

PHYSIOLOGICAL AND PERFORMANCE

EFFECTS OF CROSSFIT

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## ABSTRACT

CrossFit has grown in popularity over the past few years, which has led to an increased need for more research on this type of training. The purpose of this study was to assess the effect of CrossFit on aerobic capacity, anaerobic capacity ( $VO_{2max}$ ), power, performance, resting heart rate, resting blood pressure, and body composition. This study also assessed the rating of perceived exertion after a CrossFit workout and perceived recovery the day following a workout. The study was a pre-post design in which twelve participants completed a 30-day, 6-week, CrossFit training program. Prior to the exercise program,  $VO_{2max}$ , maximal accumulated oxygen deficit, vertical jump height, body weight, body composition, resting heart rate, and resting blood pressure were assessed for each individual. The first three workouts of the 6-week program were also used to assess performance in three CrossFit workouts that stressed all three energy systems. These same measurements were assessed at the end of the 6-week training session. Paired-samples T-tests showed statistically significant improvement for  $VO_{2max}$  (11%,  $p = .001$ ), maximal accumulated oxygen deficit (25%,  $p = .021$ ), performance in all three CrossFit workouts (CrossFit Total: 11%,  $p < .001$ ; 500m row: 4%,  $p = .017$ ; Fight Gone Bad: 31%,  $p < .001$ ), and diastolic blood pressure (14%,  $p = .014$ ). Average rating of perceived exertion for each training session was found to be  $15 \pm 2$ , and the average rating of perceived recovery was stated to be  $7.2 \pm 1.3$ . These results show that participating in a CrossFit training program based on the Training Guide can lead to improvements in aerobic capacity, anaerobic capacity, and performance using all three energy systems.

## DEDICATION

First, I would like to dedicate this dissertation to the participants that volunteered their time and effort in order to help me complete this project. I cannot name you all individually, but I hope you know how thankful I am. I can honestly say that I enjoyed getting to know you all, and please let me know if I can ever return the favor.

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## LIST OF ABBREVIATIONS AND SYMBOLS

$\alpha$	Type I error rate
ADP	Adenosine diphosphate
APFT	Army physical fitness test
APRT	Army physical readiness training
ATP	Adenosine triphosphate
BF	Body fat
BP	Blood pressure
CFT	CrossFit Total
CRT	Circuit resistance training
$d$	Effect size
FGB	Fight Gone Bad
HIIT	High-intensity interval training
HIPT	High-intensity power training
HR	Heart rate
kg	Kilogram
km	Kilometer
MAOD	Maximal accumulated oxygen deficit
MEF	Mission essential fitness
ml	Milliliter
mm	Millimeter

OBLA	Onset blood lactate accumulation
PCr	Phosphocreatine
RBP	Resting blood pressure
RHR	Resting heart rate
VO <sub>2max</sub>	Maximal oxygen uptake
WOD	Workout of the day

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## **CHAPTER 1**

### **INTRODUCTION**

CrossFit is a training program designed to “forge a broad, general, and inclusive fitness that will best prepare trainees for any physical contingency” (Glassman, 2010). CrossFit was created in 1995 by Greg Glassman, a former gymnast and fitness trainer from Santa Cruz, California. According to the CrossFit journal, the first published workout of the day (WOD) on the internet was on February 10, 2001 (Glassman, 2005).

CrossFit has grown tremendously since the first internet posting in 2001. In 2005 there were 49 CrossFit gym affiliates, and this number has grown to over 10,000 affiliates worldwide in 2013 (www.crossfit.com, 2013). The substantial increase in affiliates within these 8 years appears to be a good indicator that many people around the world participate in CrossFit, and the number continues to grow. The growing number of participants is also obvious when looking at the number of participants in the CrossFit Open Competition. The CrossFit Open Competition is open to anybody around the world that wants to participate. The number grew from approximately 26,000 people in 2011, to approximately 63,000 in 2012, and over 130,000 in 2013. The annual male and female winners of the final CrossFit games also win up to \$275,000, leading many people to make CrossFit their profession through owning a gym, coaching, and competing.

Not only has the number of participants increased, but so has its popularity. The CrossFit games have been on national television (ESPN); it has been endorsed by various companies,

such as Reebok; has led to the formation of numerous clothing, equipment, and accessory companies; and many of these companies endorse athletes around the world.

Glassman, and colleagues, recommend the participation in “constantly varied, high-intensity, functional movement” (Glassman, 2010). Functional movements are described as multi-joint movements that are performed using a wave of contractions from the core to the extremities (Glassman, 2010). This training program attempts to optimize physical competence in ten fitness domains, including: cardiovascular and respiratory endurance, stamina, strength, flexibility, power, speed, coordination, agility, balance, and accuracy (Glassman, 2010). Competency in these domains is developed through participation in a variety of exercises that can be grouped into three different categories; gymnastics, metabolic conditioning, and weightlifting. The CrossFit program attempts to stress all three energy systems (phosphagen pathway, glycolytic pathway, and the oxidative pathway), and is stated to improve performance using all three of these systems (Glassman, 2010).

Although there is an obvious increase in the popularity and participation in CrossFit, there is only a limited amount of research on this exercise program. Previous research indicates improvements regarding physical assessment tests in the military, work capacity, power, anaerobic capacity, aerobic capacity, muscular endurance, and body composition (Smith, Sommer, Starkoff, Devor, 2013; Heinrich, Spencer, Fehl, Carlos Poston, 2012; Paine, Paine, Uptgraft, Wylie, 2010; Jeffery, 2012; Patel, 2012). Although these results have been reported, more research is necessary. There is no research on the effects of a CrossFit training program on healthy college-aged subjects that do not participate in a regular exercise program. There is also minimal research on the assessment of all three energy systems (based on physiological measurements and performance tests) after participating in a 6-week program based specifically

on the CrossFit methodology as outlined in the training guide. The use of the maximal Åstrand protocol, maximal accumulated oxygen deficit (MAOD), and vertical jump in order to assess the three energy systems has not been performed in previous studies on CrossFit. A more comprehensive assessment of the physiological and performance effects on healthy individuals that was performed in this study provided the necessary insight into the benefits of this program. For the purpose of this study, we sought to address these specific research questions.

**Specific Aims/Study Questions:**

1. Does participation in a 6-week CrossFit program cause any changes in aerobic capacity, anaerobic capacity, and/or power output?
2. Does participation in a 6-week CrossFit program improve performance in workouts that stress the phosphagen system, glycolytic system, and the oxidative system?
3. Does participation in a 6-week CrossFit program affect resting heart rate, resting blood pressure, and/or body composition?

## **CHAPTER 2**

### **LITERATURE REVIEW**

There has been minimal published research performed specifically on CrossFit. The purpose of the first part of this literature review is to describe CrossFit according to the CrossFit Training Guide. This includes the purpose of CrossFit, the methodology behind the development of the program, and the physiological adaptations that are stated to occur. The second part of the review will focus on the physiological adaptations that occur by training the three energy systems (ATP-PCr, glycolytic, and oxidative), which form the foundation to CrossFit training. Next, studies performed on high-intensity training protocols (fundamental to CrossFit training) will be discussed. Finally, the few published studies performed specifically on CrossFit will be examined.

#### **CrossFit**

The information provided in this section comes directly from the CrossFit Training Guide which is accessible to the public through the CrossFit website (<http://journal.crossfit.com/2010/05/crossfit-level-1-training-guide.tpl>). The training guide, a collection of CrossFit Journal articles written by Greg Glassman, was primarily used to describe CrossFit. This was done to provide an exact description of CrossFit based on what was stated by the person who developed the program. The purpose of the guide is to describe the foundational movements and concepts that comprise the CrossFit methodology (Glassman, 2010). The introduction to the training guide specifically states that “the information contained in these



articles is foundational to the CrossFit methodology, and, along with the rest of the Journal, should support any successful training venture” (Glassman, 2010). The purpose of CrossFit as stated is to forge a broad, general, and inclusive fitness and is accomplished by not specializing in one specific mode of exercise, but participating in “constantly varied, high-intensity, functional movements” (Glassman, 2010). Functional movements are described as multi-joint movements that use a universal motor recruitment pattern; performed in a wave of contractions from the core to the extremities (Glassman, 2010). Universal motor recruitment patterns are those that are seen and used to complete a variety of tasks, unlike movements that isolate specific muscles. An important aspect to note about these movements is that they are natural; therefore when done correctly, they are safe to perform. Not only are they safe to perform, but the training guide states that an important component of these movements is that they have the capacity to “move large loads over long distances, and to do so quickly...leading to the production of high power” (Glassman, 2010). The training guide does emphasize that most exercises should be performed at a high-intensity due to “intensity being the independent variable most commonly associated with maximizing favorable adaption to exercise” (Glassman, 2010). Although this is recommended, it is important to note that intensity levels are relative to each individual participant based on ability and fitness level.

When developing CrossFit, Greg Glassman and others used three different standards for evaluating and guiding fitness. The three standards include: 1) the ten general physical skills (cardiovascular/respiratory endurance, stamina, strength, flexibility, power, speed, coordination, agility, balance, and accuracy), 2) performance of a variety of athletic tasks, and 3) using the three primary energy systems used to complete different tasks (Glassman, 2010). According to the training guide, the ten general physical skills are defined as:

- *Cardiovascular endurance* – the ability of body systems to gather, process, and deliver oxygen to the active tissues in the body.
- *Stamina* – the ability of body systems to process, deliver, store, and utilize energy.
- *Strength* – the ability of a muscular unit, or combination of muscular units, to apply force.
- *Flexibility* – the ability to maximize the range of motion of a given joint.
- *Power* – the ability of a muscular unit, or combination of muscular units, to apply maximum force in minimum time.
- *Speed* – the ability to minimize the time cycle between repeated movements.
- *Coordination* – the ability to combine several distinct movement patterns into a singular distinct movement.
- *Agility* – the ability to minimize transition time from one movement pattern to another.
- *Balance* – the ability to control the placement of the body’s center of gravity in relation to its support base.
- *Accuracy* – the ability to control movement in a given direction or at a given intensity.

The second fitness standard defined by CrossFit is based on performance of a variety of athletic tasks. An example provided by the training guide includes:

*“Picture a hopper loaded with an infinite number of physical challenges where no selective mechanism is operative, and being asked to perform feats randomly drawn from the hopper.”*

The purpose of this standard is to encourage participants not to specialize in any one specific domain of fitness as previously described.

The third and final fitness standard will be the focus of the third part of this literature review and primary focus of this research study. It is based on the three energy

systems, including the phosphagen (PCr) pathway, the glycolytic pathway, and the oxidative pathway. These energy systems are used during exercise, ranging from short anaerobic bouts of exercise to longer aerobic bouts. The training guide recommends that true total fitness develops and requires competency in each of the three energy pathways (Glassman, 2010). The use of all three energy systems is controlled by the duration, intensity, and exercises programmed for each WOD.

In order to develop a training program that incorporates all three standards of fitness previously described, CrossFit uses a variety of exercises that can be grouped into three different categories: 1) metabolic conditioning (“cardio”), 2) gymnastics, and 3) weightlifting. According to the training guide, metabolic conditioning refers to activities such as riding a bicycle, running, swimming, rowing, speed skating, and/or cross-country skiing (Glassman, 2010). Glassman (2010) states that these activities should be performed at various durations and intensity levels (anaerobic and aerobic), but does not recommend participating in more anaerobic activity than aerobic. For the purpose of this review, the term gymnastics includes all activities involving moving body weight against gravity, including but not limited to: typical gymnastics movements (summersaults, handstands), climbing, yoga, calisthenics (pull-ups, push-ups, dips, and rope climbs), and dance. Weightlifting is the final category, and refers to the Olympic sport of weightlifting. Olympic weightlifting includes two movements, the clean and jerk and the snatch (Glassman, 2010), and these lifts are stated to be based on other lifts included in this category; such as the deadlift, clean, squat, and jerk. Although this category is just known as “weightlifting” it does incorporate throwing activities as well. All of these movements are stated to be functional, multi-joint movements that are executed from the

core to the extremities (Glassman, 2010). Due to these activities being functional movements, they are deemed to be safe to perform when done correctly. Not only are these movements safe to perform, they are also stated by Glassman to elicit a profound neuroendocrine response, leading to an increase in testosterone, insulin-like growth factor, and human growth hormone and are essential to athletic development (Glassman, 2010). This claim was supported by McArdle, Katch, and Katch (2010, p. 438) who stated that resistance training in men increases frequency and amplitude of testosterone and growth hormone secretion, which creates an optimal environment for muscular growth. Glassman (2010) states that performing a combination of exercises among these three categories “encourages new skill development, generates unique stressors, crosses modes, incorporates quality movements, and hits all three metabolic pathways.” The metabolic pathways mentioned include the three systems that provide energy for all activities, the ATP-PCr (phosphagen pathway), glycolytic, and aerobic systems (oxidative pathway). These systems will be further discussed.

