

2013

# The Correlation of Repeat Sprint Measures to Predicted VO<sub>2</sub> in Recreationally Active Males

Matthew R. Miltenberger  
*Seton Hall University*

Follow this and additional works at: <https://scholarship.shu.edu/dissertations>



Part of the [Physical Therapy Commons](#)

---

## Recommended Citation

Miltenberger, Matthew R., "The Correlation of Repeat Sprint Measures to Predicted VO<sub>2</sub> in Recreationally Active Males" (2013).  
*Seton Hall University Dissertations and Theses (ETDs)*. 1897.  
<https://scholarship.shu.edu/dissertations/1897>

The Correlation of Repeat Sprint Measures to Predicted VO<sub>2</sub> in Recreationally Active Males

BY

Matthew Richard Miltenberger

Dissertation Committee:

Dr. Genevieve Pinto Zipp, Chair

Dr. Raju Parasher

Dr. Vicci Lombardi

Approved by the Dissertation Committee:

Genevieve Pinto Zipp Date 6/6/13 (Chair)  
Raju Parasher Date 6/6/13  
Vicci Lombardi Date 6/6/13

Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Health Sciences Seton Hall University 2013

## Acknowledgements

I would like to thank my committee chairperson Dr. Genevieve Zipp for all of her hard work and advisement through this process, she is a phenomenal mentor. I would also like to thank the members of my dissertation committee Dr. Raju Parasher and Dr. Vicci Lombardi; they too were instrumental in the completion of this research project. Finally, I would like to thank my family and friends for their continuous support and never ending confidence in me. Thank you.

## TABLE OF CONTENTS

ACKNOWLEDGEMENTS .....	2
LIST OF TABLES .....	5
LIST OF FIGURES .....	6
ABSTRACT .....	7
I INTRODUCTION .....	8
Statement of the Problem .....	11
Purpose of the Study .....	12
Hypotheses .....	12
II RELATED LITERATURE .....	14
TIME MOTION ANALYSIS .....	14
PHYSIOLOGY OF REPEAT SPRINTS .....	16
MECHANISMS OF FATIGUE .....	24
EXERCISE TESTING .....	32
CONCLUSION .....	37
III METHODS .....	39
OPERATIONAL DEFINITIONS .....	39
INSTRUMENTATION .....	40
DEPENDANT VARIBALES .....	41
LIMITATIONS .....	42
DELIMITATIONS .....	43
SUBJECTS .....	44
GENERAL PROCEDURES .....	44
FAMILIARIZATION .....	45
EXPERIMENTAL PROCEDURES .....	46
IV RESULTS .....	49
V DISCUSSION .....	69
VI SUMMARY AND CONCLUSIONS .....	83
VII APENDICES .....	88
A. INSTITUTIONAL REVIEW BOARD APPROVAL .....	89
B. INFORMED CONSENT FORM .....	90

C. PAR-Q FORM .....91  
D. DYNAMIC WARM-UP .....92  
E. DATA COLLECTION SHEET .....94  
F. GRAPHICAL REPRESENTATION OF METHODS .....95  
G. RECRUITMENT FLIER .....96

REFERENCES .....97

## LIST OF TABLES

TABLE 1	DEMOGRAPHIC DESCRIPTION OF SUBJECTS	.....44
TABLE 2	DESCRIPTIVE ANALYSIS OF SPRINT TIMES	.....50
TABLE 3	DESCRIPTIVE ANALYSIS OF HEART RATE	.....52
TABLE 4	DESCRIPTIVE ANALYSIS OF RPE	.....54
TABLE 5	CORRELATION TABLE PVO <sub>2</sub> – PEAK SPRINT TIME	.....56
TABLE 6	CORRELATION TABLE PVO <sub>2</sub> – MEAN SPRINT TIME	.....58
TABLE 7	CORRELATION TABLE PVO <sub>2</sub> – FATIGUE INDEX	.....60
TABLE 8	REGRESSION MODEL	.....64
TABLE 9	SIGNIFICANCE TABLE REGRESSION ANALYSIS	.....64
TABLE 10	MODEL SUMMARY OF REGRESSION ANALYSIS	.....65
TABLE 11	PARTIAL CORRELATION TABLE OF REGRESSION ANALYSIS	.....66

## LIST OF FIGURES

FIGURE 1	MEAN SPRINT TIME BY TRIAL .....	51
FIGURE 2	MEAN HEART RATE BY CONDITION .....	53
FIGURE 3	MEAN RPE BY TRIAL .....	55
FIGURE 4	PVO2 – PEAK SPRINT TIME CORRELATION .....	57
FIGURE 5	PVO2 – MEAN SPRINT TIME CORRELATION .....	59
FIGURE 6	PVO2 – FATIGUE INDEX CORRELATION .....	61

## The Correlation of Repeat Sprint Measures to Predicted VO<sub>2</sub> in Recreationally Active Males

Matthew Richard Miltenberger

Seton Hall University  
2012

Chair: Dr. Genevieve P Zipp

**Introduction:** The mechanism in which we classify sports scientifically is based upon predominance of energy systems. In court and field based sports such as field hockey, lacrosse, rugby and basketball repeat sprints which are defined as multiple short duration high intensity activities (sprinting) followed by short recovery periods is the most common mode of locomotion (Spencer et al 2004, Glaister 2007). Interestingly, it has been suggested in research that repeat sprints represent a hybrid of energy systems all contributing to performance (Bogandis et al 1996). Therefore, the purpose of this study was to investigate the relationship between repeat sprint measures and a field test evaluating the aerobic energy system. **Methods:** Subjects (n=18) performed a repeat sprint test (12 x 30 meters with 35 seconds recovery) and the Queens College Step Test (QCT) to assess predicted VO<sub>2</sub> (PVO<sub>2</sub>). Pearson correlations and regression analyses were performed between peak sprint time, mean sprint time, fatigue index, and PVO<sub>2</sub>. **Results:** Results revealed a statistically significant negative relation only between mean sprint time and PVO<sub>2</sub> (p = 0.011, R= -0.586). Additional analysis revealed that 54% of the variance in PVO<sub>2</sub> between subjects can be equally explained by peak sprint time, mean sprint time, and the fatigue index. **Discussion:** The significant negative relationship found between mean sprint time and PVO<sub>2</sub> is in agreement with the literature suggesting that the ability to maintain sprint time over multiple trials is probably related to the aerobic energy system (Dupont et al 2005, Rampinini et al 2009). This suggests that the aerobic energy system should be trained for those participating in repeat sprint based sports. The regression equation suggested that when each of the variables related to repeat sprints were held constant they contributed equally to explaining PVO<sub>2</sub>, this explains the dynamic nature of repeat sprints and may indicate the need for interval training to maintain both anaerobic and aerobic properties of performance. **Conclusion:** The main findings of this study suggest that the QCT is a valid measure in the prediction of mean sprint ability and provides further evidence to suggest the reliance of multiple energy systems during repeat sprints.



## CHAPTER I

### INTRODUCTION

Athletic activity and sports are an integral part of society today. The way we perform and train for participation in these activities should mimic the sport to obtain the most desirable results. This mode of training is referred to as the "specificity principle" which states for the most desirable and task specific effects an athlete should train in a fashion that resembles the sport or activity in which they participate. Through sport specific training adaptations can be observed at the cellular level such as an increase in mitochondrial density over time with aerobic training, neurological adaptations can occur with anaerobic training, and motor skill pattern development can occur through the physical rehearsal of task specific skills (Baechle & Earle, 2008).

Physical rehearsal or engagement in task specific physical activities include actions associated with basic general fitness tasks such as walking or jogging as well as sporting activities performed by athletes. Sport physical activities can be further separated into two categories based upon where they are performed such as field sports (field hockey, lacrosse, rugby, and soccer) or court sports (basketball, tennis, and racquetball). Physical activities can also be separated into three categories by physiological demands such as anaerobic sports which rely on the ATP- PC or glycolytic energy systems, aerobic exercise

relying on aerobic metabolism, or a combination of both energy systems. Interestingly, most field based sports involve aerobic activity with intermittent bouts of high intensity anaerobic movements such as sprinting suggesting inter-reliance on multiple energy systems to complete the tasks of the sport. Based upon the principles of sport specific training the categorization of physical activities associated with sports can be useful in developing appropriate conditioning programs so players can be taxed with the appropriate demands of their specific sport or activity (King, Jenkins, & Gabbett, 2009). The adaptations associated with different training protocols can have a profound effect on the outcomes associated with performance. An example of this can be found in a typical Wingate 30 second cycle test measuring anaerobic capacity. A Wingate test consists of a subject pedaling at maximal intensity against 7.5% of their body weight for 30 seconds on a cycle ergometer. During this time power output is recorded in terms of peak power, which is the highest power achieved, mean power which is the average power output over the 30 second time period, and finally fatigue index which is the drop in power output from peak power to minimum power. Training status of each subject can be observed through analysis of the power curve over time from the start of the test to the end of the test. If a subject is predominantly anaerobically trained the observed power curve would have a large peak power followed by a steep downward slope indicating the onset of fatigue quite rapidly, while a subject who is predominantly aerobically trained would show a lower peak power in

comparison, but the power curve would have a shallower slope, associated with the ability to maintain power for a longer period of time. Generally speaking, an anaerobically trained subject due to the nature of training would have a large peak power but also a large fatigue index, also the ability to utilize oxygen as a substrate for energy production ( $VO_2$ ) would be lower in comparison to an aerobically trained subject who would have a lower peak power but also a lower fatigue index and an increased ability to utilize oxygen ( $VO_2$ ) as a substrate for energy production. This example is representative of one all out maximal activity lasting for 30 seconds but the question arises, what the outcome would be if multiple sprints were performed in succession, what would happen to performance over time, and finally which type of athlete would perform better on the multiple sprint tests, an anaerobic athlete with a high peak power, high fatigue index and low  $VO_2$ , or an aerobic subject with low peak power, low fatigue index, and a higher  $VO_2$ .

Therefore, the focus of this paper is to provide an evidenced based perspective on the principle of repeat sprints in field based sports in an attempt to advance our understanding of repeat sprints. Repeat sprints are defined as intermittent bouts of supramaximal activity followed by short periods of active or passive recovery. Repeat sprints have been found to be the main mode of locomotion for field based sports such as field hockey and rugby along with many others (King, Jenkins, & Gabbett, 2009, and Spencer, Lawrence, Rechichi, Bishop, Dawson, & Goodman, 2004). Furthermore, physiological studies indicate

that multiple physiological systems contribute to adenosine triphosphate (ATP) or energy production during repeat sprints and therefore we can speculate that there may be multiple aspects of fatigue that can contribute to a decrease in the capacity to perform work or generate power. (Glaister, Stone, Stewart, Hughes, & Moir, 2007, Bogdanis, Nevill, Boobis, & Lakomy, 1996). Due to the complex nature of repeat sprint physiology and the frequency of repeat sprints in field based sports it is essential that this area be studied in attempt to maximize our understanding and ultimately direct the application of training.

#### Statement of the Problem

Currently, very few studies exist that investigate the relationship of field based measures of repeat sprints while running (peak or fastest time, mean sprint time, and fatigue indices) and predicted VO<sub>2</sub> measures using the Queens College Step Test (QCT). The majority of studies use laboratory settings to assess data using cycle ergometers for repeat sprint data and complex metabolic apparatus to determine VO<sub>2</sub>. Although these tests provide a great deal of data, the question arises as to the specificity of these tests and the ability to generalize the results to multiple sports. Therefore further evidence should be provided using field tests to assess the relationship between predicted VO<sub>2</sub> (PVO<sub>2</sub>) and repeat sprint ability. Establishing this relationship will give coaches the ability to assess athletes, quickly and provide practical data.

### Purpose of the Study

The purpose of this study was to determine the relationship between predicted VO<sub>2</sub> measures using the QCT and measures that evaluate repeat sprint performance including peak sprint time, mean sprint time, and fatigue index using the percent decrement formula.

### Hypotheses

Due to specific physiological adaptations associated with anaerobic and aerobic training as discussed earlier directional hypotheses were developed in agreement with expected adaptations according to training status. The following hypotheses will be tested at the  $p < 0.05$  level of significance:

- There will be a strong positive relationship between PVO<sub>2</sub> and peak sprint time
- There will be a strong negative relationship between PVO<sub>2</sub> and mean sprint time
- There will be a strong negative relationship between percent decrement fatigue index and PVO<sub>2</sub>

### Research Questions

1. Is there a relationship between peak sprint time and predicted VO<sub>2</sub> using the QCT
2. Is there a relationship between mean sprint time and predicted VO<sub>2</sub> using the QCT
3. Is there a relationship between fatigue index scores and predicted VO<sub>2</sub> using the QCT

Coaches and exercise science professionals are always investigating additional ways to quickly assess athletes and provide reliable, practical data that can enhance or change training techniques. The physiological concepts associated with repeat sprint based activities are quite complex. Thus, gaining a deeper understanding of repeat sprints especially, in the area of field based testing warrants further investigation.

## CHAPTER II

### REVIEW OF LITERATURE

The purpose of the following chapter is to provide a detailed review of related literature to reinforce the proposed research problem stated previously and provide a theoretical frame for the scientific approach of examining the research hypotheses. The following topics will be developed in further detail: time motion analysis, physiology of repeat sprints, mechanisms of fatigue, exercise testing and conclusions.

#### Time Motion Analysis

The focus of this section will be on field based sports that use repeat sprints as the main mode of locomotion and rely on a combination of energy systems. This area of emphasis is quite interesting due to the lack of studies available and the implications for sports performance. In order to investigate the relevance of repeat sprints during activity King, Jenkins, and Gabbett, 2009 used time motion analysis to study the movement of rugby league players. The researchers used a multiple camera system to evaluate one player from each positional group during an entire National Rugby League game. The results indicated that each of the positional groups had different demands placed on them during the game but overall the average work to rest ratio was approximately 1:5. The results also suggest that all players regardless of position

participated in high intensity activity for an average of four seconds and then had an average of 21 seconds of active and/or passive recovery. Similarly, Spencer et al., 2004 studied elite male field hockey players using similar time motion analysis during a high level international game. The researchers categorized the players of motion into five tasks: standing, walking, jogging, striding, and sprinting. Standing was non-active or static, walking and jogging were considered low intensity activities due to relatively low speed and high intensity activities were considered striding and sprinting due to increased speed and distance covered. The results of one match showed that on average standing accounted for 7.4% of total match time, low intensity activity accounted for 87% of game time and high intensity activity represented 5.6% of player activity during the game. These results suggest that during male field hockey matches the greatest amount of time was spent in constant motion with intermittent bouts of high intensity anaerobic activity and static activity representing a relatively low percentage of total time. The authors were able to support the theory that repeated bouts of anaerobic activity were the most common mode of locomotion during field based sports and were further able to define repeat sprints with specific work to rest ratios by reviewing the time motion analysis data. They defined repeat sprinting as a minimum of 3 consecutive sprints with less than 21 seconds of recovery between them. This criterion was satisfied 17 times within the match, with an average of 4 sprints per bout with 14.9 seconds of recovery. Another important finding in this study was



that 95% of the recovery time between sprints consisted of jogging, walking or striding with no static recovery. These results suggest incomplete physiologic recovery between sprints due to the inability of the anaerobic energy system to re-phosphorylate ATP or the inability of the glycolytic system to break down glucose fast enough to keep up with the demands. Due to the inability of the anaerobic methods of ATP production to keep up with demands there may be a reliance on the aerobic system to aid in maintenance of ATP production. Time motion analysis data provided an in depth understanding of specific locomotion patterns and when paired with exercise physiology data studies suggest that field based sports such as rugby, field hockey, lacrosse, and soccer have a high reliance on repeat sprint ability and thus the dependence on multiple energy systems.

