A Thesis

entitled

The Effects of Different Exercise Intensities on Glucoregulatory Response

by

Angela Pietras

Submitted to the Graduate Faculty as partial fulfillment of the requirements for

The Master of Science Degree in Exercise Science

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An Abstract of

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An improvement in insulin action and glycemic regulation has been associated with traditional endurance training, but many individuals state a lack of time as a barrier to exercise. High intensity interval training (HIIT) is an approach to attempt physiological adjustments that are similar to those of endurance training. There is evidence that HIIT improves glucose regulation. It is still not known how glucose responses change before, during, and after HIIT compared to moderate intensity endurance training.  **PURPOSE:** The purpose of this study is to demonstrate blood glucose responses before, during, and after an exercise session in healthy individuals and to identify any potential differences in blood glucose responses between a moderate intensity endurance training exercise session and a high intensity interval training exercise session.  **METHODS:** Five healthy adults (age=23.6 ±1.8 years, height = 169.7 ± 10.5 cm, mass = 73.3 ± 19.2 kg) participated in a moderate intensity endurance training exercise session and a high intensity interval training (HIIT) exercise session. The subjects wore a continuous glucose monitor (CGM) during the duration of the study. One session of moderate intensity consisting of 50% of the participants peak watts for 30
minutes and one session of HIIT (85% of the participants peak watts) consisting of a three minute warm up at 50% of the participants peak watts followed by high-intensity intervals following a pattern of one minute cycling at the high intensity followed by one minute rest in which the subject will cycle at 30 Watts ten times. Each high intensity interval was set to a work rate ranging from 50% to 120% of their submaximal work rate. During each of the session the participant’s instantaneous interstitial glucose was recorded. The data was collected before, during, and after completing both exercise trails.

RESULTS: To determine the potential differences in glucose response between the HIIT exercise session and the moderate intensity endurance training exercise session relative change ratios for blood glucose pre, during, and post training were recorded using the glucose values during training compared to baseline. When expressed as a ratio, there was no difference in the mean values among the different types of exercise (P=0.862). There was no difference in the blood glucose ratios between type of exercise within end of exercise (moderate: 3.7 ± 0.5 mmol/l, HIIT: 4.0 ± 0.6 mmol/l). There is not a statistically significant interaction between the type of exercise and time (P= 0.966).

There were noticeable differences when comparing blood glucose levels pre training to post training in both the moderate intensity endurance training exercise session and the high intensity interval training exercise session. CONCLUSION: It was concluded that blood glucose responses before, during, and after a HIIT exercise session were similar to that of a moderate intensity endurance training exercise session.
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List of Abbreviations

ANOVA .............................................................................Analysis of Variance

CAD ..................................................................................Coronary artery disease
CGM ..............................................................................Continuous Glucose Monitor
CVD ..................................................................................Cardiovascular Disease

HDL .................................................................................High density lipoprotein
HIIT ..................................................................................High Intensity Interval Training

SIT .....................................................................................Sprint interval training

T2DM ...............................................................................Type 2 Diabetes Mellitus

VO$_2$max ............................................................................Maximum oxygen utilization
VO$_2$peak ...........................................................................Peak oxygen utilization
Chapter One

Introduction

Approximately one third of adults (18 years and older) in the United States are considered obese (Karstoft, Christensen, Pedersen, & Solomon, 2014). Health conditions such as obesity are rapidly increasing around the world and it is estimated that 1.4 billion individuals are considered overweight or obese, and 346 million individuals have diabetes (Karstoft, et al., 2014). Due to the different effects today’s society has on individuals, these statistics will continue to increase if necessary precautions are not taken to reduce the occurrence of these diseases. If necessary precautions are not taken individuals could see an increase in blood glucose which is associated with these health conditions such as obesity and the risk of developing Type 2 Diabetes Mellitus (T2DM).

A necessary precaution to take to reduce the risk of obesity and T2DM is to participate in regular physical activity. There are some metabolic adaptations associated with traditional endurance training such as an improvement in insulin action and glycemic regulation (Babraj et al., 2009). Recommendations for improving glycemic regulation suggest performing moderate to high intensity training(exercise) for approximately 60 minutes a day to potentially see an improvement in glycemic regulation (Babraj, et al., 2009). Although this recommendation will help individuals lose weight as well as reducing their risk of T2DM, it is not ideal for the average individual who has limited time to exercise.

High intensity interval training (HIIT) typically consists of short bursts of intense exercise followed by periods of recovery. This strategy has been shown to lead to physiological adaptations that are similar to those of endurance training (Gillen et al.,
An individual who participates in endurance training undergoes specific exercise techniques over the duration of several exercise sessions. An individual who participates in an exercise session undergoes an exercise technique once. The difference between moderate and high intensity training is moderate intensity endurance training elicits 40-60% of an individual’s maximal oxygen uptake (VO$_{2\text{max}}$) which is comparable to 50-70% heart rate maximum. High intensity exercise typically elicits greater than 60% VO$_{2\text{max}}$ or greater than 70% heart rate maximum (Adams, 2013). HIIT has been established to improve time to fatigue and endurance capacity, as well as improve metabolic control (Adams, 2013).

Based on a review of the literature, there are few studies that examine sporadic high-intensity training and its effects on blood glucose responses (Gillen, et al., 2012; Mendes et al., 2013). Most studies involving high intensity training follow a protocol of continuous cycles of 60 seconds work followed by 60 seconds rest by means of either cycling or running (Gillen, et al., 2012). Gillen et al. looked at HIIT training consisting of 60 seconds cycling at 90% maximum heart rate ten times with sporadic intervals of seconds rest. The blood glucose concentration in type 2 diabetics was measured through the use of a continuous glucose monitor. The amount of time the participant’s blood glucose levels were above 10 mmol/L was reduced, as well as the duration of postprandial hyperglycemia (Gibala, Little, Macdonald, & Hawley, 2012; Gillen, et al., 2012).

Gillen et al. used continuous glucose monitors (CGM) in their study to gain a better understanding of blood glucose regulation during high intensity interval training. Continuous glucose monitors record information regarding the magnitude, direction,
frequency, duration, and the sources of fluctuations in blood glucose levels (Klonoff, 2005; Klonoff et al., 2011). These minimally invasive monitors record blood glucose concentrations every 1-10 minutes and each sensor may last for up to 7 days (Adams, 2013; Gillen, et al., 2012). Studies suggest that these types of devices may be used with type 1 diabetic patients to help them maintain the recommended target hemoglobin A1c (HbA1c) levels (Klonoff, et al., 2011; Little, Jung, Wright, Wright, & Manders, 2014). Continuous glucose monitors have been used most frequently in current studies to obtain more accurate measurements of blood glucose levels following moderate intensity endurance training or HIIT.

