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Efrain James Sanchez
Eastern Washington University

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COMPARING AEROBIC ADAPTATIONS WITH A RUNNING BASED HIGH INTENSITY INTERVAL TRAINING (HIIT) AND A CONTINUOUS ENDURANCE TRAINING (CET) PROTOCOL IN RELATIVELY HEALTHY ADULTS

A Thesis

Presented To

Eastern Washington University

Cheney, Washington

In Partial Fulfillment of the Requirements

for the Degree

Masters of Science Physical Education

By

Efrain James Sanchez

Summer 2013
THESIS OF EFRAIN J. SANCHEZ APPROVED BY

_________________________________________ DATE __________
WENDY REPOVICH, GRADUATE COMMITTEE CHAIR

_________________________________________ DATE __________
NATE LAWTON, GRADUATE STUDY COMMITTEE

_________________________________________ DATE __________
MICHAEL CONLIN, GRADUATE STUDY COMMITTEE
MASTER’S THESIS

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ACKNOWLEDGMENTS

First and foremost, I would like to thank Dr. Wendy Repovich, and express my appreciation for what she has done for me in the last years. Her support, and never ending encouragement to answer the question “why?” for everything in my thesis, school-work, and career choices was immensely important to my success in this program. As my advisor she has helped me shape my graduate thesis, as well as my future and my career, and has made me a better and smarter person.

Additionally, I would like to thank Nate Lawton. He was the first person I talked to when I started contemplating graduate school at Eastern, and I am so glad I did. He talked very highly of the program, and helped lead me to one of the best decisions of my life. Furthermore, as my second on my thesis he has put forward countless hours and resources to help me achieve my degree.

I would also like to acknowledge my boss for the last 3 years, Melissa Elfering. The job at the fitness center has been the best job I have ever had. I gained my passion for health and fitness there, and it helped me gain the confidence to pursue a graduate degree, and I owe that to Melissa. I would also like to thank Chris Hammer, for assisting me with my statistics, and helping making sure all my stats and numbers were in order.

Also, I would like to thank all of the graduate and undergraduate students that helped keep me motivated and positive at difficult times during this process. Lastly, I would like to thank my soon to be wife for always being my cheerleader, always supporting me, and bringing me countless lunches and snacks while I was at work or the graduate office.
ABSTRACT

The purpose of this study was to compare a running based High Intensity Interval Training (HIIT) protocol to a Continuous Endurance Training (CET) and their aerobic adaptations, such as increased VO$_{2\text{max}}$ and improved body composition. Recruitment of participants occurred by flyers on campus. After indicating interest, volunteers answered no, to all questions on the PAR-Q to be eligible. Pre and post testing included a submaximal VO$_2$ test, using the 12-minute Cooper run test, and body composition using the BOD POD GS (COSMED USA Inc., Chicago, Illinois). After testing, the participants were randomly stratified based on matched aerobic capacity scores to either the HIIT, CET or control group. The CET and HIIT group completed 6 weeks of 3 days/week of the training protocol. The HIIT group did 10 X 60-s workload intervals with 60-s of rest in between each interval. The CET group did 40 to 60-min moderate intensity running. Pre to post test values were compared using a student t-test with $p \leq .05$, and significance between were measured using a one-way ANOVA with a Tukey post-hoc when necessary. The HIIT and CET group found significance in regards to VO$_{2\text{max}}$ with no difference between groups. The HIIT and CET respectively showed a 5.33 ($\pm$ 4.48) ml/kg/min ($t = 4.30, p = .001$) and a 2.95 ($\pm$ 1.82) ml/kg/min ($t = -5.367, p < .000$) improvement. In regards to body composition HIIT also gained significant results with % Body Fat (% BF), Body Mass (BM), and Fat Free Mass (FFM).
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Chapter 1
Introduction

History of Fitness

The 1950’s were a ground-breaking time for the American fitness and physical activity movement. In 1953, Dr. Hans Kraus and Ruth Hirschland published a study that highlighted the poor fitness state of the American youth. This study showed that European children were much more physically fit than American children based on the Kraus-Weber Fitness Test (Kraus & Hirschland, 1953). This study motivated the American government to make a change in American fitness, led by President Dwight D. Eisenhower (Dalleck & Kravitz, 2002). In response to these findings President Eisenhower created the President's Council on Youth Fitness in 1955.

In the 1960’s, President John F. Kennedy made another big push toward exercise and fitness for health-related benefits to all Americans (Dalleck & Kravitz, 2002). In The Soft American (1960) President Kennedy spoke openly about the need for Americans to improve their fitness, and to be more physical active. Kennedy promoted many national fitness activities and youth pilot fitness programs to get the nation more active (Kennedy, 1962). Kennedy’s article outlined four points as the basis of his health and fitness campaign: a White House committee on Health and Fitness; a strong declaration that physical fitness was a concern of the federal government; an annual youth fitness conference to be attended by state governors; and direct supervision of the initiative by the Department of Health, Education, and Welfare (Sturgeon & Meer, 2006). At the end of Kennedy’s article he laid out the foundation for restructuring the Presidents Council on physical fitness (Kennedy, 1962). Although the council did not have the authority to
impose a national physical fitness program, the council did spread the word about the need for physical fitness, conducted fitness surveys, and published physical fitness information.

Although Kennedy and Eisenhower tried to make a change in the fitness world, Dr. Kenneth H. Cooper is considered “The Father of the Modern Fitness Movement” (Dalleck & Kravitz, 2002). He coined the phrase “aerobics” which became the namesake for the fitness industry. In his bestselling book, *Aerobics* (1968), Cooper inspired many to health and fitness, showing that it was not only for athletes or military, but a normal population could take part in a consistent and beneficial exercise program (Cooper, 1968). Until Cooper’s writing in 1968 most training programs and physical activity plans were primarily aimed towards the military, and training a strong competent army. Cooper advocated a change towards fitness for a general population that focused on disease prevention and treatment, through regular exercise and maintaining a high fitness level (Dalleck & Kravitz, 2002).

Aerobic exercise demands oxygen, but does not produce byproducts that impede prolonged exercise the way anaerobic work does (Cooper, 1968). For this reason, aerobic exercise can consist of long-duration continuous activity. The Cooper 12-min run test estimated aerobic capacity, and from this measure an exercise plan could be prescribed. This made it possible for the general public to test their own fitness, and create a fitness plan using a variety of exercise forms such as; swimming, cycling, walking, stationary running, handball, basketball and many others (Cooper, 1968). This test was an aerobic capacity test based on a graded treadmill VO$_{2\text{max}}$ test using gas analysis, but did not include any expensive equipment only a track to identify distance covered.
A substantial regimen of physical activity can elicit adaptation in skeletal muscle fibers, and in the circulatory system (Clausen, 1977). These adaptations lead to fitness improvement and prevention of many common diseases that currently plague Americans such as diabetes, and heart disease (Fentem, 1978; Selfridge, 2012). Cooper’s book and program was the first time a specific prescription was given to the general population and he made it easy enough that anyone could follow the program (Cooper, 1968).

While sports were included in Cooper’s exercise prescription, all training was prescribed based on time. An individual could go out for a walk, jog, or run for 30 min or more and all gain a benefit. The ease of this allowed many individuals to engage in exercise with minimal training (Cooper, 1968). This was the foundation for Continuous Endurance Training (CET). CET became one of the most commonly used techniques to train the aerobic system. One of the first widely accessible CET training modes available to the public was jogging, due to its virtually cost-free nature. At the same time as the general public took up CET, Arthur Lydiard, an elite distance coach from New Zealand was using a very similar training program for his athletes. Lydiard coached many successful marathoners in the 1960's and 1970's (Hashizume, 2004; Who invented running?, 2007). Lydiard would have his athletes run extremely high mileage workouts, called Long Slow Distance (LSD) training.

The physiological adaptations resulting from CET or LSD are the foundation of both health and sport performance. A series of principles have been developed and adapted over time to optimize the physiological changes in the most efficient way in the least amount of time (Hoeger & Hoeger, 2012). Two principles directly relate to how training can influence the outcome: progressive overload and specificity. The principle of
progressive overload consists of performing a specific form of exercise or working a specific muscle or system to fatigue in order to force adaptations (Katch, McArdle, & Katch, 2010). For a muscle or a system to adapt, the stimulus must be specific to obtain the desired effects, thus the principle of specificity (Hoeger & Hoeger, 2012).

Aerobic metabolism requires oxygen so adaptations must take place in the delivery system as well as in the muscles. The health benefits of aerobic exercise manifest themselves in the cardiovascular system (Fentem, 1978). It is well accepted by researchers that regular aerobic exercise will result in an increase in stroke volume, as well as a decrease in vascular resistance, and an increase in venous return. As a result, an increase in cardiac output, the amount of blood pumped from the heart each minute, occurs. This is demonstrated for everyone by a decreased resting heart rate and a lower heart rate for all submaximal work (Clausen, 1977). The heart is healthier because it does not have to work as hard at rest, and during exercise to supply needed blood flow to accommodate work. It is also positive for the blood vessels that deliver the blood to the muscles. The vessels adapt more quickly and more efficiently to changes in blood volume, which is shown as a decrease in blood pressure at rest. The decrease is found in both diastolic and systolic blood pressure, and at all levels of work by a lower response in systolic blood pressure (Clausen, 1977; McArdle, Katch, & Katch, 2009).

When aerobic exercise was first recommended by Dr. Cooper he was most interested in health benefits and prevention of cardiovascular disease (Cooper, 1968). In the 70’s and 80’s aerobic exercise was very popular, people were jogging, taking aerobics classes, and taking part in exercise to stay healthy. As time went on, new technologies were being created, new jobs that did not require movement were created, and many
Americans stopped moving in their daily lives and those who exercised might still be sedentary the rest of the day. This physical inactivity of American led to an obesity epidemic across the country (U.S. DHHS, 2001). Americans’ were very concerned about the high and climbing obesity rate, largely due to the negative health risks associated with excessive fat. Some of the risk factors include: impaired cardiac function, hypertension, renal disease, sleep apnea, osteoarthritis, many different cancers, gallbladder disease, and the list goes on (McArdle et al., 2009). Obesity has even been found to be more harmful compared to smoking based on earlier occurrence of myocardial infarction (Madala et al., 2008). As the body-weight of Americans has gradually increased the need to examine techniques in losing body fat became more important to researchers.

Weight loss can be broken down in its simplest form into calories in vs. calories out. The human body has a given caloric intake needed to sustain weight in a resting state, known as the basal metabolic rate. Thus, an individual must burn more calories (through daily activities and exercise) then taken in (through food) to facilitate weight loss (Welch, 1997). Because one pound is 3500 kcal, an individual must have a deficit of 500 - 1,000 kcal a day, to attain 1-2 pounds of weight loss a week (McArdle et al., 2009). Although, weight loss is often used for health benefits, weight management can also be used to optimize athletic performance.