## **Energy Systems**

CrossFit encourages the participation in activities that stress all three energy systems. The three different energy systems include the ATP-PCr system, the glycolytic (lactic acid) system, and the aerobic system. Their relative contributions to overall energy provision depend on the intensity and duration of exercise and each person’s fitness level. The names of these systems may differ depending on the source used, and the CrossFit training manual refers to these systems as the phosphagen pathway, glycolytic pathway, and oxidative pathway, respectively. Each system will be further described in the following sections. The books Exercise Physiology: Nutrition, Energy,

and Human Performance – 7th edition written by McArdle, Katch, and Katch (2010), and Physiology of Sport and Exercise – 4<sup>th</sup> edition written by Wilmore, Costill, and Kennedy (2004) were used as a reference guide for the following sections. The original sources were primarily taken from these two books for the purpose of this literature review.

### ***ATP-PCr & Glycolytic Systems***

The simplest of the energy systems is the ATP-PCr system (Wilmore and Costill, 2004, p. 123). High-intensity exercise of short duration, approximately 3 to 30 seconds, predominantly uses the ATP-PCr system (McArdle, et al., 2010, p. 163; Wilmore and Costill, 2004, p. 124). The energy provided by this system comes almost exclusively from intramuscular high-energy phosphate (phosphagen) sources, adenosine triphosphate (ATP) and phosphocreatine (PCr) (McArdle, et al., 2010, p. 163), and does not require any special structures within the cell (Wilmore and Costill, 2004, p. 124). When evaluating this energy system it must be assumed that all ATP at maximal power output regenerates via ATP-PCr hydrolysis, and adequate ATP and PCr exist to support maximal performance for about six seconds (McArdle, et al., 2010, p. 227). The term “power” is often used to describe these types of activity.

The lactic acid system, also known as the glycolytic system, provides energy anaerobically through the breakdown of glucose, termed glycolysis. Glycolysis facilitates ATP to be formed rapidly without the presence of oxygen. The energy to phosphorylate ADP during exercise comes primarily from stored muscle glycogen, which also results in the formation of lactate (McArdle, et al., 2010, p. 163). This energy system is predominant during maximal exercise lasting between 60 and 180 seconds (McArdle, et al., 2010, p. 163). This system does not produce a large amount of ATP,

but the combined actions of the ATP-PCr and glycolytic systems allow the muscles to generate force when a limited amount of oxygen is present (Wilmore and Costill, 2004, p. 125). Since glycolysis provides energy anaerobically, it can lead to the accumulation of lactic acid when oxygen is not present. An increase in lactic acid leads to an increase in the acidity of muscle fibers. This inhibits further breakdown of glycogen due to the impairment of glycolytic enzymes, and causes fatigue (Wilmore and Costill, 2004, p. 125).

When training these two energy systems, three important changes occur, including: increased levels of anaerobic substrates, increased quantity and activity of key enzymes, and increased capacity to generate high levels of blood lactate during “all-out” exercise (McArdle, et al., 2010, p. 458; MacDougall, Ward, Sale, Sutton, J.R. 1977). Increased levels of anaerobic substrates were noted in a study performed by MacDougall, et al. (1977) which indicated an increase in trained muscle’s resting levels of ATP, PCr, free creatine, and glycogen after performing a resistance training program. Another study by Neumann (1990) reported higher levels of ATP and total creatine content in trained muscles in sprint athletes compared to endurance athletes. An increase in the quantity and activity of key enzymes that control glycolysis have also been noted, especially in fast-twitch muscle fibers. However, they do not appear to achieve the magnitude observed for oxidative enzymes with aerobic training (McArdle, et al., 2010, p. 458). The final adaptation described by McArdle, et al. (2010, p. 458) is the increased capacity to generate high levels of blood lactate during all-out exercise. This adaptation is stated to “probably result from increased levels of glycogen and glycolytic enzymes, and improved motivation and tolerance to “pain” in fatiguing physical activity”

(McArdle, et al., 2010, p. 458). Wilmore and Costill (2004, p. 199) state that the concentration of lactate in the blood may become lower for a specific activity as one becomes better trained.

These two anaerobic systems can be trained and improved. The ability to perform “all-out” exercise for up to 60 seconds largely depends on ATP generated by the immediate and short-term anaerobic systems (McArdle, et al., 2010, p. 479). Activities such as American football, weightlifting, and other brief-power sports in which specific muscles are repeatedly engaged for five to ten second bursts rely primarily on the ATP-PCr system (McArdle, et al., 2010, p. 479). In order to improve this energy system, one must participate in activity that requires the use of muscles at the movement speed and power output similar to the specific sport. This type of activity will improve metabolic capacity and facilitate the recruitment and modulation of neural firing (McArdle, et al., 2010, p. 479). In order to improve the glycolytic system “the individual must repeat bouts of anaerobic activity for at least one minute, with three to five minute rest between bouts of exercise” (McArdle, et al., 2010, p. 479). The repetitions cause “lactate stacking” which produces higher lactate levels than by just one single effort. Being able to continue exercise with a greater amount of lactate allows one to increase their lactate threshold and continue exercising for a longer period, or at a greater intensity (McArdle, et al., 2010, p. 479). These two energy systems are essential for activity to start and continue, but the aerobic energy system is necessary for any activity that lasts longer than the anaerobic systems can provide energy.

### ***Aerobic System***

Aerobic metabolism is responsible for most of the energy provided when exercise lasts longer than several minutes. Oxygen being available in this process leads to the

production of more ATP than that produced by the anaerobic systems. Due to there being more ATP produced, the energy needed by the working muscle is available, and exercise can continue (McArdle, et al., 2010., p. 165).

As with the anaerobic energy systems, the aerobic pathway can be trained and improved. There are many adaptations noted that may lead to an increase in aerobic capacity. Endurance-trained skeletal muscle fibers contain larger and more numerous mitochondria than less active fibers (McArdle, et al., 2010, p. 459). Not only does the number and size of the mitochondria increase, but enzyme activity increases as well, which causes an increase in the production of ATP (Green, Barr, Fowles, Sandiford, Ouyang, 2004; Hoppeler & Flück, 2003; Starritt, Angus, Gargreaves, 1999). Endurance training also leads to an increase in the use of fatty acids as a fuel source during periods of rest or submaximal exercise in order to preserve stored glycogen (Paton, Brandauer, Weiss, Brown, Ivey, Roth, Hagberg, 2006). Although muscle fibers probably do not “change” type, they might “maximize their already existing aerobic potential” (McArdle, et al., 2010, p. 460). Endurance training may also cause moderate cardiac hypertrophy, with an increase in the volume and mass of the left ventricle (Moore and Palmer, 1999). This adaptation allows for more blood to be pumped during each ventricular contraction, providing more blood and oxygen to the active tissue. The increase in left ventricular volume and mass may also lead to a lower heart rate during rest and exercise, a larger stroke volume per contraction, and an increase in cardiac output at max (McArdle, et al., 2010, p. 463-465). Plasma volume may also be increased through aerobic training. There is a 12% to 20% increase in plasma volume that occurs after a few weeks of aerobic training (Sawka, Convertino, Eichner, et al., 2000). The increase in plasma



volume may “enhance circulatory reserve and increase end-diastolic volume, stroke volume, oxygen transport,  $VO_2$ max, and temperature-regulating ability during exercise” (Goodman, Liu, Green, 2005; Hagberg, Goldberg, Lakatta, O’Connor, Becker, Lakatta, Fleg, 1998). After training, blood flow is sent to skeletal muscles that require oxygen, and due to the increased oxidative capacity more oxygen is extracted from the circulating blood and provided to the active musculature (Schmidt-Trucksäss, Schmid, Dorr, Huonker, 2003). Another important adaptation to aerobic training is the lowering of blood lactate levels and the delaying of the onset of blood lactate accumulation (OBLA). This may be due to decreased rate of lactate formation, increased rate of lactate clearance, or a combination of the two (McArdle, et al., 2010, p. 468).

Two factors are necessary when formulating an aerobic training program. The first factor is the cardiovascular system must be stressed, and the activity must be intense enough to cause an increase in stroke volume and cardiac output. The second factor is that the cardiovascular overload “must occur from activation of sport-specific muscle groups to enhance local circulation and the muscle’s ‘metabolic machinery’” (McArdle, et al., 2010, p. 480). This stress can be applied through the participation in vigorous exercise, including various high-intensity interval training (HIIT) programs, circuit-training, and/or long, continuous efforts. The different programs can be manipulated by adjusting the duration and intensity of exercise in order to stress the cardiovascular system. High intensity training, HIIT, and circuit-training will be further discussed due to their similarity to a CrossFit program.

## **High-Intensity Exercise**

The American College of Sports Medicine (ACSM) recommends that adults should accumulate 30 to 60 minutes of moderate-intensity exercise five times per week to achieve health benefits, but also states that 20 to 60 minutes of vigorous, or high-intensity, exercise three times per week is sufficient (Garber, et al. 2011). These recommendations are also stated by the Center for Disease Control and Prevention (CDC), which promote the 2008 Physical Activity Guidelines for Americans (CDC, 2012). These guidelines recommend that Americans attain at least 150 minutes of moderate intensity activity or 75 minutes of high-intensity activity per week (CDC, 2012). As a rule of thumb, one minute of vigorous exercise is about the same as two minutes of moderate-intensity exercise (CDC, 2012). The CDC (2012) also states that there does appear to be a dose response relationship for vigorous activity, as an increase in volume of vigorous exercise is recommended for greater health benefits. This statement supported the claim made in the 1996 United States Surgeon General's Report which stated that "physical activity would reduce one's risk for coronary heart disease (CHD), as well as other problems, and vigorous activity would provide greater benefits than moderate-intensity activity" (US Dept. of Health and Human Services, 1996). These increased adaptations may be due to the idea that high-intensity exercise places a higher load on the central part of the circulation, which may cause greater cardiac adaptations (Amundsen, Rognum, Hatlen-Rebhan, Slordahl, 2008).

It has also been stated that "There is a close relationship between exercise intensity and cardiorespiratory fitness, vigorous exercise being more effective in improving fitness levels" (Ciolac, 2012). Not only does vigorous activity help improve

the quality of life for the general population, but it is also stated to be beneficial for improving exercise capacity in individuals that regularly participate in physical activity. High-intensity exercise leads to improvements in aerobic and anaerobic fitness (Hottenrott, Ludyga, Schulze, 2012; Whyte, Gill, Cathcart, 2010), and increased training intensity has been shown to improve athletic performance in previously trained runners (Acevedo & Goldfarb, 1989). Comprehensive reviews of the literature based on runners indicated that high-intensity exercise was necessary to improve aerobic capacity ( $VO_{2max}$ ) in trained athletes (Garber, et al., 2011; Midgley, McNaughton, Wilkinson, 2006). These studies imply that high-intensity exercise can provide the increased stress necessary to achieve the adaptations required to improve athletic performance. The following studies will provide more detail on the type of training involved and the adaptations noted.

### **High-Intensity Interval Training**

A HIIT protocol consists of bouts of exercise performed at a high-intensity (commonly 80-95%  $VO_{2max}$ ) that last several seconds to a few minutes, and are interspersed with varying periods of rest. It must be noted that the studies discussed used various protocols for their intervention. Also, there have been many studies performed on the effects of HIIT training on coronary heart disease (CHD) and other diseases, but this literature review will focus more on the performance effects of HIIT due to the purpose of the present study.