Iscoe et al. compared the glycemic changes in type 1 diabetics to continuous moderate intensity exercise with or without high intensity bursts. The study consisted of measuring interstitial blood glucose levels in 11 trained athletes on 2 days where the subjects were sedentary and 2 days where the subjects participated in moderate intensity exercise with or without high intensity bursts (Iscoe & Riddell, 2011). The exercise trials consisted of continuous moderate intensity cycling at 55% of the subject’s peak work rate. The continuous moderate intensity exercise with high intensity burst trials consisted of 50% of subjects peak work rate with nine 15 second burst at 100% peak work rate. These investigators concluded that continuous moderate intensity endurance training with bursts of high intensity exercise resulted in reduced post exercise hypoglycemia and a lower incidence of nocturnal hypoglycemia (27% of subjects following continuous moderate intensity exercise with high intensity bursts compared to 45% of subjects following continuous moderate intensity exercise) (Iscoe & Riddell, 2011). This study demonstrated the effects of continuous moderate intensity endurance training with short
bursts of high intensity exercise on blood glucose levels and hypoglycemia, but failed to demonstrate which exercise intensity is more effective in maintaining glycemic control. We still do not know how glucose regulation changes before, during, and after HIIT compared to moderate intensity endurance training. Thus, by comparing blood glucose responses these training intensities in healthy individuals, we will gain a better understanding of blood glucose regulation under these conditions.

Statement of Purpose

The purpose of this study is to demonstrate blood glucose responses before, during, and after an exercise session in healthy individuals and to identify any potential differences in blood glucose responses between a moderate intensity endurance training exercise session and a high intensity interval training exercise session.

Hypothesis

We hypothesize that blood glucose concentrations will be improved (minimize blood glucose highs and lows) following a high intensity interval training exercise session compared to a moderate intensity endurance training exercise session.

Specific Aims

The main objective of this study is to identify potential differences in glucoregulatory response between high intensity interval training and moderate intensity endurance exercise. The specific aims of this study are as follows:
1. To investigate the effect of a high intensity interval training (HIIT) exercise session on glucose concentrations before, during, and after exercise.

2. To investigate the effect of a moderate intensity endurance training exercise session on glucose concentrations before, during, and after exercise.

**Significance of the Study**

The potential significance of this study is to better understand blood glucose responses during exercise and the possible changes in blood glucose response due to changes in exercise intensity throughout the exercise session. We still do not know how glucose responses changes before, during, and after HIIT compared to moderate intensity endurance training; thus by comparing these training intensities with healthy individuals a better understanding of blood glucose responses under these conditions will be met. This understanding of blood glucose responses under these conditions will encourage further research to be conducted comparing these types of training intensities to better understand blood glucose regulation in diabetics under these conditions.
Chapter Two

Literature Review

Epidemics

In the United States, approximately 23% of adults have been diagnosed with metabolic syndrome (Dunn, Siu, Freund, & Boutcher, 2014). One of the factors linked to metabolic syndrome is a physically inactive lifestyle. Some of the markers of metabolic syndrome include obesity and elevated glucose levels. An individual with these markers is at a greater risk for type 2 diabetes (Dunn, et al., 2014). Inelmen et al. reported that long duration exercise programs have a poor retention rate amongst obese adults with full-time job commitments (Inelmen et al., 2005), most likely due to the belief that there is not enough time to exercise.

Physical activity not only reduces the risk type 2 diabetes mellitus (T2DM), but it also reduces the risk of cardiovascular disease (CVD). Cardiovascular disease is known as the disease of the heart and blood vessels. Some of these diseases include heart attack, stroke, congestive heart failure, and coronary artery disease (CAD) (Lippincott, Williams, & Wilkins, 2013). As individuals age, coronary blood vessels become less elastic and plaque buildup can develop leading to CAD. There are several risk factors associated with CVD. An individual with a family history at heart disease before the age of 65 in their mother or before the age of 55 in their father increases the risk of CVD (Lippincott, et al., 2013). High blood pressure is a risk factor described as systolic blood pressure greater than 140 mmHg or diastolic blood pressure greater than 90 mmHg (Lippincott, et al., 2013). Participating in regular exercise and maintaining a healthy body weight can prevent high blood pressure. Smoking is another CVD risk factor. Smoking leads to an increase in blood pressure and heart rate, increases the risk of blood clotting, and
promotes abnormal heart rhythms (Lippincott, et al., 2013). Dyslipidemia, meaning abnormal lipid levels is another risk factor. This risk factor is categorized as HDL less than 40 mg/dL, or LDL greater than 130 mg/dL, or total cholesterol greater than 200 mg/dL. Regular exercise and a dietary intake low in saturated fat can help modify cholesterol levels. Fasting blood glucose greater than 100 mg/dL is considered a modifiable risk factor (Lippincott, et al., 2013). A normal fasting glucose should fall within 60-100 mg/dL. Elevated blood glucose levels can lead to damaged coronary arteries and blood vessels (Lippincott, et al., 2013). To prevent diabetes, individuals should participate in regular exercise and eat a healthy diet. Obesity is another risk factor associated with CAD. Obesity is defined as a BMI greater than 30 or a waist girth greater than 35 inches for women and 40 inches for men (Lippincott, et al., 2013). The final risk factor for CVD is a sedentary lifestyle. A sedentary life style is defined as an individual who is not physically active on most of the days or does not participate in regular exercise for at least 30 minutes a day (Lippincott, et al., 2013).

There are a total of seven risk factors for CVD. In today’s society it is very common to see an average American have one or more risk factors. An individual with no more than one positive risk factor will be categorized as low risk for CVD. Those who have two or more positive risk factors or is 45 or older for a male or 55 or older for a female would be classified as moderate risk. An individual will be classified as high risk if they already have a cardiovascular disease, COPD, or diabetes mellitus (Lippincott, et al., 2013). There are some major similarities linking these risk factors for cardiovascular disease together. Blood pressure and cholesterol levels can be reduced with regular exercise. Regular exercise can then directly improve obesity, a sedentary lifestyle, and
fasting glucose levels. Since glucose regulation is a major determinant for preventing major diseases such as these, participating in regular exercise while monitoring blood glucose levels can better prevent the likelihood of having one or more risk factors associated with cardiovascular disease.

**Glucose Regulation**

Glucose intake and glucose regulation can be major determinants for preventing several diseases. Due to an increase in the average American’s caloric intake, glucose ingestion has increased, but glucose utilization has decreased due to a reduction in activity level. Type 2 diabetes mellitus (T2DM) is just one of these disease that has become a major epidemic in the world, and associated with a sedentary lifestyle and obesity (Adams, 2013).

Diabetes mellitus (DM) is defined as a metabolic disease in which the body is not able to produce enough or any insulin, resulting in raised levels of blood glucose. Type 2 diabetes is specified as insulin resistance in the body; whereas type 1 diabetes mellitus (T1DM) is specified as the body’s inability to make insulin characterized by T cell facilitated damage of insulin-producing pancreatic beta cells (Karstoft, et al., 2014). Type 1 diabetics do not develop DM due to obesity or a sedentary lifestyle, but they still struggle with proper nutrition and glucose regulation at the same time.