### Physiology of Repeat Sprints

Researchers in exercise science, along with coaches, have suggested that the ability to perform repeated bouts of short duration high intensity activity is essential in team sports. This mode of training has been termed repeat sprint ability (RSA). Although the concept of RSA is accepted, there has been limited research determining the physiology responsible for energy production (Spencer, Lawrence, Rechichl, Bishop, Dawson, & Goodman, 2004). The basic systems for energy production consist of the phosphocreatine system also known as the immediate energy system, which is characterized by short duration (5-9 seconds), high intensity activities. This energy system is responsible for the

immediate hydrolysis of ATP to ADP which then yields energy by cleaving off the most distal phosphate bond. The second system is referred to as the glycolytic system which is dominant during moderate duration activity (30 seconds –90 seconds). The glycolytic system uses glucose as fuel source to start a chain of enzymatic reactions that result in the production of pyruvate and ATP. At the end of glycolysis pyruvate can be transformed into lactate if there is no oxygen present or can continue on to aerobic metabolism if oxygen is present. The final energy system of interest is the aerobic system. The aerobic energy system is responsible for continually forming ATP through the utilization of macronutrients. This is considered the system that never quits and is the predominant energy source for low intensity long duration activity as well as for recovery from high intensity incremental activity (Baechle & Earle, 2008). As stated earlier, aerobic metabolism is stimulated from repetitive actions that break down ATP to adenosine diphosphate (ADP) and adenosine monophosphate (AMP). The phosphorylation of ATP during aerobic metabolism takes place in two distinct processes; the Krebs cycle in which ATP is phosphorylated at the substrate level and in the electron transport chain in which ATP is phosphorylated through oxidation. Both of these processes take place in a specialized organelle called the mitochondria. Mitochondria are specialized organelles located in subsarcolemmal spaces as well as imbedded deeper within the muscle called intermyofibrillar mitochondria. The intermyofibrillar mitochondria come into contact with the contractile proteins of muscle and have direct influence on

aerobic capabilities within the muscle. In fact, under microscopic evaluation red-pigmented muscle fibers have higher mitochondrial densities which in turn would mean greater aerobic capability when compared to pale colored muscle fiber. The structure of mitochondria is broken up into 5 distinct parts, the outer membrane that regulates flow of materials in and out, the inner membrane space that contains enzymes for exchange and transport, the matrix which contains Krebs cycle enzymes, the F complex where phosphorylation takes place and finally the inner folds or cristae which is the main site of oxidative phosphorylation (Brooks, Fahey, & Baldwin, 2005). The Krebs cycle is a series of reactions that take place to phosphorylate ATP and most importantly create NADH and FADH which are the substrates shuttled to the electron transport chain for oxidative phosphorylation. During electron transport NADH and FADH carry hydrogen atoms down the chain and reduce 1 molecule of oxygen. When the oxygen accepts the 2 hydrogen molecules water is formed and energy is created in the form of ATP. Under normal metabolic conditions this process is precise, but during exercise when metabolic demands increase as much as 15-20 times there is an imprecise coupling of hydrogen and oxygen in electron transport thus creating O<sup>2-</sup> or superoxide ion, a form of reactive oxygen species (ROS) (Brooks, Fahey, & Baldwin, 2005, McArdle, Katch, & Katch, 2007). Further reduction and imprecise coupling can also produce hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) as well as the most reactive oxygen species, the hydroxyl radical. It is essential to understand the inter-relationship between all energy

systems especially for field based sports where energy system dominance is shared.

Bogdanis, Nevill, Boobis, and Lakomy, 1996 studied the contribution of energy systems during repeat sprint activities on a cycle ergometer. The researchers recorded a variety of data including peak power, expired air, mean power output, muscle biopsy, and power drop from peak to end power (fatigue index). The methodology consisted of two different trials; trial one consisted of 2 – 30 second sprints separated by 4 minutes of recovery and the second trial consisted of a 30 second sprint followed by 4 minutes of rest and then a 10 second sprint. Several interesting results were determined from this study. Creatine Phosphate (PCr) levels, which are the main substrate responsible for ATP resynthesis in the immediate energy system decreased in the first 30 second sprint by almost 17 % from resting values, after 3.8 minutes of recovery PCr levels were resynthesized to approximately 78.7 % of resting. The use of the PCr system during the first 10 seconds correlated well with high power outputs and high pedaling speed. During the second 30 second sprint, calculations concluded that there was a decrease in glycolytic contribution by 45% and muscle PCr values were decreased; the combination of these factors resulted in a decrease in anaerobic energy contribution by approximately 41%. Although the contribution of anaerobic energy decreased, results indicated total work during sprint two decreased by only 18%, but oxygen uptake increased. These results suggest that during 1 -30 second sprint PCr is decreased and levels do not

recover to resting values within the 4 minute rest period. These results suggest that the anaerobic energy system has the inability to sustain ATP production during intermittent or repeat exercise without the help of the aerobic system. The authors found that the aerobic energy system contributed 49% of energy during the second part of the 30 s sprint. Accordingly, it appears that the ability to repeat sprints over time is closely related to the efficiency of aerobic energy system to contribute ATP. In addition, it was found that even with extraordinarily long recovery periods (> 3.5 minutes) the anaerobic system does not completely recover. This finding is especially interesting given that the average recovery time suggested by King, Jenkins, and Gabbett, 2009, was 21 seconds or less and active in nature, which is much shorter than in the previous study with static recovery. This would suggest less recovery by anaerobic energy systems, and therefore more reliance on the aerobic system to generate energy.

Similar results were reported by Gaitanos et. al., 1993 when researching 10 repetitive- 6 second sprints separated by 30 seconds of recovery. It was observed that PCr levels decreased by 57% of resting levels during the fifth sprint and 16% by the tenth sprint. They also found a significant decrease in peak power by the fifth sprint, and by the tenth sprint peak power decreased by 33%. This data suggests that there is an incomplete recovery of the PCr system during short recovery periods which would indicate lower contribution to total ATP production from this system. Shimoyama, Tomikawa, and Nomura, 2003 used 7 elite swimmers and assessed them under 3 different conditions including

continuous swimming for 10 minutes, interval swimming at 10 repetitions x 1 min swimming with 20 seconds of recovery, and 10 repetitions x 1 min swimming with 30 seconds of recovery. Blood lactate levels and accumulated oxygen uptake were recorded for all 3 trials. The results supported that continuous swimming resulted in the highest aerobic energy system contributions with 93.3%, the intermittent 20 second swimming was 81.0%, and intermittent 30 second swimming was 67.4%. The contributions from the anaerobic system consisted of 6.7%, 19%, and 32.6% for continuous, 20 second interval, and 30 second interval respectively. The results suggest that repeated swimming with varying rest intervals requires a heavy reliance on the aerobic energy system to maintain performance through the generation of ATP. In addition, there was also a significant difference between 20 and 30 second rest intervals, with shorter rest intervals relying more on the aerobic energy system; thus supporting the notion of incomplete physiological recovery during repeated bouts of high intensity exercise.

As previously stated, there seems to be a link to repeat sprint ability and the contribution of the aerobic energy system. Glaister, Stone, Stewart, Hughes, and Moir, 2007 examined the effect of endurance or aerobic training on repeat sprint ability on a cycle ergometer. The researchers used 21 recreationally active students, each of which completed 2 different protocols. The first testing protocol consisted of 20 -5 second sprints with 10 seconds of recovery (1:2 work to rest ratio). The second testing protocol which consisted of 20-5 second sprints

with 30 seconds of recovery (1:6 work to rest ratio). Anaerobic capacity, VO<sub>2</sub> max, rating of perceived exertion (RPE), and fatigue using the performance decrement formula were also assessed pre and post. After pre-testing, the experimental group participated in 6 weeks of endurance training 3 times per week for 20 minutes. The intensity was set for steady state exercise on a cycle ergometer at 70% of power needed to elicit VO<sub>2</sub> max. The subjects were provided with incremental increases to provide overload for a training effect. The concept of overload is related to specificity and adaptation, without the continual addition of higher intensities or stress no physiological adaptation will take place. In this study, overload was used to stimulate physiological aerobic adaptation. The control group in this study was instructed to continue their regular activity for the duration of 6 weeks. Post test results demonstrated that the experimental group increased VO<sub>2</sub> max by 5.3% and increased peak and mean power when compared to the control group. RPE, anaerobic capacity, and other physiologic measures showed no significant differences. The increased VO<sub>2</sub> represents the capability of the subjects to work at a higher aerobic capacity due to aerobic adaptations taking place at the cellular level, a confounding result is the increase in peak and mean power. Typically, when aerobic changes take place, there is a marked decrease in the anaerobic ability to generate power (Baechle & Earle, 2008). As a note, the authors cautioned readers in interpreting the results of their study as the experimental subjects practiced on the cycle ergometer for 6 weeks while executing the

experimental protocol, they may have gained mechanical efficiency on the ergometer due to a learning curve which the control group did not experience. This may explain the conflicting physiological response related to power. Furthermore, the researchers also suggested that aerobic training might decrease perception of fatigue and therefore subjects would be able to maintain power over time which explains mean power gains and lower fatigue index scores. The second protocol consisting of longer rest periods (1:6 work to rest ratio) demonstrated a trend toward aerobic training benefitting anaerobic repeat sprints but the authors suggest further research before definitive conclusions can be made.

Multiple studies have demonstrated that the anaerobic energy systems cannot maintain high levels of ATP production over repeated bouts of activity with varying rest periods (Bogdanis, Nevill, Boobis, & Lakomy, 1996, Durandt, Tee, Prim, & Lambert, 2006). The demands of repeat sprint sports require the maintenance of ATP production to perform at a high level of competition. The aerobic energy system has been identified as a contributor to ATP production in the later stages of repeat sprints especially during fatiguing conditions of incomplete recovery. This would suggest that by attenuating aerobic fatigue, performance may be increased during repeat sprint activities due to increased capabilities for ATP production. Understanding the mechanisms related to fatigue can provide further insight into the ability to maintain performance during repeat sprints.



## Mechanisms of Fatigue

Fatigue has been traditionally defined by multiple authors as the inability to create and sustain adequate force or power over a period of time when compared to what is expected (Glaister, 2005 & Spencer, Lawrence, Rechichi, Bishop, Dawson, & Goodman, 2004). ATP is the substance that when broken down releases energy. The energy release is due to the hydrolysis of ATP no matter which energy system is up regulated (PCr, glycolysis, aerobic). At the onset of exercise endogenous stored ATP is quickly degraded due to the lack of storage ability within the body. It is estimated that the human body stores approximately 20-25 mmol/ kg of dry muscle (dm) of ATP and at maximal turnover rates of 15mmol/ kg of dm this would suggest that stored ATP would only last for 1-2 seconds of maximal work (Glaister, Multiple Sprint Work, 2005; Spencer, Bishop, Dawson, & Goodman, 2005). In addition, as a protective mechanism it is estimated that ATP stores will only be degraded to approximately 45% of stored values, which would further suggest stored ATP contributing very little energy to maximal sprint work lasting over 1-2 seconds (Spencer, Bishop, Dawson, & Goodman, 2005). With that being said, it is the job of the metabolic energy systems to provide ATP for continual work. The inability to meet the demands of exercise will decrease performance and therefore fulfill the definition of fatigue of the inability to maintain work over a period of time. The concept of fatigue is multifaceted and complex in nature with multiple theories used to explain the nature of fatigue. No one theory is sufficient to

cover all aspects of fatigue due to the different types of exercise that may induce different internal physiological responses. The basic theories include physiological fatigue affecting the peripheral active musculature and central fatigue which affects the CNS. Physiological fatigue will be further investigated due to the direct relationship with cellular interactions of aerobic and anaerobic metabolism. The following theories of peripheral fatigue will be evaluated including inefficient muscle glycogen stores, decreased availability of PCr, acidosis due to accumulation of H<sup>+</sup> ions, accumulation of inorganic phosphates (Pi), and accumulation of reactive oxygen species within the mitochondria of the cell during aerobic respiration.

As stated earlier, the depletion of stored ATP molecules signals the onset of metabolic processes to up regulate so the demands of exercise can be met. Under maximal exercise conditions the immediate energy system or PCr system interacts directly with adenosine diphosphate (ADP) to rephosphorylate into ATP. PCr may be reconstituted during recovery periods but limits in immediate supplies may decrease the production of ATP (Glaister, Multiple Sprint Work, 2005). This concept can be illustrated through multiple studies dealing with the supplementation of creatine monohydrate. It has been well established in literature that supplementation with creatine has increased endogenous supply and has been shown repeatedly to attenuate fatigue and provide faster recovery times in strength and power athletes. This energy system has the fastest ATP turnover rate but it is also short lived, approximately 6-10 seconds

(Glaister, Multiple Sprint Work, 2005). A byproduct of the PCr system is Pi which has been linked to fatigue during high intensity activities (Westerblad, Allen, & Lannengren, 2002). During short term high intensity activity Westerblad, Allen, & Lannengren, 2002, suggest that inorganic phosphates (Pi) are the underlying cause for decreased muscle contraction ability due to the continual breakdown of creatine phosphate. This increase in inorganic phosphate may cause a decrease in ATP driven sarcoplasmic reticulum Ca<sup>2+</sup> uptake (Allen, Lamb, & Westerblad, Impaired Calcium Release During Fatigue, 2007). This would in turn decrease the ability for muscle contractions due to the inability of actin and myosin protein to bind. The next system to aid in ATP production is anaerobic glycolysis; some authors suggest that the PCr system and glycolysis are almost equal contributors during sprints lasting less than 6 seconds (Spencer, Bishop, Dawson, & Goodman, 2005). Glycolysis has a slightly slower turnover rate but can sustain ATP production with the use of glucose molecules for a longer period of time (3 minutes or less). The byproducts of glycolysis include hydrogen ions that can decrease the pH of the cell and cause increases in acidity. This increase in acidity was originally thought to impair contractile proteins, but more recent evidence may suggest glycolytic inhibition through indirect measures such as inhibition of phosphofructokinase (pfk). Pfk is the rate limiting factor in glycolysis responsible for up regulation (Glaister, Multiple Sprint Work, 2005). Another factor that may affect glycolytic capabilities is the availability of glucose in the form of muscle glycogen. Since glycolysis is dependent on the

availability of glycogen, depletion or insufficient quantities may lead to performance decrements. In most cases of short duration maximal work muscle glycogen should not be an issue but under multiple repeat sprints or long term exercise glycogen stores will be depleted (Glaister, Multiple Sprint Work, 2005). This is evident in the research performed by Machefer, et al., 2007, they examined the effect of ultra-endurance marathoners during a race. Results suggested that there was a significant drop in muscle glycogen stores as well as a decrease in antioxidant stores which may be responsible for decreases in performance. Although ultra-endurance events are extreme in nature, the research illustrates the point that nutrition must be an essential part of training, and decrease glycogen stores due to malnutrition or incomplete refueling after events or practice can lead to decreases in performance. The final energy system to be explored for possible mechanism of fatigue is the aerobic energy system. The aerobic energy system has the slowest ATP turnover rate but has been deemed as the system that never quits, at all times this system is working and at rest is the predominant energy system working off lipids as an energy source. As exercise becomes longer in duration the aerobic energy system will up regulate and eventually switch to glycogen as a fuel source. Unlike the PCr and glycolytic systems the aerobic energy system takes place in the mitochondria of the cell and uses oxygen along with a substrate, glycogen or lipids, to provide energy (McArdle, Katch, & Katch, 2007; Baechle & Earle, 2008). The use of oxygen brings to the forefront the concept of oxidation within the

mitochondria of the cell which is related to the consumption of oxygen during high intensity long duration activity. During this process, oxygen is used as a means of ATP production. Molecular oxygen in the ground state is bi-radical, having two unpaired electrons in its outer shell. Under stress, one of the electrons changes its spin to an opposing direction becoming a powerful oxidant that can interact with other pairs of electrons that are causing damage (Turrens , 2003). Alesio, Hagerman, Fulkerson, Ambrose, Rice, & Wiley, 2000 researched the effect of exhaustive aerobic exercise as well as isometric exercise on the development of fatigue biomarkers including lipid peroxidation, protein oxidation, and total antioxidants in blood after exercise. Both groups showed an increase in VO<sub>2</sub> when compared to rest with the aerobic group increasing 14x and the isometric group increasing 2x. Lipid peroxides, protein carbonyls, and total antioxidants increased in both groups. This suggests that oxidative stress was present in both exercises regardless of VO<sub>2</sub> demands. With the low VO<sub>2</sub> demand of isometric exercise and the appearance of oxidative stress the authors suggest that VO<sub>2</sub> might not be the sole mechanism for exercise induced oxidative stress. The combination of both oxidative stress and inorganic phosphate accumulation provide the most substantial evidence of fatigue for repeat sprint activities.

Oxygen is used by all living organisms to sustain life; the use of oxygen is connected with reactive forms of oxygen known as free radicals. Free radicals have a harmful impact on the body and need to be neutralized before cellular

damage occurs (Marciniak, Brzeszczynska, Gwozdziński, & Jegier, 2009).

Reactive Oxygen Species (ROS) are free radicals associated with the oxidative process; at rest low levels of ROS are produced from electron transport chain in the mitochondria (Ferriera & Reid, 2007). During long duration and exhaustive exercises, ROS formation has been known to increase with increased muscle temperature, increased CO<sub>2</sub> tension, and decreased muscle pH (Turrens, 2003; Marciniak, Brzeszczynska, Gwozdziński, & Jegier, 2009; Ferriera & Reid, 2007; Arbogast & Reid, 1998). The accumulation and production of ROS has been shown to decrease muscle function during activity (Allen, Lamb, & Westerblad, 2007). Normal functioning muscle is dependent upon calcium release from the sarcoplasmic reticulum (SR) after stimulation from a nerve impulse. Once release calcium is released from the SR it travels through the transverse tubules and binds with troponin to allow actin and myosin proteins to bind which creates a ratcheting contraction shortening the sarcomere. The contraction is maintained until calcium returns to resting levels which releases troponin to block actin and myosin binding (McArdle, Katch, & Katch, 2007). An important control of Ca<sup>+</sup> release in skeletal muscle is the Ryanodine receptor 1 (RYR-1), this receptor functions as a Ca<sup>+</sup> release channel in the SR and is the connection between SR and the transverse tubules (Allen, Lamb, & Westerblad, 2007). Allen, Lamb, & Westerblad, 2007, stated that impaired SR Ca<sup>+</sup> release occurs in fatigued muscles and contributes significantly to the decline in force production. The authors also stated that the RYR-1 receptor is redox sensitive

due to the 100 cysteine residues found on the receptor. The proximity of the mitochondria to the sarcomere provides ample opportunity for leakage of  $H_2O_2$  from the mitochondrial wall to the  $Ca^{+}$  release channels. Impairment of the  $Ca^{+}$  release channels due to ROS RYR-1 interaction will significantly reduce muscle force production and decrease ability of that muscle to perform.