A study performed by Bayati, Farzad, Gharakhanlou, and Agha-Alinejad (2011) assessed the effects of a HIIT protocol on aerobic and anaerobic performance. The protocol included a sprint-interval exercise intervention which consisted of three to five

30-second “all-out” efforts with four minutes of recovery between bouts of exercise. The intervention was performed three days per week for a four-week period. The results indicated that the HIIT protocol improved  $VO_{2max}$  in untrained subjects, increased time to exhaustion during exercise, increased peak power output, and increased maximum blood lactate levels. The authors stated that “the results of this particular study support the idea that vigorous exercise can be beneficial for improving aerobic and anaerobic capacity” (Bayati, et al., 2011).

Two particular studies were performed using well-trained cyclists. Lindsay, Hawley, Myburgh, Schomer, Noakes, and Dennis (1996) performed a study that replaced a portion of an aerobic training protocol for twelve well-trained cyclists with a HIIT protocol. The HIIT protocol consisted of six sessions of six to eight five minute intervals, which were performed at 80% of each subject’s peak power output, with 60 seconds of rest between each bout of exercise. The researchers reported an increase in peak sustained power output after four weeks, but not after two weeks. The researchers also reported an increase in exercise time to fatigue after two weeks, and an increase in performance in a 40 kilometer time-trial after four weeks. The authors stated that “the results of this study are similar to statements made in previous research that it may take around four weeks to see improvements due to HIIT training” (Lindsay, et al., 1996).

Another study that used well-trained cyclists was performed by Westgarth-Taylor, Hawley, Rickard, Myburgh, Noakes, and Dennis (1997). Participants included eight competitive cyclists who had not previously participated in any type of HIIT. The intervention consisted of six to nine 5-minute cycling bouts performed at 85% to 88% of each subject’s  $VO_{2peak}$  with a 1-minute rest between bouts. The protocol was completed

every three days for a 6-week period. The researchers reported a significant improvement in peak power and simulated time trial performance.

These two studies used protocols with a longer duration of work which made it more specific to endurance athletes, such as the cyclists that participated. Although the duration of work performed was equal to approximately 30 to 45 minutes, the amount of time was still shorter than that used for more moderate, continuous exercise.

Another HIIT protocol with a much shorter duration of work interval was used in a study performed by Tabata, et al. (1996). The protocol consisted of six to eight intervals, which included 20 seconds of work performed at a “supramaximal” intensity followed by 10 seconds of rest, for a total of 3 to 4 minutes. The authors stated that the rationale of the short bursts of work and rest was because “a HIIT program is supposed to recruit the anaerobic energy releasing system almost maximally...the short bouts of exercise, followed by the minimal duration of recovery are more specific to the anaerobic energy system” (Tabata, et al., 1996). The authors also emphasized the use of the anaerobic energy system by stating that “the anaerobic system must be used because during activity of any intensity the body’s primary energy source is adenosine triphosphate (ATP), and is resynthesized by aerobic and anaerobic processes” (Tabata, et al., 1996). This study compared the effects of a moderate-intensity endurance training protocol with the above mentioned HIIT protocol. The subjects included 14 male varsity athletes that were members of the table tennis, baseball, basketball, soccer, and/or swimming teams. Subjects were divided evenly into one of the two groups. The moderate-intensity group exercised five days per week for six weeks at 70% of their  $VO_2\text{max}$  for 60 minutes each session. The HIIT group exercised five days per week for

six weeks, and performed the previously described HIIT protocol four of the five days at an intensity of 170% of their  $\text{VO}_2\text{max}$ . On the day that the participants in the HIIT group did not complete the HIIT protocol, they exercised for 30 minutes at 70% of their  $\text{VO}_2\text{max}$  followed by four sets of intermittent exercise at 170% of  $\text{VO}_2\text{max}$ . Results indicated that the moderate-intensity protocol improved  $\text{VO}_2\text{max}$  by 5 ml/kg/min, but the participants' anaerobic capacity did not change. The HIIT protocol improved  $\text{VO}_2\text{max}$  by 7 ml/kg/min, and anaerobic capacity was improved by 28% when measured in ml/kg. The authors stated that “these results are beneficial because they show how results are specific to the type of training one participates in, and this is the first study to demonstrate an increase in both anaerobic and aerobic capacity by a specific type of training” (Tabata, et al., 1996).

This same HIIT protocol was also used in another study performed by Tabata, Irisawa, Kouzaki, Nishimura, Ogita, and Miyachi, (1997) in order to compare it to another HIIT protocol, evaluating their effects on aerobic and anaerobic capacity. The second protocol consisted of four to five bouts of exercise performed at 200% of  $\text{VO}_2\text{max}$  for 30 seconds, with two minutes of rest between each bout of exercise. Nine male subjects that were also members of a varsity sport team volunteered to participate in the study. The main findings reported by the authors were that the accumulated oxygen deficit and oxygen uptake were close to the maximum obtainable for the first protocol (20 seconds of work, 10 seconds of rest), but not for the other HIIT protocol (30 seconds of work, two minutes of rest). The authors stated that these results were important because “it shows that the first protocol stressed the anaerobic and aerobic energy systems, while

the second protocol did not, therefore in order to improve both energy systems, the first protocol appeared to be superior to the other HIIT protocol” (Tabata, et al., 1997).

Although these studies are not specific to CrossFit, they do support the use of high-intensity exercise and HIIT protocols in order to increase physical fitness in people with various athletic backgrounds. The various protocols presented show that although there is not one specific protocol that should be used, exercise performed at a high-intensity may provide fitness benefits. Not only are HIIT or HIT effective in improving aerobic and anaerobic capacity, but circuit resistance training (CRT) and cross-training have also been found to be effective as well. A review of these types of training is relevant due to the variety of exercises performed and the variety of exercise durations used being similar to CrossFit.

### **Circuit Resistance Training**

CRT is a modification of the traditional approach to resistance training. The modification is made in order to increase the caloric cost of exercise and improve many different aspects of fitness (McArdle, et al., 2010, p. 528). This type of training provides “more-general conditioning that improves body composition, muscular strength and endurance, and cardiovascular fitness” (Alcaraz, Sánchez-Lorente, Blazeovich, 2008; Ghanbari-Niaki, Saghebjo, Rahbarizadeh, Hedayati, Rajabi, 2008). As with the HIIT programs, there are many different protocols that can be used when following a CRT program. Various methods include performing as many repetitions as possible in a specific time frame (i.e. 30 seconds) of eight to fifteen different exercises (McArdle, et al., 2010, p. 528). Rest time between each exercise station ranges anywhere from 15 seconds between stations to a work-rest ratio of 1:1, and the circuit should be repeated

several times (Ballor, Becque, Marks, Nau, Katch, 1989). This type of training is stated to “offer an attractive alternative to those who desire a more general conditioning program, and offers a well-rounded fitness program” (McArdle, et al., 2010, p. 528).

A study by Harris and Holly (1987) was performed in order to assess the effects of CRT on aerobic capacity using both treadmill running and arm-crank ergometry tests. Results indicated that after participating in the CRT program, aerobic capacity increased by approximately 8% on the treadmill test, and by approximately 21% on the arm-crank test. The program also increased muscular strength, decreased BP, and improved body composition. The authors stated that “the findings take on added significance because they occurred without negative effects in a group of borderline hypertensives” (Harris & Holly, 1987). These results are beneficial because they indicate that even though the participants were not participating in traditional endurance activity they were still shown to increase their aerobic capacity.

### **Cross-Training**

Cross-training is defined as “training for more than one sport at a time or training for several different fitness components at one time” (Wilmore & Costill, 2004, p. 298). These authors also state that “for the athlete training for cardiorespiratory endurance and strength at the same time, the studies conducted to date indicate that gains in strength, power, and endurance can result” (Wilmore & Costill, 2004, p. 298). However, Dudley & Fleck, (1987) and Leveritt, Abernethy, Barry, Logan (1999) stated “the gains in muscular strength and power are less when strength training is combined with endurance training than when strength training is performed alone, but the opposite does not appear to be true for aerobic training when strength training is included” (Hickson, Dvorak,



Gorostiaga, Kurowski, Foster, 1988). Hickson, et al. (1988) reported that endurance can actually be increased with the addition of resistance training. Not all studies agree regarding compromised strength gains with concurrent resistance and endurance training program. For example, a study performed by McCarthy, Pozniak, and Agre (2002) did not indicate an attenuation of strength gains with concurrent endurance training. This particular study used 30 sedentary healthy volunteers in order to examine muscle morphological and neural activation adaptations after participating in one of three training protocols, including high-intensity strength training, cycle endurance training, or concurrent strength and endurance training. The participants were divided and randomly assigned to one of the three training programs which were completed three days per week for 10 weeks. Results indicated that a concurrent program of strength and endurance training did not impair adaptations in strength, muscle hypertrophy, or neural activation when compared to the group that just participated in strength training (McCarthy, et al., 2002). These results are important because although much research does indicate that strength gains may be hindered when combined with endurance training, not all results are consistent.

The participation in HIIT or other vigorous exercise, as well as circuit and cross-training has been shown to improve the ability to use all three energy systems. CrossFit is also described as a type of high-intensity power training (HIPT), which is stated to be a relatively new variation of HIIT that incorporates varied multiple joint movements (Smith, et al., 2013). As previously stated, stressing all three energy systems is one of the three fitness standards encouraged by CrossFit. CrossFit training will be further discussed in the following sections.

## **CrossFit Training**

To date, there has been limited research on the effects of CrossFit, or HIPT. Although there is minimal research, there have been beneficial results noted in various studies (Smith, et al., 2013; Heinrich, et al., 2012; Paine, et al., 2010; Jeffery, 2012; Patel, 2012), but many of these studies were not peer-reviewed. These benefits include: improved performance on physical assessment tests in the military; increased work capacity, power, anaerobic capacity, aerobic capacity, muscular endurance; and favorable changes in body composition (Smith, et al., 2013; Heinrich, et al., 2012; Paine, et al., 2010; Jeffery, 2012; Patel, 2012). These studies evaluating the CrossFit training program will be closely examined in the following section.

### ***High-intensity Power Training***

CrossFit may improve aerobic fitness with minimal time commitment when compared to traditional aerobic training (Smith, et al., 2013). Smith, et al. (2013) state that this type of training is different from traditional high-intensity interval training “in that it includes a lack of prescribed rest period, focuses on sustained high power output, and uses multiple joint movements.” The authors further state that “the sustained high power output associated with HIPT might serve as a stimulus for positive adaptations regarding maximal aerobic capacity and body composition.” In order to assess this hypothesis, these authors investigated the effect of a 10-week CrossFit program on body composition and aerobic capacity ( $VO_{2max}$ ) in 43 healthy adults of various levels of fitness (23 males, 20 females). Measurements were assessed before and after the completion of the 10-week program.  $VO_{2max}$  was assessed using a maximal treadmill test that utilized the Bruce protocol. The CrossFit exercise program followed the

recommendations outlined in the CrossFit training guide. Results indicated that the 10-week CrossFit exercise program resulted in significant improvements in maximal aerobic capacity and body composition in both males and females. Body fat percentage dropped by 3.7%, in absolute terms, across all individuals, and VO<sub>2</sub>max increased for males and females by 13.6% and 11.8%, respectively. These authors stated that “While HIIT has previously been shown to improve body composition and VO<sub>2</sub>max in healthy adults; this is the first investigation showing that similar benefits can be obtained using a CrossFit-based HIPT program” (Smith, et al., 2013). Based on these results, Smith et al., (2013) propose that “HIPT training could be used as an adjunct to aerobic training...and these workouts require much less time.”