**Glucose uptake during exercise.** Glucose is hydrophilic in nature, meaning it is unable to pass through the plasma membrane through the process of diffusion. Because of this, glucose transport proteins are required to transport glucose across the plasma membrane (Schwenk, Luiken, Bonen, & Glatz, 2008). The glucose transport protein GLUT1 is considered the basal glucose transporter and is most active under resting
conditions. GLUT1 can also be translocated to improve glucose uptake in reaction to muscle contraction or insulin (Schwenk, et al., 2008). GLUT4 is another glucose transport protein encrypted in the genome, and it is mostly found in skeletal and cardiac muscle. GLUT4 is not insulin mediated and is very important to glucose uptake by the active skeletal muscles during a period of increased contractions of the muscle (Schwenk, et al., 2008). During exercise, skeletal muscle is contracted, and glucose is taken up by the cell through means of facilitated diffusion reliant on the presence of GLUT4. In skeletal muscle, GLUT4 has been identified as the main glucose transporter in charge of insulin-contraction simulated glucose transport (Richter & Hargreaves, 2013). An increase of GLUT4 expression in skeletal muscle assists in improved insulin action and glucose removal (Richter & Hargreaves, 2013). From rest to exercise, blood flow in skeletal muscle can increase up to 20 fold. This increase in blood flow is the main supporter to why there is an increase in glucose uptake in the muscle during exercise (Richter & Hargreaves, 2013). It is not uncommon for diabetic patients to underestimate the importance of GLUT4 activities during exercise leading them to give themselves too much insulin during exercise. The combined effect of GLUT4 activity and excess insulin could clear glucose out of the blood resulting in low blood sugar levels known as hypoglycemia. Translocation of GLUT4 sites inside the cell to the sarcolemma is the main contributing factor to muscle glucose transport throughout exercise (Richter & Hargreaves, 2013).

When looking at the physiology of the cell, insulin-like growth factor 1 (IGF-1), binds on to insulin like receptor to turn on a single transduction mechanism. Insulin receptor substrate 1 (IRS-1), the insulin receptor substrate, is activated by adding a
phosphate group to the tyrosine of IRS-1. Phosphoinositide 3-kinase (PI3K), a group of enzymes involved in cell growth and proliferation) is phosphorylated to P1P2 followed by PDK, which is a protein kinase that is necessary for activation of several protein kinases. Protein kinase B also known as AKT is signaled to GLUT4 allowing for glucose to enter into the cell (Richter & Hargreaves, 2013). The glycogen synthase kinase 3 Beta, or GSK3B, is used to phosphorylate glycogen synthase, which can play a role in protein synthesis. After glucose has successfully been transported through the sarcolemma, glucose is phosphorylated to glucose-6-phosphate. This is the initial step in glucose metabolism by the oxidative and glycolytic pathways. An individual that does not produce enough insulin, or is lacking the receptor, will lack the signaling of this pathway, thus glucose will not be able to enter the cell. This is why mechanical loading, forces acting on the body generated through muscle contractions, is highly important. Mechanical loading can bypass this signaling pathway and directly activate AKT (Richter & Hargreaves, 2013).

When an individual is participating in endurance training, mitochondrial biogenesis occurs, and when an individual is participating in resistance training, a type of exercise using an exterior resistance to cause the muscle to contract, myofibril protein synthesis occurs. Mechanical loading of skeletal muscle can directly activate AKT and binding protein MTOR. AKT plays an important role in glucose uptake and regulating protein synthesis. The energy balance adenosine monophosphate-activated protein kinase (AMPK) will turn on glycogen phosphorylase as well as glycogen and epinephrine (Thomson, Fick, & Gordon, 2008). AMPK is an energy recognizing protein that promotes for signaling of other processes that help to further replenish adenosine tri-
phosphate (ATP) while at the same time preventing pathways that consume ATP (Thomson, et al., 2008). Glycogen synthase activity increases by the breakdown of glycogen, decreasing by AMPK activation (Nielsen et al., 2002). AMPK detects energy inside the cell and when phosphorylated inhibits the activity of mammalian target of rapamycin (MTOR). This inhibition promotes for enhanced translation by 4E Binding Protein 1 (4EBP-1) and ribosomal protein subunit 6 kinase 1 (S6K1) (Richter & Hargreaves, 2013; Thomson, et al., 2008). Following mechanical loading there is elevated translational signaling. AMP levels can become very elevated during exercises resulting in an AMP/ATP ratio that activates AMPK. AMPK can then phosphorylate and trigger TSC2 which will inhibit MTOR activity. When MTOR activity is turned off it turns off the signaling to two important proteins in protein synthesis.

Wahren and colleagues conducted several studies, during which they discovered that exercise intensity and the duration of exercise are the main factors of muscle glucose uptake during exercise (Ahlborg, Felig, Hagenfeldt, Hendler, & Wahren, 1974; Ahlborg, Wahren, & Felig, 1986). These investigators discovered that blood glucose could make up for up to 40% of an individual’s oxidative metabolism during exercise. It is clear that glucose plays an important role during exercise but more research needed to be done to understand the metabolic pathways of glucose during various training intensities.

**Interval Training**

Sprint interval training (SIT) excites fast improvements in muscle oxidative capacities that are similar to levels reached following endurance training. Gibala et al. conducted a study examining cellular adaptations in skeletal muscle following six session of endurance training or SIT. This SIT training protocol consisted of 4-6 times of all out
cycling for 30 seconds at approximately 250% of their VO$_{2peak}$ followed by 4 minutes of recovery (Gibala et al., 2006). They concluded that SIT was a time saving approach to improve skeletal muscle oxidative capacity (Gibala, et al., 2006). It was supported that there are very similar changes in muscle adaptations related to exercise in both endurance training and sprint interval training. SIT has been confirmed to improve the greatest activities of mitochondrial enzymes and improves performance during aerobic activities. Evidence of glycogen utilization during SIT training compared to endurance training given the low training volume, suggests that HIIT training is a time effective strategy to promote specific metabolic adaptations throughout exercise (Burgomaster et al., 2008).

HIIT (High Intensity Interval Training) typically consists of short bursts of intense exercise broken up by periods of recovery. This has been established to improve endurance capability, glycemic control, and time to fatigue. HIIT is a strategy to attempt physiological adjustments that are similar to those of endurance training (Gillen, et al., 2012).

**HIIT and glucose regulation in healthy individuals**

The major determinant of glucose production during moderate intensity endurance training is the rise in glucagon and a fall in insulin. For healthy individuals moderate intensity endurance training will lead to increase in muscle glucose uptake. It is believed that during high intensity interval training the rise in glucose that is released might be greater that the glucose uptake from the muscle (Camacho, Galassetti, Davis, & Wasserman, 2005). This could lead to higher blood glucose levels following exercise. The rate of glucose in the arterial blood might be higher or lower than that of venous blood. This is dependent on where the blood is being measured and what muscles were
being used during exercise (Camacho, et al., 2005). This response does not significantly impact healthy individuals, but those with diabetes may suffer from an inadequate hepatic response resulting in hyperglycemia.

