Aerobic Performance Adaptations to Duration Equated High Intensity versus Sprint Interval Training Methods in An Athletic Population

by

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A Thesis, Submitted in Partial Fulfillment
of the Requirements for the Degree of

Masters of Science

in the Graduate Academic Unit of Kinesiology

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This thesis, is accepted by the
Dean of Graduate Studies

THE UNIVERSITY OF NEW BRUNSWICK

May 2020

ABSTRACT

High aerobic capacity has been shown to be a key indicator of physical performance in field based athletes. From having the ability to maintain energy production during long duration activities as well as replenishing other metabolic systems, aerobic capacity is a necessity for athletes performing at high levels. This research set out to look at two different training modalities in improving aerobic capacity in an athletic population. Thirteen participants (9 males and 4 females, 22.1 ± 2.5 years; 171.9 ± 10.0 cm; 74.4 ± 11.3 kg) completed six-weeks of aerobic training three times per week in either High-intensity interval training (120% of VO_{2max}) or Sprint interval training (all out). In this study six participants were in the High intensity Interval group and seven were in the Sprint Interval group. Participants completed an aerobic capacity test pre and post training on a high-speed treadmill in which, $VO_{2max,}$ percentage of VO_{2max} at Ventilatory Threshold (VT), VO_2 at VT, and Fast Slope of Excess Post Exercise Oxygen Consumption (EPOC) were all measured used open circuit spirometry. Following six-weeks of training significant Time main effects were observed for VO_2 at VT (Pre 30.0 +/- 2.4 mL/kg/min, Post 32.4 +/- 3.0 mL/kg/min), and Fast Slope of EPOC Recovery (Pre 21.7 +/- 3.5 mL/kg/min, Post 23.5 +/- 3.8 mL/kg/min), over the six-week training period. Due to a small sample size, interpretation of this data should be made with caution. However, these findings suggest that HIIT and SIT methodologies do not differ in their impact on adaptations to aerobic performance variables over a six week intervention period. More data collection is necessary to allow for more complete interpretation with appropriate statistical power.

ACKNOWLEDGEMENTS

University of New Brunswick Faculty of Kinesiology

Canadian Sport Centre Atlantic (CSCA) and the CSCA High Sport Performance Centre

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List of Symbols, Nomenclature or Abbreviations

HR- Heart Rate
SV-Stroke Volume
VT- Ventilatory Threshold
VO_{2max}- Aerobic Capacity
HIIT- High Intensity Interval Training
SIT- Sprint Interval Training
EPOC- Excessive post exercise oxygen consumption
RSA- Repeated Sprint Ability
PCR- Phosphocreatine System
ATP – Adenosine Triphosphate
ADP – Adenosine Diphosphate
H^+- Hydrogen Ion

Chapter 1 - Introduction

1.1 – Importance of Metabolic Capacity in Sport

There is a vast amount of evidence related to improving metabolic performance in athletic populations (Bosquet, Leger, & Legros, 2002; da Silva Nakamura, Carminatti, Dittrich, Cetolin, & Guglielmo, 2015; Delahunt, Callan, Donohoe, Melican & Holden 2013; Gibala et al, 2006; Hazell, MacPherson, Gravelle & Lemon, 2010). Having well developed metabolic capacities has been shown to aid in athletic performance and can differentiate clinical populations, recreational athletes, and elite level athletes (Dardouri, Selmi, Sassi, Gharbi, Rebhi, Yahmed, Moalla, 2014). The variables involved in athletic performance from a metabolic perspective include; maximal oxygen consumption rate (VO_{2max}), anaerobic capacity, anaerobic power, ventilatory threshold (VT), buffering capacity, and post exercise recovery rate. Each of these variables play key roles in quantifying how well someone's metabolic systems work (Turner & Stewart, 2013). These variables all work together in order to maximize the amount of work and work rate that can be accomplished by an individual in any type of muscular action or performance (Joyce & Lewindon, 2014).

During activity, duration and intensity of work play a key role in determining which metabolic system will be the main contributor to total energy production (Rozenek, Salassi, Mier, & Fleming, 2016). For a single short burst of activity, the body relies on the phosphocreatine (PCR) system as it provides energy at the highest rate for a relatively short period of time, typically up to 6-10secs of work (Turner & Stewart, 2013, Gibala et al, 2006). Although the glycolytic system will be upregulated around the same time as the PCR system, the contribution of energy from this system will become dominate during longer duration sprint bouts (i.e. 10 -120 seconds duration) as well as when the rest periods between sprint bouts are shortened. As the duration continues, and glycolysis produces the by-products of NADH and pyruvate, the oxidative systems will become the primary contributors of energy production in the muscles and downregulate the PCR system in order for it to recover (Turner & Stewart, 2013). The aerobic system will provide the greatest amount of energy for longer duration activities lasting greater than two minutes (Manzi, Bovenzi, Impellizzeri, Carminati, Castagna, 2013) as well as during recovery periods following muscular activity, whether these periods are active or passive rest. Following exercise of any type, the body will immediately transition into a state of post-exercise oxygen consumption (EPOC) where it will work to bring the body back to a resting steady state by replenishing fuel sources (i.e. PCR, muscle glycogen, energy and oxygen debt), repairing tissue all while continually supplying working tissue during recovery (Tomlin & Wegner, 2001).

With this in mind, all of the energy systems will contribute to the overall energy production at a systemic level during an all-out sprinting type task that last longer than a single repetition. In lower threshold motor units, oxidative and glycolytic metabolism will upregulate to maximal rates. In fast twitch glycolytic fibers, glycolysis and PCR systems will contribute to energy production until either fuel sources become depleted, or metabolic waste products (i.e. Hydrogen ions, H^+) exceed buffering capacity resulting in a downregulation in the contractile activity of the high threshold motor units with fatigue (Jacobs, Fluck, Bonne, Burgi, Christensen & Toigo, 2013). Some fast twitch fibers also have aerobic metabolic capacity which will contribute to the overall energy production.

As seen from Potvin & Fuglevand in 2017 muscle fatigue during maximal intensity contractions occurs in stages from higher threshold units to lower threshold units. They created a model for muscle unit recruitment for varying intensities of maximal voluntary contractions and showed that regardless of intensity, all muscle fibers are activated and play rolls in continued muscle contraction. For higher levels of contraction higher threshold units are activated quickly and produce a lot of force but fatigue quickly. At the same time lower threshold units activate and continue to contribute to force production when higher threshold units fatigue, allowing for a sustained ability to produce force, albeit a lower absolute force. For lower intensity muscle contractions all fiber types will contribute to the overall force production until force output cannot be maintained. As contraction duration increases the lower threshold oxidative units remain, the middle tier fast oxidative units fatigue and the high threshold fast glycolytic units begin to contribute more to sustain force production.

