The effects of a four-week whole-body high-intensity training program on female athletes 2015

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Four-Week Whole-Body High-Intensity Training Program
on Female Athletes

by

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Submitted in Partial Fulfillment of the
Requirements for the Master of Science in Exercise Science Degree

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STATE UNIVERSITY OF NEW YORK COLLEGE AT CORTLAND

May 2015

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Abstract

Purpose: The purpose of this study was to examine the aerobic benefits and changes in running economy (RE) following a four-week whole-body high-intensity interval training (HIIT) program on an athletic female population. **Participants:** Fourteen female student-athletes volunteered to participate in the study. **Design:** Participants reported on two occasions for VO_{2max} and RE testing and were divided into two training groups based upon baseline VO_{2max}: Endurance (END; n=6) and HIIT (n=8). Participants completed 12 total training sessions. During each session, END completed 30 minutes of vigorous-intensity running, while HIIT completed a total of four minutes of whole-body intervals. **Measures:** Maximal oxygen consumption (VO_{2max}) was measured and RE was calculated during pre- and post-testing to determine whether aerobic or RE improvements had resulted from either experimental treatment. **Analysis:** Two two-way mixed (group x time) ANOVAs were used to compare HIIT and END pre- and post-testing changes in VO_{2max} and RE. IBM SPSS version 22.0 was used to run the statistical tests, with an alpha level of 0.05. **Conclusion:** Although HIIT did not increase aerobic capacity to a greater extent than endurance training, with a significantly shorter time commitment, high-intensity interval training was an effective stimulus for improving aerobic conditioning in the female athlete participants in their nontraditional season.

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CHAPTER 1- SUMMARY

Introduction

High-intensity interval training (HIIT) is a method of training that consists of brief bouts of exercise at or near maximal effort such as all-out sprints or cycling at a predetermined power output, interspersed with short recovery or rest periods. These periods may be as short as 10 seconds to as long as four minutes. HIIT training has been studied fairly extensively in untrained and moderately-trained populations, and has been shown to improve aerobic capacity in these groups (Astorino, Allen, Roberson, & Jurancich, 2012; Esfarjani & Laursen, 2007; Tjønna et al., 2013). Improved cardiovascular fitness brought about by high-intensity interval training has been demonstrated in the form of increased VO_{2max} and VO_{2peak}, as well as in improvements in time trials and time to exhaustion tests (Perry, Heigenhauser, Bonen, & Spriet, 2008).

With training durations of as little as 2 minutes per session (Hazell, Olver, Hamilton, & Lemon, 2012), high-intensity interval training requires a significantly reduced time commitment when compared to traditional endurance training, while still eliciting cardiovascular benefits. Traditional endurance training is characterized by long, continuous moderate to vigorous activity. The American College of Sports Medicine (ACSM) (American College of Sports Medicine, 2014) recommends at least 75 minutes per week of vigorous exercise to elicit aerobic benefits. Vigorous exercise is defined by the ACSM (2014) as somewhat hard to very hard, or greater than 75% of maximal heart rate (HR_{max}).

Improvements in aerobic capacity come about through increases in density of muscle mitochondria. Both moderate-to-vigorous intensity endurance training and high-intensity interval training have been shown to produce post-exercise increases in peroxisome proliferator-activated receptor coactivator-1α (PGC- 1α), a key regulator of muscle mitochondrial biogenesis (Little, Safdar, Bishop, Tarnopolsky, & Gibala, 2011). Gibala, Little, MacDonald, and Hawley (2012) also identified increases in other markers of mitochondrial biogenesis, such as AMP-activated protein kinase (AMPK) and p38 mitogen-activated protein kinase (p38 MAPK), after high-intensity interval training. Since mitochondrial biogenesis can be activated using low-volume HIIT, this type of training could be considered as an alternative to less time-effective continuous endurance training.

Statement of the Problem

The use of a time-effective training protocol such as high-intensity intervals may have a more practical relevance in the busy training regimens of athletes than long-duration endurance training. Studies from Astorino, Allen, Roberson, and Jurancich (2012) and Zavorsky, Montgomery, & Pearsall (1997) demonstrated that short-term HIIT programs as short as two weeks in duration resulted in significant increases in aerobic capacity. The results of these studies showed that high-intensity interval training can be an effective exercise stimulus in moderately-trained individuals, but there is very limited research regarding the effects of HIIT on highly-trained populations, such as athletic teams.

The current study examined the aerobic effect of a high-intensity interval training program on female student-athletes, a population that has been seldom studied. Additionally, the type of exercise intervals used in the current study differ from the norm. Most frequently, high-intensity cycling intervals are used to study HIIT (Astorino et al., 2012; Gormley et al., 2008; Gurd, Perry, Heigenhauser, Spriet, & Bonen, 2009), while other studies have employed high-intensity sprinting or running intervals (Esfarjani & Laursen, 2006; Farsani & Resaeimanesh, 2011; Tjønna et al., 2013). Protocols which use whole-body, high-intensity intervals have rarely been examined in a research setting. Finally, very few studies have examined the improvements in running economy that could result from high-intensity interval training. The current study sought to examine whether HIIT would result in improvements in running economy in female student-athletes in addition to exploring the aerobic benefits of high-intensity interval training.

Purpose of the Study

The first purpose of this study was to examine the changes in aerobic capacity resulting from a four week whole-body high-intensity interval training (HIIT) program on a population of female collegiate athletes. A secondary purpose was to investigate whether whole-body HIIT could improve running economy in this population. The current study tested aerobic capacity (VO_{2max}) and running economy (RE) to answer these questions.

Hypothesis

The dependent variables for the following hypotheses were VO_{2max} and Running economy. The research hypotheses were that four weeks of whole-body high-intensity interval training performed three days per week would (1) elicit a statistically significant increase in maximal oxygen consumption from pre- to post-training testing, (2) result in a statistically significant improvement in VO_{2max} compared with an endurance program, (3) elicit a statistically significant improvement in running economy from pre- to post-training testing, (4) result in a statistically significant improvement in running economy compared with an endurance program.

Delimitations

The following are delimitations of the current study:

1. The researcher conducted mandatory training sessions for the endurance (END) group and high-intensity interval training group (HIIT) in order to closely monitor exercise program adherence.
2. The choice to test VO_{2max} and running economy in a controlled lab setting to evaluate changes in fitness, rather than using a time trial or field test as a measure of aerobic fitness. Treadmill testing using the metabolic analyzer allowed the researcher to control outside variables that may otherwise affect a time trial.
3. The researcher recruited only female collegiate athletes for the study and drew the sample from only one collegiate sports team. The aim of this delimitation was to control

for large differences in initial fitness level between participants.

4. The assigned training duration of four weeks was within the range of 2-16 weeks that have been shown to induce aerobic changes in other HIIT research.
5. The choice to initiate this training program during the off-season rather than during the regular field hockey season, when some athletes play in games more often than others, and therefore may have a greater level of fitness or fatigue. This allowed all athletes to have equal training volumes outside of the experimental training.
6. Although it is understood that changes in aerobic capacity come about through skeletal muscle adaptations, the researcher chose not to perform muscle biopsies or other invasive procedures on the participants.

Limitations

The following are limitations of the current study:

1. There was an attempt made to control the dietary intake of the subjects on the test days. Performance may differ due to the intake of caffeine or alcohol or due to differing nutrition prior to testing, so the participants were asked to consume a similar meal on both days, and

were asked not to consume alcohol 24 hours prior or caffeine within eight hours of the pre- and post-testing sessions. However, a standardized meal was not provided for the participants.

2. As the preliminary and post-training testing utilized SUNY Cortland's only metabolic analyzer, only one participant can be tested at a time. This impacted the sample size, as testing a large number of participants would require more lab time than may have been available.
3. Because the athletes were in their off-season, all participants were required to continue with their normally scheduled strength training program concurrently with this study.
4. The team's spring season coincided with the second half of the present study. The athletes participated in their team's practice sessions in addition to the experimental training protocols for the last two weeks of the training intervention.

Assumptions

The following are assumptions of the current study:

1. All participants were of a similar fitness level and that motivation to complete the pre- and post-tests was comparable.
2. None of the participants performed any other unreported physical activity during the four weeks of training.

Definitions of Terms

For the purpose of the present study, the following terms were defined:

1. Burpee: Podstawski, Kasietczuk, Boraczynski, Boraczynski, & Choszcz (2012) define a burpee as a physical exercise consisting of a squat thrust from and ending in a standing position, but which can have several variations. The variation used in the study includes a push-up from the squat thrust position, and a jump at the end of each combination.
2. Endurance Training: A method of training that consists of sessions characterized by continuous, moderate- to vigorous-intensity exercise.
3. Graded Exercise Test (GXT): A multistage exercise test with gradually increasing workloads. For the purposes of this study, a GTX is comprised of submaximal stages to determine

running economy, then increasing to maximal exercise to determine an estimate of VO_{2max}.

4. High-intensity interval Training (HIIT): Operationally defined as a method of training that consists of exercise sessions characterized by intervals of vigorous exercise interspersed with low-intensity recovery.
5. Maximal Heart Rate (HR_{max}): Heart rate, expressed as beats per minute, experienced at maximal exercise. Katch et al. (2011) state that age-predicted HR_{max} is calculated using the following equation:

$$220-(\text{age of participant}) = HR_{max}$$

6. Maximal Oxygen Consumption (VO_{2max}): The maximum volume of oxygen uptake achieved, despite increased exercise intensity (Katch, McArdle, & Katch, 2011). This will be the determined by taking the average VO_2 in the last 30 second period of testing. Expressed as $ml \cdot kg^{-1} \cdot min^{-1}$.
7. Running Economy (RE): Zavorsky, Montgomery, & Pearsall (1998) define RE as oxygen consumption at a given submaximal velocity. Expressed as $ml \cdot kg^{-1} \cdot km^{-1}$.
8. Squat-Tuck Jumps: An explosive, plyometric exercise comprised of a squat and tuck jump combination.
9. Respiratory Exchange Ratio (RER): Katch et al. 2011 define RER as the ratio of the amount of CO_2 produced to the amount

of O_2 consumed. This is measured directly by metabolic analyzer and represents substrate use at the total body level during exercise and recovery.

10. Tabata Protocol: A HIIT protocol consisting of 8 intervals of 20 seconds at high intensity separated by 10-second recovery periods (McRae et al., 2012).
11. Whole-body High-intensity interval Training: Defined operationally in the current study as a mode of HIIT using whole-body exercises such as burpees and squat-tuck jumps, in contrast to running or cycling.
12. Work to Rest Ratio: A ratio of the amount of work to the amount of rest in each interval period.

Significance of the Study

The current study is one of the first to explore the aerobic benefits of whole-body, high-intensity interval training. The current study is also among the few studies to examine HIIT as a mechanism for improving running economy. Further research is needed regarding these two factors using a training stimulus of greater than four weeks. The present study will aid in the exploration of the type of HIIT, session duration, and number of sessions that are optimal for improving cardiovascular fitness.