**HIIT and glucose regulation in diseased individuals**

Adams looked at the effect of short durations of high intensity training on BG of those with diabetes. Postprandial glucose control has been demonstrated to improve over a 24 hour period after either a single session of HIIT training or a 2-week training program. These programs typically increase GLUT4 protein and decrease blood glucose levels in type 2 diabetics 48-72 hours post training (Adams, 2013). Most of the studies that involved high intensity training used a protocol of 60 working and 60 seconds rest either by means of cycling or running. Gillen and colleagues utilized a HIIT training protocol of 10 times of 60 seconds cycling at 90% max heart rate at a cadence of 80-100 rpm followed by 60 seconds rest (Gillen, et al., 2012). All participants were fitted with a continuous glucose monitor and were given personalized control diets. After analyzing the data from the continuous glucose monitor, he concluded that the time in postprandial hyperglycemia was reduced after HIIT compared to a non-exercise control day (Gillen, et al., 2012).

In a study by Mendes et al., type 2 diabetics were treated with an oral hypoglycemic agent and underwent one high intensity interval training session on the treadmill. The participants had a 5 minute warm up followed by 3 minutes walking at 70% HRR and 3 minutes walking at 30% HRR (Mendes, et al., 2013). This series was completed 5 times. The participants capillary blood glucose was measured fasting, immediately prior, at 10, 20, and 30 minutes during exercise, immediately after, and
every 10 minutes during recovery (Mendes, et al., 2013). There were not any signs of hypoglycemia or hyperglycemia during the study or recovery. The researchers concluded that HIIT training is effective and safe way to control blood glucose levels (Gillen, et al., 2012; Mendes, et al., 2013).

Little and colleagues have conducted several studies looking at the effects of high intensity interval training and glycemic control. In a study published in 2011 they examined low volume high-intensity interval training and glycemic control. Participants performed six sessions of HIIT training (10 times 60 second cycling bouts at 90% of the participants max heart rate with 60 seconds rest in between exercise bouts) over a two week period. This low volume training at just 75 minutes a week resulted in a lower twenty four hour average blood glucose concentration in individuals with T2DM (Little et al., 2011). Participants observed the average blood glucose levels were reduced from 7.6 mmol/L to 6.6 mmol/L and GLUT4 protein content was 369% higher after the training period (Little, et al., 2011).

The risk associated with glycemic control can be greater with type 1 diabetics, which is why studies using HIIT training for type 1 diabetics do not always use the standard protocol that we see with high intensity training and type 2 diabetics. Instead of $10 \times 60$ seconds at 90%max heart rate, researchers have used various protocols including four to eight 30-second max cycle ergometer sprints followed by 4 minutes rest, 11 4-second sprints followed by 2 minutes of rest, and cycling at 40% VO$_{2\text{max}}$ for 30 minutes with sixteen 4-second maximal cycles (Adams, 2013; Guelfi, Jones, & Fournier, 2005; Guelfi, Ratnam, Smythe, Jones, & Fournier, 2007). These studies resulted in blood glucose levels remaining relatively stable one hour post exercise. These studies
demonstrate that as short as 7.5 minutes of HIIT training a week may be an effective way to manage blood glucose levels. It is still unclear if improvements in blood glucose would withstand over a longer period of time and reduce HbA1c levels (Adams, 2013).

In a meta-analysis by Tonoli et al., the different types of acute and chronic exercise on glycemic control in type 1 diabetics were analyzed. HbA1c was used as a dependent variable for chronic glycemic control. Different exercise types were then classified into acute high intensity, acute aerobic, chronic aerobic, chronic strength, and high intensity interval training. The overall main finding of this meta-analysis showed that exercise has a significant impact on chronic and acute glycemic control (Tonoli et al., 2012). High intensity exercise resulted in a slight decrease in blood glucose values when compared to aerobic exercise. When looking at the most significant form of exercise for improving chronic glycemic control aerobic training is recognized to have the most improvements. After a single bout of moderate intensity exercise, all of the studies included in the meta-analysis found a decrease in blood glucose levels. This can increase the chance of a hypoglycemic episode in type 1 diabetics, but this risk can be reduced with proper nutrition and insulin reduction (Tonoli, et al., 2012). It was not possible to do a meta-analysis of HIIT due to the variation of exercise protocols amongst the studies. Some of the studies reported did conclude that there was a small fall in blood glucose levels leading to greater protection of hypoglycemia. It is also believed that the differences in changes of blood glucose might be different due to the difference in duration of exercise. When comparing studies moderate intensity can range from 30 minutes to 60 minutes whereas the high intensity training typically does not contain more than 20 minutes of work time at 80-100% of the subjects VO2max (Tonoli, et al., 2012).
The researchers concluded that physically active type 1 diabetics had a lower HbA1c level when compared to sedentary type 1 diabetics. In order to see this improvement in HbA1c levels the type 1 diabetic must have participated in moderate intensity for at least 3 months. There is still very little research in comparing a single bout of moderate exercise compared to a single HIIT session and what changes if any are present in glycemic control (Tonoli, et al., 2012). Until there is a consistency with a protocol that seems to be effective and challenging it will continue to be difficult to compare the benefits of moderate intensity exercise to HIIT in both healthy and diabetic individuals.

**Moderate intensity endurance training and glucose regulation**

Moderate intensity endurance training induces physiological adaptation that improves exercise capacity. Five to seven days’ worth of endurance training improves glycogen availability and decreases the rate of glycogen catabolism for the duration of matched-work exercise. This results in an increase in endurance capability (Gibala, et al., 2006). Moderate intensity endurance training lasting longer than an hour at 65% of an individual’s peak oxygen uptake over several weeks has been confirmed to improve skeletal muscle oxidative capacity (Burgomaster, et al., 2008).

There is very little research examining the effects of moderate intensity endurance training on glucose regulation. Over several weeks of participating in moderate intensity endurance training (participating in one 90 minute session at 45% \( \text{VO}_2\text{peak} \) and one 60 minute session at 65% \( \text{VO}_2\text{peak} \)) blood glucose concentrations slightly decreased (Henderson et al., 2008). Glucose concentrations were depressed more significantly in men than women three hours post moderate intensity endurance training. However, in
healthy individuals glucose concentrations quickly return to normal levels post exercise bouts (Henderson, et al., 2008).

**Continuous glucose monitors (CGM)**

Continuous glucose monitors (CGM) gather information regarding magnitude, direction, frequency, duration, and the sources of fluctuations in blood glucose levels (Klonoff, 2005; Klonoff, et al., 2011). The monitors can be minimally invasive by continuously monitoring interstitial fluid or they can be noninvasive by applying radiation through the skin to monitor blood vessels in the body. The minimally invasive monitors record blood glucose every 1 to 10 minutes lasting up to 7 days and the noninvasive monitors last up to 3 months. Studies suggest that these types of devices be used with type 1 diabetes patients who have Hemoglobin A1c (HbA1c) levels that are less than 7.0 to help patients maintain the recommended target levels greater than 7.0 (Klonoff, et al., 2011; Little, et al., 2014). Continuous glucose monitors have been used more frequently with current studies to obtain more accurate measurements of blood glucose levels both during training and up to 24 hours post training.