Weight loss is utilized in athletic performance to meet weight in competition, such as in wrestling and boxing (Baechle & Earle, 2008). Weight loss is also used in training for optimal performance in many endurance sports. One example is a marathon runner; a lean and slender body is optimal for competition, so the individual will not have to spend extra energy carrying the excess weight for 26.2 miles (McArdle et al., 2009).
Although many know of the positive effects and changes that occur with taking part in an exercise program, the improvements cannot be fully understood without a solid understanding of the physiological adaptations that occur.

In the 1970’s when Lydiard began training his marathoners it was known that two types of muscle fibers made up the skeletal muscle, slow-twitch (ST) or red fibers, and fast-twitch (FT) or white fibers. The ST fibers were also called red fibers because they contained myoglobin, which stained red, to store oxygen to facilitate aerobic metabolism at the highest level possible for the longest time possible (McArdle, et al., 2009). The FT fibers were white because they did anaerobic work, which did not require oxygen so myoglobin was not present, thus they did not stain red. Their purpose was to be ready to do high intensity, high velocity, and high power types of movements (Baechle & Earle, 2008).

Lydiard assumed it was necessary to overload the ST fibers specifically and thus his technique of LSD was used to make them adapt. He was very successful with his marathoners who did very high weekly mileage. Research on aerobic athletes showed significant increases in aerobic capacity, and muscle adaptations including the percent of “red” muscle fibers. This finding led to the incorrect assumption that some FT fibers became ST fibers following training (Taylor & Bachman, 1999). It was not long after that the staining techniques in muscle biopsies were improved and able to actually show that it was adaptations in some of the FT fibers where the increase in myoglobin made the fibers appear to be redder.

It is now an accepted theory that the nerve attached to the muscle fibers determines whether it is a ST or FT fiber, not what metabolism occurs within the fibers.
Those newly red fibers remained FT in all aspects but some were more efficient at using aerobic glycolysis to produce ATP for muscle work. This required reclassification of FT fibers into two types, Type IIa, called oxidative glycolytic, the ones that could become more aerobic with training, and Type IIb, called glycolytic, those that were true anaerobic fibers (Scott, Stevens, & Binder-Macleod, 2001).

Middle distance runners have long used a combination of training. In 1912, Finnish 10,000-meter Olympic runner Hannes Kolehmained used mixed interval training in preparation for that year’s Olympics (Zuhl & Kravitz, 2012). What he did not know at the time was the LSD was training his ST fibers well, and interspersing higher intensity intervals was training his FT IIa fibers to become more aerobic than anaerobic. Once fiber-typing was done with muscle biopsies it was possible to see all the changes in both fibers that occurred to make the runner as efficient as possible. Muscles adapt in a specific order to overload, and since there are two fiber types it is necessary to train each specifically.

The first adaptation to aerobic training seen is in the enzymes needed to burn the fuel for the fiber; ST fibers primarily burn fat and FT fibers primarily burn glucose, thus there are two different kinds of enzymes to supply the fuel. In both cases, the enzymes for the Kreb’s Cycle and Electron transport must increase for aerobic metabolism which takes place in the mitochondria of the muscle (McArdle et al., 2009) Slow twitch fibers already have mitochondria so training adaptation includes increased mitochondrial size and quantity. Fast twitch IIa fibers only contain a few so needs to add mitochondria right away (Katch et al., 2010; McArdle et al., 2009). To supply the amount of oxygen needed the circulatory system cannot deliver enough quickly enough so oxygen must be stored in
myoglobin in the fibers. ST fibers are already aerobic and contain myoglobin whereas the FT IIA fibers add myoglobin with aerobic training, which was why it was originally thought they were switching to slow twitch not just adapting to be more aerobic (Hawley & Stepto, 2001). Once there is more myoglobin in the FT fibers, more oxygen must be delivered so some changes in capillary density will occur. The present vessels will open further, and eventually add additional capillaries when the muscle has hypertrophied (McArdle et al., 2009).

The fuel needed for each fiber must be readily available to facilitate work. For the ST fibers that means migration of some fat cells into and around the muscle fibers. For the FT IIA fibers, that requires increasing resting glycogen stores in the cytoplasm (Carter et al., 2001; Hawley & Stepto, 2001). Finally the muscles can hypertrophy to continue to adapt though FT fibers have a greater capacity to hypertrophy than do ST fibers (McArdle et al., 2009; Scott et al., 2001). All these changes occur in cycles within the muscles and back and forth with the circulatory system, which is why training must keep changing to remain specific and to be able to overload the system. The term periodization is used to explain the various cycles, with different lengths of time indicating micro, meso, and macro time periods (Baechle & Earle, 2008).

Two measures of aerobic efficiency, VO_{2max} a measure of aerobic capacity, and the anaerobic threshold (AT) also change. If anything changes to make aerobic metabolism more efficient VO_{2max} will increase. Thus if the first change, aerobic enzymes in ST fibers have increased in a matter of days, VO_{2max} can also increase. As each additional adaptation occurs, VO_{2max} will continue to increase, sometimes in small increments, sometimes in large, depending on the impact of the change in the specific
fibers (Hawley & Stepto, 2001; McArdle et al., 2009). The second measure, AT, is the ratio of work being done aerobically to the work being done anaerobically. When the percent of anaerobic work gets too high lactic acid levels, the byproduct of anaerobic glycolysis, will increase in the blood. This will drop the pH in the worked muscle fibers, which has a negative effect on the enzymes slowing down all metabolic rates (Carter et al., 2001). When the AT happens at 60% of VO$_{2\text{max}}$, fatigue keeps the person from working any harder, or at a higher intensity. With training as aerobic metabolism becomes more efficient in ST and specific in FT IIa fibers, the AT can increase up to 80% to 85% of VO$_{2\text{max}}$ and a higher intensity of work can be maintained before fatigue sets in (Clausen, 1977). This increase in AT holds significant performance benefits to both athletes and general exercisers alike.

Training at a high intensity for increases in anaerobic capacity has consistently shown improvements in power, strength, and speed. High intensity training, as close to maximum as possible, or supramaximal to overload the system and produce fatigue has been an effective method used to improve performance in any high intensity sport or activity (Baechle & Earle, 2008). The adaptations seen in the FT muscle fibers are specific to anaerobic capacity, increasing Adenosine Triphosphate (ATP) and Creatine Phosphate (CP). These two substrates are needed for alactic anaerobic metabolism (up to 10 sec of anaerobic work). The increasing enzymes and stored creatine speed up the reactions and allow them to continue longer; effectively extending the available fuel in the phosphogen system (Baechle & Earle, 2008; Katch et al., 2010). For lactacid anaerobic metabolism (up to 2.5 – 3 min of anaerobic work) the enzymes for anaerobic glycolysis must increase (Hawley & Stepto, 2001). The muscle pH may start at a higher
level creating increased tolerance to lactic acid so the process can go longer before fatigue; when the muscle becomes acidic and the enzymes cannot function (McArdle et al., 2009). The major way to increase anaerobic function is to cause hypertrophy because the cellular adaptations have a minimal effect (Baechle & Earle, 2008; Katch et al., 2010). Fast twitch muscle fibers have a high ability to hypertrophy with a chronic training stimulus.

Coaches and researchers are always looking for a way to do more with less which began a focused line of counter-intuitive research using high intensity training to see its impact on aerobic metabolism. Studies focused on manipulating intensity levels in traditional aerobic activities, such as running or cycling and led to some very unexpected findings that it was possible to impact aerobic capacity with something previously only associated with anaerobic performance. Researchers included high-intensity anaerobic workloads and found that aerobic capacity increased following training at these intensities (Eddy, Sparks, & Adelizi, 1977).

These finding lead to the development of a new aerobic exercise trend called HIIT – High Intensity Interval Training. Researchers wanted to know what was causing the adaptation and improvement in aerobic capacity (Astorino et al., 2011; Burgomaster, Hughes, Heigenhauser, Bradwell, & Gibala, 2005; Burgomaster et al., 2007; Talanian, Galloway, Heigenhauser, Bonen, & Spriet, 2007; Perry, Heigenhauser, Bonen, & Spriet, 2008; MacDougall et al., 1998), they wanted to observe HIIT’s effect on performance (Burgomaster, Heigenhauser, & Gibala, 2006; Burgomaster et al., 2008; Gibala et al., 2006; MacPherson, Hazell, Olver, Paterson, & Lemon, 2011), whether the health benefits of aerobic training could be achieved with HIIT (Astorino, Allen, Roberson, & Jurancich,
2012; Hood, Little, Tarnopolsky, Myslik, & Gibala, 2011; Little, Safdar, Wilkin, Tarnopolsky, & Gibala, 2010; Little et al., 2011; Trilk, Singhal, Bigelman, & Cureton, 2011), and whether HIIT was able to affect body composition (Hazell, MacPherson, Gravelle, & Lemon, 2010; MacPherson et al., 2011; Trapp, Chisholm, Freund, & Boutcher, 2008; Tremblay, Simoneau, & Bouchard, 1994).

Since Americans have claimed they do not have enough time to exercise and HIIT appears to provide aerobic benefits researchers wondered, would it be possible to gain the same health benefits that have been seen with CET or mixed interval training in a shorter amount of time (Gibala & McGee, 2008)? Research suggests that HIIT may offer similar benefits as CET or mixed-interval training but in a much shorter time frame (Gibala & McGee, 2006; MacPherson et al., 2011). This may hold significant training benefits, as a lack of time is one of the most commonly cited barriers to achieving the recommended physical activity level among American adults (Trost, Owen, Bauman, Sallis, & Brown, 2002).

Many different methods have been used to create the HIIT programs. Researchers have used a variety of equipment including using cycle ergometers (Astorino et al., 2011; 2012; Burgomaster 2005, 2006, 2007, 2008; Gibala et al., 2006; Hazell et al., 2010; MacDougall et al., 1998), running on a treadmill (MacPherson et al., 2011), or even rowing (Driller, Fell, Gregory, Shing, & Williams, 2009). There have been significant variations in the work/rest intervals used ranging from as short as 10 sec up to three to four minute work intervals, with rest intervals ranging from one to four minutes of active rest (Gibala et al., 2006; Hazell et al., 2010; Hood et al., 2011; Little et al., 2011). The most commonly used work interval has been a 30 sec all-out interval (Babraj
et al, 2009; Burgomaster et al., 2005, 2006, 2007, 2008; Gibala et al., 2006; MacDougall et al., 1998). This was based on the 30 sec Wingate Anaerobic Test (WAnT) protocol, because it stressed both the alactic and lactacid anaerobic systems. The WAnT workload caused fatigue by the end of the 30 sec, and was easy to control the work intensity for each individual using the formula developed for the test.