Oxidative stress is a term used to describe the negative effects of the oxidant ROS on cellular processes and DNA. The term also refers to the imbalance between oxidants created during exercise through the metabolism of oxygen and antioxidants, which curb the negative effects of free radicals (Turren, 2003). The human body uses enzymatic and non-enzymatic reactions to scavenge free radicals and neutralize them before damage can occur, scavenging occurs within the mitochondria of the cell where aerobic metabolism takes place as well as in the cytosol and plasma where anaerobic metabolism takes place (Marciniak, Brzeszczynska, Gwozdziński, & Jegier, 2009). A key enzyme for scavenging free radicals within the mitochondria is glutathione peroxidase, responsible for scavenging hydrogen peroxide, a form of ROS (Turren, 2003). Non-enzymatic reactants to free radicals include vitamin C, E, taurine, additional amino acids, and other natural chemicals within the body (Marciniak, Brzeszczynska, Gwozdziński, & Jegier, 2009). Gonzalez, Marquina and Randon, 2008 studied the effect of aerobic exercise on uric acid, total antioxidant activity, oxidative stress, and nitric oxide in human saliva. The subjects consisted of 24 healthy male and female runners, competing in a

10,000 meter race. Saliva samples were taken before and after the race. At 60 minutes post exercise, the results showed uric acid levels the most important saliva antioxidant was decreased. In addition total antioxidant activity was decreased and salivary lipid hydroperoxides were increased, which is a measurement of oxidative stress. These results suggest that aerobic exercise has a negative impact on antioxidant levels due to the increase in total antioxidant activity (TAA). This is due to the increased amount of free radicals formed from oxidative stress during aerobic metabolism. The results also suggest that there is a positive effect on oxidative stress markers including ROS due to the increase in TAA. Evidence also suggests that there is a positive linear relationship between markers of oxidative stress and TAA. As oxidative stress markers increase there is also an increase in TAA, suggesting a stress induced physiological response to exercise induced free radical production. This data supports the idea of antioxidants working to scavenge forms of ROS during and after exercise to decrease the harmful effects associated with free radicals.

Central fatigue is another newly developing concept in which muscular fatigue can be linked to inhibition of muscle contractions as a protective mechanism from the CNS sending signals to the muscle spindles. This area is in need of further exploration to determine the mechanisms responsible for initiating inhibitory signals.

Fatigue is a marker of decreasing performance or inability to maintain performance over a period of time. Practically speaking if a coach or strength



and conditioning professional can implement training programs to attenuate the onset of fatigue athletes will perform at a higher level for a longer period of time during competition. Understanding variables related to performance and fatigue are integral into the development of such programs.

### Exercise Testing

The testing of exercise performance is essential for providing data with respect to the ability to execute specific movements. There is a wide variety of exercise tests available to determine performance, for the purposes of this study four specific protocols will be used to determine fatigue and physiological contributions of exercise.

The physiologic tests include the monitoring of heart rate changes during repeat sprinting and while predicting  $VO_2$ . Heart rate is a basic measurement of the work of the cardiovascular system. Polar FT7 Heart Rate Monitors®, Oulu, Finland, will be used to collect second by second heart rate data through a wireless system.

Maximum oxygen uptake ( $VO_2$ ) or the body's ability to utilize oxygen is considered a fundamental indicator of cardiovascular fitness (Liu & Lin, 2007 & Chatterjee, Chatterjee, Mukherjee, & Bandyopadhyay, 2004). Directly measuring  $VO_2$  consists of a very strenuous laboratory based test that may not be suitable or feasible for all populations. Therefore, it is essential that field based testing protocols be designed to reliably estimate  $VO_2$  max. One such

field based test is the Queen's College step test (QCT). The principle behind the submaximal step test is individual differences in the ability to recover after exercise, specifically differences in heart rate, where more fit, higher VO<sub>2</sub> subjects would recover faster with lower heart rates after activity (Liu & Lin, 2007 & Chatterjee, Chatterjee, Mukherjee, & Bandyopadhyay, 2004). The Queen's college step test consists of the following methodology. First the subject will warm-up for a brief period of time, they will then approach a step approximately 16 ¼ inches or 41.3 cm high and begin to practice stepping to a metronome set for 96 beats per minute. The cues of up, up, down, down will be used to help the subject keep pace. After approximately 30 seconds of practice the subject will rest for 2 minutes and prepare to begin the test. The test begins with the initiation of the metronome and the start of the timer, the subject will step for 3 minutes in total. When finished, the subject will remain standing and a recovery heart rate will be taken for 15 seconds between the 5 and 20 second mark after the cessation of stepping. Recovery 15 second heart rate will then be converted in beats per minute but multiplying by 4 ( 15 second recovery hr x 4 = recovery hr beats per minute). Heart rate will then be entered into the following formula to estimate VO<sub>2</sub> max:  $PVO_{2max} (ml/kg/min) = 111.33 - (0.42 \times \text{pulse rate in bpm})$  (Liu & Lin, 2007, Chatterjee, Chatterjee, Mukherjee, & Bandyopadhyay, 2004). Both equations have been deemed valid and reliable.

Chatterjee, Chatterjee, Mukherjee, & Bandyopadhyay, 2004 investigated the validity of the QCT in college age men. The authors used 30 college age male students with a mean age of 22.6 years, height of 166.4 cm, and a mass of 53.8 kg. The subjects underwent 2 different testing protocols, a direct measurement of VO<sub>2</sub> using an incremental cycle ergometer test with gas analysis and the indirect QCT test to predict VO<sub>2</sub>max. Results indicate that the direct analysis measured VO<sub>2</sub> max to be  $39.8 \pm 1.03$  ml/ kg/ min while the QCT estimated VO<sub>2</sub>max to be  $39.3 \pm 1.07$  ml/ kg/ min. Pearson's product moment correlation ( $r= 0.95$ ,  $p< 0.001$ ) suggest good correlation between direct and indirect measures of VO<sub>2</sub>. The author's concluded that the QCT is a recommended valid method to assess VO<sub>2</sub>max in college age males. In addition, Liu & Lin, 2007 found similar results in 31 college age males using the same 3 minute step protocol with various step heights of 30.5, 35, and 41.25 cm, the authors of this study also manipulated when recovery heart rate times were collected (5-20 seconds after test, 60 seconds after test, 1-1.5 min after test, 2-2.5 minutes after test and 3-3.5 minutes after test). When compared to direct VO<sub>2</sub> measures obtained from a graded treadmill exercise test (bruce protocol) the authors found the greatest correlation ( $r=0.50$ ) between a cadence of 96 beats per minute at a step height of 41.25 cm and recovery heart rate collected 5-20 seconds after test. The authors concluded that this protocol (QCT standard protocol) was a valid and reliable method for estimating VO<sub>2</sub>max for college age males.

This data suggests the QCT standard protocol of 3 minutes of stepping at 41.25 cm step height and collecting recovery heart rate during 5-20 seconds of recovery is a valid and effective way for estimating VO<sub>2</sub> max in college age males. Additional field tests for assessing VO<sub>2</sub> exist in multiple formats including the yo-yo test as well as shuttle run tests. In 2012, Aslan, Muniroglu, Alemdaroglu, & Karakoc investigated the relationship between intermittent sprint tests (yo-yo test, shuttle run) and treadmill running tests for VO<sub>2</sub>. The investigators used 13 amateur league soccer players. Each subject completed all 3 tests; the treadmill test for VO<sub>2</sub> consisted of a typical VO<sub>2</sub> max graded exercise protocol, the shuttle test was a 20 meter stage test and finally the yo-yo test consisted of multiple stages where the subject had to keep pace meeting specific time criteria. The results indicate moderate to good relationships for predicted VO<sub>2</sub> from the yo-yo and shuttle test,  $r = .89$  and  $.78$  respectively, when compared to actual VO<sub>2</sub> measurements from the treadmill data.

The QCT was chosen over the other tests described above due to the limited amount of equipment required, the short time period (3 minutes) required for the test duration, and the usability of the QCT in conjunction with other sport specific performance tests like agility or power testing since a subject can recover quickly from the QCT.

The last area to be evaluated is the actual protocol for repeat sprinting and the attainment of the fatigue factor between sprints. Studies suggest that repeat sprints related to field based sports are typically short in duration with

varying resting times no more than 21 seconds in duration (King, Jenkins, & Gabbett, 2009, Spencer, Lawrence, Rechichl, Bishop, Dawson, & Goodman, 2004). Glaister, Howatson, Lockey, Abraham, Goodwin, & McInnes, 2007, used 11 physically active male subjects to investigate the effects of familiarization and reliability of repeat sprint performance indices. The subjects performed 4 trials of 12 x 30 meter sprints with 35 seconds of recovery. Each trial was separated by 7 days and performed at the same time of day. The results indicate no between trial differences in measures of fastest time or mean sprint times. This suggests that multiple sprint tests can be performed with confidence without the need for familiarization of subjects. The important measure associated with the ability to repeat sprints is the measurement of fatigue. There are many different formulas associated with the calculation of fatigue (Glaister, Stone, Stewart, Hughes, & Moir, 2004). Of these the percent decrement formula has been evaluated to be the most valid and reliable. The formula is as follows: 
$$\text{Fatigue} = (100 \times \{\text{total sprint time} / \text{ideal sprint time}\}) - 100$$
 where total sprint time is equal to the sum of all sprint times from all sprints and ideal sprint time is equal to the number of sprints performed x fastest sprint time (Glaister, Howatson, Lockey, Abraham, Goodwin, & McInnes, 2007, Glaister, Stone, Stewart, Hughes, & Moir, 2004). This formula allows the researchers to determine an index of fatigue and make comparisons between and within subjects. Additionally fatigue can be measured using ratings of perceived exertion (RPE). Two different methods of acquiring RPE exist, the session method involves asking

the subject to evaluate a bout of exercise 30 minutes after completion. This encompasses the entire bout of activity and has been shown to be reliable and valid when compared to both heart rate and oxygen consumption data (Herman, Foster, Maher, Mikat, & Porcari, 2006). Although validated with continuous exercise session RPE has not been used in intermittent activity which indicates the momentary RPE method as the most suitable for repeat sprint activity. The momentary method requires the subject to provide data at timed intervals during exercise bouts. The use of appropriate valid and reliable methods is essential during data collection. The use of these testing protocols will provide an accurate assessment of the subjects ability to repeat sprints along with providing accurate physiological data.

### Conclusion

Testing the ability to engage in repeat sprints is a practical approach in determining performance levels of athletes in almost all field based activities due to the locomotor requirements of those sports. Time motion analysis suggests that repeat sprints with active recovery are the predominant mode of locomotion for sports including, field hockey, soccer, rugby, and lacrosse. Furthermore they describe specifically times in high activity like sprinting, moderate activity as in jogging or active recovery, and low forms of activity like walking or resting. According to the specificity principle athletes participating in these sports should be trained in a way that mimics the activity. In field based sports repeat sprints are the main mode of locomotion; by training athletes in

this manner coaches can ultimately provide energy system specific training resulting in more efficient ATP production thus increasing performance. Recent studies suggest that during repeat sprints there is an inability of the anaerobic energy system to keep up with energy demands, therefore to maintain performance a contribution from the aerobic energy system takes place to varying degrees dependent on rest intervals and duration of sprint times. This combination of energy systems provides the basis for energy production during activity. The ability to use field based testing in a reliable and valid manner is very desirable to coaches and strength and conditioning professionals especially when they can be used as a predictor of repeat sprint ability.

## CHAPTER III

### METHODOLOGY

The purpose of this chapter is to outline and fully explain the methodologies related to the experimental design of the study. The following sections will be explained and defined in further detail: operational definitions, limitations, delimitations, subjects, general procedures, familiarization of subjects, experimental design, and conclusions.

#### Operational Definitions

1. Repeat Sprints– describes intermittent activity patterns that are typical of many court and field based sports in which high intensity activity is followed by low intensity activity or rest. This is measured with a work to rest ratio (W: R) (Glaister, Stone, Stewart, Hughes, Moir, 2007). For the purpose of this study the repeat sprint protocol is defined as 12 x 30 meters @35 seconds of static recovery. The sprint protocol stated above (12 x 30 meters with 35 seconds of recovery) on an indoor track, using an electronic timing device was deemed valid and reliable by Glaister et al, 2007, where peak sprint times and mean sprints were collected and found to have excellent repeatability with ICC's .91 and .94 respectively. Also a similar demographic of subjects were used in both studies.



2. Fatigue – inability to maintain maximal output over time and after repeat bouts of activity. Physiologic fatigue is the inability to re-synthesize ATP at the rate in which it is required.
3. Recreational athletes – subjects who participate in moderate to vigorous activity 1-3 days per week with no affiliation to organized sport. Participation in aerobic or anaerobic activity is permissible
4. College age – subjects for this study will be between the ages of 18-24, typically what is seen in most collegiate undergraduate programs.
5. Field Test – a performance test that needs little equipment and is relatively simple to perform. Use's more specific skills than laboratory tests do. Provides instantly usable data or uses simple calculations to predict a performance outcome.

### Instrumentation

The following instruments will be used for the data collection process:

Polar FT7™ Heart rate monitor - The polar FT7 heart rate monitor is a commercially available monitor. It is fastened on the upper torso by the subject and held together by a plastic snap and Velcro. This is a wireless system in which data is collected on the wrist watch worn by the subject.

Borg Rating of Perceived Exertion (RPE) Scale – The Borg RPE scale is a subjective measure of fatigue or exertion during exercise. The scale will be represented on a 12 x 24 inch poster board in which the subjects will point to a number corresponding to their level of exertion or fatigue during the sprint

protocol. 6/20 is the lowest score which is equivalent to rest or very very very light activity while a 20/20 would mean the cessation of activity and the inability to continue with the protocol.

Brower® Infrared Timing Device – The Brower timing device was used to collect timed sprint data. The sensors were placed at the start and finish line approximately 36 inches apart and 48 inches off the ground, when the infrared beam is crossed the timer will start and when it is crossed again the timer will stop. The time for each sprint is wirelessly transmitted to an electronic keypad help by the principle investigator.

Queens College Step Test (QCT) – The QCT is a step test used to predict VO<sub>2</sub> by assessing recovery heart rate. Subjects will step up and down on a box approximately 41.25 cm in height to a metronome set at 24 steps per minute. A 15 second recovery heart rate will then be taken. The test is based on the principle that heart rate and VO<sub>2</sub> have a linear relationship and a low recovery heart rate indicates aerobic efficiency and therefore a higher PVO<sub>2</sub>.

### Dependent Variables

The following dependent variables will be collected for statistical analysis:

Predicted Oxygen Consumption (PVO<sub>2</sub>) – PVO<sub>2</sub> is the predicted ability of the body to use oxygen for energy production. Predicted values will be calculated using the QCT.

Peak Sprint Time – Peak sprint time refers to the fastest or lowest recorded time during the running (sprint) test.

Mean Sprint Time – Mean Sprint time is total time of all sprints divided by the number of sprints. Refers to the average time to complete each sprint

Fatigue Index – For the purposes of this research fatigue will be calculated using the percent decrement formula.  $\text{Fatigue} = ((\text{total sprint time} / \text{ideal sprint time}) \times 100) - 100$ . Ideal sprint time is peak sprint time x number of sprints and total sprint time is the sum of all sprint trials.

Post Sprint Heart Rate – Post sprint heart rate is the heart rate measured by the polar heart rate monitor directly after the completion of the final sprint in the protocol.

Recovery Heart Rate – Recovery heart rate is the heart rate measured by the polar heart rate monitor 15 seconds after the completion of the QCT, this number is used as part of the equation to determine PVO<sub>2</sub>.

### Limitations

The following study limitations have been acknowledged and considered when interpreting the study results:

1. Subjects worked at their maximal potential during the sprint and step test conditions
2. Subjects were honest and truthful in answering all questions on the health history form and informed consent
3. All measurement tools were calibrated and accurately depicted data
4. Subjects followed all written and verbal instructions

### Delimitations

This study has been delimited to the following

1. Recreational athletes from the East Stroudsburg University of Pennsylvania  
School of Health Sciences
2. College age males, ages 18-24
3. A sample size of 18 subjects
4. Subjects who are free from musculoskeletal injury in the upper and lower extremity within the last 12 months
5. Subjects who are free from diseases that may impact their ability to complete the exercise protocol safely and correctly (asthma, diabetes, cardiovascular)
6. Subjects who have completed the informed consent and PAR-Q form

## Subjects

Subjects for this study were male college age students (18-24 years) recruited voluntarily from the campus of East Stroudsburg University and specifically from the College of Health Sciences. IRB approved fliers were used to aid in the recruitment process. Subjects were self-identified as being free from musculoskeletal injury for at least 12 months prior to the study. Demographic data for the subjects (n=18) is described in table 1.