Considering an athletic team, high-intensity interval training could be utilized as a substitute for endurance training as a more time-efficient method of increasing or maintaining aerobic fitness. Substituting low-volume HIIT for traditional endurance training would allow for a greater amount of practice time to be made available for strength training and skill work, and game strategy. Many Division III athletics teams are allowed a short off-season practice schedule, as sanctioned by the National Collegiate Athletics Association (NCAA). For fall sports, such as field hockey, "nontraditional segment," or out-of-season practices can be held for only 5 weeks in spring, with a maximum of 16 total practice days. Aside from these few short weeks of practice, athletes are expected to maintain aerobic conditioning on their own, or through outside training programs. The current study overlapped with two weeks of the field hockey team's spring training, and was used by the participants as their off-season conditioning program.

CHAPTER 2- REVIEW OF LITERATURE

Introduction

Athletes at all levels, and coaches of these athletes, are always in search of the most efficient method for improving cardiorespiratory fitness during the off-season. Continuous, moderate-intensity exercise is the training method that has primarily been utilized for improving aerobic fitness (Tjønna et al., 2013). It has been well established that continuous endurance training increases aerobic capacity by increasing mitochondrial volume in skeletal muscle (Talanian, Galloway, Heigenhauser, Bonen & Spriet, 2006) and, therefore, results in an increase in maximal oxygen consumption (Perry et al., 2008). However, traditional endurance training requires a daily commitment of 30 minutes or more at a moderate intensity to obtain the aerobic benefits. Such a sizeable time commitment needed for endurance training may seem unreasonable for sports teams because it reduces the amount of time that can be committed to other aspects of the athletes' training, such as strength training, game strategy, and technical skill work. High-intensity interval training (HIIT) programs, which are generally only 4-30 minutes in duration per session, may serve as an effective alternative to this long-duration endurance training; triggering similar aerobic improvements with a reduced time-commitment (Gibala et al., 2012).

Many forms of exercise have been utilized in high-intensity interval training. Cycling and running are the most popular mechanisms, while whole-body plyometric intervals have been less frequently studied. Whatever form the HIIT protocol takes in research, the programs are typically much shorter in duration than a standard moderate-intensity endurance training program. However, even with the minimal time commitment, high-intensity interval training can be a powerful aerobic stimulus. Therefore, to provide information regarding previous research on high-intensity interval training and the aerobic and metabolic benefits of HIIT programs, the review has been organized into the following sections: defining high-intensity interval training HIIT and training volume, HIIT in healthy populations of varying fitness levels, HIIT and running economy, physiological changes brought about by HIIT, and a summary.

Defining high-intensity interval training

High-intensity interval training (HIIT) is also known as aerobic interval training, sprint interval training, high-intensity intermittent training, or simply as interval training (Farsani & Resaeimanesh, 2011; Hazell et al., 2012, Tabata et al., 1996, Tjønna et al., 2013, Tong et al., 2011). High-intensity interval training does not have a universal definition, but is characterized by brief bouts of near maximal exercise. The brief intervals are interspersed with short periods of rest or recovery at low intensities (Gibala et al., 2012; Tjønna et al., 2013). High-intensity intervals have been described as repeated sessions of relatively brief intermittent exercise bouts performed at intensities at or very near — approximately 90% of VO_{2peak}— maximal effort (Gibala & McGee, 2008). Authors of many studies have even prescribed intervals at an intensity above that which elicits VO_{max}, or supramaximal (Esfarjani & Laursen, 2007; Astorino et al., 2012), while other authors prescribe the intensity as a percentage of maximal HR, maximal aerobic speed, or simply as an all-out effort (Tjønna et al., 2013; Wong et al., 2010; Siahkouhian et al., 2013). HIIT protocols are generally carried out for 2-10 weeks (Astorino et al., 2012), but have been utilized as a regular training regimen for longer durations.

High-intensity interval training has taken many forms. One HIIT protocol that has been widely used is the Wingate protocol, which consists of 30-second “all-out” intervals on a cycle ergometer (Gibala & McGee, 2008; Astorino et al., 2012). Other studies have used running or sprinting for a specific duration or distance (Siahkouhian et al., 2013), while McRae et al. (2012) employed a different approach, using whole-body exercises in their protocol.

HIIT and Training Volume

Training volume can be manipulated by varying frequency, duration, and intensity (Gormley et al., 2008). At higher intensities, training volume can be held equal to moderate endurance activity by decreasing session duration or frequency of training. As an alternative to endurance training, one of the important properties of high-intensity interval training volume is the short duration needed to complete each session. Allowing athletes, patients, or clients to acquire aerobic gains as time-efficiently as possible is one practical function of HIIT. A session of around 30 minutes including adequate warm-up and cool-down characterizes at HIIT program as more time-efficient than continuous endurance sessions.

Tjønna and colleagues (2013) observed cardiovascular and running economy benefits in their subjects who completed just over 30 minutes of exercise per session. The participants warmed up for 10 minutes, completed four sets of four minute running sprints at 90% of HR_{max} interspersed with 30 seconds of active recovery, and finished with five minutes of easy running to cool down. This 33-minute protocol improved both VO_{2max} and "work economy" by 13% after 10 weeks of training. "Work economy," the measure of running economy used by the researchers, was determined based upon the participants' oxygen cost of five minutes of treadmill walking (Tjønna et al., 2013). Tong and colleagues (2011) also sought to establish a training program with minimal time commitment. These authors used a protocol which was comprised of a light 10-minute warm-up, 10 minutes of 30-second all-out cycling bouts interspersed with 60 seconds of recovery, and 10 minutes of easy cycling to cool down, to maintain session durations of 30 minutes or less.

However, some research has found that even a session length of 30 minutes is not necessary to reap the aerobic benefits of HIIT. Tjønna and colleagues (2013) also studied the effects of a single exercise bout of four minutes, or a session of 19 total minutes including warm-up and cool-down, on oxygen uptake and running economy. The results demonstrated that the solitary high-intensity interval elicited improvements in both VO_{2max} and running economy after the 10-week training program (Tjønna et al., 2013). Exercise sessions of less than 10 minutes, comprised of eight minutes of 15-second sprints with equal recovery, were used to elicit aerobic benefits in highly-trained soccer players. The high-intensity interval trained athletes performed better in endurance testing after eight weeks of training compared with their teammates who did not partake in sprint intervals (Wong et al., 2010). Brief exercise sessions were also utilized by McRae et al. (2012) and proved to stimulate desirable increases in peak oxygen uptake. The protocol used in this study required only a short warm-up of walking up and down five flights of stairs, then four minutes of high-intensity bouts. The interval training followed "Tabata protocol," (Tabata et al., 1996) in which each HIIT session consists of eight bouts of 20-second all-out intervals interspersed with 10 second recovery periods (McRae et al., 2012).

Another important aspect of exercise volume is training frequency. An investigation of two differing frequencies of HIIT on moderately active participants found that completing 24 sessions of high-intensity training over three weeks was less effective at improving VO_{2max} than the same number of sessions completed over the course of eight weeks (Hatle et al., 2014). The prescription of lower frequencies of HIIT per week has been utilized with significant results in other research. McRae and colleagues split their 25 recreationally active female subjects into three exercise groups; control, endurance, and HIIT. The experimental groups completed four weeks of HIIT or endurance training four days per week, and both groups saw significant increases in aerobic fitness with this frequency of exercise (McRae et al., 2012). Significant improvements in cardiovascular fitness through the employment a training frequency of four or fewer days per week has been supported in several recent research studies (Astorino et al., 2012; Bickham & Le Rossignol, 2004; Esfarjani & Laursen, 2006; Ferley et al., 2014; Gormley et al., 2008; Hazell et al., 2012).

Work-to-rest ratio is another factor to be considered when designing a high-intensity interval training routine. The work-to-rest ratio is the proportion of HIIT exercise time comprised of interval work compared with the recovery time. High-intensity interval training sessions may be comprised of any number of varying work-to-rest ratios. Bickham and Le Rossignol (2004) modified these ratios throughout their experiment to give shorter rest as their participants became more accustomed to the training workload. High-intensity intervals began with a 1:5 work to rest ratio, and by the end of the four week study, subjects were completing intervals at a 1:3 work to rest ratio. Zavorsky and colleagues examined the effects of employing differing rest periods during a HIIT regimen. A higher peak heart rate was reached at the end of HIIT sessions that utilized a shorter recovery period in this study (Zavorsky et al., 1998).

Finally, the duration of the HIIT program is especially important. Although studies found that a single HIIT session could produce skeletal muscle adaptations and one-day oxygen consumption similar to traditional aerobic training (Hazell et al., 2012; Little, Safdar, Bishop, Tarnopolsky, & Gibala, 2011), most high-intensity training programs include at as many as 16 weeks (Ramos, Dalleck, Tjonna, Beetham, & Coombes, 2015) and generally at least least 2 weeks of training. Numerous studies have concluded that any number of weeks of HIIT between 2 and 16 can significantly improve measures of cardiorespiratory fitness and skeletal muscle adaptations resembling endurance training (Perry et al., 2008; Sloth, Sloth, Overgaard, & Dalgas, 2013).

HIIT in Healthy Populations of Varying Fitness Levels

High-intensity interval training research has mainly focused on the cardiorespiratory effects on healthy populations, and generally uses unfit or moderately-fit individuals. Astorino and colleagues (2012) were able to demonstrate the practicality of high-intensity interval training in moderately active males and females. After only six HIIT sessions, participants in this study exhibited significant increases in cardiovascular fitness. Esfarjani and Laursen (2007) found that over a 10 week training program, longer intervals of 3 minutes and 30 seconds with shorter recovery performed at, but not above, velocity at VO_{2max} (V_{VO2max}) elicited greater changes in aerobic capacity. The concept of administering the intervals near or at maximal intensity, but not above, has been supported by other research. Gormley and colleagues (2008) tested 55 healthy but not highly fit men and women, and those subjects who completed intervals at an intensity near 100 percent of their heart rate reserve (HRR) saw significantly greater improvements in cardiovascular fitness than the groups assigned to moderate-intensity and vigorous-intensity endurance training. Rognmo and colleagues (2004) examined the benefits of HIIT on stable coronary artery disease patients, and observed a 17.9% increase in VO_{2peak} in the high-intensity group. These extreme results may be indicative of the low fitness level of the population, though, so although increases aerobic fitness should result from the regimen of the current study, the improvements will likely not be as considerable.

As previously stated, the research on the effects of high-intensity interval training athletic populations is rather limited. Siahkouhian and colleagues (2013) studied healthy, inactive men with male collegiate athletes to compare the influence of high-intensity interval training in each population. Both groups completed 30-second all-out sprints with four minute recovery between intervals for eight weeks. Maximal oxygen consumption increased significantly in both populations, but to a lesser extent with the athletic group. These results are to be expected, as the inactive population has lower baseline fitness levels, and thus, greater potential for improvement.

Additional studies have demonstrated the value of HIIT in highly-trained and athletic populations. Smith, McNaughton, and Marshall (1999) investigated the benefit of four weeks of high-intensity interval training on an endurance-trained population of middle-distance runners. Although their protocol of 60 minutes total per session — including warm-up, stretching, high-intensity intervals, and cool down — was not very time efficient, their athletic population of subjects benefitted greatly from HIIT. Not only did the subjects see significant improvements in time trials and peak running velocity, their post-training VO_{2max} was significantly increased after the four week program. Similarly, Slettaløkken and Rønnestad (2014) incorporated high-intensity intervals as a method of maintaining aerobic fitness in semiprofessional soccer players during the off-season. Though the athletes did not experience improvements in aerobic fitness after the six-week training period, completing HIIT once per week for four weeks did result in the maintenance of the aerobic capacity of the subjects, who had exhibited high VO_{2max} values prior to training.