The number of intervals, the length of the rest periods, and the length of the studies varied, but all have demonstrated increases in aerobic capacity or performance. Most have been relatively short often two to six weeks, the longest over 15 weeks. Depending on the capabilities of the lab other measures were done to determine which markers indicating aerobic capacity improvements could be seen (Gibala & McGee, 2008). The original populations were athletes (MacDougall et al., 1998) assuming they were capable of the high intensity work, but that has changed to observing untrained recreational college students (Burgomaster et al., 2005), to recent studies on adults with type 2 diabetes (Little et al., 2011). Some of the studies compared the results to more typical CET training and the results were equal if not better with HIIT (Gibala et al., 2006; MacPherson et al., 2011).

No one has compared HIIT to mixed interval training, but that type of training is normally done for performance enhancement and rarely for health related-fitness improvements. If training principles are adhered to, an athlete would follow the specificity principle and HIIT would not be a primary mode of showing aerobic adaptations, unless there were other confounding reasons. Anecdotally, it has been reported that athletes who had been injured and had reduced time to train used HIIT to allow them to compete in aerobic events (personal communication Matt Silvers).
Statement of the problem

Knowing how complex the process of adaptation is for aerobic capacity it is not unusual that there have been variations in some of the markers tested, but the consistent improvement in aerobic capacity across all the studies suggests that HIIT may have a place in aerobic training. Since all previous research has been done in a lab setting the testing and training has always been one-on-one between the researcher and the participant. A large percent of the active population enjoys doing group exercise and no study using HIIT has been done in a group setting. Since CET either walking or running is the most commonly cited form of activity in the general population a comparison was made between a group who did CET running alone to those who did HIIT running in a group on a track with the HIIT sessions lasting 20 min and the CET sessions twice or three times as long running 40 to 60 min depending on the week. Therefore, the purpose of this study was to compare adaptations in body composition and aerobic capacity in a relatively healthy college-aged population following six weeks of training between a group doing a running-based HIIT intervention and one doing running CET.

Null hypothesis

There would be no significant difference in aerobic capacity or body composition between a HIIT training group, a CET training group, and a control group after six weeks of training, tested at an alpha level of $p \leq .05$.

Operational definitions

Aerobic capacity and body composition were measured. Aerobic capacity was measured as $\text{VO}_{2\text{max}}$ in ml kg$^{-1}$ min$^{-1}$ estimated from distance covered during the Cooper 12 minute run. Body composition measures reported included body mass (BM), fat free
mass (FFM), and percent body fat (%BF). The measurement was done using air
displacement plethysmography using the BOD POD GS (COSMED USA, Concord, CA).

**Delimitations**

A convenience sample of 34 relatively healthy college-aged individuals volunteered for this study. All the participants had to be able to run continuously for 30 minutes, and answer no to all questions on the PAR-Q. Once VO$_{2\text{max}}$ was recorded from the Cooper 12 min run they were stratified randomly into one of three groups, HIIT, CET, or control. The two activity groups were over-sampled anticipating possible drop-outs or injuries and some time conflicts since the HIIT group had to train as a group at a specific time. The final counts for each group at baseline were $n_{\text{HIIT}} = 13$, $n_{\text{CET}} = 12$, and $n_{\text{Control}} = 9$. One person dropped out of the CET group and all data for that individual was removed. A one-way analysis of variance (ANOVA) was used to test for significance between groups at baseline.

**Limitations**

There are a number of limitations to this study, which need to be examined further. First, is that the HIIT group had a coach (the principal investigator) and also had numerous other people to run with during their intervention. The HIIT group met three days a week at a certain time, the principal investigator led them through a warm-up, and everyone ran together. On the other hand members of the CET group ran three times a week individually, so outside motivation may be a confounding variable in this study. This confounder was somewhat controlled by the CET group checking in with the principal investigator weekly, and the consistent RPE-based training intensity used by the CET group.
Assumptions

All participants signed a statement in the informed consent agreeing to not alter normal daily activity or eating patterns excluding study participation. There was no dietary analysis used so it must be assumed there was no change in eating behaviors. The HIIT group completed their intervention under supervision and reported their RPE following each interval, while the CET group had to run independently. The CET group did report their activity weekly so it was assumed they completed all runs in the correct time at the correct intensity.

Significance of the study

Research over the last 20 years has shown that a variety of HIIT protocols can improve aerobic capacity. All the research has taken place in a lab setting and most often using a cycle ergometer for the mode. The general public does not usually have access to a lab or a cycle ergometer (Gibala & McGee, 2008), but most are able to run. Because group exercise is also very popular, making HIIT a new class or exercise program assuming it is shown to be effective, gives trainers a new training technique. This a similar idea to the popular training programs such as Crossfit or P90X. These programs use a very intense and difficult training premise, but are paired with excitement, competition, coaching, and a group-training atmosphere.

Summary

Aerobic fitness has evolved over the last 50 years from its roots of CET and LSD training to now offering a completely different type of training that does not fit perfectly with current training principles. Using HIIT, which began as training for anaerobic metabolism, as a mode of training for aerobic capacity is an interesting conundrum? It
fits the principle of overload, but may not directly follow the principle of specificity, but
the research has shown it to be effective. Moving HIIT training from the lab to the
general public and group exercise is the next step. This chapter explained the purpose of
the study, and all the components of the research.
Chapter 2

Review of Literature

Introduction

The purpose of this study was to compare adaptations in body composition and aerobic capacity in a relatively healthy college-aged population following six weeks of training between a group doing a running-based HIIT intervention and one doing CET. The chapter provides a review of training and the training principles, adaptations with training, a review of HIIT protocols, and the physiological and performance adaptations seen with HIIT.

Training and Training Principles

Training for physical fitness is highlighted by performing physical activity, eating a well-balanced diet, maintaining a healthy body-composition, and disease prevention (Hoeger & Hoeger, 2012). Training an athlete involves preparing the individual for the highest level of performance physically, technically, tactically, psychologically and theoretically (Harre, 1982). The training techniques developed from practice and research are designed to produce desired adaptations either for health or performance by utilizing foundational training principles. Two of the principles, progressive overload and specificity together create optimum performance.

**Principle of progressive overload.** A system or a muscle has to be progressively overloaded to show continuous positive adaptations. A common example of progressive overload is the legend of Milo of Crotona. Milo carried a young calf the length of the Stadium of Olympia (200 m) every day. As the calf progressively got bigger, Milo’s body adapted to the increasing stress, so he was able to continue to lift the calf as it grew.
(Ratamess, 2012). For the body to continuously adapt, a progressing stimulus must be applied to the desired system for an extended period of time. The purpose of overload is to create fatigue to force the system to adapt and resist the fatigue the next time the stimulus is applied (Baechle & Earle, 2008; Hoeger & Hoeger, 2012) As the overload continues, the system will adapt to the increased physical demand and continue to progress in response to training (McArdle et al., 2009). Overload is accomplished by either increasing intensity (workload), an increase in time/duration or volume of training, or increasing the frequency of training (Hoeger & Hoeger, 2012). The overload principle can be applied to athletic performance, weight loss, general training for fitness, or a clinical training population. Overload can be general, applied to the whole body, or can be very specific, applied to a particular muscle fiber (Katch et al., 2010).

**Principle of specificity.** The principle of specificity states that all training and physiological adaptations are specific to the stimulus being applied (Katch et al., 2010). Thus, for a muscle or a system to adapt, the training stress must be designed specifically for the desired improvement (Hoeger & Hoeger, 2012). The specificity principle can be applied to the metabolic demands of an activity or sport or it can be applied to a skill (McArdle et al., 2009). In either case the overload stimulus or SAID – specific adaptation to imposed demand, needs to be specific to the desired outcome (Hoeger & Hoeger, 2012; Stone, Stone, & Sands, 2009)

**Health-related physical fitness components.** There are five health-related physical fitness components that are associated with prolonged training. One of the most commonly measured and sought after improvement is advancement in cardiorespiratory endurance (Ratamess, 2012). This component is based on the body’s efficiency in getting
oxygen from the cardiorespiratory system to the muscles doing aerobic metabolism.

There are three components related to the muscles, strength, endurance, and flexibility. Muscular strength, is the ability of the skeletal muscle to produce a maximal or submaximal force (Hoeger & Hoeger, 2012). Muscular endurance is a measure of the muscles ability to resist fatigue when a given stimulus is continuously applied to the muscle. Muscular flexibility is the muscles’ ability to stretch and react when a bone or joint is moving through a range of motion, without straining or injuring the muscle fibers (Baechle & Earle, 2006). Muscular flexibility is strongly associated with the ability to perform activities of daily living (Hoeger & Hoeger, 2012). The final component is body composition, which is reported as the body’s total mass, total fat mass, and total fat free mass (McArdle et al., 2009). All of the risk factors with many of our lifestyle related diseases are associated with excess body fat and obesity thus making body composition a very important factor in physical fitness.

More than fifteen years ago the Surgeon General, the National Institute of Health, the American College of Sports Medicine (ACSM), combining with the Center for Disease Control and Prevention (CDC) issued important publications on health and fitness (Thompson, Gordon, & Pescatello, 2010). The publications highlighted the need for physical activity, and the strong association with sedentary behavior and the climbing obesity rates in America (Blair et al., 1996). The Surgeon General’s Report in 1996 for the first time suggested a minimum amount of moderate intensity activity of 30 min accumulated through the day on most days of the week (Pate et al., 1996). Of the most commonly cited causes for the rising obesity rates in American is lack of physical activity (U.S. DHHS, 2001). For this reason in 2001, the Surgeon General made a call to action in
an attempt to get people moving, highlighting many factors that have lead to the obesity epidemic (U.S. DHHS, 2001). The Surgeon General’s most recent exercise prescription includes in addition to the 30 minutes per day requirement; 2.5 hours per week of moderate intensity exercise, or 1.25 hours per week of vigorous intensity training, or a combination of the two. The Surgeon General also added a suggestion of two days of non-consecutive strength training working all muscle groups (“Physical activity guidelines,” 2008).

**Frequency, Intensity, Time, and Type (FITT).** This acronym is often used to describe the four variables that can be altered for training: Frequency (times in a week), Intensity (how hard), Time (quantity and duration), and Type (mode). FITT is often used to implement and control rate of progression in training to assure fatigue is achieved. Manipulations to any of the training variables can alter program outcomes (Thompson et al., 2010). These four FITT variables are often used to apply the principle of progressive overload, and the principle of specificity.