Depending on the sport, athletes may rely on one system more than the other, but all systems work together for maximal performance (da Silva et al, 2015, Manzi, Impellizzeri et Castagna, 2014). VO_{2max} levels has been shown as a general indicator of fitness levels, but aerobic endurance is not always the leading energy provider in sport or activity (Castagna, Impellizzeri, Chaouach, et Manzi, 2013). Recent research has shown that repeated sprint ability is a key factor in determining the efficacy of an athlete in field based sport (Buchheit et al, 2013; Taylor, Macpherson, Spears & Weston, 2015; Turner & Stewart, 2013). Although having a high level of aerobic capacity is needed for a base and is predominantly used for extended recovery, repeated sprint ability is highly influenced by the ability of the PCR and anaerobic glycolysis systems to produce energy as well as the bodies' buffering capacity (Dardouri et al, 2014; Turner & Stewart, 2013). Spencer, Bishop Dawson and Goodman in 2005 reviewed how metabolic systems work together during repeated sprint activities and state that higher VO_{2max} results in a faster PCR resynthesis rate and that intensity of sprinting and rest periods play a major role in how well the body can replenish energy sources in the form of adenosine triphosphate (ATP). All athletic movements require muscles to contract resulting in the breakdown of ATP to adenosine diphosphate (ADP) and ultimately the creation of metabolic by-products. Some of these by-products can continue to be used as energy (i.e. pyruvate or lactate), however other by-products are required to be removed from the system in order to ensure the system continues to function (San-Millan and Brooks, 2017; Meyer & Wiseman, Farrell, Joyner & Caiozzo, 2011). One's ability to buffer the by-products (mainly H^+) from this breakdown during contraction will support the athlete's ability to perform in repeated trials (Jacobs et al, 2013). Through repeated sprints, high force outputs are required resulting in the activation of large volumes of muscle mass, which in turn will require greater volumes of ATP production to allow for continued muscle contraction. The failure to produce high volumes of ATP, or to clear the metabolic by-products results in a decrease in muscle force production, and a resulting decrease in repeated sprint ability.

1.2 - Role of Aerobic Capacity in Sport

VO_{2max} has been the primary focus of a great deal of research (Delahunt et al, 2013; Gonzalez-Mohino et al, 2015; La Monica et al, 2016; all soccer articles) especially in field based sports (Dardouri et al, 2014) and it has been suggested that a VO_{2max} above

60 ml/kg/min could be a defining requirement to play sport at a professional level (Castagna, Impellizzeri, Chaouach, & Manzi, 2013). Aerobic capacity has both peripheral (within the muscle), and central (oxygen delivery and waste removal) components that are required to ensure a high yield of ATP. These components are what drive the metabolic system to work at full capacity and utilize different energy sources to continually produce ATP for the system (Brooks, 2016).

Activity using the aerobic system, relies on oxygen consumption and gas exchange for the production of ATP to facilitate working for longer duration activities, like distance running, biking, or repeated endurance tasks. Intensity, and therefore sustained force output, is usually much lower in these activities, which allows for a steadier state of energy production from the aerobic system.

For repeated sprint tasks the role of aerobic energy system is to continue to produce energy while the anaerobic systems recover. In repeated sprint trials, the aerobic system is working in the background during the first few sprints as well as predominately during recovery (Gharbi, Dardouri, Haj-Sassi, Castagna, Chamari, & Souissi, 2014). During the first sprint aerobic metabolism only accounts for very small amount of the overall energy production (around 6%, Bogdanis, Nevill, Boobis & Lakomy, 1996) and may increase depending on the duration and intensity of the first sprint. During sprints later in a set on repeated sprints, the aerobic system becomes much more prominent in the contribution of ATP from a proportional perspective as the higher threshold motor units are now fatigued. The lower threshold units have been active in the background contributing as much force as possible to the task and consuming predominately ATP derived from aerobic sources. Following each set of high intensity runs, the system experiences a phase of EPOC, which draws energy from the aerobic systems to aid in the recovery of the body and replenish high threshold energy systems (Spencer et al, 2005). As the sets continue and recovery time is too short to allow for complete return to resting steady state, the overall contribution of ATP from aerobic sources increases as each subsequent EPOC phase and exercise phase begin to layer upon one another attempting to supply the working muscles with the required ATP to maintain the force output required for the exercise task. In this fatigued state the lower threshold systems continue to rely on aerobic energy production to sustain their force output (Bishop, 2012). For these reasons, the attainment of a high VO_{2max} becomes an important variable when discussing repeated interval training in field based sports (Dardouri et al, 2013). Spencer et al in 2005 discuss the need for ATP replenishment during repeated trials and that the initial fast phase of phosphocreatine resynthesis is dependent on oxygen availability. Here during the recovery periods and leading into the next set of sprints oxygen is required to replenish metabolic systems and help rid working tissue of unwanted metabolites to continue optimal conditions for muscle contractions.

1.3 – Methods of Improving Metabolic Performance

Three primary methodologies for improving metabolic capacity exist within the literature. These include; high intensity interval training (HIIT), sprint interval training (SIT), and continuous steady state training. Each method has been shown to improve metabolic function (da Silva et al, 2015; Taylor, 2015; Iaia et al, 2017; Macpherson, Spears, et Weston, 2015) following training intervention; however, there remains no definitive answer regarding which method is superior for physiological adaptation, as all have been shown to improve metabolic capacities in various populations. The focus of this research will revolve around improvements in athletic populations.

1.3.1 – Continuous Aerobic Conditioning

Continuous steady state training has been the most predominantly researched and is used heavily in endurance based sports (Delahunt et al, 2013;Gonzalez-Mohino et al, 2015;Hazell et al 2010) as it requires the greatest volume of adenosine triphosphate (ATP) to be created at a moderate rate by the aerobic system for sustained force output of the activity. For field or court based sport it is thought that this type of metabolic conditioning is important to train so that athletes can withstand longer duration performances as when the body is in the most fatigued state the aerobic system will still be working to create energy (Buchheit, Simpson, Mendez-Villanueava, 2013; Manzi et al, 2013; Manzi, Impellizzeri, Castagna, 2014). Changes in this type of training typically take longer to achieve both within a single training session as well as over the course of the total training time (Iaia, Fiorenza, Larghi, Alberti, Perri, & Girard, 2015). This is due to the aerobic system taking a much longer time to deplete available energy sources or tax metabolically (Larsen, Shing, Peake, Coombes, & Jenkins, 2002) and prescription needs to be set at a high enough intensity that it can be maintained while still pushing for fatigue. This in turn will take longer to adapt to the training stimulus especially if a solid base of capacity is already present. Most endurance based athletes must train at higher intensities for longer durations in order to build resiliency and the ability to continue to produce energy potentially hours into a training session or competition (Larsen et al, 2002).

It also should be noted that there are key distinguishing timelines during maximal aerobic work that play a pivotal role in what is occurring physiologically within the body. The first ventilatory threshold (VT1) is the point at which ventilation increases as a result of the onset of lactate accumulation within the blood. This is typically as intensity begins to increase during activity but can be easily maintained. The increase in CO_2 within the body increases the amount of buffering in order to maintain homeostasis, but residual H^+ ions are left as lactate is converted back into energy (Farrell, Joyner, & Caiozzo, (2011). The second ventilatory threshold (VT2) is the point at which ventilation has become quite heavy due to the large accumulation of lactate within the blood. This is also known as lactate threshold (Powers & Howley, 2015). Continuing beyond this point would eventually result in the achievement of VO_{2max} in which the body is using the most oxygen it can to continue the force production for the activity. Any further increase in force output is not associated with an increase in oxygen consumption. These timelines in regard to intensity play a key role in prescription of aerobic activity. The general aim is to stay above VT1 with an intensity that can be easily maintained or just below VT2. That window is key in increasing aerobic capacity when using continuous methods (Edwards, Clark, & Macfadyen, 2003).

1.3.2 – High Intensity Interval Training

High intensity interval training (HIIT) is a specific type of conditioning in which the intensity is set for a short duration interval coupled with a specific amount of passive or active rest (Gibala et al 2006). The idea behind the rest period is to allow for the body to recover and return toward a rested state (Edge, Eynon, McKenna, Goodman, Harris, &

Bishop, 2010), which will then allow for continued work in subsequent intervals at intensities higher than what could be sustained during continuous based exercise. Intensity is usually based on a percentage of VO_{2max} in HIIT protocols. What constitutes the appropriate intensity during HIIT continues to be debated (Edge et al, 2013; Laursen and Jenkins, 2002; Wood et al, 2016). It has been suggested that in most cases the intensity is set too low or is inconsistent (Iaia, Fiorenza, Larghi, Alberti, & Millet, 2017) to actually obtain the true intensity required from the original idea of high intensity created by Tabata, Irisawa, Kouzaki, Nishimura, Ogita, & Miyachi in 1997, where participants are working at a work rate above VO_{2max}, which would mimic a sport and/or competition scenario. This would in turn force the system to work at maximal capacity and recruit a lot more muscle fibers as compared to lower intensity work to allow for the production of the required force to propel the body at higher intensities.