High-Intensity Interval Training and Women

While many studies involving high-intensity interval training have drawn from populations of differing fitness levels, the majority of HIIT research looked at the effects of this training stimulus on male subjects. More recently, studies have begun to examine the outcomes of HIIT interventions on women. Farsani and Rezaeimanesh (2011) examined the effects of high-intensity interval training on female student-athletes. With session durations of less than 30 minutes, a significant increase in VO_{2max} was experienced after four weeks of this HIIT protocol. The authors concluded that just six weeks of a high-intensity interval training program can be an effective aerobic exercise stimulus for an athletic female population.

Rowan, Kueffner, and Stavrianeas (2012) studied the effects of low volume HIIT over a five-week duration on a collegiate women's soccer team. The athletes were divided into two intervention groups—endurance training and high-intensity interval training—and the training interventions were completed in addition to regular team practices. The aerobic effects in the athletes completing high-intensity intervals were not significantly different from the group partaking in endurance training. However, both training groups saw significant improvements in VO_{2max}.

HIIT and Running Economy

While most studies concerning high-intensity interval training examines the cardiovascular, fat oxydative, or anaerobic benefits, only limited research has been done regarding HIIT's influence on running economy. To gain understanding of HIIT's effects on running economy, Ferley and colleagues (2014) implemented high-intensity interval training on a group of well-trained runners. The experimental groups completed two high-intensity interval sessions per week at either level-grade or at a 10% incline at an intensity of 100% of V_{vo2max} (as determined by preliminary testing) in addition to two continuous run sessions per week at 75% of V_{vo2max}. The results of this study showed that the physiological changes in the participants that performed the incline intervals did not differ significantly from those who completed level-grade intervals. However, after the six week training intervention, both of the HIIT groups showed significant improvements in running economy and in VO_{2max} pre- to post- training, and when compared to the control group. This research supports the notion that high-intensity interval training can be an effective tool to increase VO_{2max} and improve running economy in athletic populations.

While Zavorsky and colleagues (1998) had similar findings (a decreased VO_2 at a given velocity) of improved running economy after HIIT, Bickham and Le Rossignol (2004) carried out a study which showed no significant differences. After a six week high-intensity protocol, their highly-trained subjects experienced no change in VO_{2max} or running economy. Utilizing whole-body high-intensity interval exercises as an alternative to running or cycling has been minimally studied (McRae et al., 2012). However, the effects of whole-body HIIT on running economy was not examined. These types of exercises may not only stimulate aerobic benefits, but also promote improvements in running economy for athletes whose primary sport is not running.

Physiological Changes Brought About by HIIT

In a review of literature, Laursen and Jenkins (2002) note that HIIT has been shown to affect skeletal muscle activity of both glycolytic enzymes such as hexokinase (HK) and phosphofructokinase (PFK), and oxidative enzymes such as citrate synthase (CS), succinate dehydrogenase (SDH), and cytochrome oxidase. This activity of peripheral factors is believed to be the mechanism for increased aerobic capacity following high-intensity interval training. MacDougall, Hicks, MacDonald, McKelvie, Green, and Smith, (1998) discuss that increased oxidative enzymes in skeletal muscle are generally correlated with endurance exercise, and sought to investigate the effect of high-intensity exercise on skeletal muscle enzyme activity. The results exhibited a significant increase in CS, SDH, and malate dehydrogenase (MDH) after seven weeks of low-volume HIIT, changes which the authors note are generally associated with moderate-intensity training involving a much greater time commitment.

Siahkouhian and colleagues (2013) consider the probable increases in skeletal muscle oxygen utilization to be a primary cause for the improvements in VO_{2max} in HIIT studies. Gibala et al. (2012) reported that low-volume HIIT promoted increases in markers of aerobic fitness, namely mitochondrial gene expression, similar to increases stimulated by more prolonged endurance exercise. Additional studies have examined peroxisome proliferator-activated receptor coactivator-1α (PGC- 1α), a protein in skeletal muscle that is a known regulator of muscle mitochondrial biogenesis, resulting from high-intensity interval training. Little et al. (2011) note that mitochondrial biogenesis is characteristic of traditional endurance training.

However, their research demonstrated significant increases in PGC- 1α and several mitochondrial enzymes following a single session of high-intensity interval exercise. Gurd, Perry, Heigenhauser Spriet, and Bonen (2010) also reported that high-intensity interval training resulted in skeletal muscle changes that are ordinarily linked to endurance training. Their six-week HIIT intervention resulted in a 16% increase in PGC-1α as well as significant increases in oxidative enzymes such as citrate synthase (CS) and β-hydroxyacyl-coenzyme A dehydrogenase (β-HAD). These changes in skeletal muscle enzymes and proteins occurred in conjunction with an 11% increase in VO_{2peak} in the subjects.

Excess post-exercise oxygen consumption (EPOC) has also shown to be greatly affected by high-intensity exercise. In their HIIT study, Hazell, Olver, Hamilton, and Lemon (2012) found that high-intensity interval training bouts totaling two minutes of high-intensity exercise produced an oxygen consumption over the subsequent 24-hours equivalent to 30 minutes of continuous endurance exercise. It should be noted that the majority of the 24-hour oxygen consumption of the endurance exercise condition occurred during the exercise, while the intervals caused increased oxygen consumption after the exercise session was completed.

Summary

The literature reveals that HIIT, although there are many variations and definitions (Gibala et al., 2012), can be an effective stimulus for increased aerobic capacity and improvements in running economy. In healthy sedentary, moderately fit, and athletic populations, and in male, female, and mixed populations, high-intensity interval training programs have been shown to improve VO_{2max} (Esfarjani & Laursen, 2007) and increase markers of skeletal muscle oxidative capacity and mitochondrial biogenesis (Little et al., 2011; Gibala et al., 2012). In athletic populations, high-intensity interval training has been shown to maintain (Rowan et al., 2012), and sometimes improve aerobic capacity (Slettaløkken & Rønnestad, 2014) when utilized in conjunction with usual sports training regimens.

The current study aims to determine whether a low-volume, high-intensity interval program consisting of whole-body exercises can provide similar benefits to aerobic fitness and running economy to traditional endurance training in female student-athletes during their off-season. Because HIIT has been shown to induce cardiovascular and economy benefits in less moderately-fit populations, research is needed to understand the physiological changes that this type of training can stimulate in more athletic populations. Based upon the current literature, length of session, short recovery between intervals, and a moderate training frequency are factors that must be considered when creating a HIIT program. The current study will employ sessions lasting four total minutes of high-intensity intervals, with a 2:1 work to rest ratio, and a training frequency of three days per week, allowing for adequate recovery between sessions.

CHAPTER 3- PILOT STUDY

Introduction

Continuous, moderate-intensity exercise has been the primary method of training for improving aerobic fitness. It has been well established that this type of training increases aerobic capacity by increasing mitochondrial volume in skeletal muscle, therefore increasing one's maximal oxygen consumption (Perry et al., 2008). However, this type of training requires 30-120 minutes at a moderate intensity to reap the aerobic benefits. High- intensity interval training (HIIT) programs, which are generally only 4-30 minutes in duration per session, may serve as an effective alternative to this long-duration endurance training; triggering similar aerobic improvements with a reduced time-commitment (Gibala et al., 2012). HIIT is a method of training that consists of brief bouts of exercise at or near maximal effort, interspersed with short recovery periods. Improvements in aerobic capacity come about through increases in the volume of muscle mitochondria, also known as mitochondrial biogenesis. Both moderate-intensity endurance training and high-intensity interval training have been shown to produce increases in Peroxisome proliferator-activated receptor coactivator-1α (PGC- 1α), which regulates muscle mitochondrial biogenesis. Since mitochondrial biogenesis can be activated using low-volume HIIT, this type of training should be considered as an alternative to the less time-effective endurance training.

Few studies have examined the advantages of whole-body high-intensity interval training. Additionally, research is needed concerning the benefit of high-intensity interval training on running economy. The purpose of this study was to examine the aerobic and running economy benefits of six sessions of a whole-body, high-intensity interval training (HIIT) program on a college-aged, healthy population. The hypothesis of this study was that two weeks of whole body, high-intensity interval training, performed three days per week, would elicit a significant increase in VO_{2max} and running economy in this population.

Methods

The researcher examined heart rate (HR), maximal oxygen consumption (VO_{2max}), and running economy (RE) of a healthy, college-age sample. The following sections describe participants, testing instruments, testing procedures, training protocols, and data analysis.

Participants

Six healthy SUNY Cortland students (3 males and 3 females, aged 23-25 years) volunteered to participate in a two-week, six-session training program. PAR-Q and Informed consent were completed by each participant following an explanation of all procedures and risks. The participants were randomly assigned into two experimental training groups: an endurance training group (N=3) and a whole-body, high-intensity training group (N=3). No control group was used in the current study.

Instruments

For the preliminary and post-training tests, the same Trackmaster TMX425C Treadmill (Full Vision Inc., Drive Newton, KS) was used for every participant, and all metabolic data was collected using the Ultima CPX Metabolic Analyzer (MedGraphics Diagnostics Corporation, St. Paul, MN). Heart rate information for both of the testing and training protocols using heart rate monitor chest straps with corresponding receivers (Polar Electro Inc., Lake Success, NY).

The training protocol for the endurance group was based upon standard endurance training and the intensity was chosen based on the American College of Sports Medicine definition of moderate intensity. The training protocol for the high-intensity training group, the Tabata Protocol, is a training regimen that has been shown to improve fitness in

Testing Procedures

Maximal oxygen uptake and running economy testing

Prior to beginning the training programs, all participants reported to the SUNY Cortland exercise physiology laboratory for preliminary testing. During the initial visit, upon arrival at the SUNY Cortland exercise physiology lab, all participants completed an informed contest and underwent anthropometric measurements including height (m) and body mass (kg). The participants were then familiarized with the testing equipment and test procedures prior to the baseline testing.

Each participant was fitted with a heart rate monitor chest strap (Polar Electro Inc., Lake Success, NY) to allow observation of heart rate throughout the test. The participants then completed a graded exercise test on a Treadmill (Trackmaster TMX425C, Full Vision Inc., Drive Newton, KS) to determine their baseline running economy (RE), maximal oxygen uptake (VO_{2max}), and maximal heart rate (HR_{max}). The metabolic system (Ultima CPX Metabolic Stress Testing System, MedGraphics Diagnostics Corporation, St. Paul, MN) was calibrated before each test using known gas percentages. The participants began testing with a self-selected warm up at 0% grade. After completing the warm up, the participants initiated a graded exercise test (modified from Tanner & Gore, 2013) consisting of three submaximal stages and a fourth stage to volitional exhaustion. After completion of the test, participants were permitted to remain on the treadmill for a self-selected cool-down period. All of the testing was performed on the same equipment in the SUNY Cortland exercise science department exercise physiology laboratory.