Although type, or mode, of training is the last letter in the FITT acronym it is often the most influential variable in program design. An alteration of the mode can make the training program very applicable to outcome goals and the specificity of the training system (Hoeger & Hoeger, 2012). For example, an athlete training for a marathon may use multiple modes of aerobic exercise during training, but the desired outcome is specific to running, so running will comprise most of the training program. If a member of a clinically supervised population is able to walk but unable to run during exercise all other FITT variables will be affected. There are many aerobic and anaerobic activities to
choose from when designing exercise programs, so metabolic requirements should be considered as well to assure specificity of training (Hoeger & Hoeger, 2012).

Mode of exercise is also a very important facet related to enjoyment of training and, ultimately, program adherence. If an individual enjoys exercise they are more likely to continue long-term (Trost et al., 2012). Based on the high numbers of sedentary Americans, the idea of enjoyment and training adherence is a very important facet of health and fitness.

Frequency of training controls the number of exercise bouts performed in a given time frame. The number of training sessions in one week is a common measurement. Training frequency will vary based on desired goals and the experience of the participant. A novice exerciser will most likely not need to, or be able to, train as often as an experienced exerciser (Hoeger & Hoeger, 2012). Additionally, frequency changes are based on the objectives of the training program. Just like a competitive athlete may require more training sessions each week than a recreational athlete, the goals of the general public require variable training frequencies as well. Adaptations are based on a progressive overload to the system, and that overload will be different based on the fitness or strength of the individual (Hoeger & Hoeger, 2012; Katch et al., 2010; McArdle et al., 2009). The overload of the training stimulus has to be specific to the desired adaptation.

Intensity of exercise refers to the workload applied to the body during activity (Hoeger & Hoeger, 2012). There are many different techniques to measure intensity during exercise. One of the most commonly used methods of measuring intensity during aerobic activity is heart rate (Pollock, Broida, & Kendrick, 1972). Since heart rate and
oxygen consumption are linearly correlated during activity, heart rate is frequently used as an indicator for intensity during aerobic exercise (Devan, Lacy, Cortez-Cooper, & Tanaka, 2005). Additionally, measuring heart rate is relatively easy to do, by palpation of the wrist or carotid artery or by wearing a heart rate monitor. The criterium for using HR to measure intensity is the activity must be continuous and at steady state. Therefore, measuring heart rate to determine intensity may not be feasible for some high intensity exercises due to varying and intermittent bouts. Anaerobic work is often completed before the heart rate and circulatory system has even registered that the intensity has increased.

Thus it is necessary to have other measures than heart rate for all activities that do not develop steady state. The Rating of Perceived Exertion (RPE) is a subjective measurement of the workload experienced by the participant during exercise. RPE is either measured on a 0-10 scale – for intermittent exercise, or a 6-20 scale for continuous exercise because it is based on heart rate (Borg, 1998). Both heart rate and RPE are commonly used because they are easy for participants to learn, and do not require equipment, but RPE is only as good as the training used when the participant is learning to use the scale (Hoeger & Hoeger, 2012).

Changing percentages of maximum lifts, maximum heart rates, or VO$_{2\text{max}}$ can alter intensity. Examples of such include: 70% of one-repetition maximum power clean, 90% of maximum heart rate, or 100% of VO$_{2\text{max}}$. Varying intensity will determine which training system or muscle fiber type is being used and trained. A very high intensity exercise would primarily be training the anaerobic system (FT muscle fibers), and a low to moderate intensity exercise would be training primarily the aerobic system (ST muscle
fibers) (Baechle & Earle, 2006). Altering intensity of training ties directly into the specificity principle; the metabolic stimulus must be specific to the metabolic goal. Intensity is an important variable to manipulate based on the desired system adaptations and performance goals of the training and to assure fatigue happens with each bout.

Aerobic endurance training can be altered through changing time, or duration in minutes or hours. An overload can be put onto the system by simply increasing the duration of the stimulus. Strength training time is based on completing a certain number of repetitions or a set volume. The reps and/or volume can be changed to set up a progressive overload, as well as planning for periodization. As shown in the Surgeon General’s current recommendation, intensity and time are inversely proportional. As intensity increases, the time can decrease, while still attaining the same physical fitness goals put more simply if you are going to walk you have to walk longer, but if you run you can be done sooner (Hoeger & Hoeger, 2012). Time or duration can be altered based on experience of the individual, as an example: an experienced runner may have to run much further than a novice runner to get the same training results (Hoeger & Hoeger, Katch et al., 2010).

The concept of FITT varies depending on the goals of training, and experience of the individual based on their response, needs, limitations, adaptations to exercise as well as the evolution of goals and objectives of the exercise program (Hoeger & Hoeger, 2012). The FITT principle is the basis of altering for periodization, and changing each variable can adapt and progress the program for desired goals.

**General Adaptations Syndrome (GAS).** It was suggested that fatigue is required as the result of progressive overload for adaptation to take place. This can be described as
GAS. When a stressor or a stimulus places an overload on a system or a muscle, this disrupts homeostasis. The reaction to the overload is explained through the General Adaptation Syndrome (GAS) (Stone et al., 2009). General adaptations syndrome has three response phases to the stressors. First is an alarm or shock reaction, the stressor causes a physiological reaction, in turn causing an adaptation. If the stressor subsides, the body system will return to homeostasis, and turn off the shock reaction. In regards to physical training, the first phase consists of both a shock to the system as well as soreness of the muscles. The second phase occurs if the stressor continues and is known as the adaptation or resistance phase of GAS (Selye, 1956). The body will initially resist the stressor, trying to return to homeostasis. If the stressor continues the body will adapt to the stressor, and become stronger, and an improvement in performance is to follow. As the stressor continues the third phase, exhaustion/recovery occurs due to the high training stimulus. Eventually, if appropriate rest or recovery does not accompany the stressor, the body will stop adapting and may result in injury (Selye, 1956). Unless the stressor is decreased or altered, over-training could occur. If the body is able to rest the body will recover, and could properly adapt and performance can improve further. The principle of GAS is the reason why periodization is needed to ensure adaptations can continue (Zatsiorsky, 1995).

**Periodization.** Traditional periodization models separate the overall training program into three specific time periods (Baeche & Earle, 2008). The largest time period, a macrocycle, often includes the entire training year, but could range from a couple months up to a four-year training cycle for Olympic athletes. Macrocycles are often broken up into smaller cycles called mesocycles that can last several weeks to several
months. Lastly, mesocycles are made up of smaller cycles, called microcycles, that last one to four weeks long (Hoeger & Hoeger, 2012) These three cycles can be made up into an entire periodization program for any type of specific goal.

An example of a periodization plan can be broken up into a preparatory phase (general fitness), first transition phase (transition from prep to competition), competition phase, and a second transition phase (active rest after competition phase) (Baechle & Earle, 2006). The entire season is the macrocycle, and each of the four phases is a mesocycle of the program. The preparatory mesocycle can be broken up into three microcycles of hypertrophy/endurance, basic strength, and strength/power (Baechle & Earle, 2006). The periodization program can be systematically altered to assure peak performance at the end of the season, and to peak at different times in the season if need be (Stone et al., 2009). Regardless of goals of the training program, putting periodization plan in effect can help keep the progression of the overload, and result in continuous adaptations.

Chronic training can cause numerous adaptations for both performance, and health related benefits. Utilizing these principles of training, and creating a periodization program can cause many of those adaptations (Baechle & Earle, 2006; Hoeger & Hoeger, 2012). To completely appreciate the health and endurance performance benefits that ensue with chronic training, one must understand the physiological adaptations that are occurring in the central and peripheral system.

**Physiology of Training**

To improve any metabolic system a series of changes or adaptations must occur. Depending on the system being altered, the process can be relatively simple or it can be
very complex (McArdle et al., 2009). For the two metabolic systems, anaerobic is relatively simple while aerobic is complex. Anaerobic adaptations happen in the muscle fiber but aerobic includes three systems, the respiratory, the cardiovascular, and two different muscle fiber types, which are sometimes called central – the cardiorespiratory changes, and peripheral, the muscle fibers.

When considering the anaerobic system the adaptations are occurring in the FT muscle fibers. There are only a few changes that can occur internally so the muscle has to hypertrophy before performance can be enhanced further (McArdle et al., 2009). Following the principles of training to enhance anaerobic performance, overloading the muscle forces the adaptations, and the type of overload needs to be specific to the outcome desired, whether it is power, speed, strength, or something else (Hoeger & Hoeger, 2012). It is understood that the internal adaptations in the muscle happen in a matter of weeks, and at that point the cycle for hypertrophy becomes the limitation for continued improvement (Baechle & Earle, 2006). Hypertrophy generally takes six to eight weeks to complete one cycle. Relating adaptations of the FT fibers to periodization, the microcycles can be one to two weeks, and the mesocycles six to eight weeks (Bompa & Haff, 2009).

For aerobic metabolism the process is much more complex requiring changes in ST and/or FT IIa muscle fibers, and changes to the delivery system. Most of the delivery changes take place in the cardiovascular system, but some adaptation can and does occur in the respiratory as well (Katch et al., 2010; McArdle et al., 2009). As a result it has been well established that to effectively train for an endurance event or activity, training of the cardiorespiratory system is essentially the same for either muscle fiber type, but the
overload must be specific for the different muscle fibers (Hoeger & Hoeger, 2012; Katch et al., 2010). Research on specificity of training has shown that one form of training is not able to train as effectively as combining training modes (Stone, Stone, and Sands, 2009).

**Central adaptations.** The cardiovascular system transports oxygen and nutrient rich blood to the skeletal muscles. The cardiovascular system consists of the heart, and the blood vessels, that transport the blood to the periphery (arterial system) and back to the heart (venous system) (Saltin et al., 1968). When the muscle has been overloaded the cardiovascular system adapts to deliver oxygen and nutrients to the muscles so they can function more efficiently. The adaptations within the cardiovascular system occur at different times and for different reasons and thus the training needs to be specific so the system will adapt appropriately for the muscle fiber’s need.

Aerobic metabolism requires oxygen to function, thus if sufficient oxygen is not readily available, the aerobic system will fatigue and performance will suffer. The muscle fibers can store oxygen in myoglobin, but often more oxygen is required than is available in the myoglobin so the delivery system must adapt (McArdle et al., 2009; Katch et al., 2010). As an individual takes part in a lower intensity continuous aerobic training program such as CET, the ST fibers are doing most of the work so adaptations happen in the cardiovascular system based on the fiber demands, leading to improved aerobic capacity of the fibers and improved aerobic performance overall.

The cardiovascular system is a closed system and the function of the heart is to make sure the finite amount of blood available is sent in the right quantity and to the right location. To increase the volume of blood sent to the muscles the flow must go faster. For
that to happen the heart rate increases increasing the amount of blood circulated every minute. The amount of blood leaving the heart with every beat is called the stroke volume, and that combined with the number of beats in a minute gives us the cardiac output. The cardiac output can be influenced either by the stroke volume or the heart rate, as well the vascular resistance and venous return, because if blood is not returning to the heart the cardiac output will not increase no matter how fast the heart is beating (Blomqvist & Saltin, 1983).