With this in mind, motor unit recruitment can vary depending on the interval intensity. The prescription of higher intensity intervals (i.e. greater than VO_{2max}) results in high volumes of muscle recruitment at the onset of the interval to allow for the maintenance of force demands. If the intensity is at a slower pace (i.e. 90% VO_{2max}) lower threshold motor units will initially be recruited with higher threshold units being recruited as fatigue sets in to allow for the maintenance of contractile intensity (Bishop, Girard & Mende-Villanueva, 2011). It has been established that only those tissues recruited during an activity are provided a stimulus for adaptation, therefore, if we do not stimulate tissue above normal resting load, it will not adapt (Clarkson & Trembley, 1988; Holloszy & Booth, 1977). For many studies high threshold units are not stimulated in training as the intensity is lower than what is required during sporting activities. In sport, high threshold motor units are often stimulated more frequently and unless trained outside of competition run the risk of not receiving adequate stimulus for adaptation based on the principle of specificity.

Despite the prescription of intensities set at near or above maximal, HIIT's results in VO_{2max} increases in far shorter times that traditional endurance training are well documented (Gibala et al, 2006; Tabata et al, 1997; Ziemann et al, 2011). In sport, these longer bursts of activity happen more frequently with varied recovery periods (Jastrzebski, Rompa, Szutowicz, Radziminski, 2013) which is why HIIT is becoming more prevalent in the prescription of conditioning. Research has shown that in as little as six training sessions over a period of two weeks, significant improvements VO_{2max}, mitochondrial function and even respiratory function have been achieved (Gibala et al, 2006). Edge, Bishop, Goodman and Dawson (2005) did similar research looking at HIIT and moderate intensity continuous training with both groups doing the same total work, but varied intensities. Here they produced similar results in VO_{2max} and lactate threshold and concluded that higher intensities in shorter burst can still produce significant results comparable to continuous work.

For this type of training, prescribed intensity, duration, and rest periods elicit the activation of different muscle tissue which in turn will rely on either or both of the aerobic and anaerobic systems to provide energy in both single intervals as well as repeated bouts (Dardouri et al, 2014). Muscle recruitment will also depend on the intensity prescribed in the interval(s) (Laursen & Jenkins, 2002). Both systems will be working simultaneously in this type of training and as the interval numbers increase, so will fatigue of the higher threshold motor units, which will trigger a greater proportion of the ATP contribution to come from the aerobic system during the work phase of later intervals in comparison to the initial interval. During the recovery phases, the aerobic system will contribute the greatest proportion of the ATP during each subsequent EPOC cycle achieved during the recovery periods, but as lactate levels in the blood increase so too does the anaerobic contribution (Panissa, Fukuda, Calderia, Gerosa-Neto, Zagatto & Franchini, 2018). In certain cases, such as when the intensity is too high or work duration is too long, the time it takes to fully recover is too long compared to the rest period provided, which will result in an incomplete replenishment the energy stores. This prevents the systems from returning to a true homeostatic state. However, if trained properly the body can work to restore energy faster and remove waste at a more effective rate, making recovery much quicker. Allowing the aerobic system to become taxed and drawing upon other systems will require the body to pull energy from other sources to continue functioning. As the stimulus becomes easier (as in the participant is adapting to the exercise intervention), the amount of energy required in relation to the individual's ability to produce the energy becomes less. This allows for continued force output that can also be maintained longer.

1.3.3 – Sprint Interval Training

Sprint interval training is a version of HIIT in which the work performed is at a maximal rate resulting in a significant drop off in work rate throughout the set (Taylor et al, 2015; Turner et Stewart, 2013). This drop off is a result of the body not being able to metabolically sustain the necessary energy for working tissue (Dardouri et al, 2014) and the H^+ accumulation leading to impaired muscle contraction (Girard, Mendez-Villanueva

& Bishop, 2011). Metabolically the PCR system breaks down phosphocreatine releasing more phosphate groups to attach and create more ATP for continued muscle contraction (Farrell, Joyner & Caiozzo, 2011). This system only works for about 6-10 seconds as most of the creatine phosphate will be used up and needs to be replenished, which takes approximately two minutes of fully recover (Farrell, Joyner & Caiozzo, 2011). The body's ability to buffer metabolites to continue proper energy production and remove unwanted materials is a critical component in how well the body can sustain contraction rates during this form of exercise (Turner & Stewart, 2013). Without high amounts of energy production, maximal muscle contraction rates cannot be sustained which results in a reduction in performance (i.e. velocity of running, or rate of force development cycling) as the body begins to rely more heavily on the aerobic metabolic system which provide energy at a much slower rate (Jacobs et al, 2013). If repeated trials are performed, then the amount of energy produced from the PCR system decreases and a heavier reliance on the aerobic system occurs during more high intensity interval work. As the sets continue, the aerobic system becomes a more prominent contributor of ATP to the working muscles as the anaerobic system may not fully recover between sets (Iaia et al, 2017; Taylor et al, 2015;).

Limitations in this type of exercise is the intensity of work and duration of interval and its corresponding rest period. Certain research does not actually reach that maximal state of recruitment, which would then make the intervention a High intensity interval. Also, the ratio of work to rest here allows for the system to have optimal time to recover, which does not allow for a large aerobic stimulus as the anaerobic systems are replenished during the extended rest periods. The idea of sprinting is maximal effort with a significant reduction in power production or total work done. Gibala et al in 2006 performed repeated 30 second all out bike sprints in an effort to stimulate greater metabolic adaptations from repeated sprinting. Here athletes performed 30 seconds of work with four minutes of rest in the hopes of replenishing the PCR system and allow for more time for the body to buffer out metabolites between intervals. They found that VO_{2max} adaptation changes can be found in a much shorter training time frame in SIT training, (2.5 hours), as compared to steady state work, (10.5 hours), for the same span of six session in a two week period. Although they did not specifically look at anaerobic capacity, it would be interesting to look at their fatigue index changes between intervals as the number of intervals increased. This would give a clearer indication of repeated sprint ability as the 30 second all out bike sprint is a maximal test in which full recruitment is required to continue producing force.

1.4 – Limitations in the Current Literature

There is little work comparing HIIT to SIT and the research that has set out to compare these methodologies do have vastly different durations or incorrect prescription protocols. The sprint activities utilized have components of “all out activity” over short durations that will equal out of the similar training durations as HIIT intervals or comparisons of protocols that end up showing that both modalities work within the same time parameters. No one has looked at comparing comparison of the same duration of activity with prescription of two different intensities at or above maximal levels to look at varied recruiting strategies. HIIT has the chance of reaching 100% muscle recruitment as intervals progress and fatigue sets in, where on the flipside SIT recruits 100% of the motor units during intervals and drops off due to fatigue setting in. This is an interesting comparison as it can give a clearer picture of prescription for future energy system development when working at or above maximal intensities.

1.5 – Statement of the Problem

To date, limited work has compared the training methods of HIIT (working at an intensity as a percentage of maximal aerobic capacity) and SIT (sprinting as fast as possible for the duration of the interval) when performed under the same time duration and number of set for their adaptive responses on ventilatory threshold, VO_2 at ventilatory threshold, VO_{2max}, and recovery rate following maximal intensity work.

1.6 – Purpose of the study

The purpose of this study was to determine the aerobic performance and recovery rate responses when comparing a HIIT loading method versus a SIT loading method using matched durations of work.