Experimental Protocol

All participants were briefed on the exercise training protocol after completion of preliminary testing. Each participant was also given an instruction sheet (Appendix D, Appendix E), which outlined their individual training protocol, including their target heart rates. Participants were also given a heart rate monitor (Polar Electro Inc., Lake Success, NY), which was to be worn during each training session. The training period consisted of 6 training sessions, completed every other day for two weeks. For the endurance training (ET) group, each training session consisted of 30 minutes of running at 65-75% of HR_{max} (as determined by preliminary testing). The training sessions for the HIIT group (HIIT) followed a modified Tabata protocol (Tabata et al., 1996), consisting of 8 rounds of 20-second bouts of either burpees or squat-tuck jumps, with 10 seconds of recovery between each bout. The type of exercise (burpee or squat-tuck jump) was designated for each session by the researcher and was denoted on each participants' protocol instruction sheet.

Data Analysis

Data collected in the study were from 6 college-aged men and women. Descriptive statistics for height, weight, age, HR, and VO_{2max} were recorded. Data analysis was run using Microsoft Excel 2013 with a set alpha level of 0.05. Means and standard deviations are reported for groups. To compare pre- and post-testing changes in VO_{2max} and running economy, a paired t-test was run on the means of the HIIT groups VO_{2max} and RE. To examine the group differences in means, an independent t-test was run to compare results of mean change in VO_{2max} of the HIIT group against the mean change in VO_{2max} of the endurance group, and paired t-test was also run to compare the mean change in RE of the endurance group against the mean change in RE of the HIIT group.

Results

Baseline and post-training mean (± SD) VO_{2max} and running economy for each group are reported in Table 1. No significant differences in VO_{2max} were found between groups during preliminary testing (mean difference= 1.23, $p>0.05$). There was no significant change in VO_{2max} in the HIIT group after the two-week training intervention (mean change = 3.23 ml•kg^{-1}•min^{-1}, $p > 0.05$). There was no significant change in RE in the HIIT group after the two-week training intervention (mean change = 18.99 ml•kg^{-1}•km^{-1}, $p > 0.05$, two-tailed). In comparing mean change in VO_{2max} between groups, there was no significant difference in the change in VO_{2max} between HIIT and END (mean difference= 2.10, $p > 0.05$, two-tailed). In comparing mean change in running economy between groups, there was no significant difference in the change in RE between HIIT and END(mean difference= 1.43, $p > 0.05$, two-tailed).

Table 1.

Group Means (± SD) of Pre- and Post-Training VO_{2max} and RE

Group		VO_{2max} (ml•kg^{-1}•min^{-1})	RE (ml•kg^{-1}•km^{-1})
HIIT	Pre	44.50 ± 5.39	187.85 ± 26.31
	Post	47.73 ± 3.64	206.85 ± 21.01
Endurance	Pre	43.27 ± 8.82	182.54 ± 7.66
	Post	48.60 ± 9.48	202.96 ± 20.42

Discussion

The goal of the study was to examine the aerobic benefits of a two-week, whole-body, high-intensity interval training program, and to compare the resulting changes with an endurance training program. Although Gibala and colleagues (2006) found that a two-week HIIT training intervention brought about improvements in time trials and in aerobic capacity (Gibala et al., 2006), the current study did not support those findings.

The current study used a modality that has not been widely studied. Research frequently uses cycling or treadmill running for HIIT, modes in which intensity can be quantified easily. During the current study, participants were simply told to complete their exercises "all-out," so it was unclear whether this method would elicit an appropriate intensity. Based upon the heart rate data collected during each session, the participants were able to their target heart rate ranges with the assigned HIIT protocol.

The current study did not have any significant findings. Although average VO_{2max} for HIIT did increase slightly, the improvement was not statistically significant. Mean VO_2 of each group from pre-test and post-test are displayed in Figure 1. Additionally, the change in VO_{2max} and change in RE in HIIT was not significantly greater than the change in these measures in END. As the current study had such a small pool of participants and short duration, more research is needed to examine the benefits of whole-body HIIT.

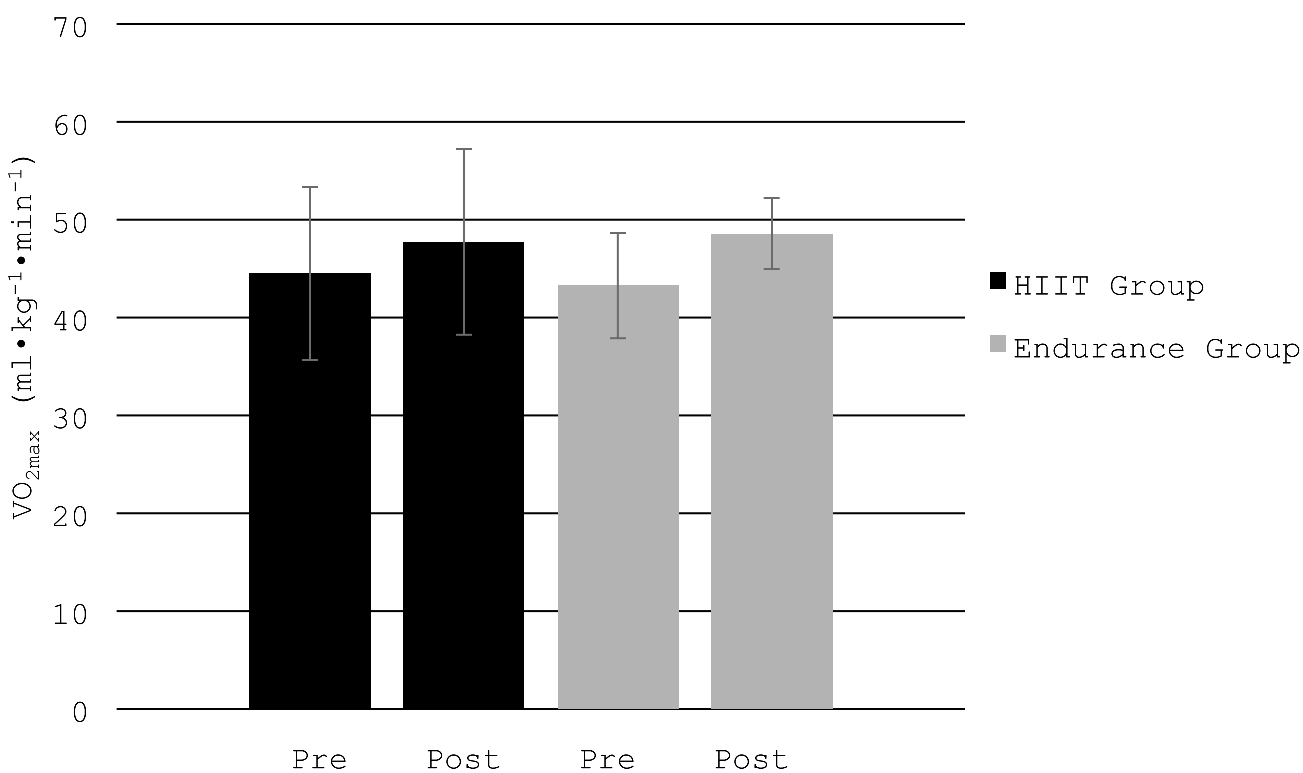

Figure 1. Mean VO_2 for each training group during the preliminary and post-training treadmill tests

CHAPTER 5- Manuscript

ABSTRACT

The purpose of this study was to examine the aerobic benefits and changes in running economy (RE) following a four-week whole-body high-intensity interval training (HIIT) program on an athletic female population. Fourteen female student-athletes volunteered to participate in the study. Participants reported on two occasions for VO_{2max} and RE testing and were divided into two training groups based upon baseline VO_{2max}: Endurance (END; n=6) and HIIT (n=8). Participants completed 12 total training sessions. During each session, END completed 30 minutes of vigorous-intensity running, while HIIT completed a total of four minutes of whole-body intervals. Maximal oxygen consumption (VO_{2max}) was measured and RE was calculated during pre- and post-testing to determine whether aerobic or RE improvements had resulted from either experimental treatment. Two two-way mixed (group x time) ANOVAs were used to compare HIIT and END pre- and post-testing changes in VO_{2max} and RE. IBM SPSS version 22.0 was used to run the statistical tests, with an alpha level of 0.05. Although HIIT did not increase aerobic capacity to a greater extent than endurance training, with a significantly shorter time commitment, high-intensity interval training was an effective stimulus for improving aerobic conditioning in the female athlete participants in their nontraditional season.

Key words: Tabata Intervals, Running Economy, Maximal Oxygen Consumption, Endurance Training

INTRODUCTION

High-intensity interval training (HIIT) is a method of training that consists of brief bouts of exercise at or near maximal effort, such as all-out sprints or cycling at a predetermined power output, interspersed with short recovery periods. The recovery or rest periods may be as short as 10 seconds to as long as four minutes. High-intensity interval training has been studied fairly extensively in untrained and moderately trained populations, and has been shown to improve aerobic capacity in these groups (2, 4, 15). Improved cardiovascular fitness brought about by high-intensity interval training has been demonstrated in the form of increased VO_{2max} and VO_{2peak}, as well as in improvements in time trials and time to exhaustion tests (11).

With training durations of as little as two minutes per session (8), high-intensity interval training requires a significantly reduced time commitment when compared to traditional endurance training, while still producing cardiovascular benefits. Traditional endurance training is characterized by long, continuous, activity at a moderate or vigorous intensity. The American College of Sports Medicine (1) recommends at least 75 minutes per week of vigorous exercise to elicit aerobic benefits.

Improvements in aerobic capacity come about through increases in density of muscle mitochondria. Both moderate-to-vigorous intensity endurance training and high-intensity interval training have been shown to produce post-exercise increases in peroxisome proliferator-activated receptor coactivator-1α (PGC- 1α), which is a regulator of muscle mitochondrial biogenesis (9). Gibala, Little, MacDonald, and Hawley (6) also identified increases in other markers of mitochondrial biogenesis, such as AMP-activated protein kinase (AMPK) and p38 mitogen-activated protein kinase (p38 MAPK), after high-intensity interval training. Since mitochondrial biogenesis can be activated using low-volume HIIT, this type of training could be considered as an alternative to less time-effective continuous endurance training. Considering an athletic team, high-intensity interval training could be utilized as a substitute for endurance training as a more time-efficient method of increasing or maintaining aerobic fitness. Substituting low-volume HIIT for traditional endurance training would allow for a greater amount of practice time to be made available for strength training and skill work, and game strategy.

While a few studies have examined the effects of HIIT on running economy (3, 5, 17), there have been mixed results. An improvement in running economy was seen after six weeks of high-intensity treadmill intervals (5) at both level grade and incline, while a different six-week protocol produced no significant improvement in RE after HIIT (3). In game play, athletes need to be as economical as possible in order to outlast their opponents, so the current study aims to expand understanding of whether high-intensity interval training can help to improve economy in athletes.