Table 1: Demographic Description of Subjects

<b>Descriptive Statistics</b>					
	<b>N</b>	<b>Minimum</b>	<b>Maximum</b>	<b>Mean</b>	<b>Std. Deviation</b>
Age	18	19.00	24.00	20.9444	1.51356
Height	18	167.64	187.96	178.5682	6.07723
Weight	18	60.90	102.27	77.4856	9.81176
Valid N (listwise)	18				

Table 1 represents the demographic data for the subjects utilized in this study, the mean age is 20.94 years +/- 1.51 years, the mean height of the subjects is 178.6 cm +/- 6.08 cm, and the mean weight of the subjects is 77.49 kg +/- 9.81kg.

## General Procedures

Prior to the start of data collection all procedures were approved by the institutional review board of Seton Hall University as well as East Stroudsburg University where the data collection took place (Appendix A). All subjects reported to the Undergraduate Laboratory prior to the start of the study to fill out an informed Consent Form (Appendix B) and a Physical Activity Readiness

Questionnaire (PAR-Q)(Appendix C). At this point subjects were also given a detailed description of the procedures involved within the research project as well as a schedule of time commitments and the opportunity to ask any questions of the primary investigator (PI).

After completion of the Informed Consent and PAR-Q Form, a board certified Athletic Trainer (ATC) evaluated both documents for all correct signatures and determined eligibility of the subjects to take part in the study based on the subject's answers. Once cleared to participate subjects were randomly assigned using their subject code, even numbered codes were in the sprint group for the first test and odd numbered subject codes were selected to the step test first. This assignment was used to counterbalance the study; each participant completed both the step and sprint protocols.

#### Familiarization of Subjects

Prior to the beginning of data collection all subjects completed 3 maximal sprints during what the PI termed a familiarization session. Additionally during this session the participant was fitted with the heart rate monitor and received a verbal explanation of the rating of perceived exertion scale. This session was used to help the subjects get accustomed to the equipment and negate any learning curve that may take place. During the familiarization period, maximum sprint time was also recorded and used to prevent pacing during the testing sessions. Each subject was required to achieve at least 90% of maximum sprint time during the first and second sprints of the testing session. If these criteria

were not met, results were discarded and the subject was asked to return the following week for data collection.

### Experimental Procedures

1. Subjects reported to the indoor track facility on the campus of East Stroudsburg University for testing. A certified Athletic Trainer was present at all times to provide any medical attention if needed. The emergency action plan developed by East Stroudsburg University was in place in case of a true medical emergency. Approximately 15 minutes before the beginning of the test subjects were fitted with a Polar® Heart rate monitor around the mid chest and a synchronized wrist watch to record data. Heart rate data was collected throughout the warm-up and continued until the cool down was complete and vital signs (heart rate) returned to normal resting conditions.

2. After securing of the heart rate monitor, the subjects participated in a 15 minute dynamic warm-up protocol (Appendix D) and then 3 minutes of quiet recovery.

3. After all pre-test data was collected the subjects reported to the start line to begin the sprint protocol.

4. Subjects performed 12 x 30 meter repeat sprints with 35 seconds of passive recovery between each sprint. A Brower infrared timing device was used to capture sprint time. These procedures were deemed valid and reliable by Glaister et al, 2007. ICC 0.94 and 0.91 for mean and peak sprint times from test-retest procedures.

5. During the 12 sprints rating of perceived exertion was collected with the Borg 6-20 scale pre sprint 1 and after sprints 2, 4, 6, 8, 10, and 12.

6. After completion of the sprint protocol the subjects participated in a 10-15 minute cool down period in which they walked approximately 200 meters and did some light static stretching of the major muscles of the lower extremity.

7. If the subject was assigned to the step protocol first they wore the heart rate monitor, performed the same dynamic warm-up and 3 minute quiet recovery before initiating the test.

8. The step test consisted of the subject stepping up and down from a step to a metronome set at 96 beats per minute (24 steps per minute) with a step height of 41.25 cm for 3 minutes.

9. The subject was given practice time as well as verbal cues of up, up, down, down while stepping to ensure the pace and step per minute requirements (24 steps/ min).

10. After completion of 3 minutes of stepping the subject was asked to sit down on the step and wait 20 seconds in which recovery heart rate was then read from the heart rate monitor.

11. After completion of the QCT the subject then completed the same cool down process as described above.

12. All data was recorded on the data collection sheet (Appendix E) and is only available to the principle investigator to insure confidentiality.



13. Appendix F represents a graphical representation of the sprint protocol and general procedures related to the methods.

## CHAPTER IV

### RESULTS

The purpose of this chapter is to present the results of the data collected using the previously discussed methods. The results are presented in the following subcategories: analysis of the data, sprint time across trials, heart rate responses post condition, rating of perceived exertion across trials, correlation of PVO2 and peak sprint time, correlation of PVO2 and mean sprint time, correlation of PVO2 and fatigue index, and regression analysis.

#### Treatment of the Data

Data was recorded and entered into Microsoft Excel® spreadsheet and then uploaded to SPSS statistical software version 20.0. Descriptive statistics were run to determine means and standard deviations for demographic data, mean sprint times, rating of perceived exertions scales, and heart rate responses. Correlational relationships were established using Pearson Product Moment Correlation two tailed tests; significance was set at the  $p = \leq 0.05$ .

A secondary analysis was performed using a multiple regression in SPSS version 20.0. Significance of the correlation was set at the  $p = \leq 0.05$ , the model was set to explain variance of PVO2 among subjects where PVO2 was the dependent variable and peak sprint time, mean sprint time, and fatigue index were set as the independent variables.

## Descriptive Analysis of Sprint Times

The first analysis performed was a descriptive assessment of the mean sprint time data. This analysis was essential for demonstrating subject compliance across sprint trials as well as providing a visual representation of fatigue across trials. Table 2 represents mean sprint times by trial and Figure 1 represents the graphical representation of mean sprint data by trial.

Table 2: Descriptive Analysis of Sprint Times

<b>Descriptive Statistics Sprint Times (seconds)</b>					
	<b>N</b>	<b>Minimum</b>	<b>Maximum</b>	<b>Mean</b>	<b>Std. Deviation</b>
s1	18	4.00	4.73	4.2867	.19229
s2	18	4.02	4.96	4.3833	.24088
s3	18	3.98	5.04	4.3750	.27851
s4	18	4.08	5.09	4.4194	.25524
s5	18	4.08	5.05	4.4561	.25581
s6	18	4.13	4.99	4.5006	.22722
s7	18	4.04	5.04	4.4933	.26637
s8	18	4.14	5.15	4.5511	.25559
s9	18	4.20	5.11	4.5728	.26663
s10	18	4.17	5.07	4.6276	.27090
s11	18	4.16	5.32	4.6539	.28030
s12	18	4.18	5.06	4.6222	.23621
<b>Valid N (list wise)</b>	<b>18</b>				

Table 2 shows the descriptive statistics for repeat sprint times by sprint number.

Figure 1: Mean Sprint Time by Sprint Trial

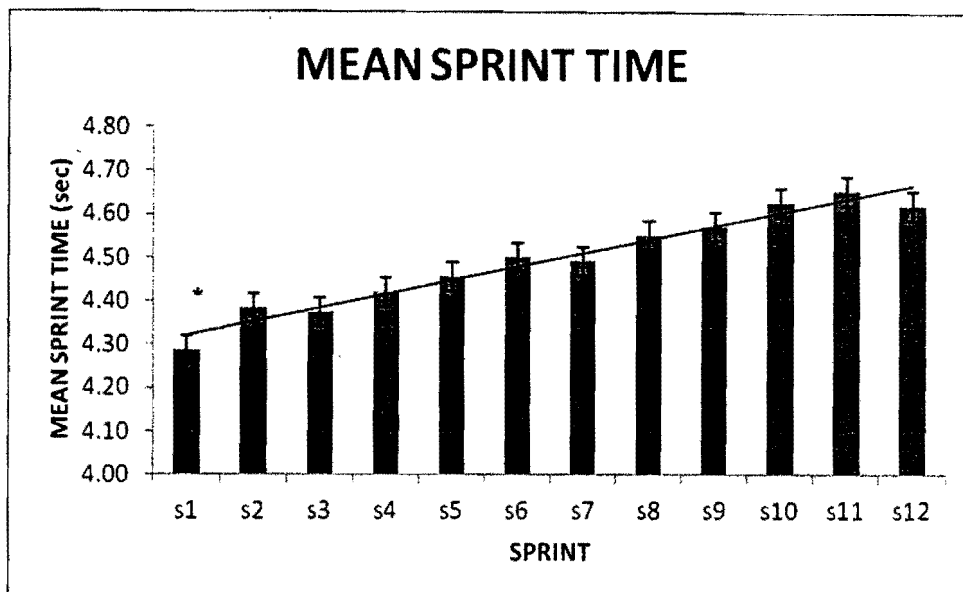


Figure 1 is a graphical representation of mean sprint time for all subjects (n=18) across 12 sprint trials. \* Represents statistically significant differences.

Descriptive data for mean sprint time across trials depicts a trend for increasing mean sprint time across trials; this is indicative of repeat sprints and shows the inability of the metabolic energy systems to keep up with demand for 12 sprints. The fastest mean sprint time of 4.28 seconds  $\pm$  .19 seconds took place in sprint 1 and the slowest average sprint of 4.65 seconds  $\pm$  .28 seconds took place in 11. Also of note, the third sprint (4.37 seconds  $\pm$  .28 seconds) was faster than the second sprint (4.38 seconds  $\pm$  .24 seconds) and the twelfth sprint (4.62 seconds  $\pm$  .24 seconds) was faster than the eleventh sprint (4.65 seconds  $\pm$  .28 seconds). Additional statistical strength was demonstrated using Repeated Measures ANOVA for each level of the sprint trials. The main result of the analysis indicated that sprint 1, which was the fastest, was statistically significantly different than all other sprint trials.

### Heart Rate Response Post Condition

The second analysis performed was the extrapolation of mean heart rate data post experimental condition. After the final sprint (12), heart rate was recorded and labeled post sprint heart rate and after the step test was performed a recovery heart rate was recorded 20 seconds after activity ceased. This analysis compared cardiovascular responses (work of the heart) after each activity. Table 3 represents the descriptive heart rate for both experimental conditions. Figure 2 is a graphical representation of the studies heart rate data.

Table 3: Descriptive Data for Heart Rate Response

<b>Descriptive Statistics Heart Rate</b>					
	<b>N</b>	<b>Minimum</b>	<b>Maximum</b>	<b>Mean</b>	<b>Std. Deviation</b>
Post sprint hr (bpm)	18	152.00	190.00	180.5556	9.14087
Recovery hr (bpm)	18	130.00	188.00	154.8889	18.02576
Valid N (listwise)	18				

Table 3 represents mean heart rate data post experimental conditions.

Figure 2: Graphical Representation of Heart Rate

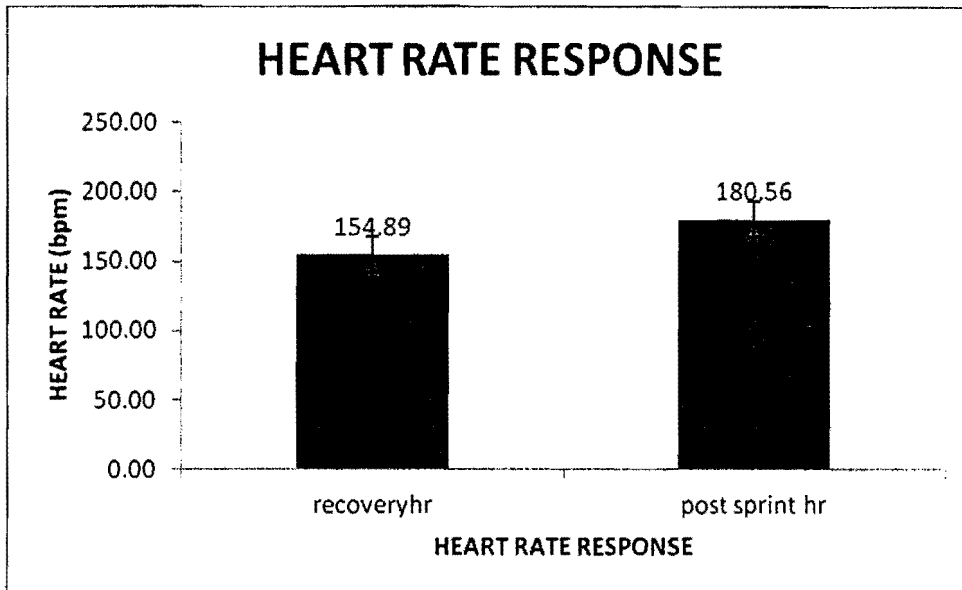


Figure 2 is a graphical representation of heart rate response

Descriptive heart rate data results demonstrate that the mean post sprint heart rate was 180.56 beats per minute  $\pm$  9.14 beats per minute. The mean recovery heart rate after the step test was 154.89 beats per minute  $\pm$  18.03 beats per minute. Upon extrapolating the data into relative terms related to percent of age predicted max ( $220 - \text{age}$ ) the results show that the post sprint heart rate was approximately 91% while the recovery heart rate from the step test was approximately 78%. These percentages of age predicted max support that the subjects were working at high cardiovascular levels during each of the experimental protocols.

### Rating of Perceived Exertion (RPE)

In this study, RPE was used as an additional verifier of fatigue and subject effort during the sprint trials given that it is a subjective measure of exertion. The Borg 6-20 scale was used, 6/20 representing very very low intensity and 20/20 representing the cessation of activity. Table 4 displays the descriptive means of RPE by sprint trial. Figure 3 provides a graphical representation of RPE by sprint trial.

Table 4: Descriptive Means of RPE Data

<b>Descriptive Statistics RPE</b>					
	<b>N</b>	<b>Minimum</b>	<b>Maximum</b>	<b>Mean</b>	<b>Std. Deviation</b>
rpe2	18	7.00	14.00	9.7778	2.07380
rpe4	18	8.00	16.00	12.0556	2.01384
rpe6	18	10.00	17.00	13.4444	1.75641
rpe8	18	12.00	18.00	15.0000	1.53393
rpe10	18	13.00	19.00	16.3889	1.75361
rpe12	18	14.00	20.00	17.6667	1.81497
<b>Valid N (listwise)</b>	<b>18</b>				

Table 4 depicts the means for average RPE by sprint

Figure 3: Graphical Representation of Mean RPE by Sprint

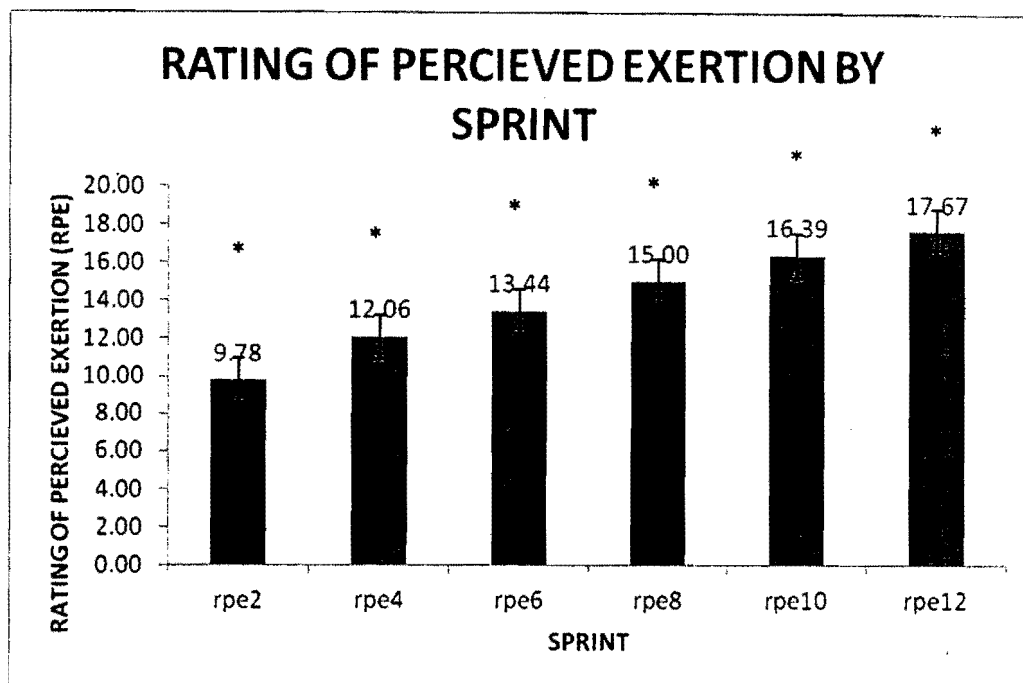


Figure 3 represents the graphically the subjective mean RPE response by sprint. \* Represent statistically significant differences.

Overall, RPE data suggests a trend for higher RPE's for each sprint during the protocol. Sprint 2 had an RPE of 9.78 +/- 2.07 and continued to increase until the end of the sprint test where mean RPE values reached 17.67 +/- 1.81. Based upon these findings it is supported that the subjects subjectively rated their exertion or fatigue from sprint as being very light to sprint 12 being very hard. This data paired with the mean sprint data described earlier are verifications of subject exertion and effort during the sprint protocol. Additional statistical strength was demonstrated using Repeated Measures ANOVA for each level of RPE during the sprint trials. The main result of the analysis indicated that RPE's at



each level were statistically significantly different from one another, indicating an increase in perceived fatigue as sprint trials persisted.