The increase in heart rate is the normal acute reaction that happens when a muscle is contracted and demands more oxygen, but the heart rate is genetically determined for how high it can go so it is the least effective change, i.e., maximum heart rate does not increase with training (Daussin et al., 2007) With chronic training, the ventricle dilates as more blood is moving through the system, thus pumping more blood each time it contracts, which is an increased stroke volume (Clausen, 1977). Eventually the heart muscle hypertrophies so it can increase the strength of each contraction and increase the stroke volume again. This means a higher cardiac output each time stroke volume increases (Blomqvist & Saltin, 1983).

When the need for oxygen drives the blood to increase the number of red blood cells to provide more hemoglobin the plasma volume must also increase to move the cells effectively (Katch et al., 2010; McArdle et al., 2009) The blood volume increases about a liter as a result of these two changes from five to six liters, so the vascular system has to respond to carry the larger volume. The arteries dilate effectively decreasing vascular resistance, and the muscles especially in the legs help move blood back to the heart every time they contract. The greater blood volume and the muscle contractions increase the
venous return back to the heart which by Starling’s Law of the Heart means greater strength of contraction and thus greater stroke volume again (Blomqvist & Saltin, 1983; Saltin et al., 1968). As a result, the total cardiac output continues to increase each time a different adaptation occurs, leading to an increase in oxygen and nutrients being transported to the skeletal muscles and other organs (Andrew, Guzman, & Becklake, 1966).

Along with the other adaptations seen, the decreased vascular resistance is usually accompanied by an improvement in systolic and diastolic blood pressure (Clausen, 1977). Hypertension is a known risk factor for cardiovascular disease, so a decrease in blood pressure with exercise is an important adaptation for health as well as performance (McArdle et al., 2009).

All of the adaptations in the cardiovascular system with chronic exercise lead to an increase maximal aerobic capacity (VO\(_{2}\text{max}\)), though the literature on no change with chronic training is not as conclusive on increased performance. The aerobic capacity measures the body’s efficiency in transporting oxygen to the rest of the body (Andrew et al., 1966). As the VO\(_{2}\text{max}\) increases, the cardiovascular system is able to transport more oxygen to the periphery (Clausen, 1977). Any improvement in VO\(_{2}\text{max}\) occurs via a combination of all the adaptations just discussed (Clausen, 1977). As the cardiovascular system is adapting to a chronic exercise stimulus and providing more oxygen, changes are also happening in the periphery in both the ST and FT IIa fibers.

**Peripheral adaptations.** To begin the discussion of peripheral adaptation it is necessary to understand that there are two different muscle fibers types (Katch et al., 2010). Skeletal muscle incudes ST muscle fibers, and FT muscle fibers, Type IIa and
Type IIb (Staron, 1997). These muscle fibers have many structural differences, adapt to different modes of stimuli, change at various rates, and are fueled very differently (Scott et al., 2001).

ST muscle fibers have slow contractility and relaxation rate, but are very slow to fatigue. The high fatigue resistance makes the ST twitch muscle fibers ideal for long-slow aerobic exercise such as jogging, swimming, cycling or any moderate intensity activity as well as all the activities of daily living. ST fibers therefore make up about 60% of all muscle fibers in the body. These aerobic muscle fibers require large amounts of oxygen to function (Scott, 2001; Staron, 1997). Fat is the primary energy source as free fatty acids for the ST muscle fibers and to completely metabolize the fats a large amount of oxygen is needed (McArdle et al., 2009).

To supply that amount of oxygen several characteristics are present. The fibers have myoglobin to hold oxygen in the fibers, and the muscles have a vast vascular bed so the blood can deliver oxygen quickly (McArdle et al., 2009). But even with these adaptations the rate of oxygen delivery cannot keep up with the oxygen requirement when the contraction rate gets too high at about 60% of VO \(_{2\text{max}}\) (Carter et al., 2001). In order to overload these muscle fibers, they must work at a higher intensity level, or increase the amount of time the fibers are being worked. This will result in several internal changes.

These fibers contain high amounts of mitochondria and myoglobin in order to facilitate oxygen transport (Scott et al., 2001). Mitochondria are the location in the fiber where aerobic metabolism takes place. To increase the aerobic capacity the mitochondria can increase in size and number. The larger they are the more aerobic enzymes are
necessary, and the more myoglobin must be present. CET or LSD training is the optimal type of training to see positive adaptations in ST muscle fibers because they are so fatigue resistant (Staron, 1997).

Of the two types of FT fibers only Type IIa fibers are capable of aerobic and anaerobic metabolism. Because they can be both, that means the specificity of training principles are extremely important. Type IIa fibers have a moderate to high power output, and are moderately fatigue resistant (Katch et al., 2010; McArdle et al., 2009). Type IIa muscle fibers have low to moderate levels of mitochondria and myoglobin in an untrained state because they are naturally an anaerobic fiber. Both can be increased with chronic training (Scott et al., 2001).

The low number of mitochondria means they will increase the number sooner than the ST fibers with the same training intensity. They burn glucose as their fuel either anaerobically or aerobically and the amount of oxygen required to metabolize glucose aerobically is much less than the amount required for ST fibers so until there is an increase in the number of mitochondria there is no need to increase the amount of myoglobin because oxygen delivery by the blood should be sufficient (Katch et al., 2010; Hawley & Stepto, 2001).

The more the FT IIa fibers are trained aerobically, the more capable they are of performing aerobic metabolism because they will increase myoglobin levels, agreeing with the principle of specificity. The training has to overload the aerobic capacity, which happens at higher but continuous training such as a 400-m sprint, or a 500-m row (Katch et al., 2010).
Type IIb muscle fibers are purely glycolytic fibers that use carbohydrates instead of fats to function (Katch et al., 2010; McArdle et al., 2009). These purely anaerobic muscle fibers have a very fast and powerful contraction and relaxation rate, but are extremely susceptible to fatigue (Baechle & Earle, 2006). The primary method of overloading Type IIb muscle fibers is increasing the intensity, speed, or weight of the exercise to a very high level (Baechle & Earle, 2006). Some examples of exercises that train Type IIb muscle fibers are short sprints, power lifting, plyometrics, anything that is short, quick and powerful.

**Adaptations in body composition.** Along with the adaptions in the central and peripheral system, is an improvement of body composition. Body composition can be measured by; skin fold test, air displacement plethysmography (BOD POD GS, COSMED USA, Concord, CA), bioelectrical impedance, hydrostatic weighing, or a DEXA scan (Katch et al., 2010). These measurements can determine an individuals total body mass, body fat, and lean body mass. In recent years, body composition has become increasingly important due to the lack of physical activity, and the high and climbing obesity rate. Due to the prevalence of disease and morbidity correlated with obesity, and over fatness government officials and American’s in general were concerned. (Must et al., 1999). The Surgeon General’s made a call to action that sought out to make a change in the climbing obesity rates, and to push America to get moving (U.S. Dept. of HHS, 2001).

The body needs energy or calories to function, thus the more the body moves and at a higher intensity, the more calories it uses. Put simply, an energy or caloric deficit is required in order for weight loss to occur (Hoeger & Hoeger, 2012; McArdle et al., 2009.
This means that the calories ingested through food and liquids throughout the day, have to be less than the calories the body burns through exercise and activities of daily living (Chambers & Swanson, 2012). Basal metabolic rate is the amount of calories the body works at rest; thus the amount of calories burnt through movement and the basal metabolic rate must be greater than the calories taken in. Since a 3,500 kcal is a pound, one must attain a 3,500-7,000 kcal deficit a week, to lose 1-2 pounds (Hoeger & Hoeger, 2012). Due to a lack of activity of a fair amount of Americans that are not attaining a caloric deficit, or burning enough calories to maintain weight, many continue to gain weight (U.S. Dept. of HHS, 2001). Two of the most commonly cited factors for people not getting enough physical activity is the lack of time, and the lack of enjoyment during training (Trost et al., 2002). This led to the question of: Is there a less time intensive form of training that will show the same results as the CET or LSD training?

**High Intensity Interval Training (HIIT)**

Originally, following the principals of training, high intensity training was used to adapt anaerobic FT fibers, and the low-moderate intensity training was used to adapt the aerobic ST fibers. Studies observed difference in training techniques between high intensity training, and moderate intensity training, and unexpectedly found aerobic capacity improvement with the high intensity training (Eddy et al, 1977). This started an aerobic training trend known as High Intensity Interval Training (HIIT) (Gibala & McGee, 2008). Researchers began to examine HIIT in regards to all of the physiological and performance adaptations only thought to be attributed to the high-volume low intensity aerobic training (Gibala & McGee, 2008). Originally thought to be too intense
and taxing on a clinical population, HIIT has recently been looked at in a clinical and sedentary population (Gillen, 2012; Hood et al., 2011; Little et al., 2011).

The primary goal of HIIT during an interval is to elicit a depletion of glycogen stores, causing an increase in muscle lactate, leading to a negative pH response. Once the interval stress is completed, the lactate will begin to return to homeostasis, and the pH will return to normal. Once the muscle is partially-fully recovered another interval is performed. By the end of the session (last interval or two) heavy fatigue should be in effect, and the body should not be able to recover fully before the next interval. High intensity interval training is generally thought to be repeated session of an “all-out” or intense interval, followed by a less intense rest/recovery period (Gibala & McGee, 2008). The work interval is usually at an intensity ≥90% of VO₂max lasting from a few seconds up to a couple minutes. The rest period usually lasts a minute to several minutes to assure the body returns back to or near homeostasis (Gibala, 2007). High intensity interval training protocol commonly utilize and inverse ratio with intensity and time, hoping to attain similar results using different protocols. As an intensity of a HIIT protocol increase, the duration of the protocol can decrease, and the rest period can increase. The same goes with an decrease with intensity, leads to an increase in workload time, with a decrease in rest period (Little et al., 2010). This is demonstrated by two very common protocol that gained similar results: The first using a 30-s all-out interval with a 4-min rest period, completing 4-6 interval (Astorino et al., 2011, 2012; Burgomaster et al., 2005, 2006, 2007, 2008; Gibala, et al., 2006; MacDougall et al., 1998) The second using 1-min of work at 90% of maximum heart rate, followed by one minute of rest, completing the intervals ten times (Gillen et al., 2012; Hood et al., 2011; Little et al.,
2010, 2011). These protocols and others have sought out to measure many of the peripheral, central, and performance adaptations seen with CET training.