Considering an athletic team, high-intensity interval training could be utilized as a substitute for endurance training as a more time-efficient method of increasing or maintaining aerobic fitness. Substituting low-volume HIIT for traditional endurance training would allow for a greater amount of practice time to be made available for strength training and skill work, and game strategy. Many Division III athletics teams are allowed a short off-season practice schedule, as sanctioned by the National Collegiate Athletics Association (NCAA). For fall sports, such as field hockey, "nontraditional segment," or out-of-season practices can be held for only 5 weeks in spring, with a maximum of 16 total practice days. Aside from these few short weeks of practice, athletes are expected to maintain aerobic conditioning on their own, or through outside training programs. The current study overlapped with two weeks of the field hockey team's spring training, and was used by the participants as their off-season conditioning program.

The first purpose of this study was to examine the changes in aerobic capacity resulting from a four week whole-body high-intensity interval training (HIIT) program on a population of athletic, college-age females. A secondary purpose was to investigate whether whole-body HIIT could improve running economy in this population. The current study tested aerobic capacity (VO_{2max}) and running economy (RE) to answer these questions. The research hypotheses were that four weeks of whole-body high-intensity interval training performed three days per week would (2) elicit a statistically significant increase in maximal oxygen consumption from pre- to post-training testing, (3) result in a statistically significant improvement in VO_{2max} compared with an endurance program, (4) elicit a statistically significant improvement in running economy from pre- to post-training testing, (5) result in a statistically significant improvement in running economy compared with an endurance program.

METHODS

Experimental Approach to the Problem

High-intensity interval training has been fairly widely studied as a method of improving the overall fitness of unfit and moderately fit populations (12, 16). However, research is reasonably limited regarding the aerobic benefits of HIIT programs in athletic populations. Few studies have examined the advantages of whole-body high-intensity interval training compared with high-intensity interval running or cycling. Additionally, research is needed concerning the benefit of high-intensity interval training on running economy.

Subjects

Fifteen healthy female SUNY Cortland student-athletes were recruited to volunteer in a four week, 12-session training program. All participants are current members of the SUNY Cortland field hockey team, an NCAA Division III varsity team. Prior to preliminary testing and training, Informed Consent and Physical Activity Readiness Questionnaire (PAR-Q) were completed by each participant following an explanation of all procedures, benefits, and risks of the study. Any individuals who answered yes to any of the questions on the PAR-Q were to be excluded from the study.

Following preliminary testing, the participants were assigned into two experimental training groups, an endurance (END) training group and a whole-body high-intensity training group (HIIT), using matched group design. Due to injury, one participant was unable to complete the experimental training and was therefore was not included in the analysis (N=14, aged 19.29 ± 0.91 years). Descriptive Statistics for participants can be found in Table 1. All methods and procedures were approved by the Institutional Review Board of SUNY Cortland prior to recruitment and data collection.

Table 1 about here.

Procedures

The study had a total duration of six weeks. A timeline of the study design is shown in Figure 1. Preliminary testing was completed during week one, then the four-week training program began at least 24 hours following the last participant's preliminary testing session. Finally, post-training testing was completed at least 24 hours after the final training session date during week six.

Figure 1 about here.

Prior to the start of the training interventions, all participants reported to the SUNY Cortland exercise physiology laboratory for preliminary testing. During the initial visit, upon arrival at the SUNY Cortland exercise physiology lab, all participants completed an informed contest and underwent anthropometric measurements including height (m), body mass (kg), and body composition measurements via bioelectrical impedance using upper-body bio impedance body fat analyzer (Omron Healthcare Inc., Bannockburn, Ill.). The participants were then familiarized with the testing equipment and test procedures prior to the baseline testing.

Each participant was next fitted with a heart rate monitor chest strap (Polar Electro Inc., Lake Success, NY) to allow observation of heart rate throughout the testing session. Heart rates were recorded at the end of each minute throughout the submaximal portion of the test and at the end of each 30-second interval throughout maximal testing. The participants then completed a graded exercise test on a treadmill (Trackmaster TMX425C, Full Vision Inc., Drive Newton, KS) to determine their baseline running economy (RE) at each of the three submaximal speeds and maximal oxygen uptake (VO_{2max}). The metabolic system (Ultima CPX Metabolic Stress Testing System, MedGraphics Diagnostics Corporation, St. Paul, MN) was calibrated with a 3.0L syringe, and the carbon dioxide (CO_2) and oxygen (O_2) sensors was calibrated using two known gas percentages before each test. Measures of oxygen consumption (VO_2) and respiratory exchange ratio (RER) were measured on a breath-by-breath basis throughout each of the testing protocols. All of the exercise testing was performed on the same equipment in the SUNY Cortland exercise science department exercise physiology laboratory.

Running Economy Testing: The participants began preliminary and post-training testing sessions, which followed a modified graded exercise test (14). The graded exercise test, shown in Table 2, consisted of three submaximal stages at given speeds for three minutes with one minute of passive recovery after each stage before beginning the subsequent stage at a faster speed. Running economy was calculated for each participant as an average of oxygen consumption (VO_2) during the last 30 seconds of each given submaximal speed and was expressed as milliliters of oxygen consumed per kilogram of body mass per kilometer traveled ($ml \cdot kg^{-1} \cdot km^{-1}$).

Table 2 about here.

Maximal Oxygen Uptake Testing: After completion of the final submaximal stage, each participant was allowed a four-minute recovery period, during which the metabolic mask could be removed and the participants were able to consume water ad libitum. Participants then remained on the treadmill for a fourth stage to volitional exhaustion. The fourth stage began at the same velocity as the first submaximal stage (2.91 $m \cdot s^{-1}$), and speed was increased 0.13 $m \cdot s^{-1}$ every 30 seconds until treadmill speed reached 3.44 $m \cdot s^{-1}$. Once the maximal speed of 3.44 $m \cdot s^{-1}$ was reached, incline was increased 1.0% every 30 seconds until volitional exhaustion. After completion of the test, participants were asked to remain on the treadmill for a three minute cool-down period at an easy walk (1.25 $m \cdot s^{-1}$) in order to collect heart rate and VO_2 recovery data. Maximal oxygen consumption (VO_{2max}) was determined by taking an average of the oxygen consumption from the final 30 seconds of maximal testing and was expressed as milliliters of oxygen consumed per kilogram of body mass per minute ($ml \bullet kg^{-1} \bullet min^{-1}$).

Experimental Protocol: All participants were briefed on the exercise training protocol after completion of preliminary testing. Following preliminary testing, groups were matched for VO_{2max} and participants were assigned randomly to an intervention group. Each participant in the experimental groups was given an instruction sheet based upon their grouping, which outlined their individual training protocol, including their target heart rates. All participants were also given a heart rate monitor and corresponding watch (Polar Electro Inc., Lake Success, NY), which were to be worn during each training session.

The training period consisted of 12 training sessions, to be completed three days per week for four weeks. For END, each training session consisted of 30 minutes of running at a vigorous intensity of 75-85% of age-predicted HR_{max}. The training sessions for the HIIT group began with a three minute easy jog to warm up, then followed a modified Tabata protocol (13), which consisted of eight rounds of 20 second bouts of either burpees or squat-tuck jumps, with 10 seconds of recovery between each bout. The burpee or squat-tuck jump was designated for each session by the researcher and were denoted on each participant's protocol instruction sheet. The prescribed intensity for the HIIT participants was an "all out" effort, with a target heart rate of 85- 95% of age-predicted HR_{max}. After the completion of four minutes of intervals, the HIIT group also completed a light 3-minute cool-down, bringing the session duration total to 10 minutes.

Training sessions for both groups were administered each Monday, Wednesday, and Friday for the four-week period at a 7:00am. Each of these sessions was overseen by either the researcher or a research assistant, in order to monitor adherence to the program and compliance to the protocol.

Statistical Analyses: Descriptive statistics for participant characteristics and dependent variables are presented as mean ± standard deviation. The independent variable was assigned training group, either high-intensity interval training or endurance training. Differences in the dependent variables, VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$) and running economy ($ml \cdot kg^{-1} \cdot km^{-1}$) after the four week training intervention, were analyzed by two separate 2 x 2 mixed analysis of variance (ANOVA) for Group (HIIT, END) by Time (Pre-training, Post-training). Statistical analyses were computed using IBM SPSS version 22.0, with an established alpha level of 0.05.

RESULTS

The goal of the study was to examine the changes in VO_{2max} and running economy following four-week exercise training interventions of either high-intensity intervals or continuous endurance sessions. Participants performed two separate graded exercise tests to determine pre- and post-intervention VO_{2max} and running economy.

Group differences in aerobic capacity were analyzed using the general linear model with a 2 (training group) x 2 (time) repeated measures analysis of variance (ANOVA) to identify any main effect. There were no outliers and the data was normally distributed for both experimental groups at both time periods. There was not a statistically significant interaction between training group and time on VO_{2max}, $F(1,12) = 0.005$, $p > 0.05$. The main effect of time showed a statistically significant difference in VO_{2max} from pre to post testing, $F(1,12) = 12.657$, $p < 0.05$. The main effect of group showed no statistically significant difference in VO_{2max} between intervention groups,

$F(1,12) = 0.290$, $p < 0.05$. A small effect size was found for VO_{2max} for both training group and time (partial $\eta^2 < .20$).

Much of the literature indicates that high-intensity interval training can be a more effective exercise stimulus for improving aerobic capacity than continuous endurance training. To examine the main effect of time on VO_{2max}, two separate paired samples t-tests were run for pre-post VO_{2max} on each group. For the high-intensity interval training group, over time there was a statistically significant increase in VO_{2max}, $M = -2.72$ ml•kg^{-1}•min^{-1}, 95% C I= [-5.17, -0.26], $t(7) = -2.61$, $p < 0.05$. For the endurance group, over time there was not a statistically significant increase in VO_{2max}, $M = -2.83$ ml•kg^{-1}•min^{-1}, 95% C I= [-5.78, -0.12], $t(5) = -2.47$, $p > 0.05$. The increased standard error in the END group due to smaller sample size may explain the lack of significance in VO_{2max} in that group while both groups had approximately the same percent change in VO_{2max}. The endurance group improved aerobic capacity by 6.2% while the high-intensity interval training group saw a 6.1% increase from pre- to post-training.

Group differences in running economy at the speed of 3.13 $m \cdot s^{-1}$ were analyzed using the general linear model with a 2 (training group) x 2 (time) repeated measures analysis of variance (ANOVA) to identify any main effect. There were no outliers and data the data was normally distributed for both experimental groups at both time periods. The data was skewed, as assessed by Levene's test of homogeneity of variances ($p < 0.05$). A logarithmic transformation was performed on the variables to correct the homogeneity of variance of running economy. There was not a statistically significant interaction between training group and time on running economy, $F(1,12) = 0.002$, $p > 0.05$. The main effect of time showed no statistically significant difference in running economy from pre to post testing, $F(1,12) = 2294.189$, $p > 0.05$. The main effect of group showed no statistically significant difference in running economy between intervention groups, $F(1,12) = .002$, $p > 0.05$. A small effect size was found for running economy for both training group and time (partial $\eta^2 < .20$).