### Peak Sprint Time and PVO2 Correlation

Peak sprint time was defined for this study as the fastest sprint performed by each subject. A low peak sprint time is characteristic of high power outputs and an anaerobically trained athlete. VO<sub>2</sub> is a measure of the aerobic energy systems efficiency to extract and utilize oxygen. The hypothesis generated for this correlation was that there will be a significant positive correlation between PVO<sub>2</sub> and peak sprint time, meaning that those subjects with higher VO<sub>2</sub> (aerobically trained) would have higher peak sprint times, or a lesser ability to generate high speeds/power. Table 5 represents the descriptive data for peak sprint times for all subjects. Figure 4 provides a graphical representation of the scatterplot for the correlation statistic.

Table 5: Peak Sprint and PVO<sub>2</sub> Correlation

<b>Correlation Peak Sprint Time and PVO<sub>2</sub></b>			
		<b>pvo2</b>	<b>peaktime</b>
pvo2 (ml/kg/min)	Pearson Correlation	1	-.466
	Sig. (2-tailed)		.052
	N	18	18
Peaktime (sec)	Pearson Correlation	-.466	1
	Sig. (2-tailed)	.052	
	N	18	18

Table 5 represents the Pearson Product Moment Correlation statistical analysis for peak sprint time and PVO<sub>2</sub>.

Figure 4: Graphical Representation of Peak Sprint Time and PVO2 Correlation

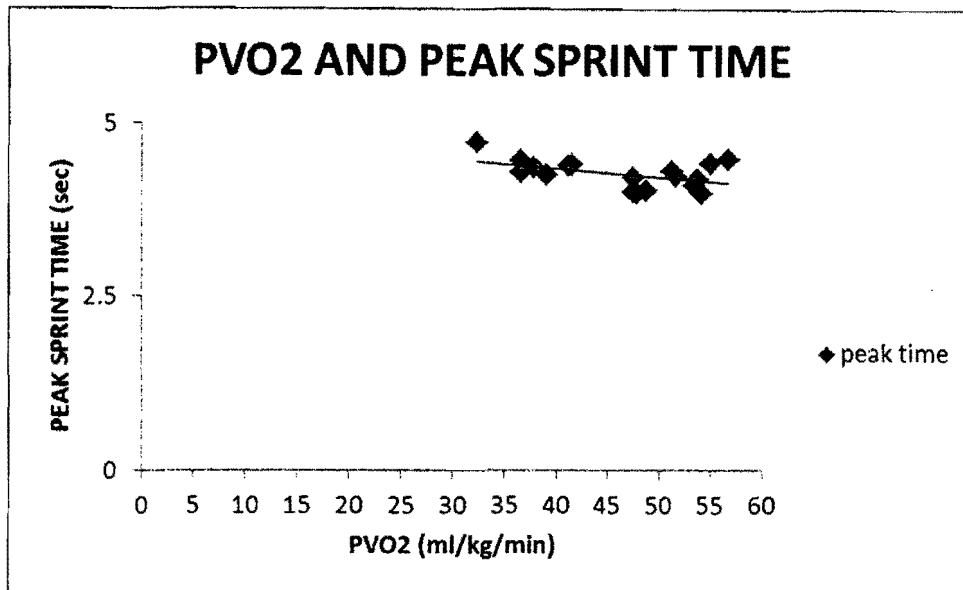


Figure 4 demonstrates the graphical correlation statistic for peak sprint time and PVO2.

Statistical analysis of peak sprint time and PVO2 show a trend toward a fair negative correlation ( $r = -.466$ ), based upon the significance level ( $p = .052$ ) being slightly outside of the accepted values for statistical significance. This trend in the data suggests that a higher PVO2 is indicative of lower peak sprint times which were not the hypothesized outcome. Peak sprint times ranged from 3.98 seconds to 4.73 seconds with corresponding PVO2's of 47.91 ml/kg/min and 32.37 ml/kg/min respectively.

#### Mean Sprint Time and PVO2 Correlation

Mean sprint time was defined for this research project as the average time (Sum of 12 sprint times / 12 sprints) for completion of 1 sprint. A low mean sprint time would be suggestive of the ability of a subject to maintain sprint times

over the course of the experimental trials. The hypothesis generated for this correlation is that there will be a statistically significant negative correlation between mean sprint times and PVO2. Table 6 represents the statistics for the Pearson Product Moment Correlation 2 tailed test for Mean Sprint time and PVO2; Figure 5 is the graphical depiction of the data.

Table 6: Mean Sprint Time and PVO2 Correlation

<b>Correlation Mean Sprint Time and PVo2</b>			
		<b>pvo2</b>	<b>meantime</b>
	Pearson Correlation	1	-.586*
<b>pvo2</b>	Sig. (2-tailed)		.011
	N	18	18
	Pearson Correlation	-.586*	1
<b>meantime</b>	Sig. (2-tailed)	.011	
	N	18	18

\*. Correlation is significant at the 0.05 level (2-tailed).

Table 6 represents the correlation statistics of mean sprint time and PVO2.

Figure 5: Graphical Representation of Mean Sprint Time and PVO2 Correlation

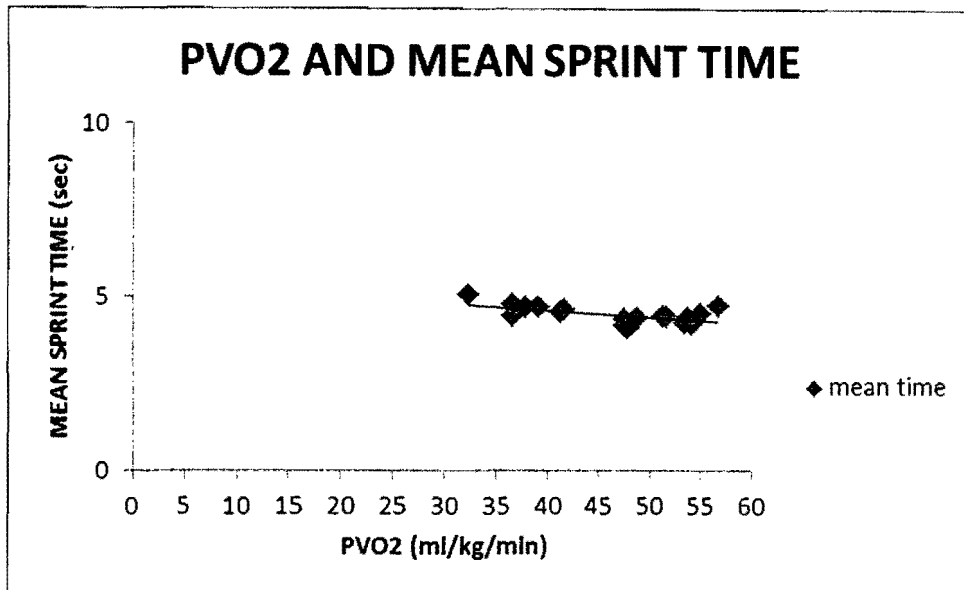


Figure 5 represents the graphical correlation between mean sprint time and PVO2.

Statistical analysis for mean sprint time and PVO2 revealed a statistically significant ( $p=.011$ ) negative correlation ( $r = -.586$ ) for the variables investigated. This correlation suggests that higher PVO2 or aerobic capacity is significantly related to lower mean sprint times and that those subjects with higher VO2's were able to maintain lower sprint times. Mean sprint times ranged from 4.11 seconds to 5.03 seconds with corresponding PVO2's of 47.91 ml/kg/min and 32.37 ml/kg/min respectively.

#### Fatigue Index and PVO2 Correlation

For the purpose of this research fatigue index was calculated using the percent decrement formula. The percent decrement formula uses all (12) sprint times as well as the fastest sprint time to determine fatigue (% decrement =

(ideal sprint time/ actual sprint time) x100) where ideal sprint time is equal to fastest sprint time x number of sprints and actual sprint time is equal to the sum of all sprint times. A lower percentage represents a low fatigue score which means that the subject was able to maintain sprint times across all trials. The hypothesis generated for these variables states that there will be a statistically significant negative correlation between fatigue index and PVO2. Table 7 represents the Pearson Product Moment Correlation statistics and Figure 6 is the graphical representation of the correlational data.

Table 7: Fatigue Index and PVO2 Correlation

<b>Correlation Fatigue Index and PVO2</b>			
		<b>pvo2</b>	<b>Percent fatigue</b>
	Pearson Correlation	1	-.380
pvo2 (ml/kg/min)	Sig. (2-tailed)		.120
	N	18	18
	Pearson Correlation	-.380	1
Percent fatigue (%)	Sig. (2-tailed)	.120	
	N	18	18

Table 7 represents the correlation statistics for fatigue index and PVO2

Figure 6: Graphical Representation of Fatigue Index and PVO2 Correlation

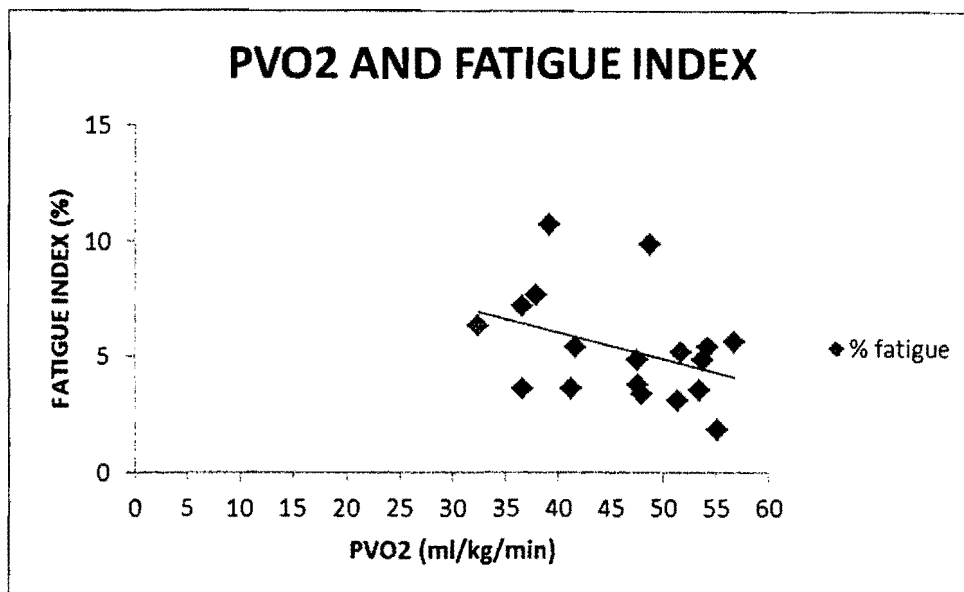


Figure 6 represents the graphical correlation between fatigue index and PVO2

Statistical analysis revealed a fair negative trend of fatigue index and PVO2 although statistical significance was not achieved ( $p = .120$ ) correlation ( $r = -.380$ ) between these two variables. The fair negative trend does reveal that subjects with higher PVO2's demonstrate lower fatigue indexes and thus warrants further investigation. The range of % fatigue is 1.89% to 10.73% with corresponding PVO2's of 55.05 ml/kg/min and 39.09 ml/kg/min respectively.

### Conclusion

The results of this study indicate multiple outcomes associated with the data collected. The mean sprint time for all subjects by trial (Figure 1) showed a trend for greater sprint times which is typical amongst repeat sprint data. In addition the data also demonstrates subject adherence to the protocol for giving maximum effort for every sprint. Another verification of effort for this study

was the use of rating of perceived exertion which is a subjective measure of fatigue and exercising intensity. RPE values demonstrated a similar trend with mean sprint time as values increased during each sprint. Heart rate responses were also recorded after the sprint protocol was completed as well as during recovery from the step test. Results indicate that sprint and step test increased heart rate to approximately 91% and 78% of age predicted maximum values demonstrating moderate to intense cardiovascular exercise.

The main data recorded to answer the research questions was that involving repeat sprint information (peak sprint time, mean sprint time, calculated fatigue index) and calculated PVO<sub>2</sub> from the step test. Pearson Product Moment Correlations were used to assess relationships between these variables. Results indicate there was no significant correlation between peak sprint time and PVO<sub>2</sub>, but the  $r$  values did show a trend toward a negative correlation meaning higher PVO<sub>2</sub> were associated with faster peak sprint times. These results do not align with the previously established hypothesis of a significant positive correlation so the research hypothesis for peak sprint time and PVO<sub>2</sub> has been rejected. The next variables assessed were mean sprint time and PVO<sub>2</sub>. Results indicate a significant negative correlation, meaning that those subjects demonstrating higher PVO<sub>2</sub>'s also have lower mean sprint times. These results are in agreement with the previously established research hypothesis so we accept the hypothesis that mean sprint time and PVO<sub>2</sub> are significantly negatively correlated. Finally, the last variables associated with the

main outcomes of the study are fatigue index calculated using the percent decrement formula and PVO2. Results indicate there is no significant correlation between fatigue index and PVO2 although when assessing the data a trend did appear for a negative relationship meaning those subjects with higher PVO2's also demonstrated lower fatigue indexes. These results do not align with the previously established research hypothesis of a significant negative correlation so the hypothesis related to fatigue index and PVO2 has been rejected.

The main significant outcome of this study demonstrates a correlation between mean sprint time and PVO2. Although other significant results were not established negative trends in the data did exist between PVO2 and peak sprint time as well as PVO2 and fatigue index and thus provides further opportunity for inquiry.

### Regression Analysis

A secondary analysis of the data was performed using SPSS version 20.0 to determine a regression equation and explanation of variance in PVO2 among the subjects. Table 8 represents the model for the regression analysis where PVO2 was the dependent or predicted variable and peak sprint time, mean sprint time, and fatigue index were the independent or predictors.



Table 8: Regression Model

Dependent Variable (Predicted)	Independent Variables (Predictors)
PVO2	Peak Sprint Time Mean Sprint Time Fatigue Index

Table 8 represents the regression model.

The first step in analyzing the regression is to assess the significance table to ensure that the regression is in fact a functional model that can be statistically substantiated. Table 9 represents the significance table for the model; this table indicates the model is in fact statistically significant with a p value of 0.010.

Table 9: Significance Table for Regression Analysis

ANOVA						
Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	527.423	3	175.808	5.507	.010 <sup>b</sup>
1	Residual	446.971	14	31.927		
	Total	974.394	17			

Table 9 represents the ANOVA table of significance for the regression analysis

Once the model was deemed significant the model summary, Table 10 can be assessed. Of particular importance is the  $R^2$  value representing the percentage of explanation of variance using the model created. Also of importance is the significance that all 3 predictor variables are related to the dependent variable. Table 10 indicates an  $R^2$  value of .541 or 54.1% of variance in PVO2 could be explained by the regression model. In other words just over

half of the variance is explained by peak sprint time, mean sprint time, and fatigue index.

Table 10: Regression Model Summary

<b>Model Summary</b>				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.736	.541	.443	5.65036

Table 10 represents the model summary of the regression analysis

To further explain the inter-relationship between each independent variable and PVO<sub>2</sub> or the dependent variable a coefficient analysis was performed to explain the contribution of each variable within the regression model. Table 11 illustrates the partial correlation and significance of each variable as it relates to the explanation of variance. Peak sprint time, mean sprint time, and fatigue index all are significant within the model with p values of 0.035, 0.032, and 0.038 respectively. When evaluating the partial correlations of each variable peak sprint time, mean sprint time, and fatigue index all demonstrate similar moderate R-values of 0.530, -0.538, and 0.523.

Table 11: Partial Correlation Table

Partial Correlation Table								
Model	Unstandardized		Standardized	t	Sig.	Correlations		
	Coefficients		Coefficients			Zero-order	Partial	Part
	B	Std. Error	Beta					
(Constant)	-52.810	80.563		-.656	.523			
peaktime	792.905	339.504	21.059	2.335	.035	-.466	.530	.423
meantime	-768.267	321.882	-23.949	-2.387	.032	-.586	-.538	-.432
percentfatigue	31.634	13.772	9.730	2.297	.038	-.380	.523	.416

Table 11 represents the partial correlation table for the regression model.

## CHAPTER V

### DISCUSSION

The purpose of this chapter is to reflect upon and integrate the study findings with that of the current literature to further explain and determine the significance of the study results. Therefore, this chapter has been arranged to discuss mean sprint time data, heart rate responses, RPE values, and correlation results between PVO<sub>2</sub> and peak sprint time, PVO<sub>2</sub> and mean sprint time, and PVO<sub>2</sub> and fatigue index in relation to previously conducted research studies.

#### Descriptive Analysis of Sprint Times

The results of the present study demonstrate an increase linear trend in mean sprint times across trials. The significance of this trend supports that the subjects did adhere to the request for maximal effort during each sprint attempt. Interestingly, Glaister, Howatson, Lockey, Abraham, Goodwin, and McInnes, 2007, found similar responses using the exact same sprint protocol with 11 physically active male college students. Their research provided insight in to the expected sprint results from the 12x30 meter protocol with 35 seconds of recovery by assessing test-re-test reliability. The results of their research show that peak and mean sprint times R-values for repeatability are .91 and .94, respectively; they also provide a figure of mean sprint times over trials that has the same trend line at the present research which demonstrates similar results

and adherence of subjects to the protocol. It was imperative that in this study we first established this relationship or further analysis would not be appropriate as valid interpretations of the data would not be possible.