Kapitza et al. conducted a study with sixteen male type 1 diabetics who were physically active. The patients were placed into the moderate intensity (30 minutes every second day) or intense training group (greater than 60 minutes a day). The participants underwent exercise activities before and after the 14 day program and during the training program they were asked to walk, jog, or bike (Kapitza et al., 2010). The participants experienced blood glucose variability before, during, and after exercise. These results would be expected due to the lack of a controlled protocol in the study; however this study suggest that CGM should be utilized for physical active type 1 diabetics as no
general recommendation can be given when it comes to different training intensities (Kapitza, et al., 2010).

**HIIT versus Moderate Intensity Endurance Training**

Little et al., followed up their research with a study comparing high intensity interval training with continuous moderate intensity endurance training. Ten overweight or obese participants performed either a single HIIT training session using the same HIIT protocol as his previous study or 30 minutes of continuous moderate intensity endurance training (35% peak watts) (Little, et al., 2014). All participants were fitted with a CGM twenty four hours prior to the training session. Little and colleagues concluded that the lasting effects of HIIT proved to be more than that of continuous moderate intensity endurance training with postprandial glucose increase following breakfast 24 hours post exercise to be lower with HIIT compared to moderate intensity endurance training (Little, et al., 2014). This study demonstrates that HIIT might be an effective way to improve glycemic control, but it fails to demonstrate how HIIT compares with moderate intensity endurance training for improving health outcomes overtime.

In another study by Gibala et al., the physiological adaptations associated with low-volume high-intensity interval training were reviewed. It has been documented that after several weeks of low-volume HIIT training adaptations in glycogen utilization can be observed. These adaptations include a decreased rate of glycogen utilization and improved resting glycogen content (Gibala, et al., 2012). These findings were found using a standardized protocol of 60 seconds of exercise at 90% of the participants maximal work rate followed by 60 seconds of recovery. This protocol appears to be both effective and efficient for inducing skeletal muscle adaptations (Gibala, et al., 2012).
Guelfi et al. had type 1 diabetics come into the laboratory on two separate occasions. During one visit they participated in 30 minutes of moderate intensity endurance training and on the other visit the participants participated in high intensity training consisting of continuous cycling at 40% VO$_{2\text{max}}$ interspersed with 4 seconds of maximal effort every 2 minutes. The duration of the HIIT training was based on various sports (Guelfi, et al., 2005). Upon completion of the trials Guelfi concluded that both training protocols resulted in a decline in blood glucose, however the decline was slightly greater with moderate intensity endurance training compared to HIIT (Guelfi, et al., 2005).

Conclusions

It is important to compare moderate intensity endurance training to high intensity interval training exercise to observe the changes in glycemic control. There seems to be a consistent protocol in most of the HIIT research consisting of 10 bouts of 60 seconds of work at 90% of a participant VO$_{2\text{peak}}$ followed by 60 seconds. There has been very little research involving a high intensity interval training protocol that has varied intensities during the high intensity training session. This type of varied intensities (an average of 85% of the participant’s peak watts) is important because it better reflects daily activities of individuals rather than the contrived setting of a clinical facility. HIIT training has been recognized to be effective in glycemic control over time but fails to demonstrate the immediate response. We still do not know how glucose regulation changes before, during, and after different exercise intensities.
Chapter Three

Methodology

Subjects.

The results of previous studies (Gist, Freese, & Cureton, 2014; Haidar et al., 2013; Henderson, et al., 2008; Iscoe & Riddell, 2011; Radermecker, Fayolle, Brun, Bringer, & Renard, 2013) indicate a significant decrease in blood glucose levels have been identified through continuous glucose monitors (CGM) with the number of participants ranging from 10 to 15. It was proposed that twenty healthy men and women, between the ages of 18 and 40 years, be recruited for this study, however due to limited CGM sensors only five participants were recruited. Participants did not have any signs, symptoms, or known diagnoses of a cardiovascular or pulmonary diseases or musculoskeletal injuries based on their responses to a standardized medical history questionnaire (Appendix A). Participants with any previous medical history of cardiovascular, autoimmune, or pulmonary disease or musculoskeletal injuries that would prevent them from participating in exercise training were excluded from the study. This study was approved by the Institutional Review Board at the University of Toledo and was performed in accordance with the Declaration of Helsinki.

Instrumentation.

Blood glucose was measured using continuous glucose monitors (CGM) (Dexcom). This device is designed to detect blood glucose trends and track patterns in individuals 18 and older. Dexcom’s CGM is a wireless monitor and has three parts including a sensor, a transmitter, and a receiver. This monitor provides a glucose reading every five minutes for up to seven days. The monitor provides alerts and an alarm will
sound to alert the participant when blood glucose levels are outside the participants target range. The device helps detect hypoglycemic or hyperglycemic episodes assisting in short and long term treatment options for individuals with diabetes. A self-monitoring blood glucose method was used to calibrate the device. The investigators were trained on how to use the device. The subjects were assisted on inserting and removing the sensor. Instructions about the device and how to use the device were given to each subject. The CGM was calibrated by obtaining a blood glucose reading using a One Touch Ultra glucose meter. Two hours after insertion the CGM required two blood glucose readings in order to calibrate the sensor. A One Touch Ultra glucose meter was utilized by inserting a test strip into the test port of the meter. An individual’s fingertip was pricked using a lancet. The fingertip was gently squeezed to obtain a round drop of blood. The blood sample was applied to the meter by moving the test strip toward the drop of blood. After the blood sample was applied to the meter a blood glucose reading will be displayed on the screen. This blood glucose reading was used to calibrate the CGM.

A polar heart rate monitor was used throughout the YMCA submaximal test to determine the suggested resistance for the various stages of the test. The sub-maximal bike test is used to evaluate the physical work capacity and to estimate an individual’s maximal oxygen uptake. This test was used to establish the relationship between the individual’s heart rate and work rate. The test began with the initial work rate set to 0.5 Kp and the participant was instructed to begin cycling at 50-rpm. Each stage lasted 3 minutes. Two minutes into the first stage the participant’s heart rate and blood pressure was recorded. The heart rate was measured using a polar heart rate monitor. Heart rate was taken again at 2:45 min into each stage. A steady-state heart rate had to be achieved
before the participant could move on to the next stage. At this point in the test the course of action was determined. If the participants achieved steady-state heart rate (within 6 bpm) the participant proceeded to the next stage (Figure 1). If the participants heart rate is not at a steady-state (>6 bpm difference) the participants heart rate was monitored until steady-state is reached. The participant continued through the stages until their target heart rate was reached. Once the participant had reached their age predicted maximum heart rate the test was stopped. This value was used for the moderate and high intensity interval training exercise sessions.