### ***CrossFit in the Military***

As of 2012, most training research conducted by the military emphasized combat readiness and overall performance improvements on the Army Physical Fitness Test (APFT), which assesses aerobic and muscular endurance (Headquarters, Dept. of the Army, 2010). The Army Physical Readiness Training (APRT) program is commonly used by the Army in order to improve performance on the APFT (Kraemer, et al., 2004; Kraemer, Vogel, Patto, Dziados, Reynolds, 1987). APRT is a program that is conducted five times per week and focuses on mobility, strength, and endurance (Heinrich, et al., 2012). The program consists of a warm-up, 50 minutes of aerobic and resistance training, and a cooldown (Heinrich, et al., 2012). The APRT appears to be a popular training program, and circuit-style programs that emphasize functional fitness exercises performed at a high-intensity have gained popularity within the military (Amos, 2006; Bergeron, 2011). Due to the increased popularity of high-intensity circuit training, Heinrich, et al. (2012) conducted a study in order to compare the effects of APRT to

another training program known as Mission Essential Fitness (MEF). MEF was created to address perceived weaknesses of the APRT program and focuses on movements in multiple planes using a variety of speeds in a circuit format (Heinrich, et al., 2012). Exercises performed within this program focus on strength, power, speed, and agility through the use of bodyweight, barbells, dumbbells, resistance bands, medicine balls, sleds, and tires. The exercises also include multi-joint movements including, but are not limited to Olympic lifts, squats, bench press, pull-ups, and plyometrics (Heinrich, et al., 2012). Although these authors did not describe this exercise program as “CrossFit” it appears they used a similar methodology for developing the training program as described in the CrossFit training guide (Glassman, 2010).

Sixty-seven Army soldiers that were currently active in regular physical training volunteered to participate in this study. Participants were randomly assigned to one of two groups, the MEF intervention group ( $n = 34$ ) or the APRT intervention group ( $n = 33$ ). Both groups attended 15 sessions during the 8-week period, averaging two sessions per week. Measurements that were taken before and after the 8-week intervention included: the APFT (as many push-ups as possible in one minute, as many sit-ups as possible in one minute, one and a half-mile run, and a 2-mile run), physiological indicators (RHR, RBP), body composition, and field fitness indicators (Kasch 3-minute step test, bench press, flexibility, power, and agility). Those that participated in the MEF program significantly improved their push-ups, two mile run time, step test, bench-press, and flexibility compared to those that completed the APRT program (Heinrich, et al., 2012). Additionally, MEF training improved the comprehensive fitness domains, including strength, power, cardiorespiratory endurance, muscular endurance, flexibility, and mobility (Heinrich, et al., 2012). Heinrich, et al., (2012) stated that these results were seen after a “relatively low dose of training” (2 sessions per week). These outcomes

support the use of functional exercises performed at a high-intensity in order to improve many fitness domains.

A study performed by Paine, et al. (2010) also used military personnel in order to “test the efficacy of the CrossFit fitness program and methodology to increase the physical fitness of U.S. Army Soldiers.” For the purpose of this study, fitness was defined as “an athletes’ work capacity across broad time periods and modal domains, as stated in the CrossFit training guide” (Pain, et al., 2010). By this definition, these authors stated that in order to demonstrate a high level of work capacity, one must have the ability to perform tasks using any of the three major metabolic pathways that provide energy (phosphagen, glycolytic, and oxidative) (Paine, et al., 2010). In order to assess the efficacy of CrossFit, the authors selected 14 Army soldier volunteers (9 men, 5 women) with varying CrossFit experience from a larger group of applicants. The reasoning for selecting a broad range of athletes was to “evaluate the ability of CrossFit to improve physical fitness regardless of fitness level or experience” (Paine, et al., 2010). The volunteers participated in a CrossFit training program five times a week for six weeks, and it was required that they attended at least four sessions per week. The six-week training program was based on the CrossFit programming methodology as described in the CrossFit training guide. Four assessments were conducted before and after the six week CrossFit training program, including the APFT and three benchmark WODs (“Fran”, “Fight Gone Bad”, and “CrossFit Total”) from the CrossFit website ([www.crossfit.com](http://www.crossfit.com)). Each WOD was selected based on “their diversity from one another and their collective ability to test the athletes’ performance across different metabolic pathways and modalities” (Paine, et al., 2010).

The authors reported four important findings from this study. Each participant experienced an overall increase in work capacity, ranging from 3.71% to 41.92%, based on

performance in each post-training assessment when compared to pre-training. Participants that started the program as “above average” still experienced significant gains in work capacity, and none of the “above average” participants had decreases in overall work capacity. The participants’ also showed improvement in each assessment even though they did not train specifically for each individual test. It was also reported that the participants in the study experienced “relatively equal increases in power output across all four assessments...indicating a balanced increase in performance across metabolic pathways and modalities” (Paine, et al., 2010). These authors stated that they “believe that the CrossFit program’s prescription of high-intensity combined with constant variance is one of the primary reasons that the above-average participants in the study experienced gains in work capacity” (Paine, et al., 2010). This improvement was specifically noted in one particular subject that was stated to be “one of our most fit athletes” (Paine, et al., 2010). This athlete experienced a gain of 28.32% in overall work capacity, which is surprising considering he/she was in above-average physical conditioning prior to the study (Paine, et al., 2010). Although the authors do credit the CrossFit program for the results noted in the study, they also acknowledge that some of the results may have been due to some of the participants having a minimal level of fitness prior to participation. They also acknowledged that the introduction of new movements at a high-intensity would lead to positive adaptations regardless of the program used.

These studies support the use of CrossFit, or other similar functional training programs in the military in order to improve performance and better prepare soldiers for duty. Although these results are important for the military population, it is necessary to look at the benefits of this type of training for the civilian population. It is also necessary to compare CrossFit to other

recommended exercise training guidelines. Relatively few studies employing CrossFit have been performed with this population.

### ***CrossFit vs American College of Sports Medicine Recommended Guidelines***

Not only is CrossFit important in the military but the CrossFit training guide states that “all individuals across a broad facet of fitness levels and abilities, from Olympic athletes to hometown grandparents, have the need to increase power output and can benefit from CrossFit methodologies” (Glassman, 2010). This emphasis on fitness for the general population has also been encouraged by various organizations, such as the ACSM and the National Academy of Sports Medicine (NASM) (Jeffery, 2012). A cross-sectional study by Jeffery (2012) was performed in order to test the ability of CrossFit training methodologies to train an athlete’s anaerobic and aerobic capacities and to compare these results to those obtained from individuals that trained according to ACSM’s recommended guidelines for exercise. The ACSM recommended guidelines for exercise include performing cardiorespiratory exercise a minimum of 3-5 times/week for at least 30 minutes a session, and strength training a minimum of 2-3 times/week involving all major muscle groups (Garber, Blissmer, Deschenes, et al., 2011). Thirty-seven volunteers participated in this study, 19 (15 men, 4 women) participated in CrossFit and 18 (15 men, 3 women) adhered to the ACSM guidelines. In order to be eligible, those that were in the CrossFit group must have trained at an official CrossFit affiliate gym at least three to four times per week for a minimum of the previous four months. Participants in the ACSM group consisted of people that followed the ACSM guidelines for the last four months. Both groups participated in multiple assessments (Margaria Kalamen Power Test, the Anaerobic Step Test, and Cooper 1.5-mile run) in

order to determine anaerobic power and aerobic capacity. Results indicated that the only category in which those that participated in CrossFit were significantly more fit than those that followed ACSM guidelines was in the males' performance on the Margaria Kalamian Power Test, which assessed the phosphagen pathway. Although the results were not statistically significant, women who participated in CrossFit performed better on the Margaria Kalamian Power Test, and men and women that participated in CrossFit performed better on the Anaerobic Step Test (Jeffery, 2012). Although there were a limited number of women, those who participated in CrossFit performed better on the Cooper 1.5-mile run than women who followed the ACSM guidelines, although this difference was not statistically significant. These results indicate that although not statistically different, there were still trends for greater anaerobic and aerobic capacity for those who participated in CrossFit. The author stated that based on the results, it appears that "CrossFit is one of the first programs to incorporate overall fitness of high anaerobic capacity along with aerobic capacity" (Jeffery, 2012). Although these results were stated, it must be noted that the goals of the ACSM guidelines are not necessarily to improve anaerobic capacity. The volume of training could have also been different between the two groups leading up to the tests.

Pratik Patel (2012) also performed a study in order to compare CrossFit to the ACSM recommended guidelines for exercise. The purpose of this study was to examine the differences in glucose control, fitness, and body composition between a standard aerobic and resistance exercise training program (ACSM guidelines) and a CrossFit training program in overweight and obese physically inactive adults. The study consisted of 23 participants who were randomly assigned to one of the two groups, 12 (7 men, 5



women) participants in the CrossFit group and 11 (3 men, 8 women) in the ACSM group. Both interventions were performed three times per week for eight weeks totaling 24 exercise sessions. The ACSM group completed 50 minutes of aerobic exercise on Mondays, Wednesdays, and Fridays; and performed 20 minutes of strength training on Mondays and Wednesdays. The CrossFit group completed a total of 24 exercise sessions, which lasted up to 60 minutes in duration. Various measurements were assessed before and after the eight-week intervention, including fasting plasma glucose levels, an oral glucose tolerance test, peak aerobic capacity ( $VO_{2peak}$ ), and a variety of fitness tests (sit and reach, standing broad jump, vertical jump, push-ups, sit-ups, 40-meter dash, and the stork balance test). Results indicated that the eight weeks of exercise training improved muscular endurance, specifically push-ups, for both groups and sit-ups in the CrossFit group. Improvements in peak aerobic capacity were noted for the CrossFit group only. However, there were no changes in glucose control noted for either group (Patel, 2012). These results further support the use of CrossFit in order to improve muscular endurance and peak aerobic capacity. Also, these results are important because these benefits were seen after exercising for a significantly less time than recommended by the ACSM (Patel, 2012).

### **Summary**

CrossFit is an exercise training program that incorporates high-intensity, constantly varied functional movements in order to prepare individuals for many different tasks using all three energy systems. Therefore, CrossFit recommends the use of various exercises, ranging from gymnastics to weightlifting to metabolic conditioning, in order to improve capacity in these energy systems. Although there is limited literature specific to

CrossFit, research has been performed on similar exercise programs; such as HIIT, circuit training, and cross-training. Research on these various programs has shown benefits in all three energy systems for a variety of participants, and through a variety of protocols.

Although limited, the studies that have been performed on CrossFit training have indicated physiological and performance benefits resulting from this type of training. These include improvements in performance on physical assessment tests in the military, work capacity, power, aerobic capacity, anaerobic capacity, muscular endurance, and body composition. Although previous literature has shown improvements due to CrossFit, research is still needed. Only one of these articles that have investigated CrossFit specifically is a peer-reviewed article (Smith, et al., 2013). No previous study has used lab and field tests in order to assess the results of a 6-week program that follows the guidelines outlined in the CrossFit training guide (Glassman, 2010) with college-aged participants. The purpose of the present study was to extend these findings and further explore the effects of a CrossFit training program on aerobic capacity, anaerobic capacity, power, and performance on three CrossFit workouts corresponding to the three energy systems.

## CHAPTER 3

### METHODS

#### Study Design

This study was a pre-post assessment using healthy volunteers that did not participate in a specific exercise program, but did participate in some type of daily physical activity. The volunteers participated in a 6-week (30-day) CrossFit program between the pre- and post-program assessments.

#### Subject Recruitment

A power analysis for  $VO_{2max}$  revealed that 9-12 subjects were necessary to detect a moderate effect of  $d = 0.5$ , assuming a correlation between the repeated measures of 0.9,  $\alpha = 0.05$ , and power  $\approx 0.8$  (Potvin and Schultz, 2000; Park and Schutz, 1999). Male and female college-aged students (19 – 29 years old) were recruited to participate in the study. Subjects must have been healthy enough to participate in physical activity. Interested participants were screened prior to their first visit by phone, email, or in person (see Appendix A). They were required to meet the public health recommendations for physical activity (150 minutes of moderate intensity physical activity per week) (Haskell, et al., 2007), but not have been participating in a regular vigorous exercise training program. Examples of physical activity the subjects participated in before the study included, but were not limited to: walking to class, household chores, attending and helping at various sporting events, and sporadic exercise. Those that participated in CrossFit previously were not eligible to participate in the study. Sources for

participant recruitment included a flyer describing the study posted on Facebook, and on the UA CrossFit Club website. In addition to the flyer, prospective participants were recruited via word of mouth around The University of Alabama. In order to ensure subject safety and compliance with study instructions, only individuals capable of communicating in English were allowed to participate in the proposed study.