DISCUSSION

The aim of the study was to determine the aerobic effects and changes in running economy from a four week, whole-body high-intensity interval training program, and to compare the resulting changes in aerobic capacity and running economy with an endurance training program. These variables were evaluated by graded exercise test prior to and following the four-week training intervention. The HIIT intervention used a modality that has not been widely studied. Research frequently uses cycling or treadmill running for HIIT, modes in which intensity can be quantified more easily. The HIIT group participants in this study were told to complete their exercises "all-out," and were given heart rate ranges as a target. Based upon the heart rate data collected during each session, the participants were able to meet the designated target heart rate ranges with the assigned HIIT protocol.

The research hypothesis stating that four weeks of whole-body high-intensity interval training would significantly increase maximal oxygen consumption from pre- to post-test in the HIIT group was accepted. The hypothesis that the improvement in VO_{2max} of the HIIT group would be significantly greater than the VO_{2max} change in the END group was rejected. With regard to running economy, the HIIT intervention resulted in some improvement in RE during the second submaximal stage, but was not significantly more economical from pre- to post-test.

Additionally, HIIT group RE was not improved significantly compared with the END group. Mean (± SD) VO_{2max} and running economy for each submaximal speed are given in Table 3.

Table 3 about here.

Based upon the literature, several physiological adaptations similar to those following traditional endurance training can occur after high-intensity interval training. Increases in oxidative enzymes and markers of mitochondrial biogenesis demonstrate that HIIT can be a potent aerobic stimulus (7, 9, 10). Given that the study did not examine muscle samples from the participants, it can only be inferred based upon the significant increases in aerobic capacity that such physiological adaptations have occurred

Running economy did not improve with either experimental group in the study (Figure 2). Although much of the literature on high-intensity interval training and running economy saw significant improvements, the type of HIIT may have been the determining factor. Some studies have found a significant improvement in RE with HIIT programs (5, 17). The high-intensity interval sessions were performed on a treadmill in those studies, making them more suited to develop economy during the intervals. Conversely, Bickham & Le Rossignol (3) also utilized treadmill HIIT, and exhibited no significant difference in RE after six weeks. There were no significant differences in RE in the current study, which may be attributed to the mode of high-intensity training used. Additionally, there was a small effect size for running economy, due to the small sample size of the study.

Figure 2 about here.

The participants of the study were field hockey players, whose regularly scheduled training coincided with the experimental training. In the first two weeks of the four-week training intervention, the athletes were additionally required to attend three strength training sessions per week lasting 60 minutes each. In addition to the experimental training and strength training, in weeks three and four, the team's nontraditional segment (off-season) began, so each of those weeks included three practice sessions of 60-120 minutes each. At the end of week three, the team had a scheduled scrimmage day, in which each athlete took part in 150 total minutes of game play. The total weekly exercise time commitment for each of the experimental groups is displayed in Table 4.

Table 4 about here.

A major finding of the study was that although the HIIT group did not show a significant improvement over the END group, both of the experimental training groups saw an increase in aerobic capacity after the four-week training intervention (Figure 3). On average, the participants had approximately a 6% increase in VO_{2max} from pre-testing to post-testing. The aerobic changes after four weeks of training were significant, regardless of training intervention—HIIT group increased 6.1% while END group saw an improvement of 6.2%. Although the percent change in aerobic capacity was slightly greater in the endurance training group, a paired samples t-test revealed that the improvement was not statistically significant. This can be attributed to the smaller sample size of the END group. A comparison of the mean VO_{2max} for each group is shown in Figure 3. The improvements in VO_{2max} cannot be solely attributed to the training intervention, as all subjects were participating in concurrent training.

Figure 3 about here.

For these athletes, the four-week training program may not have been a long enough exercise stimulus to see a significant difference between groups, as all participants were already highly fit. According to ACSM fitness guidelines, the average VO_{2max} of both the END and HIIT groups was well within the "excellent" category for aerobic fitness (1). However, it is important to note that the HIIT group showed significant aerobic increases from pre- to post-testing and similar improvements in VO_{2max} to the END group after the four-week intervention, with significantly reduced time commitment (Figure 4). Although HIIT did not increase aerobic capacity to a greater extent than endurance training, with a shorter time commitment, high-intensity interval training was an effective stimulus for improving aerobic conditioning in the female athlete participants in their nontraditional season.

Figure 4 about here.

PRACTICAL APPLICATIONS

With regard to athletes and coaches, the application of high-intensity interval training as a method of conditioning would eliminate the need for extended periods of time to be spent on traditional endurance training. Athletes can obtain similar aerobic benefits in a more time efficient manner, which could allow for more time to be committed to other important practice segments.

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Table 1

Baseline Descriptive Characteristics of the Subjects (N=14)

(Mean ± standard deviation)

Age (y)	19.29 ± 0.91
Height (m)	1.64 ± 0.05
Body Mass (kg)	63.17 ± 5.35
Body Fat (%)	21.5 ± 3.45
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	44.96 ± 3.27
Running Economy ($ml \cdot kg^{-1} \cdot km^{-1}$)	213.42 ± 15.43

Table 2

Graded Exercise Test

Running Economy Test		
Time (min:sec)	Speed	Grade
0:00 – 2:59	2.91 m•s^{-1}	0.0%
3:00 – 3:59	Rest	-
4:00 – 6:59	3.13 m•s^{-1}	0.0%
7:00 – 7:59	Rest	-
8:00 –10:59	3.35 m•s^{-1}	0.0%
11:00 – 14:59	Rest	-

VO_{2max} Test		
Increasing speed and grade until failure:		
Time (min:sec)	Speed	Grade
15:00 - 15:29	2.91 m•s^{-1}	0.0%
15:30 - 15:59	3.04 m•s^{-1}	0.0%
16:00 - 16:29	3.17 m•s^{-1}	0.0%
16:30 - 16:59	3.31 m•s^{-1}	0.0%
17:00 - 17:29	3.44 m•s^{-1}	0.0%
17:30 - 17:59	3.44 m•s^{-1}	1.0%
18:00 - 18:29	3.44 m•s^{-1}	2.0%
18:30 - 18:59	3.44 m•s^{-1}	3.0%
19:00 - 19:29	3.44 m•s^{-1}	4.0%
19:30 - 19:59	3.44 m•s^{-1}	5.0%
20:00 - 20:29	3.44 m•s^{-1}	6.0%
20:30 - 20:59	3.44 m•s^{-1}	7.0%
21:00 - 21:29	3.44 m•s^{-1}	8.0%
21:30 - 21:59	3.44 m•s^{-1}	9.0%

Recovery		
Time (min)	Speed	Grade
3:00 from failure	1.25 m•s^{-1}	0.0%

Table 3

Results from Running Economy and VO_{2max} Pre-and Post-Training Intervention Tests

	HIIT (N=8)		END (N=6)	
	Pre	Post	Pre	Post
Running Economy Test				
Speed 1 ($2.91\ m{\bullet}s^{-1}$)	211.2 ± 14.9	212.3 ± 10.1	209.7 ± 13.6	214.9 ± 25.4
Speed 2 ($3.13\ m{\bullet}s^{-1}$)	214.1 ± 16.4	212.2 ± 10.5	213.8 ± 18.1	216.6 ± 21.2
Speed 3 ($3.35\ m{\bullet}s^{-1}$)	209.6 ± 15.1	211.4 ± 11.4	208.7 ± 16.8	211.2 ± 17.9
VO_{2max} Test				
VO_{2max}	44.64 ± 3.74	47.35 ± 3.16	45.39 ± 2.80	48.22 ± 2.42

Note: Running economy: $ml{\bullet}kg^{-1}{\bullet}km^{-1}$
VO_{2max}: $ml{\bullet}kg^{-1}{\bullet}min^{-1}$

Table 4

Exercise time commitment for groups (minutes per week).

	Week 1	**Week 2**	**Week 3**	**Week 4**	**Total**
Experimental Training					
HIIT	30	30	30	30	120
Endurance	90	90	90	90	360
Strength Training					
HIIT	180	180	180	180	720
Endurance	180	180	180	180	720
Team Practice					
HIIT	0	0	300	300	300
Endurance	0	0	300	300	300
Competition					
HIIT	0	0	150	0	150
Endurance	0	0	150	0	150
Weekly Total					
HIIT	210	210	660	510	1590
Endurance	270	270	720	570	1830
Weekly Aerobic Total					
HIIT	30	30	480	330	870
Endurance	90	90	540	390	1110

Note: Total exercise time between groups was compared.