<table>
<thead>
<tr>
<th>1st Workload</th>
<th>25 Watts 0.5 Kp</th>
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<tbody>
<tr>
<td>HR &lt; 80</td>
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<td>HR 90-100</td>
<td>HR &gt; 100</td>
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<table>
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</tr>
</thead>
<tbody>
<tr>
<td>100 Watts 2.0 Kp</td>
<td></td>
</tr>
<tr>
<td>75 Watts 1.5 Kp</td>
<td></td>
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<tr>
<td>50 Watts 1.0 Kp</td>
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</table>

<table>
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<th>150 Watts 3.0 Kp</th>
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</thead>
<tbody>
<tr>
<td>125 Watts 2.5 Kp</td>
<td></td>
</tr>
<tr>
<td>100 Watts 2.0 Kp</td>
<td></td>
</tr>
<tr>
<td>75 Watts 1.5 Kp</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
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<th>4th Workload</th>
<th>175 Watts 3.5 Kp</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 Watts 3.0 Kp</td>
<td></td>
</tr>
<tr>
<td>125 Watts 2.5 Kp</td>
<td></td>
</tr>
<tr>
<td>100 Watts 2.0 Kp</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 1. YMCA submaximal test protocol*

**Experimental Protocol.**

During the first visit to the Human Performance and Fitness Promotion Lab the research investigator described the purpose, methodology, as well as risks and benefits of the study to the participant. The participant was instructed to read through the informed consent form which provided in depth information regarding the purpose, methodology,
risks, and benefits of the study. It is at this time that the participant was able to ask any questions they might have regarding this study. Once all of these steps were completed and the participant still wanted to participate in the study, the participant was instructed to sign the informed consent form. Following the signing of the informed consent form the participant was instructed to complete a Medical History Questionnaire (Appendix A). Baseline data was collected including weight (kilograms), height (centimeters), age (years), and heart rate (beats per minute).

**Visit 1.** The participants estimated \( \text{VO}_{2\text{max}} \) was calculated to determine the work rate needed to achieve an area under the curve of 85% of the participant’s age predicted maximum heart rate (220-their age). In order to obtain this work rate a YMCA Sub-Maximal Bicycle test was performed. The participants resting heart rate and blood pressure was taken. The participant was instructed to begin pedaling at a cadence of 50 reps per minute (rpm). Once the participant has reached their age predicted maximum heart rate the test will be stopped. This value was used for the moderate and high intensity interval training exercise sessions.

The participant was provided with a continuous glucose monitor (CGM). The sensor was inserted in the abdomen under the skin to monitor the blood glucose levels in the interstitial fluid. The participant was instructed on how to use the CGM throughout the study. The participant will also be provided with an overview of the CGM including how to calibrate it, know what various alerts mean, and how to change the sensors. To ensure proper calibration the participant were asked to come back to the lab 12 hours after the initial insertion to ensure the participant understood how to properly calibrate the monitor.
Throughout the duration of the study each participant was given a log to record the time and amount of food consumed throughout the study.

**Visit 2.** At least 24 hours after visit 1, the participant returned to the Human Performance and Fitness Promotion Lab. Upon arrival the participant was fitted to a heart rate monitor and blood glucose was measured. The bike was programmed to 50% of the participant’s peak watts determined from the YMCA submax test during visit 1. The participant was instructed to begin cycling on the bike with no resistance at a moderate speed for 3 minutes to warm up. After three minutes the workload was automatically adjusted to the predetermined workload. The participant cycled at this work rate continuously for 30 minutes with their blood glucose measured and recorded using the continuous glucose monitors. Once the exercise session was completed the participant’s blood glucose was measured.

**Visit 3.** At least 36 hours after visit 2, the participant returned to the Human Performance and Fitness Promotion Lab to participate in the high-intensity interval training exercise session. Upon arrival the participant was fitted with a heart rate monitor, and blood glucose was measured. The bike was programmed to the area under the curve (the average workload over time) correlated to 85% of the participants max heart rate. The participant was instructed to begin cycling on the bike at 50% of their peak Watts at a moderate speed for 3 minutes to warm up. After three minutes the workload was automatically adjusted to the high intensity intervals predetermined to achieve the desired workload (Appendix B). High-intensity intervals were randomized, and each subject performed a pattern of one minute cycling at the high intensity followed by one minute rest in which the subject cycled at 30 Watts ten times for a total of 20 minutes.
The total exercise time from warm up to finish lasted 23 minutes. Each high intensity interval was set to a work rate ranging from 50% to 120% of their submaximal work rate predetermined by the submaximal bike test. The participant’s blood glucose was measured after the exercise session.

The CGM continued to measure the glucose level until 24-hours post-exercise. These measurements were recorded in the provided log along with food intake. Upon completion of the study, the participants CGM results were downloaded for analyzing on a computer. This allowed the researchers to identify trends in blood glucose and identify patterns.

**Measurements.**

Instantaneous blood glucose (mg/dL) was recorded during the initial calibration of the CGM and every twelve hours after that using a One Touch Ultra glucose meter. The glucose levels of interstitial fluid were recorded every five minutes using the continuous glucose monitor. With the sensor inserted into the abdomen, glucose in the interstitial fluid was measured every five minutes and a glucose reading was transmitted to the receiver where it was displayed on the monitor.

**Data Processing.**

Upon completion of the exercise visits, the monitor was hooked up to the Dexcom program on the password protected computer in the Cardiopulmonary and Metabolism research lab at the University of Toledo. Under the patient tab in the Dexcom program the researchers were able to review every glucose value that was recorded throughout the duration of the study. These glucose readings were extracted and imported into excel. The researchers were able to look at the glucose changes pre, during, and post the
moderate intensity endurance training exercise session and the HIIT exercise session. To determine the potential differences in glucoregulatory response between the HIIT exercise session and the moderate intensity endurance training exercise session relative change ratios for blood glucose pre, during, and post training were recorded using the glucose values during training compared to baseline.

**Statistical Analysis.**

For the measures made repeatedly by the participants a two way repeated ANOVA was conducted to analyze the effect of the healthy individual’s on the predicted outcome.
Chapter Four

Results

Subject Demographics.

The mean age of study participants (n=5, 3 Female, 2 Male) was 23.6 ± 1.8 years (range 22 to 26 years), mean height was 164.3 ± 10.6 cm for females and 177.8 ± 0.0 cm for males (range 152.4 to 177.8 cm), mean weight was 60.9 ±10.0 kg for females and 91.8 ± 11.4 kg for males (range 52 to 99.79 kg), and mean peak watts was 176.8 ± 8.9 watts for females and 230.9 ± 56.7 for males (range 167 to 271 watts)(Table 1).

Blood Glucose.

When expressed as a ratio, there was no difference in the mean values among the different types of exercise (Table 1) (F= 0.035, P=0.862, Power = 0.050, effect size = 0.265). There was no difference in the blood glucose ratios between type of exercise within end of exercise (moderate: 3.7 ± 0.5 mmol/l, HIIT: 4.0 ± 0.6 mmol/l; p > 0.05). There was no difference in blood glucose ratios between type of exercise within 60 minutes post exercise (moderate: 5.3 ± 0.9 mmol/l, HIIT: 5.0 ± 1.1 mmol/l; p > 0.05). There was no difference in blood glucose ratios between type of exercise within 120 minutes post exercise (moderate: 5.4 ± 1.0 mmol/l, HIIT: 5.2 ± 1.0 mmol/l; p > 0.05).