### **Study Measures**

Participants came to the Exercise Physiology Laboratory at The University of Alabama on four occasions. On the first visit, participants completed a medical history form (see appendix B) and 24-h history questionnaire (see Appendix C). The 24-h history questionnaire was also completed prior to the second  $\text{VO}_{2\text{max}}$  assessment at the end of the 6-week training period. Participants also provided written informed consent in accordance with University Institutional Review Board policy.

Once the participants provided informed consent, anthropometric measurements were taken. Measurements included height, weight, and body fat percentage. Height was assessed to the nearest tenth of a cm, and weight was assessed to the nearest tenth of a kg using a digital scale (BWB-800, Tanita Corporation, Tokyo, Japan). Body fat percentage was assessed using the Jackson and Pollack 3-site skin fold algorithm (chest, abdomen, and thigh for men; and triceps, suprailiac and thigh for women) (Jackson & Pollack, 1978), using Lange Skinfold Calipers (Beta Technology Incorporated, Cambridge, Maryland). Resting heart rate (RHR) was assessed through the palpation of the radial artery, and resting blood pressure (RBP) was assessed using auscultation of the brachial artery. Once the measurements were taken, participants completed a graded exercise test to volitional fatigue on a motorized treadmill (Trackmaster TMX 425C, Full Vision Inc., Newton, KS) in order to measure maximal aerobic

capacity ( $VO_{2max}$ ). The graded treadmill exercise test is one of the most utilized methods for evaluating  $VO_{2max}$ , and the accurate measurement of  $VO_{2max}$  is critical when evaluating aerobic fitness (Miller, Dougherty, Green Crouse, 2007). The modified Åstrand protocol was used during the graded treadmill exercise test (Miller, et al., 2007). The graded exercise test began with a warm-up, and the participant breathed room air through a mouthpiece connected to a tube for measurement of oxygen uptake. Heart rate (HR) was monitored using a wireless heart rate monitor (Polar, Stamford, CT) worn by the participants. The participants warmed-up for 5 minutes starting at a speed set to 4.0 km/h slower than the predetermined running speed. Each minute, the speed was increased by 0.8 km/h so the participant was at his/her starting pace at the end of the 5-minute period. The test started at an initial stage of 9.66 km/h (6 mph), although this speed may have varied slightly depending on each participant's current level of fitness and comfort on the treadmill. The speed was maintained throughout the protocol, and the grade was increased by 2% every 2 minutes until the subject could no longer continue (volitional fatigue). Oxygen uptake was measured by open-circuit spirometry using a metabolic gas analysis system (True-One 2400, ParvoMedics, Sandy, UT). At the completion of the modified Åstrand protocol, the participants rested for approximately 25 minutes, and then performed five submaximal exercise sessions corresponding to 30%, 40%, 50%, 55%, and 60% of his/her  $VO_{2max}$  until a steady state was reached for each session. The ACSM metabolic equation (ACSM, 2006) was used to estimate the speed necessary for the submaximal bout of exercise. For each subject, the results of the submaximal treadmill speed to the steady-state  $VO_2$  were plotted and checked for linearity, and a linear relationship was determined by calculating the regression of the steady-state  $O_2$  uptake on exercise intensity (Medbo, et al., 1988). The

regression line was used to estimate the speed needed to elicit 120% of  $VO_{2max}$  (Zagatto, et al., 2011) for the maximal accumulated oxygen deficit (MAOD) protocol that was used.

MAOD was used to measure anaerobic capacity, and was performed at least 24 hours after the  $VO_{2max}$  test. This protocol is one of the most commonly used procedures to estimate anaerobic capacity (Zagatto, Redkva, Loures, Kalvo Filho, Franco, Kaminagakura, Papoti, 2011; Medbo, Mohn, Tabata, Vaage, Sejersted, 1988; Hill, Davey, Stevens, 2002). As with the modified Åstrand protocol, this test was performed on a motorized treadmill (Trackmaster TMX 425C, Full Vision Inc., Newton, KS). The treadmill was set at a 10% grade to keep the treadmill speed reasonably low, even at the highest exercise intensity (Medbo, et al., 1988). Pulmonary gas exchange was measured breath-by-breath using a metabolic gas analysis system (True-One 2400, ParvoMedics, Sandy, UT). HR was monitored using a HR monitor (Polar, Stamford, CT) worn by each participant during the session. The protocol that was used to assess anaerobic capacity was similar to that used by Medbo, et al. (1988). The participants ran at approximately 50% of their  $VO_{2max}$  for 15 minutes, rested for 10 minutes, and then a supra-maximal exercise effort at 120% of  $VO_{2max}$  was performed to exhaustion. The regression line from the submaximal exercise sessions was used to determine the speed necessary to elicit 120% of  $VO_{2max}$ . MAOD was determined by calculating the difference between estimated  $VO_2$  demand and  $VO_2$  integrated over time in the maximal exercise (Zagatto, et al., 2011).

After completing the MAOD, the participants rested for approximately 20 minutes, and then performed 3 vertical jumps. Measurement of each participant's vertical jump was used in order to assess his/her muscular power output, which is an indicator of the use of the phosphagen energy system. The performance of movement tasks, including jumping, requires maximization of the velocity of either the body segments or entire body, and is an indicator of the body's

ability to produce power (Pazin, Berjan, Nedeljkovic, Markovic, Jaric, 2013). The vertical jump has been frequently used in research in order to assess power. Each participant was given 3 jumps, and the highest jump was recorded. Participants were allowed to practice if they felt it necessary. The participants were allowed to jump however they wanted, but were advised to start with their feet hip-width apart. They were not instructed on a specific depth to squat before the jump, but were allowed to squat to whatever depth was most comfortable. Vertical jump height was measured using a Vertec Jump Trainer (Vertec Jump Trainer, Sports Imports, Columbus, OH).

The following week, participants completed the three workouts that were used to assess performance. One workout was performed each day, on consecutive days, and they were included as part of the 6-week training program. The CrossFit workouts were performed at CrossFit Innovate, located in Northport, Alabama. CrossFit Innovate has been a CrossFit affiliated gym since 2009, and has multiple coaches that are at least Level 1 certified by CrossFit. All exercise sessions were overseen by a Certified Athletic Trainer (ATC) who was also Level 1 CrossFit certified. The workouts were common CrossFit workouts, and included: the CrossFit Total, a 500-m row for time, and “Fight Gone Bad”. The CrossFit Total is a strength assessment that requires the individual to perform back squats, deadlifts, and shoulder presses in order to determine a one-repetition maximum with each lift. This WOD was used to assess strength and the phosphagenic pathway. A 500-m row using a rowing ergometer was used in order to assess the glycolytic pathway. Participants were advised on the proper technique for using the rowing ergometer, and were then instructed to row 500 m as fast as possible. The final WOD that was performed is a common CrossFit benchmark workout called “Fight Gone Bad” (FGB). This consists of three rounds of five different multi-joint exercises, including: wall ball shots, sumo

deadlift high-pulls, box jumps, push presses, and rowing. Participants performed as many repetitions as possible of each exercise for one minute, and then immediately moved to the next exercise until all five exercise movements were complete. The participants then had a one minute break between each of the three rounds. This WOD took exactly 17 minutes to complete, and relied primarily on the oxidative energy pathway. Each participant was able to modify the workout as needed in order to perform each exercise, and the same modifications were made for the post-test assessment. Repetitions were only counted if the participant completed a full range of motion required for each exercise. These three WODs were performed at the beginning and the end of the CrossFit training program, but only one WOD was completed each day.

### **CrossFit Training Program**

The remaining WODs were designed based on the recommendations presented in the CrossFit training guide (see Appendix D). Each exercise session took approximately one hour, including a warm-up, WOD, and a cool-down. Participants were educated on the workout each day, and instructed on how to properly perform each movement in order to ensure safety and decrease the risk of injury. Each workout can be found in Appendix G. Participants exercised together in a group based on their schedules, and multiple times were offered each day in order to ensure each participant could participate. The participants were allowed to attend whatever class worked best for their schedule on each given day, so there was not a specific amount of rest between each training session for the 6-week period. The PI was at every training session, along with other personnel that have a level 1 certification in CrossFit. CrossFit recommends following a 3 day on 1 day off cycle or 5 days on and 2 days off cycle. The 5 days on and 2 days off cycle was used for this study due to possible scheduling conflicts over the weekends. Participants were asked to participate in 30 CrossFit exercise sessions spread out over a six-week



period (5 sessions per week). Participants were allowed to miss a total of 2 exercise sessions, but not in the same week or in consecutive weeks.

HR was monitored and recorded at the end of each workout completed through the palpation of the radial artery. Rating of Perceived Exertion (RPE) for each exercise session was recorded at the end of each WOD using the Borg RPE scale (Borg, 1998) (see Appendix E). Perceived recovery was also assessed prior to beginning each WOD using a 10-point recovery scale (Laurent, et al., 2011) (see Appendix F).

Participants were instructed to perform each WOD at a vigorous intensity, relative to each person's ability and fitness level. All of the exercises were modified for each participant if necessary in order to ensure safety throughout the completion of the WOD, and to allow all participants to complete each workout.

### **Statistical Analysis**

Descriptive and inferential statistics were generated using IBM SPSS Statistics, version 21. Mean values were determined on the indicated outcome measures. A paired-samples T-test was used to compare the pre and post measurements. The primary outcomes were whether participating in CrossFit results in a change in aerobic capacity, anaerobic capacity, muscular power, performance of the three benchmark WODs, bodyweight, body composition, RHR, and/or RBP. Statistical significance was set an  $\alpha$  level of 0.05.

## CHAPTER 4

### RESULTS

Twelve participants, 4 men and 8 women (Table 4.1), completed the study. All participants completed all of the required pre and post-tests, as well as at least 28 out of 30 exercise sessions. Two participants had to discontinue participation, one due to illness unrelated to the study and the other due to scheduling conflicts. Average session RPE and perceived recovery ratings for the 6-week training program are presented in Table 4.2. The recovery scale used was a 10-point scale, with a 5 meaning “adequately recovered” and a 10 meaning “Very well recovered” (Laurent, et al., 2011) (see Appendix F). It was found that the participants reported feeling at least “adequately recovered” on most days, even though they exercised for five days each week. Only 6% of the total responses among all of the participants were below a 5. Table 4.3 presents the percentage of times a score of 5 or above was reported.

Table 4.1: *Characteristics of Participants (Mean  $\pm$  SD; n = 8 Women and 4 Men)*

<b>Characteristics</b>	<b>Females</b>	<b>Males</b>	<b>Mean of Both Genders</b>
<i>Age</i>	21.6 $\pm$ 1.6	23.5 $\pm$ 3.3	22.3 $\pm$ 2.3
<i>Height (cm)</i>	165.6 $\pm$ 5.0	177.2 $\pm$ 3.7	169.5 $\pm$ 7.2
<i>Weight (kg)</i>	63.5 $\pm$ 6.7	86.6 $\pm$ 16.0	71.2 $\pm$ 15.1
<i>Body Fat %</i>	27.5 $\pm$ 4.1	19.1 $\pm$ 7.6	24.7 $\pm$ 6.6
<i>VO<sub>2peak</sub> (ml/kg/min)</i>	37.2 $\pm$ 7.5	44.0 $\pm$ 4.7	39.5 $\pm$ 7.3

Table 4.2: Average Session RPE and Recovery for Each Participant (Mean  $\pm$  SD)

<b>Participant</b>	<b>RPE</b>	<b>Recovery</b>
1	16 $\pm$ 2	7.3 $\pm$ 1.0
2	15 $\pm$ 2	8.7 $\pm$ 0.8
3	16 $\pm$ 2	7.1 $\pm$ 1.2
4	16 $\pm$ 3	6.3 $\pm$ 1.6
5	15 $\pm$ 3	7.2 $\pm$ 1.7
6	16 $\pm$ 4	6.1 $\pm$ 2.1
7	13 $\pm$ 2	6.2 $\pm$ 1.3
8	16 $\pm$ 3	7.9 $\pm$ 1.5
9	17 $\pm$ 3	7.7 $\pm$ 1.6
10	15 $\pm$ 2	7.6 $\pm$ 1.0
11	16 $\pm$ 2	7.6 $\pm$ 0.7
12	15 $\pm$ 1	6.2 $\pm$ 1.1

Table 4.3: Reported Recovery for Each Participant (% of Reports)

<b>Participant</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>
1	0	22	39	22	17	0
2	0	0	4	39	43	13
3	17	4	42	25	13	0
4	17	17	29	8	13	0
5	8	4	21	33	17	4
6	24	10	10	19	10	5
7	25	29	17	21	0	0
8	4	8	38	13	17	21
9	14	10	23	23	14	18
10	4	8	29	42	17	0
11	0	8	25	63	4	0
12	10	41	32	10	0	0

Statistically significant differences were noted for nine variables, including: diastolic BP,  $VO_{2max}$ , anaerobic capacity, CrossFit Total, deadlift, squat, shoulder press (the three lifts comprising the CrossFit Total score), 500m row, and Fight Gone Bad (FGB). Bodyweight, body fat percentage, RHR, and systolic BP were not significantly different between the pre and post CrossFit training program measurements (Table 4.3). These results are displayed in Figures 1-3.