1.7 - Hypotheses

H_1- Following six weeks of training, Aerobic Capacity (VO_{2max}) will be significantly greater in the HIIT group compared to the SIT group as assessed by a Group by Time interaction effect.

H_2- Following six weeks of training, VO_2 at Ventilatory Threshold (VT), (represented as an absolute volume of VO_2) will be significantly greater in the HIIT group compared to the SIT group as assessed by a Group by Time interaction effect.

H_3- Following six weeks of training, VT (represented as a percentage of VO_{2max}) will be significantly greater in the HIIT group compared to the SIT group as assessed by a Group by Time interaction effect.

H_4- Following six weeks of training, Recovery (represented as a decrease in Fast Slope of Excessive Post Exercise Oxygen Consumption post VO_{2max} test) will be significantly faster in the HIIT group compared to the SIT group as assessed by a Group by Time interaction effect.

1.8 – Operational Definitions

VO_{2max} was measured using open circuit spirometry and was defined as the point when the participant achieves two of the following: Reached a heart rate within 10 beats of their age predicted heart rate based on the HRmax=208-(age x 0.7) equation, the participant reached an Respiratory Exchange Ratio (RER) of at least 1.10, a plateau in VO_2 is sustained with further increase in work rate (Haff & Dumke, 2012), or the participant experienced volitional fatigue.

Fatigue index was defined as the ratio of the change in work rate from the maximum output to the minimum output during the 30 second Wingate compared to the maximum output (Haff & Dumke, 2012).

Recovery rate was defined as the fastest rate of change in oxygen consumption over one minute following completion of the maximal aerobic capacity protocol (Haff & Dumke, 2012).

1.9 – Assumptions

Participants performed the necessary training intervention, both the workout program and the metabolic energy system development program to their maximal ability

Participants also refrained from training outside the intervention, in order to avoid confounding variables that could result in changes in metabolic capacities

1.10 - Limitations

Training or activity outside of the training intervention, such as sports related competitions or practices cannot be equated. It is assumed that participants kept a regular sport schedule outside of the training intervention that stayed consistent from week to week.

1.11 - Delimitations

Participants selected for this research were all competitive university athletes.

During all workouts, to ensure proper training and protocols are followed, a Certified Strength and Conditioning Specialist supervised all training sessions.

Chapter 2 - Review of Literature

2.1 – Comparison of Training Methods

Research on metabolic conditioning has shifted to start comparing two or more different types of metabolic conditioning protocols (Gibala et al 2006), especially within athletic populations (Dardouri et al, 2014). Finding the optimal training load and duration is key for maximizing improvements, especially when there is only limited time for adaptation (Jastrzevbski, Rompa, Szutowicz, & Radzminski, 2013). The most noted comparison is between continuous steady state exercise and some version of High intensity interval training. Both methods have been shown to increase VO_{2max}, ventilatory threshold and overall metabolic function in a variety of populations (Foster, Farland, Guidotti, Harbin, Roberts & Schuette, 2015; Hazell et al, 2010; Helgerud, Hoydal, Wang, Karlsen, Berg, Bjerkaas & Hoff, 2007). These training studies revolve around the comparison of different training intensities, vastly different protocols, or durations in order to see if there is a significant difference in metabolic adaptation as a result of the training. These comparisons have shown that continuous steady state protocols, achieve similar results to High intensity interval training (with the right intensity and duration prescribed) (Esfarjani & Laursen, 2007; Gibala et al, 2006; Macpherson & Weston 2015). These adaptations occur faster in high intensity interval training as it utilizes more muscle tissue due to the nature of the activity, and the aerobic and anaerobic systems work together as a result of the change from rest to work (Buchheit & Mendez-Villanueva 2014; Iaia et al, 2017). Steady state conditioning remains constant throughout the individual training session until working tissue cannot be provided with enough energy to continue to apply the required force to maintain the power associate with the steady state activity. Depending upon the intensity of the work, this fatigue takes much longer to achieve in continuous training compared to HIIT training (Foster et al, 2015).

Comparison between High intensity intervals (HIIT) and sprint interval training (SIT) has become more popular in research (Macpherson et Weston, 2015; Iaia et al, 2017) as it is more sport specific for field-based sports and both still require a lower duration of work as compared to steady state exercise (Buchheit & Mendez-Villanueva, 2014;). HIIT is categorized as repeated intervals with specific durations working at an elevated intensity (i.e. steady state near or above maximal aerobic power for a short duration). SIT is similar to HIIT but at a much higher intensity in which maximal exertion is required throughout the interval resulting in a decrease in work rate as high threshold motor units begin to fatigue and reduce their contribution to overall force output (i.e. steady state cannot be maintained throughout the work interval). Within sprint interval training there is always the point at which intensity cannot be maintained, whether it be peak or average power drop off, due to overall fatigue from the phosphocreatine (PCR) system. This point or timeline is typically researched in running linear sprints, or most notably on a bike (Taylor et al, 2015). Gibala et al (2006) performed research focused around repeated Wingate tests in which the participant performed 30-second intervals to work as hard as they can at a fixed external resistance of 7.5% load / kg body mass and then had a rest period for four minutes of either low cadence spinning or no cycling. This time frame is necessary to properly allow the Phosphocreatine system to recover, but as the intervals continue, the recovery of the Phosphocreatine system cannot keep up with the demand and the reliance falls upon the glycolytic and oxidative systems to produce energy, resulting in a significant loss in power output and a greater fatigue rate throughout the intervals. Again, this is where the buffering ability plays a significant role in regulating the by-products of such intense work and keep systems within the body working at full capacity with necessary fuel and the ability to continually perform muscular contractions (Barnett et al, 2004; MacDougal et al, 1998). With the onset of more metabolic byproducts being created that cannot be removed (mainly H^+) at a fast enough rate, glycolytic enzymes become inhibited (Turner & Stewart, 2013) as well as a lack of ATP creation for actin-myosin coupling resulting in a reduced force production.

2.1.1 – Aerobic Capacity Improvements

The aerobic system specifically can produce energy for extended periods of time and is the system that continues producing energy during prolonged events. Typically, aerobic type training consists of submaximal work (Laursen, Shing, Peake, Coombes & Jenkins, 2002) for extended periods of time, the choice of training for more endurance-based athletes, such as running or cycling. This “steady state” type of training has been shown to improve the biochemical and physiological pathways due to the increase in need of energy at the muscle cellular level (Dubouchaud, Butterfiled, Wolfel, Bergman & Brooks, 2000; Larsen et al 2002). By increasing the body’s ability to transport and utilize oxygen, aerobic training is necessary for increasing energy supply to working tissue and continue work (Gibala et al., 2006). Maximal volume of oxygen consumption (VO_{2max}) is typically associated with this system as it takes an extended period of time and “ramp up” to achieve this value. This value is a general indication of fitness level, especially for high performance athletes. A typical value of 60 mL/Kg/min or higher is considered to be a high value for soccer players (Jastrzevbski, Rompa, Szutowicz, & Radzminski, 2013).

da Silva et al in 2015a, performed two generic aerobic training systems based on peak running velocity in U20 elite soccer players. Their training was a 1:1 work to rest ratio and the groups either ran a 10 repetition by 12 second shuttles (with changes of direction) or 20 repetitions by 6 second shuttles (no change of direction). Distance covered, heart rate and an incremental treadmill test were performed to find peak velocity. They found small increases in lactate threshold, velocity at VO_{2max}, and distance covered and velocity in the Carminatti's intermittent test. The authors state that although increases in VO_{2max} were found, it is not the best indication for verifying sport performance as there are other factors such as repeat sprint ability to account for. This brings the question of although their maximal oxygen uptake did not experience large improvements did their buffering capacity improve due to the nature of their training intervention. Aerobic capacity prescription is typically based on a percentages of maximum heart rate, velocity, percentages of VO_{2max} or distances covered (Iaia et al, 2015; Ziemann et al, 2011).