**Physiological adaptations with HIIT.** Although HIIT training utilizes only a fraction of the time commitment a LSD or CET program uses, HIIT has seen many of the same adaptations. In as little as six HIIT sessions, an improvement in exercise performance/capacity has been seen ranging from 9.6% increase (Burgomaster et al., 2006) to a 100% increase (Burgomaster et al., 2005) in exercise capacity, effectively doubling the amount of time to exhaustion. Aerobic capacity, however, has been more controversial seeing mixed results in VO$_{2\text{max}}$ measurements with shorter HIIT protocols. Two study showing no significant results in regards to VO$_{2\text{max}}$ (while still showing peripheral adaptation markers) (Burgomaster et al., 2005; Gibala et al., 2006), while numerous other studies utilizing the same protocols have shown significant results (Astorino et al., 2011, 2012; Hazell et al., 2010). Although, HIIT protocols any longer than two weeks consistently show significant improvement in aerobic capacity (Burgomaster et al., 2008; MacDougall et al., 1998; MacPherson et al., 2011). It seems as though there is a minimum amount of HIIT training required to see a consistent improvement in aerobic capacity.

Along with the improvement in aerobic capacity and endurance performance, are the coinciding physiological adaptations in the central and peripheral system. One of the first adaptations seen with a CET as well as HIIT is an improvement in the aerobic enzymes, cytochrome oxidase and citrate synthase (Burgomaster et al., 2005, 2008; Gibala, et al., 2006). These adaptations are directly correlated to an increase in oxidative capacity (Gibala & McGee, 2008). Additionally, is an increase in mitochondria size and
number, effectively increasing oxygen being transported to the muscle (Gibala, 2009). The increases are most likely in both the FT and ST fibers but may be in different ratios, as both can adapt with training.

Along with the increase in oxidative capacity and the physiological variables that come with HIIT and CET there is also an improvement in fat and carbohydrate metabolism (Gibala & McGee, 2008). High intensity interval training increases fat oxidation, as well as conserving the glycogen stores during exercise (Perry et al., 2008; Talanian et al., 2006). The glycogen stores are conserved, even though there is an increased amount of stored glycogen at rest due to the training intervention (Burgomaster et al., 2005; Perry et al., 2008). This might suggest that the FT Ila fibers are beginning to adapt, but the ST adapt more quickly and are carrying the majority of the increased aerobic capacity. A chronic HIIT protocol causes a decrease in lactate build-up (Bayati et al., 2011; Burgomaster et al., 2005), and an increased lactate recovery during rest (Bayati et al., 2011). Along with the improvements in lactate and glycogen stores, were also increases in ATP and PCr production in the FT muscles (Burgomaster et al., 2008). This would suggest that the FT IIb fibers are also adapting to the stimulus.

Not only does HIIT show improvement in aerobic capacity and the muscles, but there may also be physiological adaptations in the cardiovascular system. Although adaptations in the muscles and endurance performance have been consistent, HIIT’s effect on central improvements is not as conclusive (Astorino et al., 2012; MacPherson et al., 2011). It seems as though there is a minimum amount of HIIT sessions need (>2-weeks) to elicit adaptations in stroke volume, heart rate, cardiac output, or plasma volume
(Daussin et al., 2008; Trilk et al., 2011). Additionally, a population with a lower fitness level at baseline is able to show adaptations more quickly in the cardiovascular system.

Continuous endurance training is known to be effective in improving body composition because of the capacity to burn calories during the high-volume long duration exercise (Hoeger & Hoeger, 2012). HIIT, however, is focused around low-volume, time efficient training, thus not thought to cause enough of a caloric deficit to affect body composition changes (Gibala & McGee, 2008; Gillen, 2012. Therefore it is difficult to explain how HIIT has consistently shown improvement in in body composition in protocols lasting at least six weeks (MacPherson et al, 2011; Trapp et al., 2008). One possible explanation is some of the body composition changes may be attributed to an increase in FFM, and not actually much of a loss of total body fat when reporting as a percent rather than actual fat loss (MacPherson et al., 2011). In at least one study that measured with DEXA (Trapp et al., 2008) changes in fat location were seen. A decrease in abdominal fat was seen in the HIIT group but not in the CET group which is consistent with research that suggests that fat location may be more important than the actual percent (Blair et al., 1996). Although the mechanism for body composition changes with HIIT is still controversial, a decrease in appetite after the interval sessions may be a part of the cause (Trapp et al., 2008). Moreover, over time an increase in FFM is known to cause an increase in caloric burn, thus possibly contributing to a change in body fat.

**Conclusion**

As lack of time is one of the most commonly cited reason for people not getting enough physical activity, observing training method that takes up less time is the clear
next step. If the goal were to decrease time-spent training, the obvious alteration would be to make the intensity higher to make up for the decrease in duration. A substantial amount of research has been done on HIIT programs in the last twenty-years. It has been shown to elicit many of the same improvement as CET in as short as a two-week protocol. Both peripheral and central adaptations are found when using a HIIT protocol, but it seems that a certain amount of time and volume are needed to show adaptation peripherally in a healthy population. Although, it remains inconclusive how effective different modes of HIIT are, exactly how much work does it take to show many of the adaptations that are seen.
Chapter 3

Methods

Introduction

The purpose of this study was to compare adaptations in body composition and aerobic capacity in a relatively healthy college-aged population following six weeks of training between a group doing a running-based HIIT intervention and one doing CET. This chapter reviews participants and sampling, testing protocols and instruments, procedures for the running-based HIIT and CET program, and statistical data analyses.

Participants

A convenience sample of 34 relatively healthy college-age men and women volunteered to take part in this study. All participants were relatively healthy based on the PAR-Q by answering no to all questions, and all had to be able to run continuously for 30 min. Participants were stratified randomly into one of the three groups based on similar VO$_{2\text{max}}$ results from the Cooper 12 min run. The HIIT and the CET group were over-sampled anticipating possible drop out or injury, and time conflicts because the HIIT group had to train at a particular time. At baseline, the groups were $n_{\text{HIIT}} = 13$, $n_{\text{CET}} = 12$, $n_{\text{Control}} = 9$. One participant had to drop out of the CET group, and all of their data was removed. A one-way ANOVA calculation was used to determine that the groups were not significantly different at baseline.

Instruments and Measurements

This study used air displacement plethysmography to measure body composition using the BOD POD Gold Standard (COSMED USA Inc., Concord, CA), and the 12 min Cooper Run test to estimate VO$_{2\text{max}}$. The BOD POD GS (COSMED USA Inc., Concord,
CA) measured the participants’ body volume, and with the participants’ body mass, determined their body density. Once body density was assessed, body composition could be measured using the SIRI equations. The Cooper 12 min run test estimates \( V_O^{2max} \) by assessing the total distance covered by the participants in 12 min. This test was validated in 1968 when Cooper measured a correlation of .90 between the Cooper 12 min run results, and gas analysis \( V_O^{2max} \) results (Cooper, 1968). Both tests were performed pre and post the 6-week training intervention.

Table 1. Pre test means ± standard deviation, for all groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total</th>
<th>HIIT</th>
<th>CET</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>M (18), F (15)</td>
<td>M (6), F (7)</td>
<td>M (6), F (5)</td>
<td>M (6), F (3)</td>
</tr>
<tr>
<td>Age</td>
<td>22.55 ± 2.87</td>
<td>23.15 ± 3.46</td>
<td>21.73 ± 3.04</td>
<td>22.67 ± 1.41</td>
</tr>
<tr>
<td>Aerobic Capacity</td>
<td>44.73 ± 6.31</td>
<td>44.72 ±7.11</td>
<td>43.51 ± 5.90</td>
<td>46.25 ± 5.95</td>
</tr>
<tr>
<td>(ml·kg(^{-1})·min(^{-1}))</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body Mass (lb)</td>
<td>171.66 ± 41.12</td>
<td>159.59 ± 37.38</td>
<td>174.19 ± 37.74</td>
<td>186.01 ± 49.07</td>
</tr>
<tr>
<td>% Body Fat</td>
<td>16.99 ± 7.11</td>
<td>17.59 ± 7.65</td>
<td>17.85 ± 5.56</td>
<td>15.06 ± 8.34</td>
</tr>
<tr>
<td>Fat Free Mass (lb)</td>
<td>142.77 ± 36.26</td>
<td>132.6 ± 37.14</td>
<td>143.47 ± 34.35</td>
<td>156.59 ± 36.50</td>
</tr>
</tbody>
</table>

The HIIT intervention was a 1:1 work to rest ratio following the research conducted by Little et al., (2011) with 10 x 60 sec repeats or an all-out sprint followed by active, walking recovery (Hood et al., 2011; Little et al., 2011). There was no change in the number of intervals through the six-week intervention because the intensity was based on an RPE of 9-10 on the RPE Borg CR10 scale. The HIIT program began on the indoor track where eight laps equals one mile (200 m track). After one week of training inside, once the weather improved training moved to the outside track where four laps equals
one mile (400 m track). All runners trained together and were supervised by the principal investigator who recorded an RPE for each runner following each high intensity interval.

The CET running protocol was based on previous research that included CET as a variable (Burgomaster et al., 2008; MacPherson et al., 2009). Burgomaster et al., (2008) compared a biking CET to a biking HIIT, and MacPherson et al., (2011) compared a running CET to a running HIIT. The protocol was changed every two weeks, altering the Time variable of FITT to overload the system. The protocol was changed every two weeks with the overload for the training done by increasing time from 40 min to 50 min to 60 min. The participants had to keep the intensity at an RPE of 4-5 on the RPE Borg CR10 scale for the entire time.

**Procedures**

Prior to beginning the study, the procedures and protocols were reviewed and approved by the Eastern Washington University Institutional Review Board (IRB) to assure the safety and well being of the participants. Following approval from the IRB committee, selection for the study began. Recruitment was done by setting up signs in the URC fitness center, around campus, in the dorms, and in the Physical Education Classroom building. All volunteers were contacted and asked if they could run continuously for 30 min and asked to fill out a PAR-Q to ensure that the participants were healthy enough to take part in the study. If the participants checked “yes” on any of the questions in the PAR-Q they were excluded from the study. Once enough volunteers had been recruited an informational meeting was held.

At the informational meeting all participants were briefed on exactly what was expected of them throughout the study. This included their pre- and post-testing, and the
Pre- and post-test measurements. Two tests were done before and after the intervention for all participants. Body composition analysis was done using air displacement plethysmography to estimate body volume (BOD POD GS, COSMED USA Inc., Concord, CA). First the subject disrobed into minimal clothing and got their body weight measured by standing on a calibrated scale connected to the BOD POD software. Then the BOD POD GS measured the air displacement in the empty chamber, against a known volume, and again when the participant is in the chamber. The body volume equals the reduced air volume when the subject enters the chamber. Once the body volume was measured, body density was determined using total body mass and the body volume. From body density body fat percentage, fat free mass, and total body mass of the participants was determined.