Table 4.4: Pre- vs Post-CrossFit Training Measurements (Mean ± Standard Error)

Measurement	Pre-CrossFit	Post-CrossFit	p-value	% change
Bodyweight (kg)	71.2 ± 4.3	71.7 ± 4.2	0.261	0%
Body Fat %	24.7 ± 1.9	24.0 ± 1.6	0.317	3%
Resting HR (beats/min)	67.5 ± 2.6	66.7 ± 2.3	0.814	1%
Systolic BP (mm Hg)	115.5 ± 1.9	113.3 ± 1.3	0.145	2%
Diastolic BP (mm Hg)	75.3 ± 1.7	*66.0 ± 2.0	0.014	14%
VO <sub>2max</sub> (ml/kg/min)	39.5 ± 2.1	*44.0 ± 2.0	0.001	11%
Anaerobic Capacity (ml/kg)	31.5 ± 3.1	*39.2 ± 4.5	0.021	25%
Vertical Jump (cm)	45.3 ± 1.3	46.1 ± 1.1	0.437	2%
CrossFit Total (kg)	200.0 ± 60.4	*222.6 ± 56.8	< 0.001	11%
Deadlift (kg)	93.0 ± 26.9	*103.8 ± 23.2	0.015	12%
Squat (kg)	71.6 ± 24.2	*80.7 ± 23.8	< 0.001	13%
Shoulder Press (kg)	35.3 ± 10.4	*38.2 ± 11.2	0.003	8%
500-m Row (s)	120.8 ± 4.1	*115.7 ± 3.8	0.017	4%
Fight Gone Bad (reps)	190.6 ± 11.9	*250.0 ± 10.5	< 0.001	31%

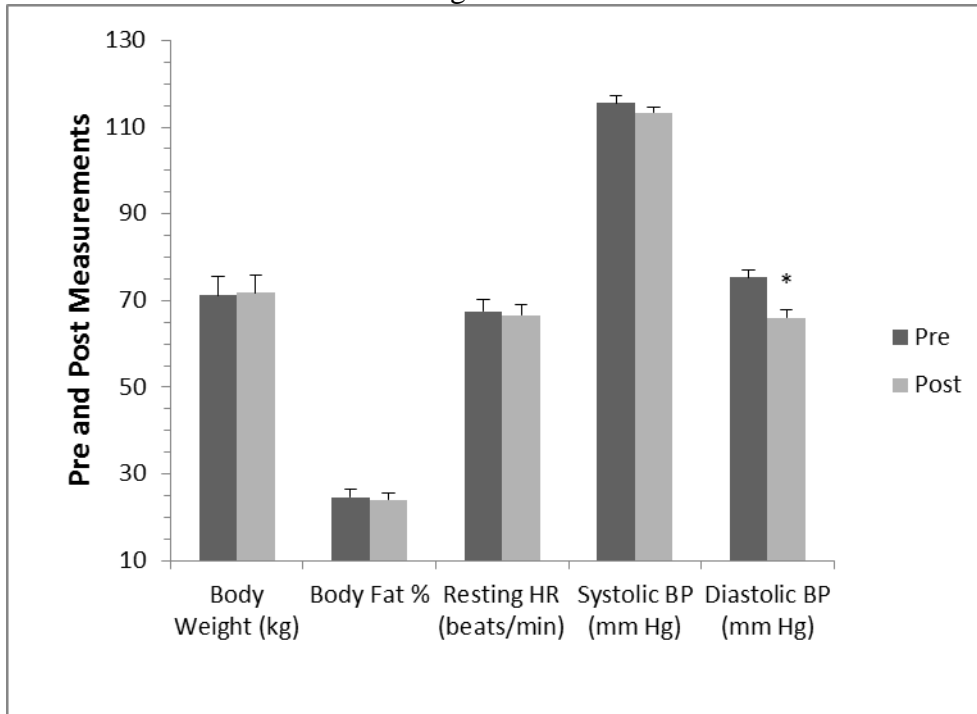
\* denotes significant difference at p < 0.05.

Improvement was seen from the pre-test to the post-test measurements in most variables. Although the other variables were not statistically significantly different, there appeared to be a trend for improvement in all of the variables except for bodyweight.

The purpose of the study was to assess changes in aerobic capacity, anaerobic capacity, and power; changes in performance in three benchmark CrossFit workouts; and changes in RHR, RBP, and body composition. Analyses indicated a statistically significant improvement in aerobic capacity (VO<sub>2max</sub>) (p = .001) and anaerobic capacity (p = .021), but there was not a significant difference in power (vertical jump) (p = .437). There was statistically significant improvement in all performance measurements, including the CrossFit Total (p < .001), a 500m row for time (p = .017), and FGB (p < .001). Not only was there an improvement in the CrossFit Total, but there was statistically significant improvement in each lift used to calculate the CrossFit Total score; including the deadlift (p = .015), squat (p < .001), and the shoulder press (p = .003). There was not a significant change in RHR (p = .814), body composition (p = .317), or systolic BP (p = .145). There was however, significant improvement in diastolic BP (p = .014).

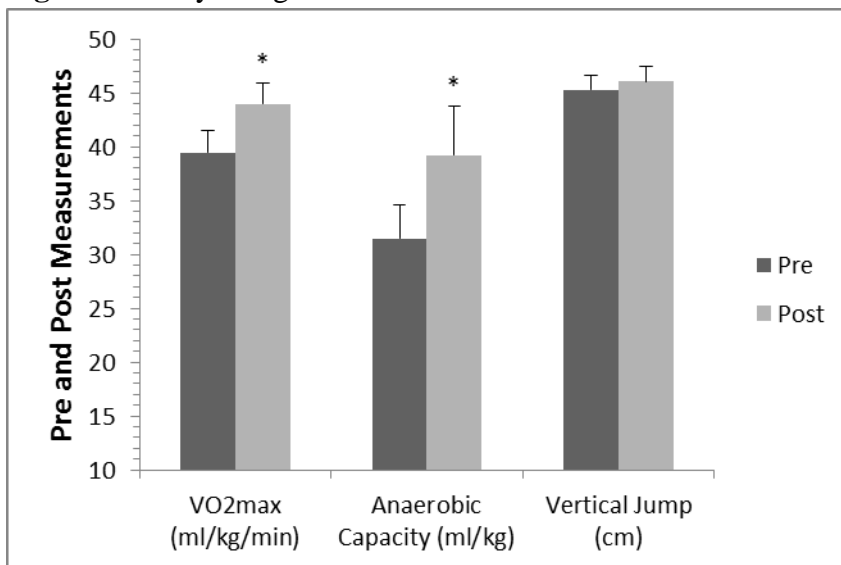
Although there was not a statistically significant change in RHR, body composition, or resting systolic BP there was a trend for improvement.

**Figure 4.1:** Anthropometric, Resting Heart Rate, Resting Blood Pressure Measurements Pre- vs Post- CrossFit Training



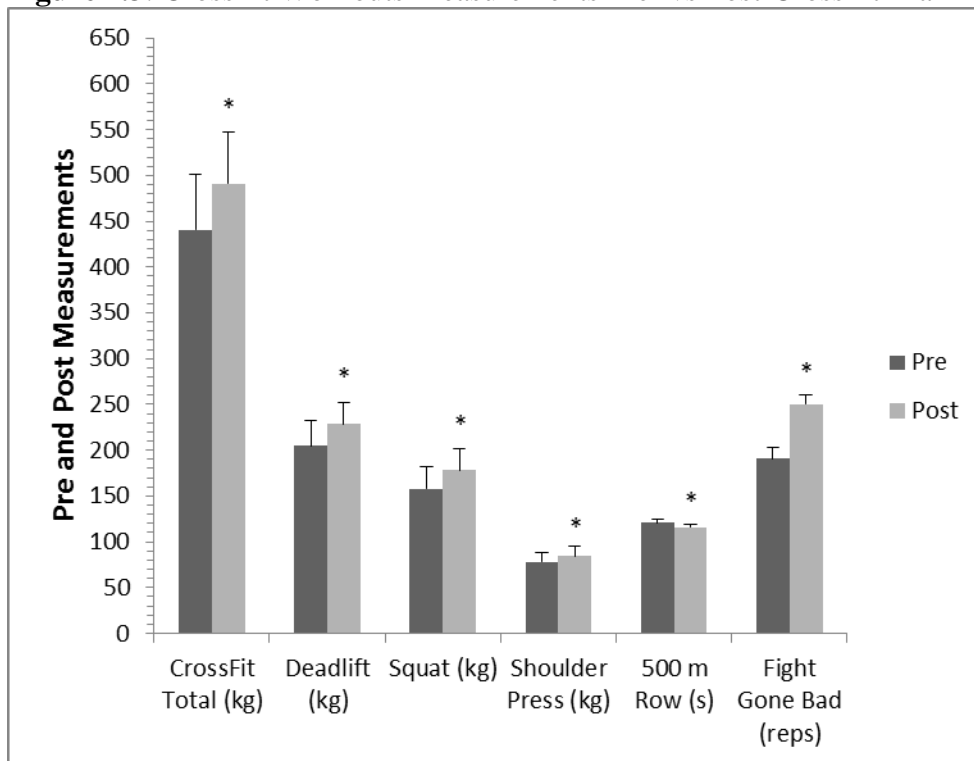
\* denotes statistical significance,  $p < 0.05$ .

**Figure 4.2:** Physiological Measurements Pre- vs Post-CrossFit Training



\* denotes statistical significance,  $p < 0.05$ .

**Figure 4.3:** CrossFit Workouts Measurements Pre- vs Post-CrossFit Training



\* denotes statistical significance,  $p < 0.05$ .

## **CHAPTER 5**

### **DISCUSSION**

CrossFit, created in 1995, is becoming a popular exercise program for people of all ages around the world. There were approximately 10,000 affiliated gyms worldwide at the time this research was performed. It has led to the development of many local and world-wide competitions that have attracted over 130,000 people to participate in the 2013 CrossFit Open. Although CrossFit is becoming a popular training program, there is limited research concerning the effects of this type of training. To the best of our knowledge, this is one of the first studies to examine the effects of a 6-week CrossFit program based on the recommendations found in the CrossFit training guide. This was also the first study to evaluate the effects of a 6-week CrossFit training program on bodyweight, body composition, RHR, RBP, aerobic capacity, anaerobic capacity, vertical jump, and performance in three benchmark workouts that use the three energy systems previously discussed. This study demonstrated that 6 weeks of CrossFit does improve aerobic capacity ( $VO_{2max}$ ), anaerobic capacity, performance in multiple CrossFit workouts, and diastolic BP. Although improvement was noted for these variables, there was not a significant improvement in bodyweight, body composition, RHR, resting systolic BP, or vertical jump.

As stated earlier, the 6-week training program was based on the recommendations provided in the CrossFit training guide (Glassman, 2010). The template for the exercise program can be found in Appendix D. It is not surprising that improvement was seen in a variety of

measures. Participants did not participate in a regular exercise training program prior to this study, and improvement was not unexpected. However, it should be appreciated that the present study supports the use of CrossFit training to improve measures of physiological capacity and/or physical performance relying on the three different energy systems in as little as six weeks. This study also showed that CrossFit can be an effective and safe training program for people that do not participate in regular exercise.

