max} stimulated moderate to large improvements in both maximal and submaximal performance indicators (Seiler et al, 2013).

Tabata, Nishimura, Kouzaki et al (1996) compared two training experiments using a mechanically braked cycle ergometer. First, the effect of moderate-intensity endurance training (70% VO_{2max}, 60 min/day, 5 days/wk, for 6 weeks in duration). Anaerobic capacity remain unchanged while VO_{2max} increased significantly ($p < 0.01$) from 53 ± 5 mL/kg/min to 58 ± 3 mL/kg/min.

Second, to quantify the effect of very high-intensity intermittent training (170% $VO_{2max,}$ 7-8 sets of 20s/10s rest between sets [Wingate], 5 days/wk, for 6 weeks in duration). Following the training period, VO_{2max} increased by 7 mL/kg/min (Tabata et al, 1996). Another one-time study reproduced such Wingate protocol (IE1) compared to 200% $VO_{2max,}$ 4-5 sets of 30s/2min rest between sets (Tabata, Irisawa, Kouzaki et al, 1997). Both groups continued until the point of exhaustion, or when subjects were unable to maintain a pedaling frequency of 85 rpm. The accumulated oxygen deficit of IE1 (69 ± 8 mL/kg) was not significantly different from the max accumulated oxygen deficit of the subjects (69 ± 10 mL/kg), whereas the IE2 value (46 ± 12 mL/kg) was considerably less ($p < 0.01$) than the maximum value (Tabata et al, 1997).

Nybo, Sundstrup, Jakobsen et al (2010) compared interval training to traditional exercise interventions. Thirty-six untrained men were divided into 3 groups for a total for 12 weeks: 1) interval running (INT: total training time of 40 min/wk), 2) prolonged running (150 min/wk), and

3) strength training (150 min/wk). Conclusions of the study included a superior increase in VO_{2max} in the INT group (14% ± 2%) compared with the other two interventions (7% ± 2% and 3% ± 2%), suggesting INT to be an effective training stimulus eliciting for enhancement of cardiorespiratory fitness (Nybo et al, 2010).

HIIT and clinical populations

A wide variety of studies have been conducted examining the effect of HIIT within differing clinical populations. Many studies suggest that this type of exercise is more suitable for such populations for an assortment of reasons.

Smodlaka (1963) was one of the first researchers to examine the effects of high intensity training among cardiac patients. Interval training was becoming a successful coaching mechanism within the sports world, but its consequences within sick communities remained unnoted. After further examination, research suggested that the spiking (intensity intervals) and dropping (rest intervals) allowed the heart rate to increase to an optimal value without quickly tiring these compromised patients (Smodlaka, 1963).

Research conducted by Meyer, Samek, Schwaibold et al (1996) examined the physical responses to different modes of interval exercise in patients with chronic heart failure (CHF). Within this particular population, it is important that skeletal muscles are stressed with high-intensity stimuli while cardiac stress is minimized. Sixteen male CHF patients performed 3 separate interval exercise tests at varying intensities of maximum short time exercise capacity (MSEC): 50% (30/60 s), 70% (15/60 s), and 80% (10/60 s). Results concluded that compared to an intensity level of 75% VO_{2peak}, work rate during interval bouts was between 143 and 221%, while cardiac stress was 83-88% lower. Such findings are significant because exercise training is typically prescribed at 75% VO_{2peak} achieved during a graded exercise test. However, much higher work rates with lower cardiac stress were attained during interval training. Therefore, exercise guidelines using a basis of 75% VO_{2peak} may be underestimating the capacity at which patients are able to perform (Meyer et al, 1996).

Guiraud, Juneau, Nigam et al (2010) compared the acute cardiopulmonary responses in four different single bouts of HIIT in an attempt to identify the most optimal method within patients with coronary heart disease (CHD). Nineteen stable CHD patients performed four separate HIIT interventials at 100% of maximal aerobic power (MAP). Intervals varied in duration (15:15s for mode A and B, 60:60s for mode C and D) and recovery type (0% MAP for mode A and C, 50% MAP for mode B and D). Time to exhaustion was longer in modes with passive recovery (mode A and C) despite similar values when examining time spent above 80% VO_{2max} (Guiraud et al, 2010).

The ability of intensity training to increase aerobic capacity has also been studied in patients with Coronary Artery Disease (CAD). Rognmo, Hetland, Helgerud et al (2004) observed twenty-one stable CAD patients who were randomly assigned to either a high-intensity interval group (80-90% VO_{2peak}) or moderate-intensity interval group (50-60% VO_{2peak}) three times per week. After 10 weeks, VO_{2peak} increased by 17.9% in the high-intensity group and 7.9% in the moderate-intensity group, suggesting that higher intensity interval exercise is superior to moderate for individuals with stable CAD.

When examining patients who recently underwent coronary bypass surgery (24-26 days following the procedure), interval training bouts appear to be more effective compared to continuous training because it yields an enhancement in physical performance and an economization of cardiac function (Meyer, Lehmann, and Sunder, 1990). In peripheral arterial occlusive disease (stage II) and severe chronic obstructive pulmonary disease, interval training allows patients to initiate an endurance exercise regimen (Meyer and Foster, 2004).

Numerous researchers have questioned whether HIIT is appropriate within a sedentary population. The effect of 2 weeks of very high-intensity sprint interval training (SIT) on metabolic and vascular risk factors in overweight/obese sedentary men was examined by Whyte, Gill and Cathcart (2010). These participants completed 6 sessions of 4-6 30-second Wingate anaerobic sprints with 4.5 minutes of recovery between each set over a 2-week period. VO_{2max} increased by 8.4% with only 15 minutes of total exercise during the training intervention (Whyte et al, 2010). Further research is needed to assess whether such exercise regimens are sustainable over time within this population. Babraj, Vollaard, Keast et al (2009) concluded the efficacy of a high-intensity exercise protocol, involving only ~250 kcal of physical work weekly, substantially improves insulin action within young sedentary subjects.

Summary

In spite of the well-recognized benefits of physical activity, millions of people are physically inactive, and that statistic has increased exponentially over the past few decades

(Reichart et al, 2007). There is a general consensus amongst researchers that high-intensity interval training has significant capacity to increase $VO_{2max.}$ However, the most beneficial work load and interval ratios are still under determination. Further research must be conducted in order to gauge such scientific inquiries.

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