Laursen & Jenkins (2002) reviewed HIIT specifically in endurance athletes and found that most research did in fact find improvements in aerobic time trials and buffering capacities, but mixed results on VO_{2max} changes. They claim that this is due to already highly developed aerobic systems, mitochondrial function and lactate thresholds. The changes were more optimizing of these systems in regards to energy expenditure and metabolic enzyme activity, but not pushing them above their threshold or maximal limits. Here the consensus of working at a 1:2 work to rest ratio working at intensities above

80% of peak aerobic power output or the max aerobic speed would be enough of a stimulus to garner a change in at least buffering capacity response in trained individuals and potentially a VO_{2max} change in untrained individuals.

Table 1: Summary of Aerobic System Changes by Training Method

	Author	Date	Participants	Intervention Methods	Training Variable	Key Measure Pre-Post change	Response
Continuous and HIIT	Edge, Bishop, Goodman and Dawson	2005	20 Female Students VO_{2peak} ~ 42±	3 sessions/wk 5 weeks Group 1: HIIT @ 120% LT with 4-10 sets by 2minsduration Group 2: Continuous @ 80-95% LT for 12-30 mins duration	VO_{2max} (mL/kg/min)	Continuous: 10% Increase $p<0.05$ HIIT: 12% Increase $p<0.05$	Both methods improved VO_{2peak} but HIIT had better RSA total work performed due to better PCR recovery
Continuous And HITT	Foster et al	2015	65 Recreationally Active Males and Females	Continuous: 20 mins of continuous exercise at a Power output that required a VO_2 of 90% ventilatory threshold HIIT: 20 mins of 30s work interval (100% peak aerobic	VO_{2max} (mL/kg/min)	Continuous: VO_{2max} pre: 33.6 (+/- 5.4) VO_2max post: 40.1 (+/- 6.3) HIIT: VO_{2max} pre: 34.2 (+/- 9.1) VO_2max post:	3 x for 8 weeks of 3 groups (2 HIIT 1 steady state) found HIIT improved VO_{2max} just as much as steady state but in much less time, but not superior in untrained

				power) paired with 60 seconds of active recovery		40.6 (+/- 8.7)	individuals
HIIT	Chia et Cheng	2016	38 Recreationally Active Men	HIIT 10s: 48 x 10sec cycling sprints at 85% VO_{2max} with 20secs of active recovery HIIT 60s: 8x 60secs at 85% VO_{2max} with 120secs of active recovery	VO_{2max} (mL/kg/min)	HIIT 60: VO_{2max} pre: 51.9 (+/- 9.2) VO_2max post: 61.4 (+/- 12.2) HIIT 10: VO_{2max} pre: 52.6 (+/- 9.5) VO_2max post: 61.0 (+/- 9.6)	Both HIIT Groups (60 and 10secs work) increases in VO_{2max} in 4 weeks (3 sessions per week)
HIIT	Zieman, Grzywacz, Lusczczyk, Laskowski, Olek	2011	21 Recreationally Active Men VO_{2max} ~ 48mlkg	6x90sec cycling at 80% VO_{2max} at 60rpm with 180second passive recovery	VO_{2max} (mL/kg/min)	VO_{2max} pre: 50.1 (+/- 3.1) VO_2max post: 55.6 (+/- 5.5)	5.5 ml*kg increases in 3x6weeks of training at 80% VO_{2max}
HIIT	Da Silva, Nakamura, Carminatti, Dittrich, Cetolin, Guglielmo	2015	17 U-20 Elite Soccer Players VO_{2max} ~ 50+	Both Groups set to 100% Peak Running Velocity Group 1: 10x 12sec shuttle	VO_{2max} (mL/kg/min)	Group 12:12 VO_{2max} pre: 53.7 (+/- 5.6) VO_2max post: 55.8 (+/- 2.8)	4 training sessions x 6 weeks at Peak Running Velocity showed small increases in VO_{2max}

				runs (with a change of direction at 6 seconds) with 12 second recovery Group 2: 20 x 6sec shuttle runs with no changes of direction and 6 secs of recovery		Group 6:6 VO_{2max} pre: 59.1 (+/- 2.7) VO_2max post: 60.0 (+/- 3.5)	but not significantly different between groups
SIT	Machpherson and Weston	2015	23 Semi Pro Soccer Players (25+/- 4yrs old)	4-6 30second sprints	VO_{2max} (mL/kg/min)	VO_{2max} pre: 52.7 (+/- 4.7) VO_2max post: 55.7 (+/- 6.4)	2 weeks (6 training sessions) increased VO_{2max} from Yo-Yo Tests, only calculated, not necessarily improvements
SIT and HIIT	Fernandez-Fernandez, Zimek, Wiewelhove, Ferrauti	2012	31 Competitive Male Tennis Players (VO_{2peak} of ~55)	HIIT: 3 x3 90second runs at 90-95% HRmax with 3 mins of active recovery SIT: 3 x 10 x 5	VO_{2max} (mL/kg/min)	HIIT: Pre VO_2peak: 56.3 (+/- 4.0) Post VO_2peak: 59.1(+/- 2.9)	3 x 6 weeks resulted in VO_{2Peak} increases in both, not significantly different in either group

				second all out sprints with 15 secs rest		SIT: Pre VO_2peak : 55.6 (+/- 5.0) Post VO_2peak : 58.6(+/- 2.9)	
Continous And HIIT	Gonzalez - Mohino et al	2015	11 Recreational Runners VO_{2max} ~50)	HIIT: 1:1min Work to rest ratio of 100:50% Max aerobic speed Continuous: 75% Max aerobic speed continuous	VO_{2max} (mL/kg/min)	Continuous VO_{2max} pre: 55.48 (+/-8.45) VO_2max post: 51.66 (+/- 6.68) HIIT VO_{2max} pre: 57.71 (+/-8.92) VO_2max post: 56.20 (+/- 6.85)	3x 6 weeks resulted in increased Max Aerobic Speed, reaching VO_{2max} at much higher speeds and better runny economy.
SIT	Barnett et al	2004	16 Untrained Recreationally Active	3-6 30second sprints cycling	VO_{2peak} (L/kg/min)	VO_{2peak} pre: 3.78 (+/- 0.11) VO_{2peak} post: 4.09 (+/- .12)	3 x 8weeks resulted in 8% increase in VO_{2peak}. Increases in muscle oxidation, but not glycolytic capacity

It is evident from most of this research, there is a need for better understanding of how the adaptation occurs for high level athletes in aerobic based training. The comparisons between methods do show a small increase in VO_{2max} however since they were limited in their scope (only looking at VO_{2max}), potentially looking at more variables could give a clearer picture of the full extent of the improvements. It is also clear that the comparison between different training measures yield similar results if the intensities and duration are equal to each other, however it is much harder to improve ventilatory threshold in elite level athletes. Instead the goal should be working more at improving the efficiency of the buffering system and improving the function of energy production.

2.1.2 Assessment of System

The gold standard for measuring the aerobic system's capacity is with Gas Exchange using a specific graded protocol on either a bike or a treadmill (Helgerud etl al, 2007). Depending on the athlete being tested, the specific instrument used to determine activity (i.e. bike or treadmill) can have a significant effect on whether a VO_{2max} is truly achieved. For instance, in many bike protocols the participants are required to hold a certain wattage or revolutions per minute during a stage against a set resistance. However, these measures are either too hard to achieve or two hard to maintain resulting in peripheral muscle fatigue, rather than central fatigue (i.e. cardiorespiratory). Cyclists can typically reach a VO_{2max} on a bike representing a balance between central and peripheral fatigue because they have trained their body to do work against the resistance as part of their sport specific training (Ricci & Leger, 1983). A treadmill protocol is more practical for assessing running VO_{2max} as it relates more to the "on the field" experience as compared to cycling, which does not.