The second test was a 12 min Cooper Run Test to estimate aerobic capacity. The Cooper Run Test was completed on a 200 m indoor track. The estimate of VO_{2max} was based on the total distance covered in 12-min. To be a valid test the participant is supposed to run at the fastest speed possible that they can run for 12 min (Cooper, 1968). That was explained to all participants and they were encouraged to not stop and walk but to run continuously for the full 12 min. Time was announced at regular intervals during the run. At 12 min each participant stopped and the distance covered to the nearest 50 m...
was recorded. Once the distance in meters was established, the maximal oxygen consumption (VO$_{2\text{max}}$) was estimated using the VO$_{2\text{max}}$ table provided with the test (Beam & Adams, 2010; Cooper, 1968).

**HIIT protocol.** The HIIT group had to undergo further briefing to assure proper technique and intensity during the HIIT protocol. This was done prior to the first HIIT session. Before beginning each HIIT session all participants completed a set dynamic warm-up for 5-10 min. After the warm-up the participants began the HIIT running session with a 1:1 work to rest ratio (Hood et al., 2011; Little et al., 2011). One HIIT interval was 60 sec of all-out running followed by 60 sec of active rest (walking) and 10 intervals were completed during each session. During each rest period the principal investigator asked the participants’ RPE to estimate their perceived exertion. The distance covered was not a factor, only the intensity of the run.

Because this was a running protocol the workload could not be controlled as it can be with a cycle ergometer. Therefore, prior to beginning the training regiment, participants were told that each workload interval was to be an all-out effort for the entire minute. The participants were familiarized with RPE as a measure of intensity, and told that they should be at an RPE of a 9-10 on the Borg CR 10 scale (Borg, 1998). This had to be as hard as the participants could go for a minute, and elicited high fatigue levels by the end of the session. To assure an all-out effort everyone ran together and individuals were “cheered on” during each interval.

**CET protocol.** The CET group completed all training sessions independently. Prior to beginning each CET session, participants completed a 5-10 min easy walk or jog to warm-up. The CET intervention was 40, 50, or 60 min of running, three days a week,
for six weeks. The first two weeks the participants jogged for 40 min, increased to 50 min the next two weeks, and finally 60 min the last two weeks. Instead of a set percentage of effort, like other studies, CET participants were advised to run at an intensity of a 4-5 based on the Borg CR10 scale. The CET group reported (in person or by email) to the principal investigator at the end of each week, and explained their training week, and described the intensity.

**Control group.** The control group did not take part in a training intervention during the six weeks. They were told not to significantly alter their current training program or diet during the study. They only completed the pre- and post-testing.

**Data Analyses**

Using SPSS this study compared pre- to post-measurements for all groups using a dependent sample paired $t$ test. The paired $t$ test measured the pre and post % BF, FFM, and BM, from the BOD POD and change in the estimated VO$_{2\text{max}}$ values from the 12 min Cooper Run Test. The significance level was set at $p \leq .05$. To compare the HIIT, CET, and control group, a one-way analysis of variance (ANOVA) was also done to compare change between (at baseline and pre to post difference) groups for all variables, using a Tukey post-hoc test when significance was found.

**Summary**

The purpose of this study was to compare adaptations in body composition and aerobic capacity in a relatively healthy college-aged population following six weeks of training between a group doing a running-based HIIT intervention and one doing CET. This study adds to the research of HIIT, giving a
more practical and accessible face to interval training, and helps gain some insight into
the effectiveness of a running-based HIIT protocols.
Chapter 4

Results

Introduction

The purpose of this study was to compare adaptations in body composition and aerobic capacity in a relatively healthy college-aged population following six weeks of training between a group doing a running-based HIIT intervention and one doing CET. This chapter offers a review of the results of the statistical analysis used in this study.

Descriptive Statistics

Thirty-four participants were initially recruited to take part in this study. Participants were matched based on their 12 min Cooper test results, and into either a $n_{\text{HIIT}} = 13$, $n_{\text{CET}} = 12$, or $n_{\text{Control}} = 9$. This was done to assure similar fitness levels in each group. The HIIT and CET groups had higher number of participants to combat the potential of attrition based on injury, or lack of time. Because the HIIT group had to do their intervals at a specific time some of the participants had to request not to be in that group. One participant that was in the CET group dropped out based on time and school conflicts. The mean pre- and post-results and standard deviations for aerobic capacity, \%BF, BM, and FFM are reported in Table 2, for all groups.

Aerobic Capacity

A paired sample $t$ test was implemented to examine the changes in pre- and post-body composition and aerobic capacity, after a 6-week training intervention. Both the HIIT and CET groups found significant improvement in regards to $\text{VO}_{2\text{max}}$, and the control group saw no difference ($p < .05$) (see Table 2). High intensity interval training
and CET had an improvement pre to post of 5.33 (± 4.48) ml·kg\(^{-1}\)·min\(^{-1}\) (t = -4.30, p = .001) and 2.95 (± 1.82) ml·kg\(^{-1}\)·min\(^{-1}\) (t = -5.367, p < .000) respectively. No significant difference was found between the pre-to-post measure for HIIT and CET (F(2,30) = 4.608, p > .05). There was significant difference found between the HIIT and the control group (F(2,30) = 4.608, p = .015), but not between the CET and control group (F(2,30) = 4.608, p = .405), based on the one-way ANOVA.

Table 2. Mean ± standard deviation for pre and post-test measurements.

<table>
<thead>
<tr>
<th>Group</th>
<th>VO(_{2}\max) (ml·min(^{-1}))</th>
<th>%BF</th>
<th>BM (lb)</th>
<th>FFM (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIIT Pre</td>
<td>44.72 ± 7.11</td>
<td>17.59 ± 7.65</td>
<td>159.59 ± 37.38</td>
<td>132.60 ± 37.14</td>
</tr>
<tr>
<td>HIIT Post</td>
<td>50.05 ± 10.09**</td>
<td>15.33 ± 7.51**</td>
<td>157.70 ± 36.59*</td>
<td>134.72 ± 37.91**</td>
</tr>
<tr>
<td>CET Pre</td>
<td>43.51 ± 5.90</td>
<td>17.85 ± 5.56</td>
<td>174.19 ± 37.74</td>
<td>143.47 ± 34.35</td>
</tr>
<tr>
<td>CET Post</td>
<td>46.46 ± 5.51**</td>
<td>17.95 ± 5.32</td>
<td>173.85 ± 35.53</td>
<td>142.92 ± 33.44</td>
</tr>
<tr>
<td>Control Pre</td>
<td>46.25 ± 5.95</td>
<td>15.06 ± 8.34</td>
<td>186.01 ± 49.07</td>
<td>156.59 ± 36.50</td>
</tr>
<tr>
<td>Control Post</td>
<td>47.24 ± 3.62</td>
<td>15.08 ± 7.77</td>
<td>184.69 ± 46.47</td>
<td>155.43 ± 34.12</td>
</tr>
</tbody>
</table>

*p < .05, **p < .01

Body Composition

The HIIT group showed significant decreases in % BF (-2.25 % ± 1.41) (t = 5.76, p < .000). Along with significant improvement within the HIIT group, there was also a significant reaction between groups, showing difference between the HIIT and CET group (F(2,30) = 9.779, p = .001), and HIIT and Control (F(2,30) = 9.779, p = .003). The HIIT group found a significant difference in BM decreasing 1.88 lb (± 2.30) from pre- to post-test (t = 2.963, p = .012). Neither the CET nor the control group had any significant difference pre to post in BM. No significant difference was found between the HIIT,
CET, or control group on BM (F(2,30) = .940, p > .05). The results for FFM were the same; the HIIT group was the only one that showed a significant difference after the 6-week intervention increasing 2.11 lb (± 2.11) (t = -3.611, p = .004). There was no significant difference between the HIIT and CET group (F(2,30) = 4.415, p > .05) based on the one-way ANOVA. However, there was a significant difference between the HIIT group and the control group (F(2,30) = 4.415, p = .031).

Summary

The HIIT group found significant changes in 6-weeks in aerobic capacity, %BF, BM, and FFM. The CET group found no changes in body composition markers, but found significant adaptations with VO_{2max}. Although the HIIT intervention elicited significant adaptations among all of the tests, there was no significant difference between the HIIT and the CET group based on VO_{2max}, BM, and FFM. Additionally, there was no significant reaction found between the HIIT and the control group based on BM.
Chapter 5
Discussion

Introduction

The purpose of this study was to compare adaptations in body composition and aerobic capacity in a relatively healthy college-aged population following six weeks of training between a group doing a running-based HIIT intervention and one doing CET. This chapter discusses the results, their comparisons with other studies, and recommendations for future research.

Principal Findings

Numerous studies have reported significant increases in aerobic capacity and endurance performance following a HIIT protocol (Burgomaster et al., 2005; Gibala et al., 2006; Hazell et al., 2010; MacPherson et al., 2011). This study exhibited similar results with the HIIT group increasing estimated VO$_{2\text{max}}$ by 5.33 mlkg$^{-1}$min$^{-1}$ (11.9% from baseline) and the CET group improved 2.95 mlkg$^{-1}$min$^{-1}$ (6.8% from baseline) with no significant difference found between groups (F(2,30) = 4.608, p > .05). This is one of the few studies, which used a protocol that was not performed in a lab setting. There are many factors that could be at play showing these improvements in estimated VO$_{2\text{max}}$.

First, there could have been an improvement in exercise efficiency (MacPherson et al., 2011). As participants go through the protocol, they performed running training three days a week for six-weeks. As a result, the exercise efficiency during the 12-minute Cooper run test may have improved. For the Cooper 12-minute run test it has been suggested in research on the validity and reliability that a Standard Error of the Estimate (SEE) of 10% is acceptable (Zwiren, Freedson, Ward, Wilke, & Rippe, 1991). Using an
error range of ± 4.5 ml kg\(^{-1}\) min\(^{-1}\) as acceptable criteria it is possible that the improvements seen, at least in the CET group where the improvement was only 2.95 ml kg\(^{-1}\) min\(^{-1}\), were simply improvement in running-test efficiency from pre to post, and not physiological adaptations to training.

In the present study only the HIIT group showed a significant decrease in % BF (t = 5.762, p < .000), as well as in BM (t = 2.963, p = .012), and a significant increase in FFM (t = -3.611, p = .004). Of the studies reporting body composition changes in a HIIT group they had to be at least six weeks long, which is similar to the present study (Astorino et al., 2012; Hazell et al., 2010; MacPherson et al., 2011; Trapp et al., 2008; Tremblay et al., 1994). Two studies that included CET groups had different results, one decreased %BF (MacPherson et al., 2010), and the longer study, 15 weeks, showed a slight but non-significant increase in their CET group (Trapp et al., 2008).