To date, there is limited research specific to CrossFit. Of the articles that are accessible, many are not published in peer-reviewed journals. Although there has not been much research performed on CrossFit, the studies that have been performed have noted many benefits for this exercise program. These benefits include: improved performance on physical assessment tests in the military (i.e. Army Physical Fitness test - max repetitions of pushups in two minutes, max repetitions of sit-ups in two minutes, 1.5-mile run, 2-mile run), increased work capacity, increased power, increased anaerobic capacity, increased aerobic capacity, increased muscular endurance, and favorable changes in body composition (Smith, et al., 2013; Heinrich, et al., 2012, Spencer, Fehl, Carlos Poston, 2012; Paine, Uptcraft, Wylie, 2010; Jeffery, 2012; Patel, 2012). The purpose of this study was to extend these findings and use laboratory and field tests in order to assess the effects of CrossFit (as recommended in the training guide) on bodyweight, body composition, RHR, RBP, aerobic capacity, anaerobic capacity, power, and performance. The results were similar to those found in previous studies. Although this study did not result in a significant change in body composition as noted by Smith, et al. (2013), both studies resulted in an increase in  $VO_{2max}$  when assessed with a graded maximal treadmill test. Smith, et al. (2013) reported the increase after a 10-week



program that followed the CrossFit Training Guide, whereas results for this study were noted after just 6 weeks. Paine, et al. (2010) noted an improvement in performance of three benchmark CrossFit workouts, two of which were also used in this study (CrossFit Total and FGB), after following the training guide recommendations for 6 weeks. These workouts were used to assess all three energy systems. The other three studies investigating the effects of CrossFit (Heinrich, et al., 2012; Jeffery, 2012; and Patel, 2012) also reported improvements in work performed (as many push-ups and/or sit-ups as possible in a given time), aerobic capacity, anaerobic capacity, and power. These results were noted after performing CrossFit for 2-3 times per week for a training period ranging from 8 weeks to 4 months. Results were similar to the results of the present study, although study methodology varied.

Although the results were similar, the methodology of the present study was different from that employed by the previous studies mentioned. The present study used a specific group of participants that did not currently participate in a vigorous-intensity exercise program. Multiple parameters were assessed; including RHR, RBP, body composition, and bodyweight. Also, a combination of laboratory and field tests was used to assess for any changes due to the training program. Unlike the previous studies, the present study assessed anaerobic capacity by calculating the MAOD using a graded exercise treadmill test. Only one previous CrossFit study had used a graded exercise treadmill protocol with direct measurement of oxygen uptake to assess aerobic capacity prior to the present study (Smith, et al., 2013). The present study also assessed performance using each of the three energy systems through various workouts specific to CrossFit, which was done in only one previous study prior to this one (Paine, et al, 2010).

The CrossFit training guide emphasizes that most exercises should be performed at a high-intensity due to “intensity being the independent variable most commonly associated with maximizing favorable adaptation to exercise” (Glassman, 2010). Although high-intensity exercise is recommended, based on the recommended template, it does not necessarily mean all exercise should be anaerobic. The template can be found in Appendix D, and the design of each day’s workout should be noted. The intensity level is relative to each individual participant and each WOD performed. Based on the template used for the five continuous day program; days 1 and 5 are skill days, days 2 and 4 are higher intensity days, and day 3 incorporates more moderate level activity for a longer period of time. Although intensity level was relative to each individual, each participant was encouraged to go as quickly as possible, or to accomplish as much work as possible while maintaining correct technique in the given amount of time for each WOD. The longest duration for the actual workout during the 6-week training period of this study was 20 minutes, excluding the warm-up and cool-down. Using this template, improvements were seen in  $VO_{2max}$  and anaerobic capacity, as well as in the performance of the three benchmark workouts that collectively used all three energy systems. This is important to note because improvement was seen in aerobic capacity even though the longest workout only lasted 20 minutes. Anaerobic capacity was also improved even though the participants only participated in 2 days of high-intensity workouts, where the work to rest interval was critical. Critical work to rest interval means that participants were encouraged to complete the workout as fast as possible, while resting as little as possible, and these workouts were typically shorter in duration.

The ACSM and CDC encourages the participation in vigorous-intensity activity, and states that the same benefits can be seen in a shorter amount of time when compared to longer duration moderate-intensity activity (Garber, et al., 2010; CDC, 2012). There also appears to be a dose response relationship for vigorous-intensity activity and greater health benefits (CDC, 2012). Moreover, Ciolac (2012) stated that there is a close relationship between exercise intensity and cardiorespiratory fitness, with vigorous-intensity exercise being more effective in improving fitness levels than moderate-intensity exercise.

Improvements in aerobic and anaerobic capacity have been noted in previous studies that predominantly used high-intensity training (Bayati, et al., 2011; Lindsay, et al., 1996; Westgarth-Taylor, et al., 1997; Tabata, et al., 1996; Tabata, et al., 1997; Hottenrott, et al., 2010; Acevedo & Godfarb, 1989; Garber, et al., 2011; Midgley, et al., 2006). These studies have noted an improvement in aerobic capacity, anaerobic capacity, peak power output, peak sustained power, maximum blood lactate levels, and time to fatigue. Although improvements have been noted due to high-intensity training, most of these studies were performed using cycling or running unlike the present study that used a combination of the three different categories of exercise previously mentioned (metabolic conditioning, gymnastics, weightlifting). The present study demonstrated an improvement in performance in the three benchmark workouts; CrossFit Total, 500 m row, and FGB, which together utilized all three energy systems; as well as aerobic and anaerobic capacity when tested using graded treadmill tests. These results support the use of various exercises performed at a high intensity to improve the capacity of all three energy systems.

The improvements in aerobic capacity and strength performance in the present study are similar to those seen in previous studies based on circuit resistance training (CRT). CRT is performed to increase the caloric cost of exercise and improve many different aspects of fitness (McArdle, et al., 2010, p. 528). This type of training provides more-general conditioning that improves body composition, muscular strength and endurance, and cardiovascular fitness (Alcaraz, Sánchez-Lorente, Blazevich, 2008; Ghanbari-Niaki, Saghebjo, Rahbarizadeh, Hedayati, Rajabi, 2008). CRT has been shown to improve aerobic capacity, strength, body composition, and blood pressure (Harris & Holly, 1987). Although CrossFit and CRT are not exactly the same thing, they do share many of the same elements, and have similar results. As noted with CRT, CrossFit also improved aerobic capacity and strength. An improvement in body composition was not noted for the present study, but has been reported in a previous study using CrossFit (Smith, et al., 2013). CrossFit also resulted in an improvement in anaerobic capacity, which was not noted as a benefit of CRT.

In general, when compared to some other training programs, the CrossFit training program evaluated in the present study compares favorably. A review article on the effects of HIIT on cardiorespiratory fitness (Ciolac, 2012) presented a study (Ciolac, Bocchi, Greve, Guimaraes, 2011) that compared the effects of a 40 minute HIIT program that was performed three times per week for 16 weeks to a continuous moderate-intensity exercise program that was performed for the same duration. Results indicated a 16% increase in  $VO_{2max}$  for the HIIT protocol, and an 8% increase for the moderate-intensity protocol compared with an 11% increase in  $VO_{2max}$  in six weeks in this study.

Tabata, et al. (1996) also compared a HIIT program to a moderate-intensity program over a 6-week period, the same duration as the present study. The HIIT protocol resulted in a 14% increase in  $VO_{2max}$  and a 28% increase in anaerobic capacity. The present study found a 26% increase in anaerobic capacity in six weeks. The moderate-intensity protocol resulted in a 9% increase in  $VO_{2max}$  and no significant change in anaerobic capacity. Bayati, et al. (2011) compared the effects of two different HIIT protocols that were performed three times per week for 4 weeks on aerobic capacity. The first protocol was three to five 30-second intervals with 4 minute rests between each. The second protocol was 6 to 10 intervals with a two minute rest between each. The exercise programs resulted in an increase in  $VO_{2max}$  of 10%.

Harris and Holly (1987) investigated the effects of nine weeks circuit resistance training on aerobic capacity, upper-body strength (bench press), lower-body strength (leg press), RHR, and RBP. The authors reported increases of 8% in  $VO_{2max}$ , 13% in upper-body strength, and 53% in lower-body strength, no change in RHR, and a 5% decrease in resting diastolic BP. The CrossFit training program evaluated in the present study resulted in an 11% increase in  $VO_{2max}$ , 25% increase in anaerobic capacity, and a 14% decrease in resting diastolic BP. Although the assessment measures utilized by Harris and Holly (1987) were different than those utilized by the current study (upper-body strength: bench press vs shoulder press, respectively and lower-body strength: leg press vs squat, respectively) results indicated an 8% increase in upper-body strength, and a 13% increase in lower-body strength.

### **Study Limitations**

The study was a pre-post design, so some improvements could have been due to

familiarization with the testing protocols. Although this may have been a limitation, measurements taken while assessing  $VO_{2max}$  indicated that the majority of participants were within 10 beats/min of their calculated maximal HR for both tests. Moreover, average maximal HR for the pre-tests ( $196.1 \pm 10.0$  bpm) was somewhat higher than that recorded for the post-tests ( $191.7 \pm 5.9$  bpm). This indicates that participants did not give less of an effort during the pre-tests assessment compared to the post-tests. Also, CrossFit uses many movements that were not familiar to all participants; therefore, there was a learning curve at the beginning of the program in order to instruct all of the movements. This could have decreased the intensity level during the workout, in order to ensure proper technique throughout the entire workout; so these results are most generalizable to inexperienced participants. This is a common limitation for anybody starting a new exercise program.

## **Conclusion**

The present study is noteworthy because several different variables in the lab, as well as in the field were assessed. After just 6 weeks of CrossFit, improvements were noted in nine out of the fourteen variables assessed (diastolic BP,  $VO_{2max}$ , anaerobic capacity, CrossFit Total, maximum deadlift, maximum squat, maximum shoulder press, 500 m row, and FGB). The results are also noteworthy because the longest workout performed was 20 minutes long, and many were shorter in duration. Improvements in aerobic capacity, anaerobic capacity, and strength after such short-duration workouts, comprising a short duration training program, are important because it supports the use of high-intensity exercise. Improvements demonstrated after a training program utilizing

short duration workouts is also noteworthy because time seems to be a major reason impeding many individuals from exercising (Booth, Bauman, Owen, 1997).

Previous literature, including this study, has found positive benefits for the CrossFit exercise program. Although benefits have been noted, more research is necessary. Future research should evaluate the effects of CrossFit training in different age groups and in individuals with different athletic backgrounds particularly compared to HIIT and other high-intensity programs, assess athletes that have participated in CrossFit for an extended period of time, and assess athletes that compete in the CrossFit games. CrossFit also publishes a daily WOD via the internet, [www.crossfit.com](http://www.crossfit.com), so future research should assess the workouts that are programmed and recommended from the CrossFit headquarters. Although more research is warranted, the present study shows that CrossFit training results in improved exercise capacity associated with all three different energy systems.

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**APPENDIX A**  
**HEALTH SCREENING QUESTIONNAIRE**

# Screening Questionnaire for Potential Healthy Subjects

Contact information:

Name: \_\_\_\_\_

Cell phone: \_\_\_\_\_

Home phone: \_\_\_\_\_

E-mail: \_\_\_\_\_

Are you available for at least 1 hour Monday through Friday between 6a and 9p? \_\_\_\_\_

---

Biographical information:

Age: \_\_\_\_\_

Ht: \_\_\_\_\_

Wt: \_\_\_\_\_

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Medical information:

What medical problems do you have, such as high blood pressure, diabetes, or breathing difficulty? Have you ever been diagnosed with asthma? \_\_\_\_\_

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What medications do you take (including herbal supplements and over-the-counter medications)?

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Wellness information:

Do you smoke? \_\_\_\_\_

Have you ever smoked? If yes, when?