Certain field based tests such as the 20m Shuttle Run or Montreal Track Test have been used as a general predictor of VO_{2max} (Leger & Boucher, 1980; Leger, Mercier, Gadoury, & Lambert, 1988) based on which stage and level is achieved and calculated with their own respected regression equations. The idea is that as the test progresses the levels get faster and forces the system to work harder. Since it increases linearly, the idea is that VO_{2max} will increase linearly as well, very similar to a treadmill graded test in which speed and/or grade are adjusted in a linear fashion. These shuttle or track tests have yielded similar results to gas exchange but are not as completely accurate. As compared to a treadmill graded test with gas exchange, specific changes in VO_{2max} can be monitored and the grade and speed are changed at specific intervals very similar to the shuttle tests. The changes of direction are typically omitted or corrected for in these tests, as it creates too much of an anaerobic stimulus (Buchheit & Mendez-Villanueva., 2014) and thus is not as accurate a measure of aerobic capacity as it could be.

2.1.3 Maximal Aerobic Speed (MAS)

Maximal Aerobic Speed (MAS) is categorized as the lowest running speed or velocity in which maximal oxygen uptake can be achieved or plateau, measured in meters/second (Léger, Mercier, Gadoury, & Lambert, 1980). It can be measured in a variety of tests, typically covering a specific distance and recording the total time it took. With these values, they can be put into a "corrective" equation in order to give a more accurate rating of MAS.

This type of measurement is great for sport as it gives a great indication or aerobic power for an athlete in sport that is highly aerobic, i.e. relying on their aerobic system to supply energy during a long game. Interval training can be set based on these values to determine a certain distance an athlete needs to cover in a certain amount of time to achieve the desired workload. At 100% MAS an athlete is not running at full velocity, but intervals can be set higher to try and challenge the athlete and work on maximal running velocity. Changes of direction are typically limited as it elicits more of an anaerobic stimulus which brings in more variables, such as increased muscle activation and proprioception (Buchheit, 2008), in order to return back to the start area of the interval.

The 20m Shuttle Run test (Léger et al., 1988) and the Montreal Track Test (Leger & Boucher, 1980) have both been utilized to quantify MAS using the last stage of the test reached by the participant as their highest running velocity. The Shuttle run needs a “corrective” equation to account for changes of direction, as MAS is more accurate when performed in a straight path. The Yo-Yo Intermittent test has also been used and has been used by more field-based teams as it allows for a “recovery” portion, as compared to the other two which are continuous running as the stages increases.

2.1.4 – Buffering Capacity Improvements

Training for improvements in buffering capacity are all based on lactate levels in the blood and the onset of lactate threshold. Finding the level of intensity and/or duration it takes for the participant to reach lactate threshold will give a better understanding on how training can be programmed. Typically, percentages of intensity or allowing the body to achieve lactate threshold is utilized as a training tool which allows the body to work under higher stress situations. Steady state training has been shown to decrease muscle lactate concentrations by increasing lactate clearance and lowering the amount produced at lower intensities (Dubouchaud et al, 2000). Athletic populations can also switch between lipid and carbohydrate oxidation for energy much faster and when needed as compared to the general population (San-Millan & Brooks, 2017). This is helpful as the body can have an energy source more readily available for activity and still continue producing energy for muscle contraction instead of halting all together.

Table 2: Buffering Capacity Changes by Training Method

	Author	Date	Participants		Training Variable		Response
HIIT and Continous	Edge et al	2005	20 female students VO_{2peak} 40+	3 sessions/wk 5 weeks Group 1: HIIT @ 120% LT with 4-10 sets by X duration Group 2: Continuous @ 80-95% LT for 12-30 mins duration	LT, Phosphocreatine and H^+	LT: HIIT 8% improvement Continuous 10% improvement Both p<0.05 PCR and H+ Significant Decrease p <0.05	3x 5 weeks of training either HIIT (6-10, 2 min intervals at 120-140% LT) or Continuous (20-30mins at 80-95% LT). Both groups increased H+ and Lactate after the tests, but not significant enough difference between groups, but saw increas

							es in PCR which would account for better RSA in both groups. Both work, HIIT works in far less time
HIIT	Edge et al	2013	12 Women (VO_{2max} ~ 40)	3 x 5 weeks of training at either HIIT 1:1 or HIIT 1:3 work to rest ratio	Muscle Biopsy, Muscle H^+, Lactate Content, PCR	Blood lactate increase (HIIT 1 :12.9 +/- 1.8mmol. HIIT 3: 15.5+/- 3.0) post exercise , H+ increased (79.2+/- 2.6 to 125+/- 8nmol, and 78.4+/- 3.2 to 155+/- 15nmol) and PCR content was less (83.1+/-	3x 5 weeks of training in either a 1:1 or 1:3 work to rest ratio yielded decrease in H^+, and lactate content but no significant decrease in PCR, however rest did not play a signific

						8.6 to 63.4 +/- 9.8mmol and 82.5+/- 9.3 to 52.8+/- 8.3mmol)	ant enough role to warrant a difference between the groups
SIT	Barnett et al	2004	16 recreationally active males	3 x 8 weeks of sprint training (30 second sprints with 3 mins rest)	Muscle Biopsy, High Energy Phoshpagens, glycogen, lactate and PFK and CS	CS Activity in training group increased (10.5 to 14.9 umol, p<0.01) PCR degradation during sprint exercise increased (p<0.05)	A 42% increase in CS activity and 17% increase in PFK, but not change in fibre type distribution
SIT	MacDougall et al	1998	12 Recreationally active men	4-10 30 second cycling sprints with 4 mins of recovery	Enzyme Activity	PFK ~49% higher (p<0.05) CS ~36% higher after training	3x for 7 weeks of sprint training (30 sec Wingates with 4 mins rest repeated) showed maximal

							enzyme activity in hexokinase, PFK, and CS.

Here the research has shown what happens at the microscopic level and looks at the more isolated changes during these types of metabolic adaptations, but still not fully linked to the much larger picture of all systems working together. Taking a more holistic approaching and looking at all systems together needs to be performed on an athletic population. This type of training does in fact increase enzymatic activity in both recreationally active and trained participants and gives a better idea of how things are working within the body if no increases on the global scale of aerobic or anaerobic capacities do not change.

2.2 – Limitations in the Literature

Limitations in the research surround the fact that HIIT and SIT have not had a comparison that truly shows the proper training capacities and intensities together within the same study. Along with this most research only looks at HIIT and SIT individually or against steady state work only to show that the same results can be achieved in a much smaller time frame. Also, research does not compare the same work to rest ratios, the focus centers around ensuring the same total work is performed, but varied rest to allow for a better system recovery. A recent study by Wood et al (2016) indicate that they have not come across any research directly comparing HIIT vs SIT. Their research approach used both HIIT and SIT training interventions, but upon further investigation, they used two HIIT workouts, one just being more intense than the other, but neither being maximal in nature. They also had a very small sample size of active adults whereas training athletes may yield different results as well as utilizing a SIT training protocol with a decrease in output throughout each interval rather than holding intensity at a constant rate.

As well most research is looking at interval and rest periods that are vastly different. For SIT, large amounts of rest are given to fully replenish the participant. For HIIT the rest is based on the goal of the intensity prescribed in the study, which can vary significantly. For both cases this is again looking at the metabolic systems individually and not linking them together. Having a protocol with similar work to rest ratios, but varying intensity is needed to see specifically the difference intensity has on metabolic adaptations. These two types of training methods come down to which is the better recruitment strategy for improving metabolic performance.