#### Heart Rate Responses Post Condition

The elevation of heart rate is a natural response during physical activity for many different reasons including but not limited to delivery of oxygenated blood to working muscles and removal of metabolic byproducts. The results of this study indicated an expected increase in heart rate under both the sprint and step test conditions. In relative terms heart rate increased to approximately 78% of age predicted max for the step test and 91% of age predicted maximum heart rate for the sprint test. These values suggest that under both conditions subjects experienced moderate to intense cardiovascular exercise with reflexive responses in heart rate. Heart rate is known to have a positive linear relationship with VO<sub>2</sub> during exercise, which is the basis of the prediction equation for the QCT ( $111.33 - (0.42 \times \text{recovery heart rate})$ ), as time passes with the cessation of exercise heart rate decreases returning closer to a state of homeostasis which is a sign of efficiency of the cardiovascular system. The amount of heart rate decrease within the first 20 seconds after activity determines your PVO<sub>2</sub> for the QCT; according to the equation a better (lower) recovery heart rate is indicative of a higher VO<sub>2</sub> (Chatterjee, Chatterjee, Mukherjee, & Bandyopadhyay, 2003 and Liu & Lin 2007). If we use this method of extrapolation and apply it to the data collected during the current study, it

would suggest that after the completion of the sprint protocol subjects VO<sub>2</sub> was much higher than after the step test. This argument or assumption is in agreement with Glaister, 2005 who following critical reviewing multiple study findings evaluating the physiological response during repeat sprint, suggested that the average physiological work performed during repeat sprint activity is similar to that of continuous aerobic work with average VO<sub>2</sub>'s at 60% -75% of maximum and heart rate responses between 70% and 90% of maximum values. The results calculated in this study for heart rate data post sprint of 91% of maximum values is in agreement with Glatzer's review findings and most importantly show that VO<sub>2</sub> was also elevated during and after the repeat sprint trials. This elevation of VO<sub>2</sub> or up regulation of the aerobic energy system is thought to supplement the anaerobic energy system in production of ATP by supporting PCr resynthesis and attenuating fatigue during repeat sprint activities which is advantageous for athlete's ability to maintain performance over time (Bogdanis, Nevill, Boobis, & Lakomy, 1996).

#### Rating of Perceived Exertion (RPE)

As previously stated, RPE is a subjective measure of fatigue and exertion. Since this measure is based on an individual's perception it is difficult to statistically correlate these values to ones performance. For example, if subject one perceives a sprint as being a 14/20 and subject two perceives that same sprint as a 16/20 those values are different for each subject yet, RPE is an accurate assessment of how they are individually feeling during that specific

sprint. Chen, Fan, & Moe, 2002 performed a meta-analysis on the validity of RPE measures against physiologic measures as a means to address this concern. Their results indicate R-values of .62, .57, .64, .63, .61, and .72 for heart rate, blood lactate, VO<sub>2</sub> max, VO<sub>2</sub>, ventilation, and respiration rate respectively. Although the results of the meta-analysis demonstrated moderate relationships between some physiologic measures and RPE the authors did not find any articles to date that studied the relationship between RPE and other fatigue measures such as the percent decrement formula or any repeat sprint measures, with that being said for the purpose of this study RPE was used as an indicator of subjective perceived fatigue and exertion between sprint trials 2, 4, 6, 8, 10, and 12 and thus must be viewed that way when interpreting the findings. Typical results would indicate that if subjects gave maximal effort during each trial an increase in RPE would be seen as sprints progressed. According to the data collected during this study (Table 4) RPE numbers increased progressively between sprints, from 9.78/20 (+/- 2.07) after sprint 2 to 17.67/20 (+/- 1.81) after sprint 12. This suggests that the subjective perception of exertion increased as the sprint protocol progressed and we suggest is further verification of subject adherence to exert maximal effort during sprints which allows for confident evaluation of the data.

#### Peak Sprint and PVO<sub>2</sub> Correlation

Peak Sprint time is defined as the fastest sprint time performed by the subject and is related to the ability to generate power. In other words the faster

the sprint the greater ability to perform work in a short period of time (Baechle and Earle, 2008). In general, the greater ability to generate power or perform faster peak sprint times would be suggestive of someone who is predominantly anaerobically trained. The adaptations associated with anaerobic training include increase in muscle girth, increase in muscle fiber size, increase in strength and power, and finally increases in short term endurance of the anaerobic energy system pathways (Baechle and Earle, 2008). These adaptations are all very desirable for max power or max speed type of sports where one maximal effort is required then complete recovery, for instance the shot put or javelin throw in track and field would be an example of this. Intense anaerobic training would also limit factors associated with aerobic metabolism such as a possible decrease in aerobic enzymes, small changes in  $\text{VO}_2$ , no change in capillary density, as well as no changes in mitochondrial density (Baechle and Earle, 2008). According to the physiological adaptations previously established above we can say the expectation or hypothesis for the relationship between  $\text{PVO}_2$  and peak sprint time would be positively correlated, meaning that low (fast) peak sprint times would generally be associated with anaerobic training adaptations, which minimize aerobic adaptations; therefore these subjects would demonstrate lower  $\text{PVO}_2$  values.

The results of the present study indicate a negative correlation between peak sprint time and  $\text{PVO}_2$ ; even though the data was not significantly correlated the negative trend cannot be ignored. Specifically the data analysis



resulted in an R-value of  $-.466$  ( $p=0.052$ ). Also of interest is the secondary analysis of partial correlations related to the explanation of differences in PVO<sub>2</sub>. The results of the regression analysis of the current study suggest that peak sprint time, mean sprint time and fatigue index play equal parts in the explanation of PVO<sub>2</sub> meaning that both aerobic and anaerobic adaptations are important for repeat sprint performance. This concept is perplexing due to distinct physiological changes associated with training. However, Glaister, Stone, Stewart, Hughes, and Moir, 2007 found similar results when evaluating the influence of 6 weeks of endurance training on multiple sprint performances. Specifically, over the course of 6 weeks subjects exercised aerobically on a cycle ergometer increasing workload each week to overload and make sure adaptation occurred. VO<sub>2</sub> max using gas analysis was measured along with mean and peak power during the repeat sprint protocol. Results of their study indicated a 53.8% increase in VO<sub>2</sub> max and surprisingly also showed an increase in mean power and peak power during the repeat sprint protocol. These study findings would lead us to infer that aerobic training did indeed increase repeat sprint performance even though clear aerobic adaptation took place due to the increase in VO<sub>2</sub>. This concept is also supported by the current study through the negative correlation found between PVO<sub>2</sub> and peak sprint time as well as the significant partial correlation found between peak sprint time and PVO<sub>2</sub>. In other words, aerobic as well as anaerobic adaptations are both significant contributors to repeat sprint performances.

Although the research conducted by Glaister, Stone, Stewart, Hughes, and Moir, 2007 was quite interesting and provided some basis for aerobic training as the main mode of exercise for repeat sprints, the authors cautioned the interpretation of the data due to increases in peak and mean power which might have been associated with the learning curve of riding the cycle ergometer and therefore subjects increased ability was not physiological but mechanical. Nevertheless, a trend was depicted in both the present study as well as in previous literature and thus further investigation is warranted in this area.

Upon further reflection of the data, an additional explanation for the observed negative trend in the current study may be due to the subject pool recruited. Subjects needed to be currently recreationally active, participating in moderate to vigorous activity 1-3 days per week with a history of participating in repeat sprint based sport and not currently involved in organized sports. Participant's specific type of activity engagement was not controlled for so that variable may have affected the outcome of the data analysis. For instance the range of PVO<sub>2</sub> for the subjects was 32.37ml/kg/min to 56.73 ml/kg/min which indicates that some subjects were in the 10<sup>th</sup> percentile for age established norms while other subjects were in the 90<sup>th</sup> percentile for age established norms (McArdle, Katch, & Katch, 2007). But upon further analysis the mean PVO<sub>2</sub> for all subjects was 46.28 ml/kg/min which is between the 70<sup>th</sup> and 80<sup>th</sup> percentile for age established normative data. These percentile scores show that the

average subject had a moderate to high PVO2 indicating that most of the subjects were aerobically trained and furthermore that the participant pool was homogeneous with elevated PVO2 values. The presence of a homogeneous group could have skewed the data to show a negative relationship between PVO2 and peak sprint time.

### Mean Sprint Time and PVO2 Correlation

The correlation of mean sprint time and PVO2 is extremely important due to the nature of most field and court based sports. The ability to maintain sprints over a period of time or number of trials may be more significant to a coach when evaluating an athlete than 1 sprint ran as fast as possible. Mean sprint time for the purpose of this study was defined as the average time it took to complete the total number of sprints (sum of sprint times / number of sprints). A low mean sprint time would be characteristic of a subject that is able to maintain sprinting capabilities over all trials. Differences in training status can affect mean sprint time or mean power output; this can be illustrated by analyzing the results of a typical 30 second Wingate test for anaerobic power. The Wingate test is a cycle ergometer protocol that consists of a subject pedaling as hard as possible for 30 seconds against a resistance equal to approximately 7.5% of body weight in kilograms. The test evaluates the immediate energy system as well as the glycolytic system and output variables are usually peak power, mean power, and fatigue index. Subjects who are anaerobically trained typically have a large peak power output but then tend

to fatigue quickly which inflates the fatigue index which is measured as a % of drop from max power to minimum power at the end of the test. However, a subject that is aerobically trained has a quite different outcome. Aerobically trained subjects tend to have lower peak power outputs than their anaerobically trained counterparts but the aerobic subjects are able to maintain the intensity for a longer period of time, in essence the mean power generated is sustainable which in turn shows a smaller fatigue index as well (Baechle and Earle, 2008, McArdle, Katch, and Katch, 2007). If we take the information from a standard Wingate test and apply it to repeat sprints and specifically mean sprint time we would expect to see a similar relationship, those subjects more aerobically trained, higher PVO<sub>2</sub>'s, should have lower mean sprint times. The results of the present study show a statistically significant ( $p = .011$ ) negative correlation ( $r = -.586$ ) between mean sprint time and PVO<sub>2</sub>. This is in agreement with previous studies conducted by Rampinini, Sassi, Morelli, Mazzoni, Fanchini, and Coutts, 2009, where the researchers investigated the relationship between Vo<sub>2</sub> and repeat sprint measures in amateur and elite soccer players. In this study subjects completed a VO<sub>2</sub> max test on a treadmill using gas analysis, a 40 meter repeat sprint test as well as a VO<sub>2</sub> uptake kinetics test on the treadmill. Multiple correlations were done between VO<sub>2</sub> and repeat sprint measures, the authors found a statistically significant negative correlation, R-value of  $-.45$ , between mean sprint time and VO<sub>2</sub> max. Interestingly, similar results were found by Dupont, Millet, Guinhouya, and Berthoin, 2005 who studied

the correlation of VO<sub>2</sub> kinetics and VO<sub>2</sub> max to the ability to repeat sprints. They found that VO<sub>2</sub> kinetics which is the transitional dynamic nature of VO<sub>2</sub> from rest to exercise as well as VO<sub>2</sub> max are both correlated to lower mean sprint times and lower accumulated decreases in speed. Overall, the results shown in previous studies are very similar to those found in the present study and led us to infer that VO<sub>2</sub> max, whether predicted or laboratory tested, influence mean sprint time during repeat sprint activity.

#### Fatigue Index and PVO<sub>2</sub> Correlation

A calculation of fatigue represents the decrease in performance during physical activity. Fatigue is calculated as  $((\text{ideal sprint time} / \text{actual sprint time}) - 100) \times 100$ , where ideal sprint time is fastest sprint time multiplied by number of sprints and actual sprint time is the sum of all sprints (Glaister, Howatson, Lockey, Abraham, Goodwin, and McInnes, 2007). Fatigue measures are essentially looking at overall performance much like mean sprint time, with that being said the expectations of training status would hold true where anaerobically trained subjects would have a large fatigue index and aerobically trained subjects would have smaller fatigue index due to ability to maintain output.

Rampinini, Sassi, Morelli, Mazzoni, Fanchini, and Coutts, 2009, investigated the relationship between VO<sub>2</sub> and fatigue index using the percent decrement formula, along with other variables related to repeat sprints, in amateur and professional soccer players. The researchers found a significant negative correlation, R-value = -.65, for measured VO<sub>2</sub> and fatigue index, thus indicating

a moderate relationship between the two variables which suggests that subjects with higher VO<sub>2</sub> values would exhibit less fatigue during repeat sprints.

Consistent with the findings of Castanga, Manzi, D'Ottavio, Annino, Padua, and Bishop, 2007 who studied the relationship between maximal aerobic power and the ability to repeat sprints in young basketball players is our data which showed no statistically significant correlation ( $r = -.380$ ,  $p = .120$ ) between PVO<sub>2</sub> and fatigue index. In Castanga et al. they measured VO<sub>2</sub> peak as well as repeat sprint indices using a basketball specific protocol. Their results indicated an average fatigue index value of 3.4% and correlation R-value of  $-.32$  ( $p = .54$ ). The researchers concluded that VO<sub>2</sub> peak is not related to fatigue index or ability to repeat sprints; they suggest that other factors such as lactic acid buffering capabilities might be more important determinants of repeat sprint ability. The lack of statistical correlation between fatigue index and VO<sub>2</sub> is also demonstrated by Carey, Drake, Pliego, and Raymond, 2007, who studied 11 female collegiate hockey players. The researchers assessed VO<sub>2</sub> max as well as repeat sprint on the ice and found no significant correlation ( $r = -.422$ ,  $p > .05$ ) between fatigue index and VO<sub>2</sub> max for their subjects. Upon, additional analysis they determined that only 17.8% of the variance in VO<sub>2</sub> max was explained by fatigue index values thus the authors concluded that aerobic capacity has a very small relationship with fatigue index in female hockey players.

Interestingly, the literature related to the relationship between fatigue index measures and VO<sub>2</sub> is not in agreement. In general, the consensus

between authors involving inconsistent results between studies is related to varying rest intervals between sprints and varying durations of sprints. Both of these variables would provide different percentages of energy system recovery. Differences in recovery would dramatically affect fatigue measures during repeat sprint research and provide inconsistent data for comparison.

### Regression Analysis

The secondary regression analysis provides insight into the relationship between the variables regarding repeat sprints and PVO<sub>2</sub>. Interestingly, this model suggests that each repeat sprint variable, peak sprint time, mean sprint time, and fatigue index can explain over half of the variance in PVO<sub>2</sub> among the subjects. This is quite different from the correlational analysis performed with single variable relationships; once the independent predictor variables were kept constant significant relationships emerged, this finding starts to explain the dynamic nature of repeat sprints, meaning that both aerobic or mean sprint times, and anaerobic or peak sprint times may be significant to the overall performance of repeat sprint sports. In addition, this secondary result also suggests that all repeat sprint sports may not be the same physiologically, data has established that VO<sub>2</sub> does in fact help with recovery during repeat sprint movements but the explanation of variance of PVO<sub>2</sub> is equally explained by both mean sprint time (aerobic adaptations) and peak sprint time (anaerobic adaptations) suggesting that each plays a significant role with performance. This becomes important when classifying repeat sprint based sports; instead of

describing those activities as “repeat sprint sports”, data suggests that a further breakdown of primary and secondary energy systems may be warranted. For example, the sport of American football is in essence a repeat sprint based sport; there are small bouts of high intensity movements followed by rather lengthy recovery periods. In the same category of repeat sprint sports is the game of soccer; high intensity bouts of short duration activity followed by short periods of active or passive recovery. Although both categorized the same, each sport has a different requirement to perform at optimal levels; so categorize these as the same would be an injustice and not truly speak to the demands of the sport. A better label may be that football is anaerobic with aerobic components, where training would consist of primarily increasing anaerobic measures with a minor emphasis on aerobic measures, while soccer would be classified as aerobic with anaerobic components where training would focus on aerobic adaptations with a secondary emphasis on anaerobic adaptation. The common link between both sports is still the mode of locomotion and the reliance on the aerobic system for recovery but training adaptations can be manipulated to favor either the aerobic energy system of anaerobic energy system depending on the needs of the sport. This classification system leads in to the question of training; research has shown that optimizing both systems is impossible (McArdle, Katch, and Katch, 2007). However interval training or intermittent training with various work to rest ratios where higher ratios would be indicative of anaerobic adaptations and lower



ratios would indicate aerobic adaptations has been shown to increase measures of performance such as aerobic power, anaerobic peak power, and anaerobic capacity (Gaiga and Docherty, 1995).

The regression model is able to explain 54.1% of variance in PVO<sub>2</sub> from indices of repeat sprints which is indicative of training status. Conversely, it is also important to understand the remaining 45.9% of unexplained variance within the model. There are multiple factors that can manipulate VO<sub>2</sub> independent of training status including genetic makeup of the subject which deals with the amount of type I and type II muscle fibers within the body. A type I muscle fiber dominant person contains more aerobic enzymes and greater number of mitochondria among other physiological adaptations that would predispose them to a greater VO<sub>2</sub> regardless of training compared to a person with type II muscle fiber dominance. These genetic factors may explain up to 20-30% of differences in VO<sub>2</sub> among subjects. Another explanation of variance in VO<sub>2</sub> is due to percent of lean muscle mass. A greater amount of lean muscle mass will increase VO<sub>2</sub> exponentially since muscle is metabolically active more energy is needed to complete tasks (Mcardle, Katch, and Katch 2007).