Blood glucose and time. There is not a statistically significant interaction between the type of exercise and time (F= 0.311, P= 0.966, Power = 0.050). There is a statistically significant difference in the mean values among the different levels of time (F= 3.891, P=0.002, Power = 0.920). This is expected given that blood glucose levels dropped during exercise and returned back to baseline or higher 60 minutes to 120 minutes post exercise (Figure 2-3).
Table 1

*Demographics of Subjects*

<table>
<thead>
<tr>
<th>Demographics</th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td># of subjects</td>
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<td>2.00</td>
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<tr>
<td>Age (y/o)</td>
<td>22.3±0.6</td>
<td>25.5±0.7</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>164.3 ±10.6</td>
<td>177.8±0.0</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>60.9±10.0</td>
<td>91.8±11.4</td>
</tr>
<tr>
<td>Peak Watts</td>
<td>176.8 ±8.9</td>
<td>230.9±56.7</td>
</tr>
</tbody>
</table>

Table 2

*Means and Standard Deviations for Relative Change Ratios*

<table>
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<tr>
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<th>Moderate Intensity</th>
<th>High Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 min</td>
<td>0.1 ± 0.2</td>
<td>0.0 ± 0.1</td>
</tr>
<tr>
<td>5 min</td>
<td>0.0 ± 0.1</td>
<td>0.0 ± 0.1</td>
</tr>
<tr>
<td>10 min</td>
<td>0.0 ± 0.1</td>
<td>0.0 ± 0.1</td>
</tr>
<tr>
<td>15 min</td>
<td>-0.1 ± 0.1</td>
<td>-0.1 ± 0.1</td>
</tr>
<tr>
<td>20 min</td>
<td>-0.1 ± 0.1</td>
<td>-0.1 ± 0.1</td>
</tr>
<tr>
<td>End of Ex</td>
<td>-0.2 ± 0.1</td>
<td>-0.2 ± 0.1</td>
</tr>
<tr>
<td>60 min post</td>
<td>0.2 ± 0.2</td>
<td>0.1 ± 0.2</td>
</tr>
<tr>
<td>120 min post</td>
<td>0.2 ± 0.2</td>
<td>0.2 ± 0.3</td>
</tr>
<tr>
<td>Fasting</td>
<td>-0.1 ± 0.2</td>
<td>-0.1 ± 0.1</td>
</tr>
</tbody>
</table>
**Figure 1.** The relative change of glucose levels over time.

**Figure 2.** The change of glucose levels over time.
Chapter Five

Discussion

The purpose of the present study was to demonstrate blood glucose responses before, during, and after exercise sessions in healthy individuals and to identify any potential differences in blood glucose responses between a moderate intensity endurance training exercise session and a high intensity interval training exercise session. It was hypothesized that blood glucose concentrations will be improved (minimize blood glucose highs and lows) following a high-intensity interval training exercise session compared to a moderate intensity endurance training exercise session. The primary findings of the present study did not support this hypothesis.

Blood Glucose regulation before, during, and after exercise training.

The primary findings of the present study did not support the hypothesis, but they do support the purpose of the study. Through the use of the continuous glucose monitors blood glucose concentrations was portrayed pre, during, and post a moderate intensity endurance training exercise session and a HIIT exercise session. The continuous glucose monitors successfully recorded interstitial glucose levels every five minutes throughout the duration of the study and immediate changes in blood glucose were seen. These immediate changes in blood glucose were then compared to fasting blood glucose to obtain relative change ratios.

Only one other research study has tested blood glucose levels pre, during, and post moderate intensity exercise compared to high intensity interval training, similar to that of the present study. Guelfi et al. had 7 type 1 diabetics undergo a 30 minute session of moderate intensity exercise and a single session of 30 minutes of high intensity
training (continuous exercise at 40% \( \text{VO}_{2\text{peak}} \) interspersed with 4 second sprints every two minutes) (Guelfi, et al., 2005). The participants wore a CGM during both sessions. There was a statistical difference between pre and post blood glucose levels in the moderate intensity and high intensity trials (Guelfi, et al., 2005). There was not a statistical significant difference between the two trials. However, the researchers concluded that the decline in blood glucose levels was less with high intensity interval exercise compared to moderate intensity exercise during exercise and recovery in type 1 diabetics (Guelfi, et al., 2005).

The present study demonstrated a similar response to that of Guelfi research; however we were unable to test type 1 diabetics due to several possible risks associated with diabetics and exercise. There were noticeable differences when comparing blood glucose levels pre exercise to post exercise in both the moderate intensity endurance training exercise session and the high intensity interval training exercise session. Mean blood glucose levels immediately before endurance exercise was 4.50±0.7 in females and 4.47±0.43 in males. Mean blood glucose levels immediately post endurance exercise were 3.7±0.7 mmol/l in females and 3.75± 0.04 mmol/l in males. There is a noticeable decrease in blood glucose levels following 30 minutes of moderate intensity endurance training exercise. Mean blood glucose levels immediately before HIIT exercise was 4.76±1.09 mmol/l in females and 4.50 ± 0.3 mmol/l in males. Mean blood glucose levels immediately post HIIT exercise was 3.94 ± 0.72 mmol/l in females and 4.08 ± 0.40 mmol/l in males. There is a significant decrease in blood glucose levels pre and post HIIT exercise. Although this decrease in blood glucose levels during exercise is significant, when comparing blood glucose regulation between the moderate intensity
endurance training exercise session levels to the high intensity interval training exercise session there is not a statistically significant difference

This decrease in blood glucose levels is to be expected due to glucose carried in the blood and utilized by muscles as an energy supply (Guelfi, et al., 2005). The duration of the moderate intensity endurance training exercise session was only 30 minutes and the HIIT exercise session was 23 minutes, resulting in a similar decline in blood glucose over time. During a short moderate intensity exercise session there is an increase in glucose uptake by the muscle, which is balanced by an increase in hepatic glucose production (Adams, 2013). This balance results in a slight decrease in blood glucose levels or no decrease at all and blood glucose levels remained unchanged. During HIIT, glucose is the primary fuel source for muscles, dependent on the exercise intensity and duration of the training. Catecholamine levels increase, causing an increase in glucose production that can be greater than of glucose utilization during exercise (Adams, 2013). This will result in a slight increase of blood glucose levels during and up to an hour post exercise. The plasma levels will increase which will stabilize the glucose level and glycogen will be restored to the muscle (Adams, 2013). This increase in blood glucose is not always observed, rather a decline in blood glucose similar to that of moderate intensity exercise is observed. This can all be dependent on the duration and intensity of the HIIT, as well as the blood glucose levels prior to training (Guelfi, et al., 2005).