The BOD POD was used in both the present study and the study by MacPherson et al., but Trapp et al., used DEXA. This is potentially important because that allowed a measurement of abdominal fat in addition to changes in overall percent fat. Trapp et al., found the abdominal fat weight (kg) showed the same trend as percent fat, that the HIIT group lost significantly more abdominal fat than the CET group. They also measured insulin change and the insulin response improved in the HIIT group which could have strong implications for using HIIT in clinical populations where insulin resistance may be related to their fat weight even when overall percent body fat does not change.

Since all the research reported fat loss in their HIIT groups including the present study, but there were differences in whether fat loss occurred in CET groups, there is no way of knowing what the physiological cause was for the fat loss. It has been suggested
that high-intensity exercise may cause a decrease in appetite, or a decreased attraction to energy-dense food (Trapp et al., 2008; Tremblay et al., 1994). The interval sessions are very difficult and in the present study they were done mid-morning so it is possible even though the participants were encouraged not to change their eating behaviors they may have taken in less calories than required to balance the increased activity.

Enjoyment

A recent idea contributing to the success of HIIT has been that participants seem to enjoy HIIT programs more than a traditional CET program. Regardless of the endless list of health and performance advantages of consistent exercise, individuals are still reluctant to engage in a consistent program (Trost et al., 2002). Some of the most commonly cited reasons why individuals do not take part in enough physical activity are “lack of time” and “lack of enjoyment”. Enjoyment was not a variable measured in this study, but several participants reported they enjoyed the HIIT protocol. At least one study using HIIT and other modes found those who did HIIT had the greatest enjoyment (Bartlett et al., 2011). Those in the CET group did not report enjoyment or a desire to continue after the study. Then again, the current study may have seen enjoyment due to the team aspect of the HIIT program, as well as the constant coaching and motivation from the principal investigator.

Future Research

While our study has found significant results in a few of the elements of general aerobic fitness, it should not be interpreted that HIIT can elicit all of the adaptations of CET. First, more research needs to be done to be sure what adaptations a HIIT protocol of this nature can elicit. This study solely measured body composition and aerobic
capacity, and it is likely that numerous adaptations happened to achieve these improvements, but none of that is known based on the narrow scope of this study. Additionally, there seems to be many lingering questions on why a HIIT protocol could elicit improvement in body composition. This needs to be further examined, and answer why such a low volume exercise can show adaptations with such a low caloric expenditure in such a short period of time.

Second, more research needs to be done on running-based HIIT protocols. A running-based training program does not need any equipment, or any type of set resistance. Thus a running-based HIIT program may be more accessible to a wider population, and should be researched further to assure its effectiveness compared to other protocols. Additionally, researchers should try comparing different modes of exercise directly to each other. Such as comparing a cycling, running, and rowing protocol, based on different aerobic adaptations and body composition.

Additionally, many of the studies that have been conducted have been short – two to six weeks long protocols, which is not thought to be long enough to see many of the possible aerobic adaptations. Thus longer HIIT programs should be looked at to see the long-term effects of HIIT on the various aerobic adaptations. Future studies should examine adaptations that happen throughout the protocol, so researchers can understand when the adaptations occur.

Conclusions

For many years endurance athletes have been taking advantage of the benefits of HIIT training. More recently, HIIT has been highlighted as an alternative method to CET, for attaining endurance performance, and certain health benefits for non-athletes. Not
only is it another way of showing these improvements, but it also shows these improvements in only a fraction of the time commitment as a normal CET program. As seen in this study, HIIT showed similar results to CET in regards to aerobic capacity in utilizing 2.5 times less of a training volume. In regards to body composition changes, the low-volume HIIT showed significantly higher results compared to the CET programs. A wide range of research on different HIIT programs, durations, populations, and different physiological measurements could possibly provide an alternative to CET training for general and health fitness.
References


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Appendix A: PAR-Q

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES NO
1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
2. Do you feel pain in your chest when you do physical activity?
3. In the past month, have you had chest pain when you were not doing physical activity?
4. Do you lose your balance because of dizziness or do you ever lose consciousness?
5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
7. Do you know of any other reason why you should not do physical activity?

If you answered YES to one or more questions
Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.
• You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
• Find out which community programs are safe and helpful for you.

NO to all questions
If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:
• Start becoming much more physically active — begin slowly and build up gradually. This is the safest and easiest way to go.
• take part in a fitness appraisal — this can also be an excellent way to determine your basic fitness so that you can plan the best way for you to be active. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:
• If you are not feeling well because of a temporary illness such as a cold or a fever — wait until you feel better.
• If you are or may be pregnant — talk to your doctor before you start becoming more active.

PLEASE NOTE: As your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes:

“I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.”

NAME __________________________

SIGNATURE __________________________

DATE __________________________

SIGNATURE OF PARENT or GUARDIAN (for participants under the age of majority)

WITNESS __________________________

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

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Appendix B: Informed Consent Form

Informed Consent Form

"Comparing aerobic adaptations with a running based High Intensity Interval Training (HIIT) and a Continuous Endurance Training (CET) protocol in relatively healthy adults"
In partial fulfillment of the Master’s Thesis for Efrain Sanchez

Principal Investigator     Responsible Project Investigator
Efrain Sanchez     Wendy Repovich, Ph.D., FACS
214 N. 2nd St Cheney, WA 99004   Physical Education, Health and Recreation Dept.
360-560-2304     200 Physical Education Bldg.
efjsanchez@aol.com     Cheney, WA 99004-2476

Purpose and Benefits
The objective of this study is to compare a running-based HIIT protocol to a CET protocol (the most common form of aerobic activity) and their effect on aerobic fitness and body composition. If you are selected into either the HIIT or CET groups you will benefit by receiving six-weeks of training for free. If you are in the control group we will inform you of the results and provide information about programming if you decide to start one or the other forms of training following the study.

Procedures
As a subject in this study, you will be tested before and after the intervention in the Human Performance Lab, including a body composition test using the BOD POD Gold Standard (COSMED USA Inc., Chicago, Illinois), and the 12-min Cooper Run Test to estimate your aerobic capacity. Following the pretest you will be randomly assigned to the HIIT or CET, or control group. The intervention groups will train for six weeks 3-times per week using either the HIIT or CET protocols.

Body Composition:
We will use the BOD POD Gold Standard to determine body composition. The BOD POD is an egg shaped chamber just big enough to fit one person. The test is done via a body volume measure that compares the volume in the empty chamber, to the chamber with a cylinder that is a known volume, compared to the volume of the chamber with you in it. This volume will be compared to your body weight and used to calculate body density and then body composition.

Aerobic Capacity:
You will take part in the 12-min Cooper Run Test to estimate your VO$_{2\text{max}}$. This test will be done on the indoor track. Following an adequate warm-up you will run at as fast a pace as possible as far as you can in 12 minutes. The principal investigator will use your total distance covered to estimate your aerobic capacity.

Intervention:
HIIT Group
For each training session you will begin with a 5-10 minute warm-up. Then you will complete the HIIT protocol where you will alternate 1 minute of running as fast as you can, with a walking recovery for a total of 20 minutes (10 sprints).
CET Group
For each training session you will begin with a 5-10 minute warm-up. For the first two weeks of the running CET intervention participants will run continuously for 40-min, the second two weeks will be 50-min, and the last two weeks will be 60-min. All runs will be at a moderate pace of 65% of VO2 or an RPE of 4-5 on the 0 – 10 RPE scale.

Risk, Stress or Discomfort
All participants must take part in the body composition test using the BOD POD Gold Standard. During this test the participants must wear minimal clothing (ex. bathing suit). Due to the nature of the test there will be a potential risk for stress or discomfort. Adverse effects during or after the HIIT or CET protocol and the 12-min Cooper Test are muscle soreness, muscle cramping, nausea, fatigue, and possible muscular injury. Very rarely, abnormal physiological changes could occur during the test or intervention. These include abnormal blood pressure, fainting irregular, fast, or slow heart rhythm, and in rare instances heart attack, stroke, or death.

Inquiries
Any questions about the procedures used in this study are encouraged. If you have any concerns, questions, or would like more information please contact Wendy Repovich or Efrain Sanchez prior to signing the informed consent form. We can be reached at (509)-359-7960; wrepovich@ewu.edu, and (360)-560-2304; efjsanchez@aol.com respectively.

Other Information
In this study you will not be anonymous, the principal investigator will be supervising the testing and interventions. All data will be reported in aggregate so your data will not be able to be identified. All participation in this study is voluntary and the participants will not be penalized or punished if the training protocol is not completed. To participate in this study you will have to confirm that you are able to run continuously for 30 minutes. You are also being asked to not change your diet or activity level outside of the study protocols while you are taking part in the study. If you have any concerns about your rights as a participant in this research or any complaints you wish to make, you may contact Ruth Galm, Human Protection Administrator, (509) 359-6567 or rgalm@ewu.edu.

__________________________
Signature of Principal Investigator     Date

Subject Statement
My participation in this study is completely voluntary. I am free to refuse participation and to stop at any point in this study. I understand the study procedures that I will perform, and the possible risks that go along with the testing and training. Knowing all of the risks and discomforts, and being allowed to ask questions that have been answered to my satisfaction, I consent to take part in this study. I am not waiving my legal rights by signing this form. I understand I will receive a signed copy of this consent form.

__________________________
Signature of Subject     Date
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<td>10</td>
<td>VERY VERY HARD (MAXIMAL)</td>
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Appendix D: Study Flyer

Want to try a new type of workout?
Interested in improving your cardiovascular fitness?
Want to take a free Body Composition and Cardiovascular test?

If you answered yes!

Come and take part in our high intensity interval training study!

We are looking for 45 “relatively healthy” men and women between the age of 18-30 to volunteer for this study. Potential participants have to be able to jog for 30-minutes without stopping.

This study will be conducted between
April 8th-May 31st

Participants will randomly assigned into either the HIIT, CET, or control group, and will also perform pre and post tests (body composition and an aerobic capacity test)

- High Intensity Interval Training (HIIT) group: 6 week training protocol 3x per week, 10 x 60-second interval, with 60-seconds of rest
- Continuous Endurance Training (CET) group: 6 week training protocol 3x per week, 40-60 minutes of jogging at a moderate intensity
- Control group: Only performs pre and post testing

Efrain Sanchez (efjsanchez@aol.com or 360-560-2304)
Or
Wendy Repovich (wrepolovich@ewu.edu or 979-4544)
VITA

Author: Efrain J. Sanchez

Place of Birth: Toutle, Washington

Undergraduate Schools Attended: Eastern Washington University

Degrees Awarded: Bachelor of Science, 2011, Eastern Washington University

Honors and Awards: Graduate Assistantship, Exercise Science Department, 2012-2013, Eastern Washington University

Professional Experience: Instructor Internship, Eastern Washington University, 2012-2013

Assistant Fitness Center Director, Eastern Washington University, 2012-2013

Personal Trainer, Eastern Washington University, 2010-2013