### Conclusion

The current study has collected and analyzed many different variables in hopes to clarify the relationship between repeat sprint ability and PVO<sub>2</sub>. First, it was determined that mean sprint times and RPE showed typical trends of increasing as sprint trials progressed which is indicative of maximal effort and

adherence to the sprint protocol. This data also provided some insight into fatigue patterns associated with repeat sprint activities. Secondly, heart rate data was assessed between post sprint and recovery heart rate after the step test. The present data established that the subjects were working between 78% and 91% of their age predicted maximum values for step test and sprint test respectively, which is a typical response during moderate to intense activity. Increases in heart rate to this magnitude would also indicate that VO<sub>2</sub> was also augmented during this time due to the linear relationship of heart rate and VO<sub>2</sub>.

The main correlational findings in this study found there to be a trend toward a negative relationship between peak sprint time and PVO<sub>2</sub> which according to literature is quite perplexing but may warrant further research into the nature of that relationship. Additional correlational analysis was performed between mean sprint time and PVO<sub>2</sub>. A significant negative correlation was found, which was in accordance with the hypothesis and the literature review. This suggests a relationship between maintenance of repeat sprint performance and PVO<sub>2</sub>. Finally, the last main correlation was executed between fatigue index and PVO<sub>2</sub>; it was hypothesized that a significant negative relationship would be found between fatigue index and PVO<sub>2</sub>, as higher PVO<sub>2</sub> would allow preservation of sprint times over all trials; however, no significant relationship was found between these two variables. Interestingly several authors found similar results indicating that homogeneous samples, differences in recovery time in between each sprint, and length of the sprint can influence metabolic

pathways as to recovery rate and that in turn will influence amount of fatigue calculated.

Although the literature offers a wide range of theoretical perspectives surrounding the concept of repeat sprints; the current research suggests that mean sprint time and PVO<sub>2</sub> have a moderate relationship this is supported by earlier research and speaks to the interrelationship of both aerobic and anaerobic pathways and how they must work together for optimal performance. The current results of this correlation suggest that training focused on increasing VO<sub>2</sub> will also decrease mean sprint time during repeat sprint activities which is essential for performance.

## CHAPTER VI

### SUMMARY AND CONCLUSIONS

The purpose of this chapter is to summarize the main results of this study, provide conclusions with respect to the theoretical and practical applications of the results, and finally provide recommendations for further research.

#### Summary of Results

The data collected and analyzed during this research project offers the following main results:

1. Although a negative trend exists, there is no statistically significant correlation between peak sprint time and PVO<sub>2</sub>.
2. There is a statistically significant negative correlation between mean sprint time and PVO<sub>2</sub>.
3. Although a negative trend exists, there is no statistically significant correlation between fatigue index as calculated from the percent decrement formula and PVO<sub>2</sub>.

#### Conclusions

The way that sports and activities are classified is twofold; in simplistic terms sports can be classified into multiple categories by the actions of the sport whether it is a contact or non-contact sport, the type of equipment used, or even if the sport is predominantly an upper extremity or lower extremity sport or

activity. In scientific terms sports can be divided into clusters based upon the metabolic energy system which primarily forms ATP for energy. In other words activities are considered aerobic or anaerobic. This grouping is easily done with activities that are obviously dominated by one system; for example a 2 mile long slow distance run is easily identifiable as a dominantly aerobic activity and on the other end of the spectrum a 40 meter sprint is dominantly the immediate anaerobic energy system. The question of hybrid sports or repeat sprint sports comes into question as lines are blurred between predominance of energy systems responsible for ATP production. This is especially important to strength and conditioning coaches as knowing and understanding energy system contribution is of the utmost importance for the designing and implementing of appropriate training programs.

The literature provides evidence that strongly suggested a reliance on the aerobic energy system as a contributor during repeat sprint activities. Thus indicating that multiple energy systems are responsible for generating energy in the form of ATP and determining the significance and influence of each one of these energy systems becomes very important. The present study investigated the relationship between predicted measures of oxygen utilization ( $VO_2$ ) and multiple indices of repeat sprints such as peak sprint time, mean sprint time, and fatigue and demonstrated that subjects with higher predicted measures of  $VO_2$  also had lower mean sprint times. This result can be interpreted in that greater efficiency to utilize the aerobic energy system (higher  $VO_2$ ) allowed the subjects

to maintain sprint times throughout the entire protocol. The key part of the interpretation is within the definition of mean sprint time which is the maintenance of sprints over a period of time. This definition is in alignment with time motion analysis data which defined repeat sprints as multiple bouts of high intensity work separated by very short rest periods. During a game or match the ability to maintain sprint time over the course of multiple sprints is optimum for performance. For example, if a soccer athlete performs one sprint at maximal capability but each successive sprint gets exponentially slower, that athlete is no longer an effective player for the course of a game; but if that player can maintain maximal sprint speed or close to it for multiple sprints that player now demonstrates a high degree of performance for the entire game. The relationship established during this research suggests that mean sprint time has a significant relationship to predicted VO<sub>2</sub>, meaning that players demonstrating higher PVO<sub>2</sub>'s may in fact be able to maintain sprint speed for a longer period of time, essentially making them more effective players during competition.

Additionally, this research also provided some insight into the utilization of predictive tests for measurement of VO<sub>2</sub> and there relation to repeat sprints. The use of predictive field tests is inviting to coaches due to the low cost, minimal equipment, and marginal time for completion of the tests. The step test in particular was chosen because of its submaximal nature and length of test being only 3 minutes in duration. Given that previous literature has established the validity and reliability associated with the step test when compared to gas

analysis and found strong correlations between them the results of this test can be inferred to be valid and reliable. When discussing the importance of field tests we established a relationship between PVO<sub>2</sub> from the step test and mean sprint time; essentially we can use the results from a step test as an indicator of athletic performance in repeat sprint based sports.

From a practical standpoint, step test information can be used twofold. One instance may be the predictive nature of how an athlete might be able to perform on the field and two the results can be used to help develop sports specific training because if we know that performance in the step (PVO<sub>2</sub>) has a significant correlation with mean sprint time then we can prescribe exercises to increase PVO<sub>2</sub> therefore increasing performance during repeat sprint activities.

The conceptual frame for this research project was based in practicality, a repeat sprint protocol using running provided more realistic and generalizable data to multiple sports than previous cycle ergometer studies. Furthermore, a field prediction test for VO<sub>2</sub> was used instead of a laboratory test so that practical data can be derived from a simple equation thus giving coaches and strength and conditioning professional's usable data quickly. The established relationship between PVO<sub>2</sub> and mean sprint time is quite applicable to repeat sprint based sports and can shape training programs as well as predict the success of athletic performance.

### Recommendations for Further Research

Based upon thoughtful review of the study findings and current evidence several recommendations for additional research to further investigate the topic of repeat sprint activities and the relation to predicted VO<sub>2</sub> measures can be made. The first recommendation would be to increase sample size for stronger statistical power and greater generalization across multiple populations of recreational athletes. Additionally, since this study is relating athletic performance and repeat sprint ability, in the future it may be advantageous to use repeat sprint athletes of different genders from specific sports such as field hockey, soccer, lacrosse, and rugby for sports specific results according to sport and gender. Finally, according to the time motion analysis section of the literature review most repeat sprint based sports have relatively short recovery times, less than 21 seconds, and typically that recovery is characterized as active not passive. In future research decreasing the rest time between sprints and/ or using active recovery between sprints may provide more insight and provide additional practical information into the relationship between repeat sprint and PVO<sub>2</sub>.



CHAPTER VII

APPENDIXES

APPENDIX A  
INSTITUTIONAL REVIEW BOARD APPROVAL



February 13, 2013

Matthew Miltenberger  
2149 North 5th Street  
Stroudsburg, PA 18360

Dear Mr. Miltenberger,

The Seton Hall University Institutional Review Board has reviewed the information you have submitted addressing the concerns for your proposal entitled "The Correlation of Repeat Sprint Measures to Predicted VO<sub>2</sub> in Recreationally Active Males". Your research protocol is hereby approved as revised under full review.

Enclosed for your records are the signed Request for Approval form, the stamped original Consent Form and recruitment flyer. Make copies only of these stamped documents.

The Institutional Review Board approval of your research is valid until October 16, 2013. During this time, any changes to the research protocol must be reviewed and approved by the IRB prior to their implementation.

According to federal regulations, continuing review of already approved research is mandated to take place by October 16, 2013 after this initial approval. You will receive communication from the IRB Office for this several months before that date.

Thank you for your cooperation.

*In harmony with federal regulations, none of the investigators or research staff involved in the study took part in the final discussion and the vote.*

Sincerely,

*Mary F. Ruzicka, Ph.D.*  
Mary F. Ruzicka, Ph.D.  
Professor  
Director, Institutional Review Board

cc: Dr. Genevieve Pinto Zipp

Please review Seton Hall University IRB's Policies and Procedures on website (<http://www.provost.shu.edu/IRB>) for more information. Please note the following requirements:

**Adverse Reactions:** If any untoward incidents or adverse reactions should develop as a result of this study, you are required to immediately notify in writing the Seton Hall University IRB Director, your sponsor and any federal regulatory institutions which may oversee this research, such as the OHRP or the FDA. If the problem is serious, approval may be withdrawn pending further review by the IRB.

**Amendments:** If you wish to change any aspect of this study, please communicate your request in writing (with revised copies of the protocol and/or informed consent where applicable and the Amendment Form) to the IRB Director. The new procedures cannot be initiated until you receive IRB approval.

**Completion of Study:** Please notify Seton Hall University's IRB Director in writing as soon as the research has been completed, along with any results obtained.

**Non-Compliance:** Any issue of non-compliance with regulations will be reported to Seton Hall University's IRB Director, your sponsor and any federal regulatory institutions which may oversee this research, such as the OHRP or the FDA. If the problem is serious, approval may be withdrawn pending further review by the IRB.

**Renewal:** It is the principal investigator's responsibility to maintain IRB approval. A Continuing Review Form will be mailed to you prior to your initial approval anniversary date. Note: No research may be conducted (except to prevent immediate hazards to subjects), no data collected, nor any subjects enrolled after the expiration date.

**REQUEST FOR APPROVAL OF RESEARCH, DEMONSTRATION OR  
RELATED ACTIVITIES INVOLVING HUMAN SUBJECTS**

All material must be typed.

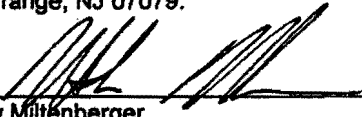
PROJECT TITLE: The Correlation of Repeat Sprint Measures to Predicted VO2 in Recreationally Active Males

---

---

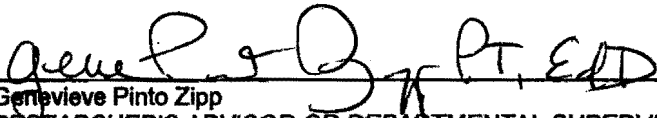
**CERTIFICATION STATEMENT:**

In making this application, I(we) certify that I(we) have read and understand the University's policies and procedures governing research, development, and related activities involving human subjects. I (we) shall comply with the letter and spirit of those policies. I(we) further acknowledge my(our) obligation to (1) obtain written approval of significant deviations from the originally-approved protocol BEFORE making those deviations, and (2) report immediately all adverse effects of the study on the subjects to the Director of the Institutional Review Board, Seton Hall University, South Orange, NJ 07079.

  
\_\_\_\_\_  
Matthew Miltenberger  
RESEARCHER(S) OR PROJECT DIRECTOR(S) \_1/15/13\_  
DATE

\*\*Please print or type out names of all researchers below signature.  
Use separate sheet of paper, if necessary.\*\*


My signature indicates that I have reviewed the attached materials and consider them to meet IRB standards.

  
\_\_\_\_\_  
Genevieve Pinto Zipp  
RESEARCHER'S ADVISOR OR DEPARTMENTAL SUPERVISOR \_1/15/13\_  
DATE

\*\*Please print or type out name below signature\*\*

The request for approval submitted by the above researcher(s) was considered by the IRB for Research Involving Human Subjects Research at the January 2013 meeting.

The application was approved  not approved  by the Committee. Special conditions were  were not  set by the IRB. (Any special conditions are described on the reverse side.)

  
\_\_\_\_\_  
DIRECTOR,  
SETON HALL UNIVERSITY INSTITUTIONAL  
REVIEW BOARD FOR HUMAN SUBJECTS RESEARCH \_2/13/13\_  
DATE

APPENDIX B  
INFORMED CONSENT FORM

FEB 13 2013

Approval Date

**Informed Consent Form**

Seton Hall University

The Correlation of Repeat Sprint Measures to Predicted VO<sub>2</sub> in Recreationally Active Males

**Researcher's Affiliation**

Matthew Miltenberger, who is a Temporary Instructor in the Exercise Science Department at East Stroudsburg University and a Graduate Student at Seton Hall University in the department of Graduate Programs in Health Sciences in the School of Health and Medical Sciences, has requested the subjects participation in a research study at East Stroudsburg University. The title of the research is: The Correlation of Repeat Sprint Measures to Predicted VO<sub>2</sub> in Recreationally Active Males.

**Research Purpose**

The subject has been informed that the purpose of the research is to evaluate the relationship between the ability to repeat sprints and aerobic capacity as measured by the Queens College Step Test. The indices being tested will be sprint time, heart rate, rating of perceived exertion, and predicted aerobic ability through the Queen's College Step test (QCT), which is a simple aerobic stepping exercise. The subject understands that if he chooses to participate in this study the subject will be asked to report to the testing area 3 times for approximately 1 hour each.

**Research Procedures**

The subject has been informed as part of the research protocol he will be asked to come to the Koehler field house indoor track to fill out the PAR-Q form and informed consent and perform 3 maximal 30 meter sprints. The second visit for testing will include the subjects participation in either the repeat sprint protocol which will consist of 12 x 30 meter sprints separated by 35 seconds of passive recovery or the Queens College Step Test, which will involve the subject stepping up and down to a metronome for 3 minutes at a pace of 24 steps per minute. The third meeting will consist of the test not performed either sprint or step. Additionally, procedures will include the subject wearing a heart rate monitor on the wrist and torso, as well as pointing to a rating of perceived exertion chart.

Expiration Date  
OCT 16 2013

FEB 13 2013

Approval Date

**Voluntary Nature**

The subject understands that his participation in this study is of a voluntary nature. The subject also understands that at any time during the course of the research he can withdraw from participation without any penalty or repercussions.

**Anonymity**

The subject understands that the results of the research study may be published but the subjects name or identity will not be revealed. Additionally, there will be no identifying marks which could link the subject to any individual data.

**Confidentiality of Records**

In order to maintain confidentiality of the subject's records, Matthew Miltenberger will provide the subject with a subject code and that will be the only way data will be identified. Additionally, the subject understands that records will be kept secure behind a lock and key in Matthew Miltenberger's file cabinet. At no point will any data with identifying marks become available to the public.

**Records**

The subject understands that Matthew Miltenberger will be the only person with access to any confidential records. The subject understands their records will be kept for a period of three years after which time they will be destroyed.

**Risks or Discomforts**

The subject understands that there are foreseeable risks or discomforts if the subject agrees to participate in the study. The possible risks include muscle soreness, muscle strains, dizziness, falling due to low oxygen levels, or other musculoskeletal injuries during or after the sprint protocol and step test. The subject understands that immediate medical attention is their right through the East Stroudsburg University Health Center or at the local Hospital located adjacent to the campus. The subject understands if they have further questions about possible risks or discomforts they can contact Matthew Miltenberger at any time for further explanation.

Expiration Date  
OCT 16 2013



FEB 13 2013

Approval Date

**Direct Benefits**

The subject understands that the possible benefits of their participation in this research may include gaining some knowledge into the research process.

**Monetary Compensation**

The subject has been informed that he will not be compensated for participation.

**Medical Treatment Compensation**

The subject has been advised that the research in which they will be participating does involve risk. The foreseeable risk of injury is musculoskeletal and can be handled by either the East Stroudsburg University Health Center located in the Flagler-Metzgar building in the center of campus or handled by Pocono Medical Hospital located adjacent to the university is also available 24 hours per day 7 days per week.

**Alternative Procedures**

The subject understands there are no feasible alternative procedures available for this study that may be advantageous.

**Contact Information**

The subject has been informed that any questions the subject may have concerning the research study or participation in it, before or after consent, will be answered by the principle investigator Matthew Miltenberger, 200 Prospect Street, East Stroudsburg Pa, 18301, Office #248 Koehler field house, 570-422-3551. Additional information can be obtained from Dr. Genevieve Pinto Zipp, Seton Hall University, Graduate programs in Health Sciences, School of Health and Medical Sciences; 400 South Orange Avenue, South Orange NJ 07079 or at 973-275-2457. The subject understands that in case of injury, if the subject has any questions about rights as a subject/ participant in this research, or if the subject feels they have been placed at risk, the subject can contact the Chair of the Institutional Review Board: Dr Mary Ruzicka at 973-313-6314, Seton Hall University. 400 South Orange Avenue, South Orange NJ 07079.