The findings of this study demonstrate that blood glucose during a HIIT exercise session declines at a similar rate to that of the moderate intensity endurance training exercise session. There was a slightly greater decline of blood glucose levels during and post moderate intensity exercise when compared to HIIT, but the change was not great
enough to be statistically significant. This could be due to the duration of the exercise sessions to be similar or the intensity was not high enough to see a greater difference between the different exercise intensities.

**Limitations.**

One limitation of this study was the number of subjects that we were able to recruit for this study. After conducting a power analysis (Appendix B) it was suggested to have a sample size of 11-13. Due to the limited supply of continuous glucose monitor sensors, only five subjects were able to be recruited for this study. This low sample size could be the reason why there was not a statistical difference between the two exercise sessions. A larger sample size could have resulted in a stronger power for the study.

The second limitation to this study was the inability to control several factors that could have affected the participant’s blood glucose levels throughout the study. The participants were asked to keep a log of the food they ate and at what time, but no restrictions were made about what they could or could not eat. Also, the participants were not restricted on when to eat and when to stop eating before and after exercise. This could have resulted in greater fluctuations during exercise as well as a lesser or greater amount of stored energy to perform the exercise trials. It has been reported that short bouts of exercise immediately before a meal reduced postprandial glucose control in insulin resistant populations (Francois et al., 2014). Although none of the participants were insulin resistant, eating a meal following the HIIT session could have resulted in reduced postprandial glucose control.

The last limitation to the study is the accuracy of the YMCA submaximal test. There is room for human error with measuring heart rate and blood pressure, as well as
the calculations that need to be performed in order to determine the participants VO$_{2\text{max}}$. If the VO$_{2\text{max}}$ was not calculated properly, the moderate intensity exercise session as well as the HIIT exercise session could be too low in resistance in order to achieve the work demand required by the participant. If the high intensity interval training exercise session was not equivalent to 85% of the participants true VO$_{2\text{max}}$, the difference of intensities between the two exercise sessions may have not been great enough to see a difference in the two intensities.

**Recommendations for Further Research.**

First it is recommended that more subjects be studied. Secondly, future research could focus on different exercise intensities as a training program to look at blood glucose regulation over time. This analysis could be done using a CGM to monitor blood glucose levels over several weeks while the subjects underwent several weeks of training consisting of both moderate intensity endurance training and HIIT. By having the same subjects undergo the different exercise intensities over several weeks potential differences in blood glucose control might be seen. This analysis could be done on both healthy subjects and subjects who have been clinically diagnosed with Diabetes Mellitus to see if HIIT has an effect on blood glucose regulation before, during, and after exercise. It is also recommended that more research look at blood glucose control before, during, and after exercise using a HIIT protocol varied intensities similar to the protocol used for this study.

**Conclusions.**

Overall, the continuous glucose monitor (CGM) was a useful tool for demonstrating blood glucose control before, during, and after exercise. The CGM
measured blood glucose levels every five minutes during both exercise intensities. There was a statistical significant difference between pre and post blood glucose levels with the moderate intensity endurance training exercise session and high intensity interval training exercise session. There was not a significant difference in blood glucose control between moderate intensity endurance training exercise session and HIIT exercise session. This study provides insight for further studies to be done using continuous glucose monitors to examine blood glucose control and exercise. This understanding of glucose control before, during, and after HIIT exercise compared to moderate exercise will encourage further research to be conducted comparing these types of exercises to better understand blood glucose regulation in diabetics under these conditions.
References


## Appendix A

### Medical History Questionnaire

- **Age:** ________
- **Gender:** M/F
- **Subject ID #:** ________

- **Weight (lbs.):** _______  **(kg):** _______
- **Height (in):** _______  **(cm):** _______

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<tr>
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<th><strong>Yes</strong></th>
<th><strong>No</strong></th>
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<tbody>
<tr>
<td>Family history of heart disease? i.e. Heart attack, bypass, stroke, or sudden death before age 55 in 1st degree male relative (father, brother, son) or before age 65 in 1st degree female relative (mother, sister, daughter)</td>
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</tr>
<tr>
<td>Smoking habit? i.e. Current cigarette smoker or one who has quit within the previous 12 months</td>
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<tr>
<td>High blood pressure? i.e. &gt;140/90 on two separate occasions or currently on antihypertensive medication</td>
<td></td>
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</tr>
<tr>
<td>Abnormal cholesterol levels? i.e. Total Cholesterol &gt;200mg/dL, or LDL &gt;130 mg/dL, or HDL &lt;35 mg/dL, or currently on lipid lowering medication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High fasting glucose? i.e. Fasting blood glucose &gt;110 on two separate occasions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Are you inactive? i.e. Accumulate &lt;30 minutes of moderate physical activity on most days of the week</td>
<td></td>
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</tr>
</tbody>
</table>

If you can answer **yes to 2 or more** above please obtain **medical clearance** for exercise from your **personal physician**.

### Other Health Related Questions:

**Prescription Medications:**
- ______________________________________
- ______________________________________
- ______________________________________

**Allergies:**
- ______________________________________
- ______________________________________
- ______________________________________

**Do you have any orthopedic conditions/arthritis that may limit your activities?**
- ______________________________________
- ______________________________________
- ______________________________________

**Are you pregnant? If yes, how many weeks?**
- ______________________________________
- ______________________________________

**Do you have any other problems or medical conditions not addressed on this form including any disorders that might affect the ability of your blood to clot normally?**
- ______________________________________
- ______________________________________

**How long have you had your medical condition(s)?**
- ______________________________________
- ______________________________________
**Do you current have any of the following?**

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<thead>
<tr>
<th>Question</th>
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<th>No</th>
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<td>Pain in the chest, neck, jaw, or arms?</td>
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<td></td>
</tr>
<tr>
<td>Shortness of breath at rest or with mild exertion?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dizziness or fainting?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Awakened by a shortness of breath?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swelling in your ankles?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rapid heart rate while at rest?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg pain or cramping while walking; stops with rest?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart murmur?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unusual fatigue or shortness of breath with usual activities?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If you can answer *yes* to *any* of the above please obtain medical clearance for exercise from your personal physician.

**Do you have a history of the following?**

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart attack or stroke?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart surgery (CABG, angioplasty, other)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metabolic disorder (diabetes, kidney, thyroid)?</td>
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</tr>
<tr>
<td>Respiratory problems (asthma, COPD)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hospitalization or surgery within the last 6 months?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If you can answer *yes* to *any* of the above please obtain medical clearance for exercise from your personal physician.

Signature: ___________________________________________ Date: ________________

Appendix B

High Intensity Interval Training Protocol
### Appendix C

#### Sample size for ANOVA

<table>
<thead>
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<th>Sample Size</th>
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<tr>
<td>Standard Deviation</td>
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<tr>
<td>Number of Groups</td>
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<tr>
<td>Power</td>
<td>0.800</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.0500</td>
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</table>

<table>
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<tr>
<td>Standard Deviation</td>
<td>4.100</td>
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<tr>
<td>Number of Groups</td>
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<tr>
<td>Power</td>
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</tr>
<tr>
<td>Alpha</td>
<td>0.0500</td>
</tr>
</tbody>
</table>