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Do you participate in physical activity (i.e. walking to class, yard work, etc.)? What type? \_\_\_\_\_

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Approximately how many minutes of physical activity do you perform in a week? \_\_\_\_\_

Have you ever experienced problems during exercise or physical activity? If yes, please describe.

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Have you ever participated in high-intensity physical activity and/or CrossFit?

\_\_\_\_\_

If yes, when and for how long?

\_\_\_\_\_

Have you participated in consistent planned exercise within the past year?

\_\_\_\_\_

Additional Comments

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**APPENDIX B**  
**MEDICAL HISTORY FORM**

**SELF-ADMINISTERED PRE-EXERCISE MEDICAL HISTORY**

Date \_\_\_\_\_

Name \_\_\_\_\_

Last First  
MI

Address \_\_\_\_\_

Street  
Apt #

City State Zip Code

Contact \_\_\_\_\_

Home Phone Cell Phone Email

Date of Birth \_\_\_\_\_ Age \_\_\_\_\_ Sex \_\_\_\_\_ Ht \_\_\_\_\_

Wt \_\_\_\_\_  
MM/DD/YYYY

Occupation \_\_\_\_\_

Emergency Contact \_\_\_\_\_

Name Relationship Phone

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Mark any of the following that apply to you (adapted from Preparticipation Health Screening and Risk Stratification. In: *ACSM's Guidelines for Exercise Testing and Prescription*, edited by W. R. Thompson, N. F. Gordon, and L. S. Pescatello. Philadelphia, PA: Wolters Kluwer; Lippincott Williams & Wilkins, 2010, p. 18-39)

- Pain, pressure, or other discomfort in the chest, neck, jaw, arms, or other areas
  - Shortness of breath at rest or with mild exertion
  - Dizziness or syncope
  - Shortness of breath when you lie down or that wakes you up while sleeping
  - Swollen ankles, or any unexplained swelling
  - Your heart feels like it is skipping beats or racing while at rest
  - Pain when walking that is relieved with rest, especially pain in the calf or thigh muscle
  - Known heart murmur told to you by a physician
  - Unusual fatigue or shortness of breath with usual activities
- 

Do you have high cholesterol (defined as LDL cholesterol  $\geq$  130 mg/dL or total cholesterol  $\geq$  200 mg/dL)? If yes, what are the values? \_\_\_\_\_

Do you know your HDL cholesterol? If so, what is the value? \_\_\_\_\_

List any medicines, drugs, and herbal products or dietary supplements you are now taking: \_\_\_\_\_

Have you ever suffered from exercise-induced rhabdomyolysis? Yes \_\_\_\_\_ No \_\_\_\_\_

Explain any other significant medical problems you consider it important for us to know: \_\_\_\_\_

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Adapted from AHA/ACSM Health/Fitness Facility Preparticipation Screening Questionnaire as shown in: Preparticipation Health Screening and Risk Stratification. In: *ACSM's Guidelines for Exercise Testing and Prescription*, edited by W. R. Thompson, N. F. Gordon, and L. S. Pescatello. Philadelphia, PA: Wolters Kluwer; Lippincott Williams & Wilkins, 2010, p. 18-39

Assess your health status by marking all *true* statements:

**History**

You have had:

- \_\_\_\_\_ a heart attack
- \_\_\_\_\_ heart surgery
- \_\_\_\_\_ cardiac catheterization
- \_\_\_\_\_ coronary angioplasty (PTCA)
- \_\_\_\_\_ pacemaker/implantable cardiac defibrillator/rhythm disturbance
- \_\_\_\_\_ heart valve disease
- \_\_\_\_\_ heart failure
- \_\_\_\_\_ heart transplantation
- \_\_\_\_\_ congenital heart disease

**Symptoms**

- \_\_\_\_\_ You experience chest discomfort with exertion
- \_\_\_\_\_ You experience unreasonable breathlessness
- \_\_\_\_\_ You experience dizziness, fainting, or blackouts
- \_\_\_\_\_ You take heart medications

**Other health issues**

- \_\_\_\_\_ You have diabetes
- \_\_\_\_\_ You have asthma or other lung disease
- \_\_\_\_\_ You have burning or cramping sensation in your lower legs when walking short distances
- \_\_\_\_\_ You have musculoskeletal problems that limit your physical activity
- \_\_\_\_\_ You have concerns about the safety of exercise
- \_\_\_\_\_ You take prescription medications
- \_\_\_\_\_ You are pregnant

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**Cardiovascular Risk Factors**

- \_\_\_\_\_ You are a man older than 45 years
- \_\_\_\_\_ You are a woman older than 55 years, have had a

- \_\_\_\_\_ hysterectomy, or are postmenopausal
  - \_\_\_\_\_ You smoke, or quit smoking within the previous 6 months
  - \_\_\_\_\_ Your blood pressure is > 140/90 mm Hg
  - \_\_\_\_\_ You do not know your blood pressure
  - \_\_\_\_\_ You take blood pressure medication
  - \_\_\_\_\_ Your blood cholesterol level is > 200 mg/dL
  - \_\_\_\_\_ You do not know your cholesterol level
  - \_\_\_\_\_ You have a close blood relative who had a heart attack or heart surgery before age 55 (father or brother) or age 65 (mother or sister)
  - \_\_\_\_\_ You are physically inactive (i.e., you get < 30 minutes of physical activity on at least 3 days per week)
  - \_\_\_\_\_ You are > 20 pounds overweight
- 
- \_\_\_\_\_ None of the above

**APPENDIX C**

**24 – HOUR HISTORY QUESTIONNAIRE**

24-Hour History

ID \_\_\_\_\_  
Date \_\_\_\_\_  
Time \_\_\_\_\_

1. How many hours of sleep did you get last night? (please circle one)  
1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12  
(hrs)

2. How many hours of sleep do you normally get? (please circle one)  
1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12  
(hrs)

3. How many hours has it been since your last meal or snack? (please circle one)  
1 **1.5** 2 **2.5** 3 **3.5** 4 **4.5** 5 **5.5** 6 **6.5** 7 **7.5** 8 **8.5** 9 **9.5** 10 **10.5** 11 **11.5** 12 **12.5** 13 **13.5** 14 **14.5**  
15 (hrs) List the items below:

4. When did you last have:
- a cup of coffee or tea?
  - cigarettes?
  - drugs (including aspirin)?
  - alcohol?
  - herbal or dietary supplements?

5. How many glasses of water or other beverages have you consumed in the last 24 hours?  
12 3 4 5 6 7 8 9 10 11 12 13 14

6. When did you last consume water or another beverage? \_\_\_\_\_ How much? \_\_\_\_\_  
(glasses)

7. What sort of physical activity did you perform yesterday?

8. What sort of physical activity have you performed today?

9. Describe your general feelings by checking one of the following:

_____excellent	_____good	_____very bad
_____very, very good	_____neither good nor bad	_____very, very bad
_____very good	_____bad	_____terrible

**APPENDIX D**  
**CROSSFIT TRAINING GUIDE RECOMMENDATIONS**

## CrossFit Exercise Program

The 6 week CrossFit exercise program will be based on the recommendations from the CrossFit training guide. This guide is accessible to the public at <http://journal.crossfit.com/2010/05/crossfit-level-1-training-guide.tpl>. Provided is the template that was used in order to develop the 6 week program.

### Template

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
<b>Wk 1</b>	M	G W	M G W	M G	W	Off	Off
<b>Wk 2</b>	G	M W	G W M	G W	M	Off	Off
<b>Wk 3</b>	W	M G	W M G	W M	G	Off	Off

\* The template for weeks 4-6 will be the same as 1-3. Although the template will be the same, the WODs will be different. M = metabolic conditioning, G = gymnastics, W = weightlifting.

### Exercises by Modality

<b>Metabolic Conditioning (M)</b> “Cardio”	<b>Gymnastics (G)</b> Bodyweight Exercises	<b>Weightlifting (W)</b> Weightlifting, powerlifting, & Olympic lifts
Run Bike Row	Air Squat Pull-up Push-up Dip Handstand Push-up Rope Climb Muscle-up Press to Handstand Back Extension Sit-up Jumps Lunges Burpees	Deadlifts Cleans Presses Snatch Clean and Jerk Medicine Ball Drills Kettlebell Swing Squats Thrusters



## Workout Structure

Days	Single Modality Days	Two Modality Days	Three Modality Days
<b>Priority</b>	Modality Priority	Task Priority	Time Priority
<b>Structure</b>	M: Single Effort G: Single Skill W: Single Lift	Couplet repeated 3-5 times for time	Triplet repeated for 20 minutes for rotations
<b>Intensity</b>	M: Long, Slow Distance G: High Skill W: Heavy	Two moderately to intensely challenging modalities	Three lightly to moderately challenging modalities
<b>Work Recovery Character</b>	Recovery not a limiting factor	*Work/rest interval management critical	Work/rest interval marginal factor

\* Made intense by pace, load, reps or some combination. Ideally the first round is hard but possible, whereas the second and subsequent rounds will require pacing, rest, and breaking the task up into manageable efforts.

**APPENDIX E**

**BORG RATING OF PERCEIVED EXERTION SCALE**

## Rating of Perceived Exertion

**6** No exertion at all

**7** Extremely light

**8**

**9** Very light

**10**

**11** Light

**12**

**13** Somewhat hard

**14**

**15** Hard (heavy)

**16**

**17** Very hard

**18**

**19** Extremely hard

**20** Maximal exertion

Borg, G. (1998) *Borg's Perceived Exertion and Pain Scales*. Champaign, IL, Human Kinetics, 4.

**APPENDIX F**  
**RECOVERY SCALE**

## Perceived Recovery Scale

<b><u>Perceived Recovery Status Scale</u></b>		
10	Very well recovered / Highly energetic	} <u>Expect Improved Performance</u>
9		
8	Well recovered / Somewhat energetic	
7		} <u>Expect Similar Performance</u>
6	Moderately recovered	
5	Adequately recovered	
4	Somewhat recovered	} <u>Expect Declined Performance</u>
3		
2	Not well recovered / Somewhat tired	
1		} <u>Expect Declined Performance</u>
0	Very poorly recovered / Extremely tired	

Laurent, C.M., Green, J.M., Bishop, P. A., Sjkovist, J., Schumacker, R. E., Richardson, M. T., Curtner-Smith, M. (2011). A practical approach to monitoring recovery: development of a perceived recovery scale. *J Stength Cond Res*, 25(3), 620-628.

**APPENDIX G**

**DAILY WORKOUTS**

	<b>Monday</b>	<b>Tuesday</b>	<b>Wednesday</b>	<b>Thursday</b>	<b>Friday</b>
<b>Week 1</b>	CrossFit Total	500 m row	Fight Gone Bad	3 Rounds: 400 m run 15 pushups 25 situps	15 min run
<b>Week 2</b>	Burpees	5 Rounds: 200 m run 10 goblet squat	20 min AMRAP: 5 deadlift 10 ring row 50 jump rope	5 Rounds: 5 hang power clean 20 situps	4 Rounds: 800 m run 200 m walk
<b>Week 3</b>	Front Squat & Power clean skill work	3 Rounds: 400 m run 10 knee raises 20 box jumps 10 pushups	20 min AMRAP: 10 push press 20 lunges 400 m run	5 Rounds: 10 kettlebell swings 30 jumprope	Pullups
<b>Week 4</b>	20 min run at moderate pace	21-15-9 Thrusters Ring row	20 min AMRAP: 3 wall-walk 5 Curtis P's 200 m run	3 Rounds: 50 jumprope 15 burpees 15 squats 15 situps	5 sets: 3 deadlifts Snatch review
<b>Week 5</b>	Back/Hip extension GHD situps 5x10 squat jumps	4 Rounds: 15 wallballs 200 m run	20 min AMRAP: 1 min row/bike 10 pushups 20 kettlebell swings	4 Rounds: 5 powerclean 5 front squat 10 ring row 15 burpees	5 Rounds: 400 m jog 400 m faster pace run
<b>Week 6</b>	8 min: Every min on the min-1 wall walk, hold 20s	3 Rounds: 400 m run 15 power cleans	CrossFit Total	500 m row	Fight Gone Bad