Figure 1. Timeline of experimental design

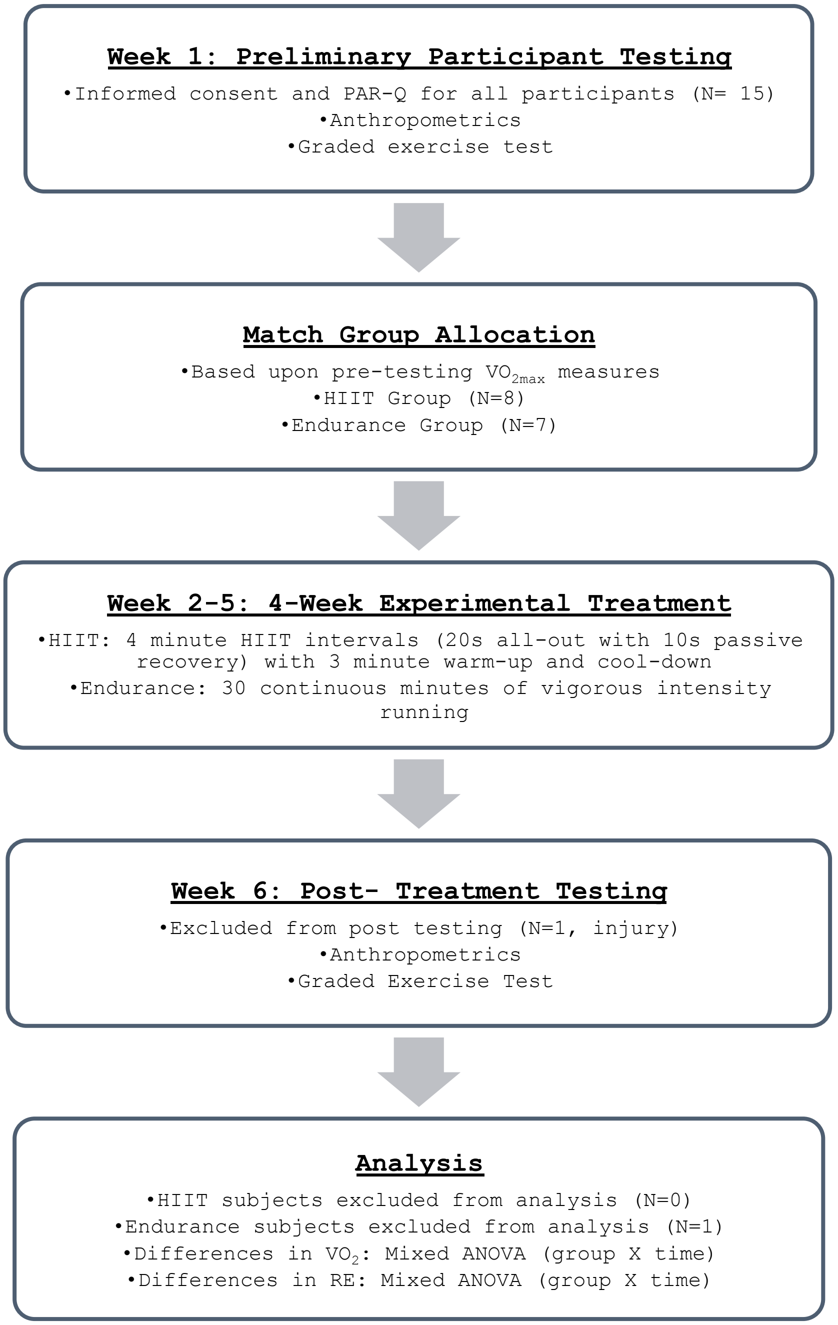

Figure 2. Weekly Exercise Time Commitment by Training Group

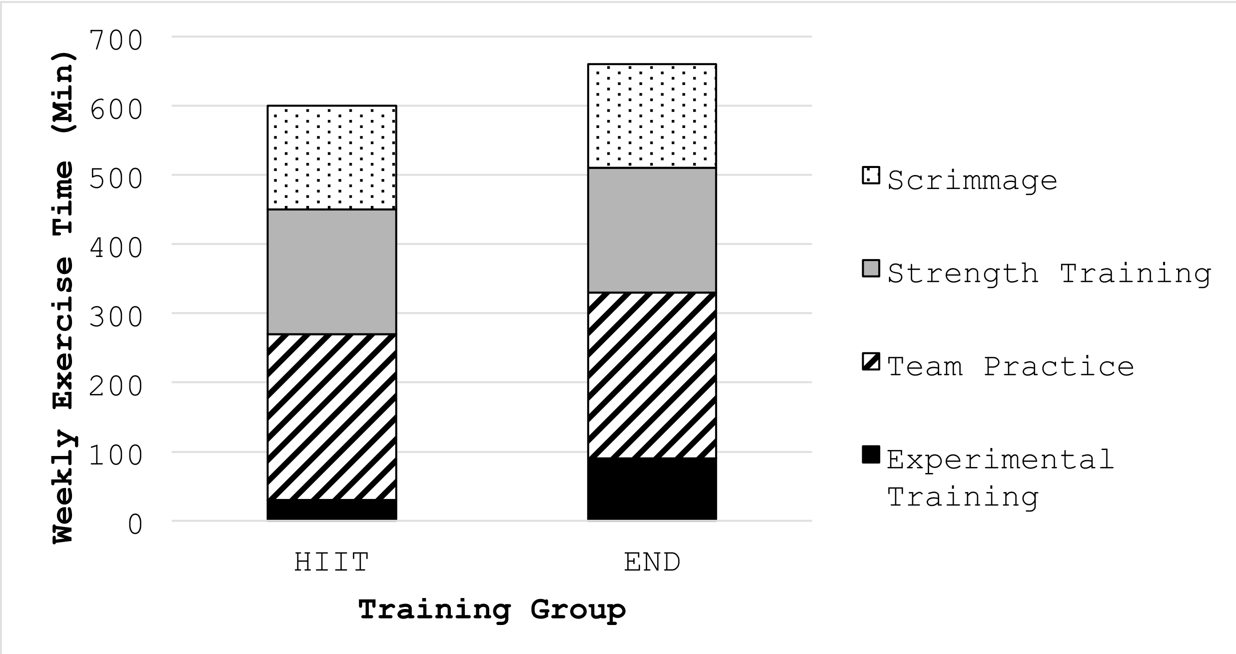

Figure 2. Training Hours Per week from a sample week of training for each group, divided into four categories: Scrimmage, strength training, team practice, and experimental training. END group completed a greater number of exercise minutes per week than HIIT group.

Figure 3. Running Economy at Varying Running Speeds

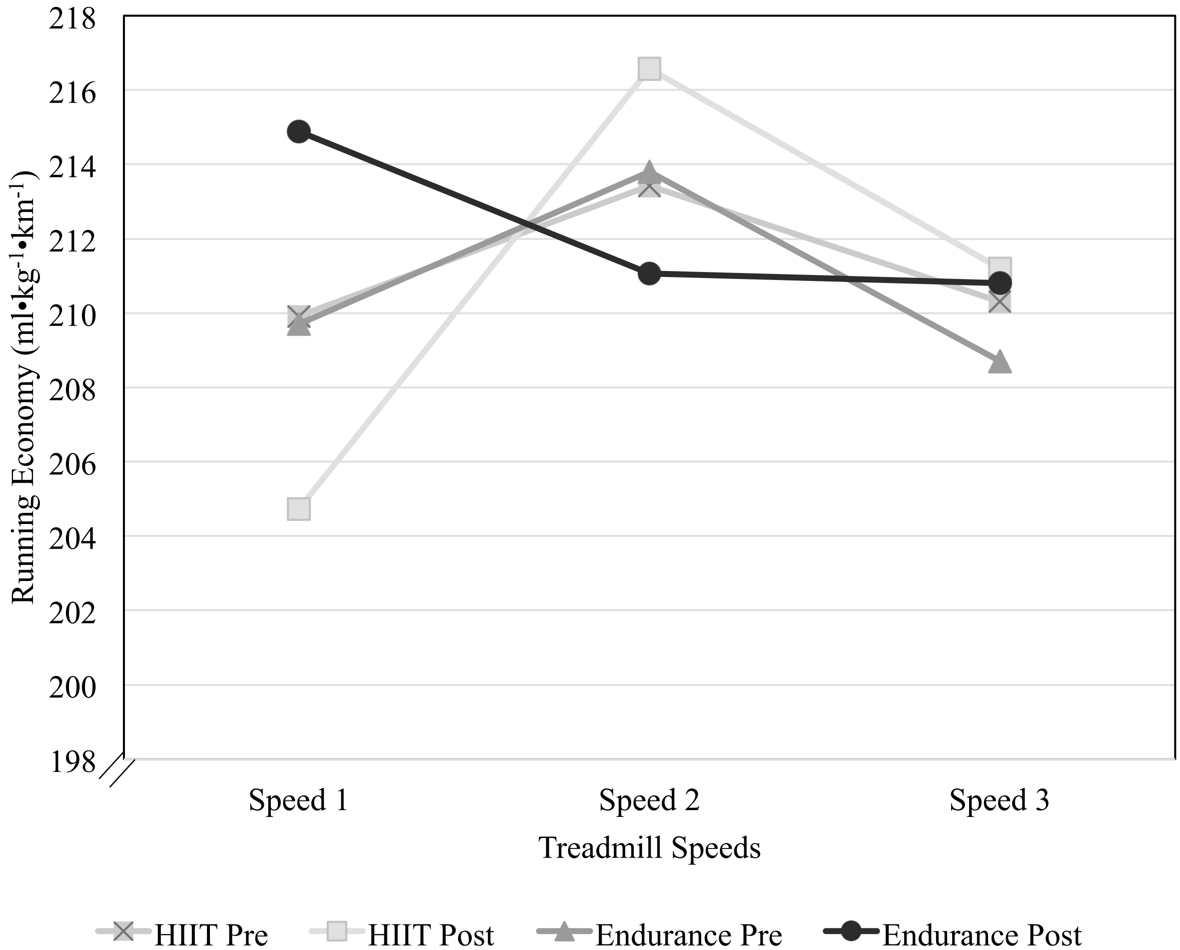

Figure 3. Running Economy of Training Groups at Submaximal Treadmill Speeds. No significant differences between groups ($p > 0.05$).

Figure 4. Mean in VO_{2max} comparison of Pre-test and Post-test for both training groups.

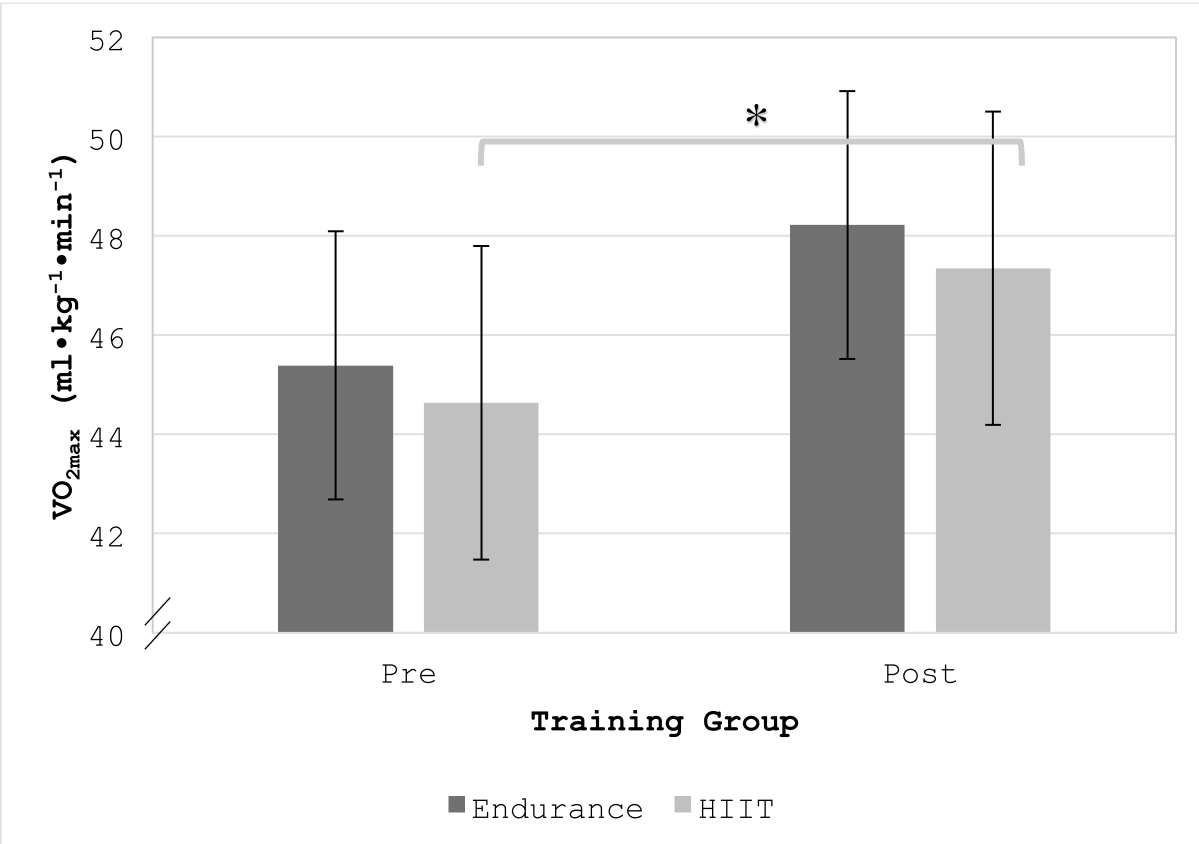

Figure 4. A comparison of the changes in VO_{2max} from pre- to post-test for both training groups. Post-VO_{2max} of HIIT and END were significantly different from pre-VO_{2max}. There were no between-group differences ($p > 0.05$).
*$p < 0.05$ significantly different from pre-test of training group.