Chapter 3 - Methods

3.1 – Participants

Prior to research starting, ethical approval for research with human participants was obtained from both the University of New Brunswick and St. Thomas University Research Ethics boards (REB 2019-040). Seventeen participants volunteered to participate in the study. All participants were recruited from St. Thomas Tommies University Varsity Teams in Fredericton, NB. Of those seventeen, thirteen (9 males and 4 females) (22.1 ± 2.5 years; 171.9 ± 10.0cm; 74.4 ± 11.3 kilograms) completed the study. Four participants had to withdraw from the study. One participant aggravated a pre-existing hip flexor issue before final testing, two participants were withdrawn due to time constraints, and one participant was not cleared from their blood pressure checks post VO_2max testing. Inclusion criteria for participation in the research was strictly adhered to.

Inclusion criteria:

1. Between the ages of 19 and 35 years old.
2. Currently play a collegiate level sport such as basketball or soccer
3. Must be in offseason of said collegiate sport

3.2 – Experimental Design

Participants performed pre-testing in the lab before training began in order to establish baseline measurements. First participants were asked to complete a graded aerobic exercise protocol on a treadmill while open circuit spirometry monitors gas exchange. Upon completion of the test, the participants were required to sit and rest while EPOC was monitored via open circuit spirometry. Once EPOC was recorded participants were disconnected from the gas exchange cart and given ample time to rest and were cleared to leave the lab once blood pressure and heart rates were back down to resting level. Participants were randomly sorted into the either a HIIT or SIT group based on a randomized block design stratification method using a Sealedenvelope.com to perform the randomization. Participant groupings were not determined until following testing, allowing for the blinding of the researcher to the group of the participant prior to testing. Metabolic training each week used the following protocol:

Table 3: Intervention Guidelines for each Training Week for Both HIIT and SIT

Week	Interval Number	Interval	HIIT Pace	SIT Pace
1	4	1:1min	120% MAS	All Out
2	4	1:1min	120% MAS	All Out
3	6	1:1min	120% MAS	All Out
4	6	1:1min	120% MAS	All Out
5	8	1:1min	120% MAS	All Out
6	8	1:1min	120% MAS	All Out

Each participant underwent pre and post testing as well as a six week intervention in which they performed training three times per week in the Canadian Sport Centre Atlantic High Performance Centre supervised by the primary researcher who is a Certified Strength and Conditioning Specialist through the National Strength and Conditioning Association. Following the training period, the testing was repeated to obtain post testing measures and a comparison of training interventions were made. Participants completed at least 85% of their sessions and did not miss more than three sessions during the training time. Had participants missed three sessions or two back to back, then their data would be omitted from the study. This was not the case for the participants recording in this research.

Participants were asked to keep a consistent schedule outside of training in regards to sleep and nutrition as well as keep a normal routine in regards to their sport. Having three sessions a week with a weight program and three days of conditioning it was told that participants did not need to go to the gym on top of the intervention.

3.3– Testing Protocol

Each participant filled out a "Get Active Questionnaire: Canadian Society for Exercise Physiology; 2017" form before completion of any testing which can be found in Appendix D. They also had their height and weight measured on a stadiometer and digital scale.

3.3.1-Aerobic Capacity (VO_{2max}**)**

Participants followed a graded VO_{2max} test protocol on the treadmill in which speed increased at specific intervals set to reach either a VO_2 plateau or the participant volitional fatigue. The testing protocol followed the speeds and progressions from the Australian 20m Beep Test but performed on a treadmill (without changes of direction) and is listed below.

Table 4: Treadmill Graded Exercise Protocol

Time (mins)	Speed ($km\text{-}h^{-1}$)	Grade (%)
0-2	8.0	+1.0
3-4	9.0	+1.0
4-6	10.0	+1.0
6-7	10.5	+1.0
7-8	11.0	+1.0
8-9	11.5	+1.0
9-10	12.0	+1.0
10-11	12.5	+1.0
11-12	13.0	+1.0
12-13	13.5	+1.0
13-14	14.0	+1.0
14-15	14.5	+1.0
15-16	15.0	+1.0
16-17	15.5	+1.0
17-18	16.0	+1.0
18-19	16.5	+1.0

After voluntary fatigue a one-minute rest was given and then a confirmation stage was performed at 1.0 km above the level the participant reached until a second voluntary fatigue occurs to see if VO_{2max} was achieved.

From this test VO_{2max} was measured from the gas exchange cart (Parvomedic True One 2400), heart rate (with a Polar heart rate monitor and chest strap) and rate of perceived exertion using the Borg Scale (Borg, 1982), were also measured. The test concluded upon the participant either reaching peak of a VO_{2max} plateau when intensity was raised to the next level, RER reaching above 1.10, a heart rate within 10% of predicted maximal, or voluntary fatigue of the participant.

3.3.1.1 – Aerobic Capacity Assessment Variables of Interest

Following the aerobic capacity assessment, the following variables were determined in order to assess for pre-post intervention changes: Aerobic capacity was calculated as the average of the final 30 seconds of the last successful stage of exercise, VT1 was measured using the V-slope method. This was performed by taking the slopes of the two lines of best fit of the Volume of Oxygen Consumption versus the Volume of Carbon Dioxide Production curve and looking at the point of intersection. This point was classified as the Ventilatory Threshold (VT). An example of this is listed below by Ghosh (2004):

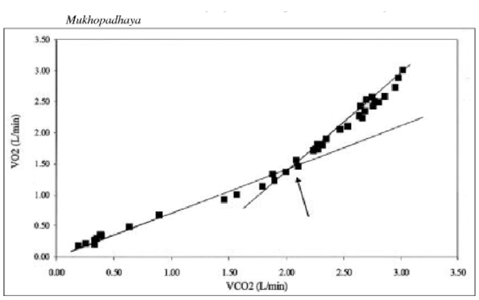

Figure 1: Depiction of VT Slope method by Ghosh (2004).

Once confirmed this point was also used to calculate VO_2 at VT as well as the percentage of VO_{2max} at VT.

3.3.2 - Excessive Post Exercise Oxygen Consumption (EPOC)

Following the VO_{2max} test on the treadmill participants were asked to keep the breathing apparatus on from the open circuit spirometry system for a period of up to 10 minutes to allow for the assessment of the fast slope of EPOC and heart rate recovery. The fast slope of EPOC and changes are what are going to be of most interest giving the best indication of recovery.

3.3.2.1 – Recovery Rate Variables of Interest

Following the EPOC assessment, the following variables were determined in order to assess for pre-post intervention changes: This was measured by looking at the difference in VO_2 drop over a rolling 1 minute average (looking at breaths every 15 seconds) and finding the steepest drop as the optimal recovery rate. As well upon completion of the graded test oxygen consumption for five minutes will be calculated and used as a measure of recovery in conjunction to EPOC fast slope recovery.

3.4 – Experimental Protocol

Upon completion of the pretesting participants underwent a six week training intervention in which they performed training three times per week. Training included a strength training program, in Appendix A, as well as a specific metabolic conditioning program listed below:

Each participant was assigned to either the HIIT or SIT group and perform the training protocol listed in Appendix A.

The HIIT group followed a protocol of running to a pace that matches 120% of their maximal aerobic speed (which was determined from their VO_{2max} test on the high speed treadmill). This was used to calculate how much distance can be covered in 1 minute accounting for both linear running and changing of direction. This pace will be kept using a Gymboss™ Timer that participants wore while performing interval work. In most cases the experimenter would monitor time in order to count distance covered.

The SIT group followed a protocol of running as fast as they can while trying to maintain as high a velocity as possible throughout the trial.