Expiration Date  
OCT 16 2013



**Signatures**

The subject has read the above information. The nature, demands, risks, and benefits of the project have been explained to the subject. The subject knowingly assumes the risks involved and understands that they may withdraw their consent and discontinue participation at any time without penalty or loss of benefit. In signing this consent form, the subject is not waiving any legal claims, rights, or remedies. A copy of this signed and dated consent form will be given to the subject.

*"The Department of Health and Human Services requires that you be advised as to the availability of medical treatment if a physical injury should result from research procedures. No special medical arrangements have been made regarding your participation in this project. If you are a registered student at SHU, you are eligible to receive medical treatment at the University Health Service. If you are not a registered student at the University, immediate medical treatment is available at usual and customary fees at the local community hospital. If you are a registered student at ESU, you are eligible to receive medical treatment at the University Health Center.*

**Subject's Signature** \_\_\_\_\_ **Date** \_\_\_\_\_

I certify as the principle investigator that I have explained to the above individual the nature and purpose, the potential benefits, and possible risks associated with the participation in this research study, have answered any questions that have been raised, and have witnessed the above signature. I have provided the subject/ participant a copy of the signed consent document.

**Signature of Investigator** \_\_\_\_\_ **Date** \_\_\_\_\_

THIS PROJECT HAS BEEN APPROVED BY THE SETON HALL UNIVERSITY INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN SUBJECTS AND THE EAST STROUDSBURG UNIVERSITY OF PENNSYLVANIA INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN SUBJECTS.

Seton Hall University  
Institutional Review Board

FEB 13 2013

Approval Date

School of Health and Medical Sciences  
Department of Graduate Programs in Health Sciences  
Tel: 973.275.2076 • Fax: 973.275.2370  
400 South Orange Avenue • South Orange, New Jersey 07079 • [gradmeded.shu.edu](http://gradmeded.shu.edu) **Seton Hall University**  
6/2007

Expiration Date  
OCT 16 2013

APPENIX C  
PAR-Q Form

# PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

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

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

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

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

If  
you  
answered

## YES to one or more questions

Talk with your doctor by phone or in person **BEFORE** you start becoming much more physically active or **BEFORE** you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

## NO to all questions

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

### DELAY BECOMING MUCH MORE ACTIVE:

- If you are not feeling well because of a temporary illness such as a cold or a fever — wait until you feel better, or
- If you are or may be pregnant — talk to your doctor before you start becoming more active.

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

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

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

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

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

NAME \_\_\_\_\_

SIGNATURE \_\_\_\_\_

DATE \_\_\_\_\_

SIGNATURE OF PARENT  
OR GUARDIAN (for persons under the age of majority) \_\_\_\_\_

ADDRESS \_\_\_\_\_

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



© Canadian Society for Exercise Physiology www.csep.ca/forms

APPENDIX D  
DYNAMIC WARM-UP

## Dynamic Warm-Up

### Pre-Sprint Protocol

1. Each subject will jog at approximately 60% pace for 400meters around an indoor track
2. A dynamic stretching protocol will be administered for 15 minutes prior to the start of sprints.

Each exercise will be performed for 20 meters and repeated twice

- Form running
  - High knees
  - Butt kicks
  - Backward run
  - Back peddle
  - Side shuffles
  - Knee to chest stretch
  - Straight leg kick stretch
  - Toe walks
  - Heel walks
  - Leg swings
  - Drop step lunges
  - Forward lunges
  - Progressive sprints from 50 to 80% of maximum ability
3. At the conclusion of the warm-up the subject will rest for approximately 3 minutes before beginning the sprint protocol.

### Post- Sprint Protocol

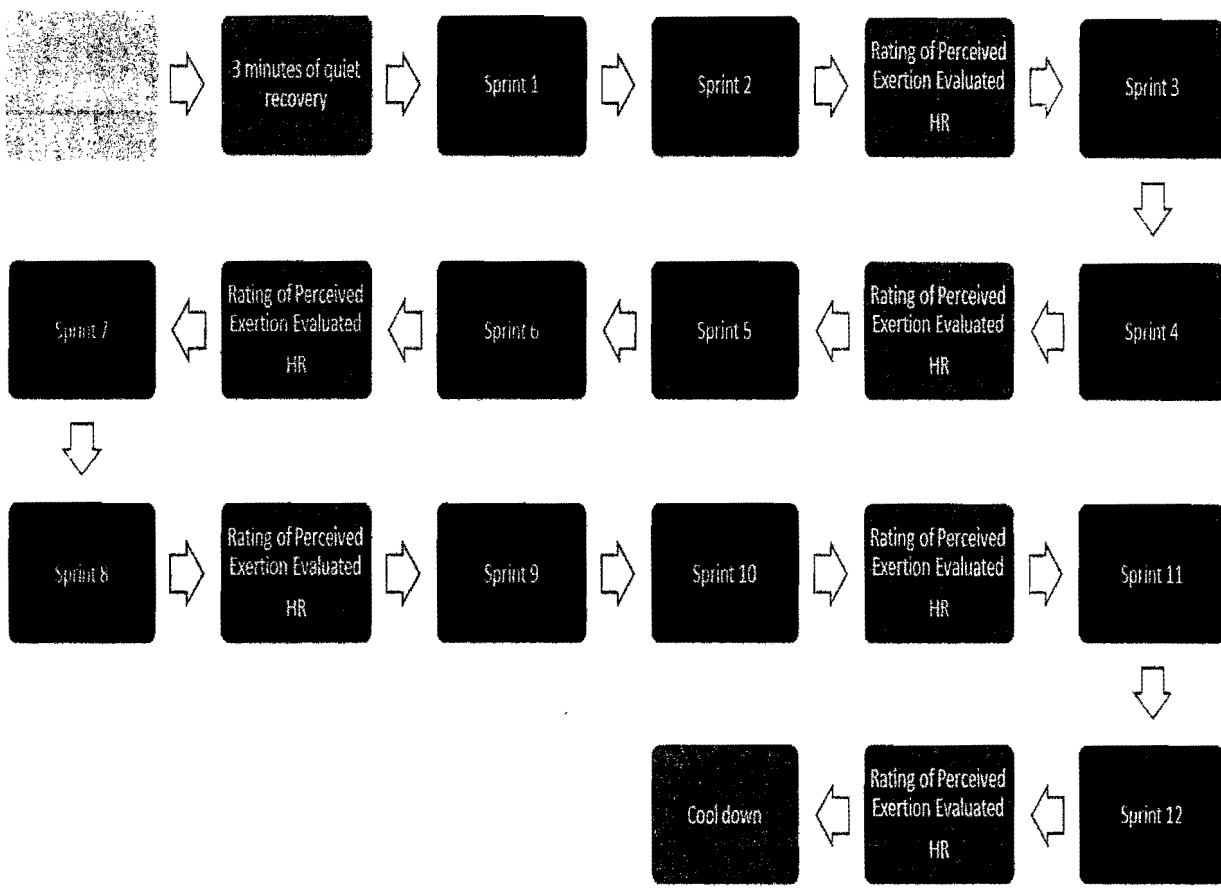
1. After the subject has completed the repeat sprints a cool down will be administer as follows:
  - Jog 200 meters at 40% pace
  - Participate in static stretching consisting of stretches for all major muscle groups of the lower extremity. Each stretch will be help for 60 seconds and performed 3 times
    - Quadriceps stretch
    - Hamstring stretch
    - Gluteus stretch
    - Gastrocnemius stretch
    - Adductor stretch
2. After stretching all subjects will have access to treatment modalities including, ice bags, cold whirlpools, and cold wraps.

APPENDIX E  
DATA COLLECTION SHEET





APPENDIX F  
GRAPHICAL REPRESENTATION OF METHODOLOGY



Graphical representation of sprint protocol data collection process

APPENDIX G  
RECRUITMENT FLIER

# Interested in Exercise Testing?

Do you work out regularly?

Volunteer to Get Involved With Research!!!!

**Title:** The Correlation of Repeat Sprint Measures to Predicted VO<sub>2</sub> in Recreationally Active Males

**Purpose:** The purpose of the study is to determine if there is a relationship between repeat sprint ability and predicted aerobic capacity (VO<sub>2</sub>)

**Procedures:** Include performing a 12 x 30 meter repeat sprint protocol, wearing a heart rate monitor, giving a rating of perceived exertion, and determining your predicted aerobic capacity using an aerobic exercise step test.

**Who:** Recreationally active males, 18 -24 years old. All subjects are volunteers and can quit the study at any time without penalty. Anonymity and confidentiality will be maintained at all times. Subject data will not be available for view by anyone besides the primary researcher. All data will be secured in a locked cabinet or drawer and identifying marks will not be used in publication of the dissertation or subsequent journals.

**Time:** Subjects will be asked to come to the field house indoor track 3 times for approximately 1 hour each visit

**When:** February 2013

**Where:** Koehler Field House, Indoor Track

**Contact:** Matt Miltenberger, temporary faculty Department of Exercise Science  
Seton Hall University Doctoral student  
Department of Graduate Programs in Health Sciences  
School of Health and Medical Sciences  
570-422-3551

Seton Hall University  
Institutional Review Board

[mmiltenber@esu.edu](mailto:mmiltenber@esu.edu)  
[miltenma@shu.edu](mailto:miltenma@shu.edu)

~~This study has been approved by the Seton Hall University Institutional Review Board as well as the East Stroudsburg University Institutional Review Board.~~

Approval Date

Expiration Date

OCT 16 2013

Seton Hall University  
6/2007

## References

- Alessio, H. M., Hagerman, A. E., Fulkerson, B. K., Ambrose, J., Rice, R. E., & Wiley, R. L. (2000). Generation of Reactive Oxygen Species After Exhaustive aerobic and Isometric Exercise. *Medicine and Science in Sport and Exercise*, 1576-1581.
- Allen, D., Lamb, G., & Westerblad, H. (2007). Impaired Calcium Release During Fatigue. *Journal of Applied Physiology*, 296-305.
- Allen, D., Lamb, G., & Westerblad, H. (2008). Skeletal Muscle Fatigue: Cellular Mechanisms. *Physiology Review*, 287-332.
- Arbogast, S., & Reid, M. (1998). Oxidant Activity in Skeletal Muscle Fibers is Influenced by Temperature, CO<sub>2</sub> level, and Muscle Derived Nitric-Oxide. *American Journal of Physiology*, 194-200.
- Aslan, E., Muniroglu, S., Alemdaroglu, U., Karakoc, Baris. (2012). Investigation of the Performance Responses of Yo-YO and Shuttle Run Tests with Treadmill Run Test in Young Soccer Players. *Pamukkale Journal of Sports Sciences*, 104—109.
- Baechle, R., & Earle. (2008). *Essentials of Strength Training and Conditioning*. Chicago: Human Kinetics.
- Bogdanis, G., Nevill, M., Boobis, L., & Lakomy, H. (1996). Contribution of Phosphocreatine and Aerobic Metabolism to Energy Supply During Repeat Sprint Exercise. *Journal of Applied Physiology*, 876-884.
- Borg, G., Hassmen, P., & Langerstrom. (1987). Perceived Exertion related to Heart Rate and Blood Lactate in Arm and Leg Exercises. *European Journal of Applied Physiology*, 679-685.
- Brooks, G., Fahey, T., Baldwin, K. *Exercise Physiology: Human Bioenergetics and Its Application*. (2005). New York, McGraw-Hill.
- Carey, D., Drake, M., Pliego, G., Raymond, R. (2007). Do Hockey Players Need Aerobic Fitness? Relation between VO<sub>2</sub>max and Fatigue During High Intensity Intermittent Ice Skating. *Journal of Strength and Conditioning Research*, 963-966.
- Castanga, C., Manzi, V., D'Ottavio, S., Annino, G., Padua, E., Bishop, D. (2007). Relation between Maximal Aerobic Power and the Ability to Repeat Sprints in Young Basketball Players. *Journal of Strength and Conditioning Research*, 1172-1176.

- Chatterjee, S., Chatterjee, P., Mukherjee, P., Bandyopadhyay, A. (2004). Validity of the Queen's College Step Test for use with Young Indian men. *British Journal of Sports Medicine*, 289-291.
- Chen, M., Xitao, F., Moe, S. (2002). Criterion Related Validity of the Borg Ratings of perceived Exertion Scale in Health Individuals: A Meta-analysis. *Journal of Sports Sciences*, 873-899.
- Durandt, J., Tee, J., Prim, S., & Lambert, M. (2006). Physical Fitness Components Associated with Performance in a Multiple-Sprint Test. *International Journal of Sports Physiology and Performance*, 150-160.
- Dupont, G., Millet, G., Guinhouya, C., Berthoin, S. (2005). Relationship between Oxygen Uptake Kinetics and Performance in Repeated Running Sprints. *European Journal of Applied Physiology*, 27-34.
- Ferriera, L., & Reid, M. (2007). Muscle- Derived ROS and Thiol Regulation in Muscle Fatigue. *Journal of Applied Physiology*, 853-860.
- Gaiga, M., Docherty, D. The Effect of an Aerobic Interval Training Program on Intermittent Anaerobic Performance. *Canadian Journal of Applied Physiology*, 452-464.
- Gaitanos, G., Williams, C., & Boobis, L. (1993). Human Muscle Metabolism During Intermittent maximal Exercise. *Journal of Applied Physiology*, 712-719.
- Glaister, M. (2005). Multiple Sprint Work. *Sports Medicine*, 757-777.
- Glaister, M., Howatson, G., Lockey, R., Abraham, C., Goodwin, J., & McInnes, G. (2007). Familiarization and Reliability of Multiple Sprint Running Performance Indices. *Journal of Strength and Conditioning Research*, 857-859.
- Glaister, M., Stone, M., Stewart, A., Hughes, M., & Moir, G. (2004). The Reliability and Validity of Fatigue Measures During Short-Duration Maximal-Intensity Intermittent Cycling. *Journal of Strength and Conditioning Research*, 459-462.
- Glaister, M., Stone, M., Stewart, A., Hughes, M., & Moir, G. (2007). The Influence of Endurance Training on Multiple Sprint Cycling Performance. *Journal of Strength and Conditioning Research*, 606-612.

- Gonzalez, D., Marquina, R., & Rondon, N. (2008). Effects of Aerobic Exercise on Uric Acid, Total Antioxidant Activity, Oxidative Stress, and Nitric Oxide in Human Saliva. *Research in Sports Medicine*, 128-137.
- Herman, L., Foster, C., Maher, M., Mikat, R., & Porcari, J. (2006). Validity and Reliability of the session RPE Method for Monitoring Exercise Training Intensity. *South African Journal of Sports Medicine*, 14-17.
- Hopkins, W. (2000). Measures of Reliability in Sports Medicine. *Sports Medicine*, 1-15.
- King, T., Jenkins, D., & Gabbett, T. (2009). A Time-Motion Analysis of Professional Rugby League Match-Play. *Journal of Sports Sciences*, 213-219.
- Liu, C., Lin, K., (2007). Estimation of VO<sub>2</sub>max: A Comparative Analysis of Post-Exercise Heart Rate and Physical Fitness Index from 3-Minute Step Test. *Journal of Exercise Science and Fitness*, 118-123.
- Machefer, G., Groussard, C., Zouhal, H., Vincent, S., Youssef, H., Faure, H., et al. (2007). Nutritional and Plasmatic Antioxidant Vitamins status of Ultra Endurance Athletes. *Journal of the American College of Nutrition*, 311-316.
- Marciniak, A., Brzezczynska, J., Gwozdziński, K., & Jegier, A. (2009). Antioxidant Capacity and Physical Exercise. *Biology of Sport*, 197-213.
- McArdle, W., Katch, F., & Katch, V. (2007). *Exercise Physiology: Energy, Nutrition, and Human Performance*. Philadelphia: Lippincott, Williams, & Wilkins.
- Rampinini, E., Sassi, A., Morelli, S., Mazzoni, S., Fanchini, M., Coutts, A. (2009). Repeated-Sprint Ability in Professional and Amateur Soccer Players. *Applied Physiology, Nutrition and Metabolism*, 1048-1054).
- Shimoyama, Y., Tomikawa, M., & Nomura, T. (2003). The Effect of Rest Periods on Energy System Contribution During Interval Swimming. *European Journal of Sport Science*, 1-11.
- Spencer, M., Bishop, D., Dawson, B., & Goodman, C. (2005). Physiological and Metabolic Responses of Repeated-Sprint Activities. *Sports Medicine*, 1025-1044.
- Spencer, M., Lawrence, S., Rechichi, C., Bishop, D., Dawson, B., & Goodman, C. (2004). Time-Motion Analysis of Elite Field Hockey with Special Reference to Repeated-Sprint Activity. *Journal of Sports Science*, 843-850.

Turrens, J. (2003). Mitochondrial Formation of Reactive Oxygen Species. *Journal of Physiology*, 335-344.

Westerblad, H., Allen, D., & Lannengren, J. (2002). Muscle Fatigue: Lactic Acid or Inorganic Phosphate the Major Cause? *International Union of Physiology/ American Physiological Society*, 17-21.