CHAPTER 5- APPENDICES

Appendix A. High-Intensity Interval Training Protocol

Instruction Sheet

HIIT Protocol Name________________________

To be completed every Monday, Wednesday, and Friday, for 4 weeks:

- Begin with a light 3 minute warm up of easy jogging
- Set timer for 20 seconds per interval & 10 seconds of recovery.
- Complete 8 rounds of the prescribed exercise (see below)
- Try to complete as many repetitions as possible. Your target heart rate is greater than 85% of HR_{max}________
- Cool down for 3 minutes at a light intensity.

Exercises: (Target heart rate _______________bpm)

Burpees: Begin in standing position. When interval starts:

1. Drop into a squat
2. Place hands on the ground in front of you, shoulder width apart
3. Hop your feet back, landing in a push-up position
4. Complete one push-up
5. Hop feet back into squat position
6. Jump straight up from squat
7. Repeat steps 1-6, completing as many repetitions as possible in the 20 second interval

- Squat-Tuck Jumps: Begin in standing position. When interval starts:
  1. Drop into a squat
  2. Explode off of the ground and bring arms straight out in front of you at chest height
  3. Tuck knees in to touch your arms at chest height
  4. Land in squat position
  5. Repeat steps 2-4, completing as many repetitions as possible in the 20 second interval

- -

I, _________________________, do agree to completing each of these twelve (12) exercise sessions fully and to the best of my ability.

Signature _________________________ Date _____________

Appendix B. Endurance Training Protocol Instruction Sheet

Endurance Training Protocol Name___________________

To be completed every Monday, Wednesday, and Friday, for 4 weeks:

- Run continuously for 30 minutes, keeping your heart rate within the target zone.

- Target Zone = 75-85% of HR_{max} __________

_ _

I, ________________________, do agree to completing each of these twelve (12) exercise sessions fully and to the best of my ability.

Signature ________________________ Date _____________

Appendix C. Document of Informed Consent

Document of Informed Consent
Department of Kinesiology
State University College at Cortland

TITLE: The Effects of a Four-Week Whole-body High-intensity Interval Training Program on Female Athletes.

STUDENT INVESTIGATOR: Lindsey Taylor, (802) 345-9368

FACULTY SUPERVISOR: James Hokanson, PhD., (607) 423-1854

PURPOSE: The purpose of this study will be to examine the aerobic benefits of a four week whole-body high-intensity interval training (HIIT) program on an athletic female population and to investigate whether this type of HIIT can help to improve running economy in this population.

PROCEDURES: The data gathered from the testing will be used to determine the running economy, maximal oxygen uptake, and maximal heart rate of each participant. As a participant, you will be requested to report to the Exercise Physiology lab for a fitness test. This will take approximately 30 minutes, and will tell us how fit you are at the beginning of the program. You will then be asked to complete a 4-week training protocol, based upon the group that you will be placed into. Members of the endurance training (EG) group will complete 30 minutes of continuous running at 70-80% of their determined maximal heart rate (as determined by the preliminary fitness test). The high-intensity interval training (HG) group members will complete 4 minutes of whole-body HIIT at an all-out intensity. Both training regimens will be completed every Monday, Wednesday, and Friday for 6 weeks, beginning at least 48 hours after preliminary fitness testing. Each participant will then be requested to complete another 30-minute fitness test to assess changes in fitness after the program.

RISKS: The proper precautions will be to taken to ensure that the testing area, as well as all of the equipment being used, is safe for all participants involved in the study. The primary risk associated with this study is the physical discomfort that will be experienced during the two fitness tests and during the experimental training sessions. The risk of injury in this study is minimal. A proper warm-up will be allowed for all participants to minimize the risk of muscular injuries.

BENEFITS: The results of this study may indicate whether whole-body, high-intensity interval training is as effective, or more effective, than traditional endurance training, based upon changes in running economy and aerobic capacity.

CONFIDENTIALITY: All of the data from the experiment will be stored in a locked cabinet, and the data on the computer will be stored anonymously with your identity protected.

FREEDOM TO WITHDRAW: Participation in this study is completely voluntary, and you may withdraw from the study at any time, for any reason. You will not have any negative consequences from the investigators, the Kinesiology Department, your coaches, or your team if you do not participate in this study, or if you decide to withdraw once you have started.

For more information about this study please contact Lindsey Taylor (802) 345-9368 or Lindsey.Taylor02@cortland.edu. This study has been approved by the Institutional Review Board at SUNY Cortland. For more information about research at SUNY Cortland or information about the rights of research participants, please contact the Institutional Review Board by email irb@cortland.edu, or by phone (607) 753-2511

I have read and understand the activities requested for my involvement in this project, and I consent to participate.

Name: ___________________________ Telephone#: _____________________

Signature: ____________________________ Date: ______________

Researcher's Signature: ______________________________
Date: ___________________

Appendix D. Physical Activity Readiness Questionnaire

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

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 is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. 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; or
- If you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If 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.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

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.

1:12

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Appendix E. ANOVA Summary Tables

Table E1

2x2 ANOVA with Repeated Measures on VO_{2max} and Training Intervention Groups

Source	ss	df	ms	F	p
Between Subjects					
Training Group	4.505	1.00	4.505	0.290	0.600
Within Subjects					
Time	52.71	1.00	52.716	12.657	0.004
Time*Training Group	0.023	1.00	0.023	0.005	0.942

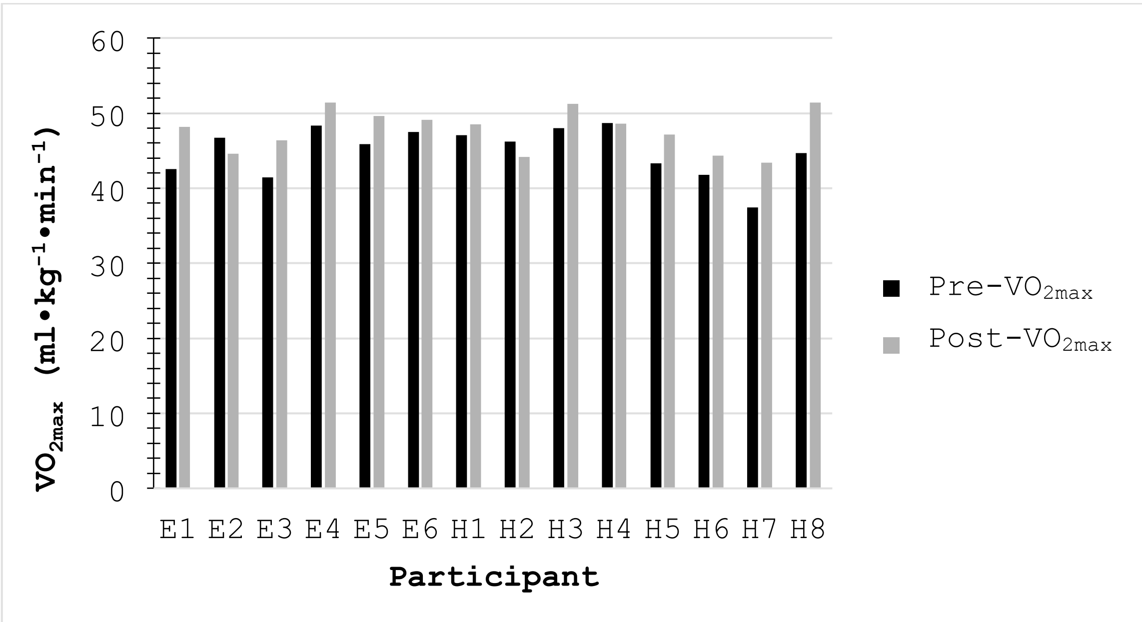
Table E2

2x2 ANOVA with Repeated Measures on Running Economy (Speed #2) and Training Intervention Groups

Source	ss	df	ms	F	p
Between Subjects					
Training Group	0.000	1.00	0.000	0.099	0.758
Within Subjects					
Time	0.000	1.00	0.000	0.005	0.943
Time*Training Group	0.000	1.00	0.000	.696	0.420

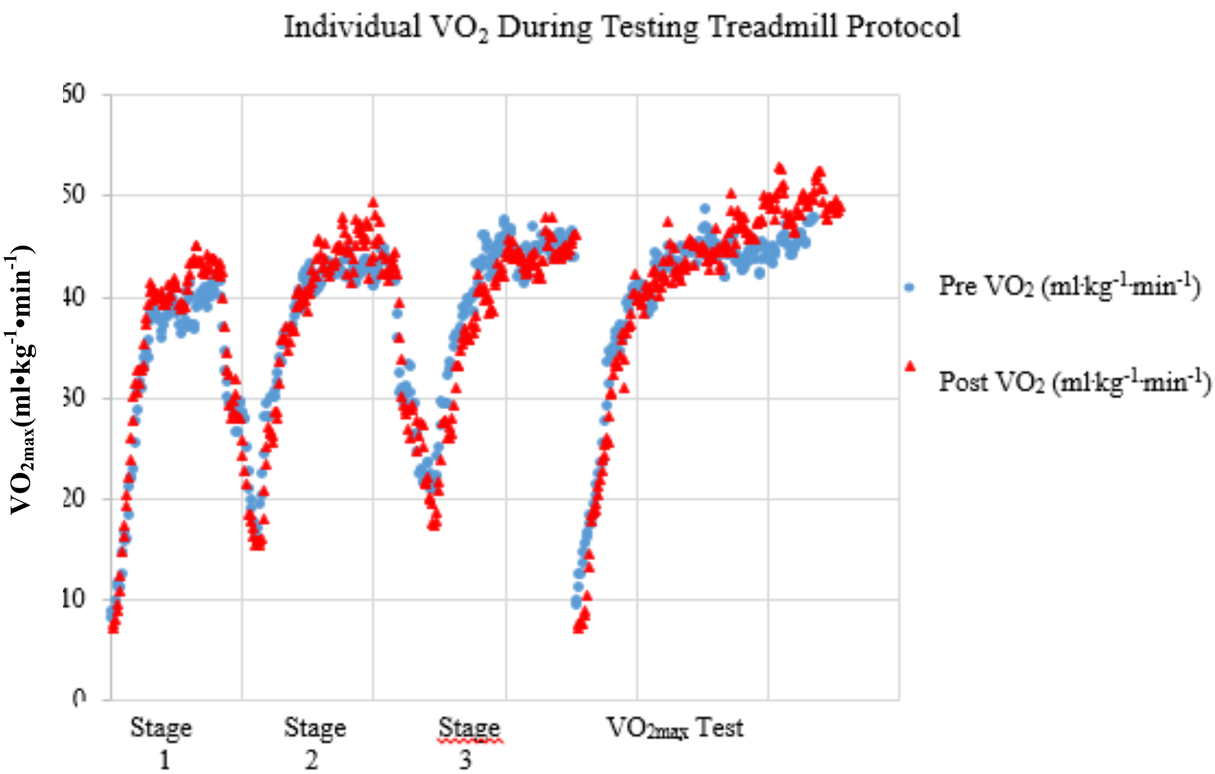
APPENDIX F. Comparison of VO_{2max} of Each Participant

Individuals in the endurance training group are labeled with E. Individuals in the HIIT group are labeled with H.



APPENDIX G. Comparison of Pre-and Post-Training VO_2 of a Single Participant.

Comparison of VO_2 of individual HIIT participant throughout treadmill Pre- and Post-testing protocol.



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