The participants (regardless of group) ran 20-meter change of direction shuttles for one minute with a one minute rest for the specific number of sets as listed in Appendix A. Distance covered was recorded for each participant regardless of groups to allow for the assessment of training volume as well as ensure the participants in the HIIT group maintained their desired pace.

The weight workout protocol by both groups followed a basic strength phase loading scheme with linear periodization through six weeks. Basic lifts were utilized and were programmed as a Tri-superset with enough rest to not garner a confounding metabolic response. The workout routine can be found in Appendix A.

3.5 Work Calculations from Interval Intervention

Distance covered by every participant within the intervention was recorded from each training session completed. The amount of distance covered was measured to the last five-meter mark crossed in a twenty meter straight away. These distance were used with the participants starting body weight and a calculation of Work (weight x distance) was used as a comparison to see if there is a difference between the amount of work performed both HIIT and SIT groups.

3.6 – Data Analysis

For this experiment the statistical software R was used for data analysis. Data was assessed for normality using the Shapiro-Wilk Normality test. As well as a Levene's test was used to assess homogeneity of variance in the sample. Work calculations within the intervals for each participant were analyzed using a Mixed Model ANOVA due to the large sample size. To see if there were significant differences between the group for the measured variables a Wilcoxon ranked sum test (Mann-Whitney U-Test) was used to determine if there were significant differences between groups. A Wilcoxon signed rank test was used to determine differences between the two assessment timepoint. The between groups variables was Group (HIIT vs. SIT) and the within variables was Time (Pre vs Post). An interaction effect of Group x Time was assessed and is the primary assessment of interest by using the percent changes from pre to post training.

Dependent Variables:

Model 1: Aerobic Assessment 1
VO_{2max}
Model 2: Aerobic Assessment 2
VO_2 at Ventilatory Threshold, Percentage of VO_{2max} at Ventilatory Threshold
Model 3: Recovery Rate
1minute of fast slope of EPOC recovery rate
5minutes of oxygen consumption
Model 4: Work Assessment
Distance Covered during Intervention

Independent Variable: Training Groups (HIIT and SIT)

Chapter 4: Results

From this experiment a total 18 participants were recruited, two participants could not maintain the minimum completion percentage, two participants were injured under circumstances outside of training during the intervention and one participant was not cleared from initial prescreening. Thirteen participants completed six weeks of training three times a week. Seven participants were randomly assigned to the HIIT group and six were randomly selected to the SIT group after prescreening and baseline testing. These participants were randomly allocated to their groups using a sealed envelope method, that was blind to the research. Participants kept an attendance of 92.1 +/- 6.5% completion of total sessions throughout the training period. Compliancy rate of the attended sessions was 100%.

Table 5: Anthropometrics of Participants Tested

Group	**Age (years)**	**Height (cm)**	**Weight (kg)**
HIIT	21.9+/- 2.8	168.50+/-11.55	70.60+/- 13.77
SIT	22.2+/-2.3	174.80+/-8.30	77.61+/-8.50

4.1 Assumption Assessment for a Mixed Model Analysis of Variance

Tests for normality on the data were conducted using the Shapiro-Wilk test for normality and can be seen in below:

Table 6: Shapiro Wilks Test for Normality at each Time Point for HIIT and SIT Groups

Value	**Group**	**Time Point**	**P Value**
VO_{2max}	HIIT	Pre Post	0.830 0.490
	SIT	Pre Post	0.240 0.870
VO_2 at VT	HIIT	Pre Post	0.730 0.180
	SIT	Pre Post	0.180 0.265
Percent of VO_{2max} at VT	HIIT	Pre Post	0.700 0.980
	SIT	Pre Post	0.002 0.380
EPOC Recovery	HIIT	Pre Post	0.210 0.401
	SIT	Pre Post	0.667 0.447
O_2 Consumption	HIIT	Pre Post	0.27 0.69
	SIT	Pre Post	0.099 0.797

The only statistic that was not normally distributed was Percentage of VO_2 at VT Pre ($p=0.001$). To rectify this Wilcoxon non parametric tests will be used to look at the main effects of time, group and interaction effects due to the smaller sample size collected in this study.

4.2 Interval Breakdown from Training Day for HIIT and SIT

As an example of the training load applied to the participants, the work performed during week four day three for the HIIT and SIT groups can be assessed. As seen in figure 2, the pattern of training load is consistent with the intention of the researcher during the training days. The HIIT group maintained a consistent volume of work over the six sets of training, while the SIT group started with a higher volume of work performed at during the initial sets transitioning to a lower volume of work being performed during the later sets. This indicates that the SIT group was experiencing fatigue as a result of the training load, consistent with the expectations of the training intervention.

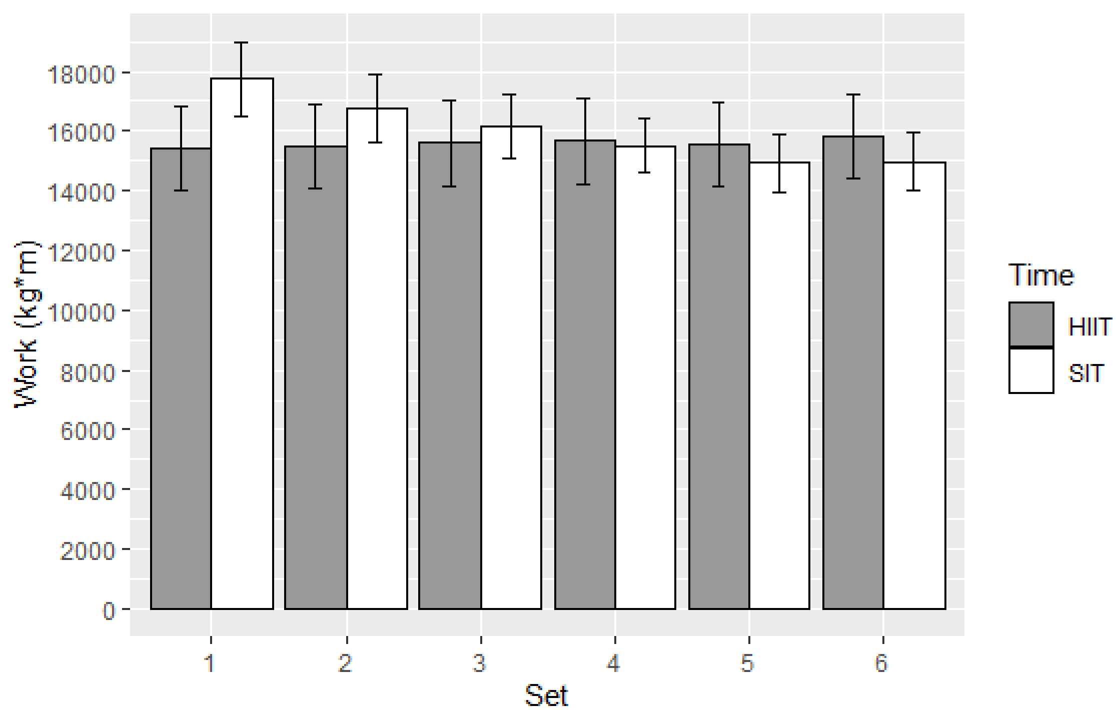

Figure 2: Work performed during interval sets for both HIIT and SIT groups during Week 4 Day 3 of the training intervention.

4.3 Work Calculation During Intervention

Total work, as a measure of kilogram meters, was used as a compliance measure for this research to show each participant's performance within the intervention regardless of training group. From the measure for Work there was a significant main effect for Time (F(1,5)= 221.9, p<0.001) and no significant main effect for Group (F(1,5)=0.67, p= 0.430). There was no significant interaction effect (F (1,5) = 0.9, p = 0.485). The Work measurement during training for both training groups and timepoints are presented in figure 3.

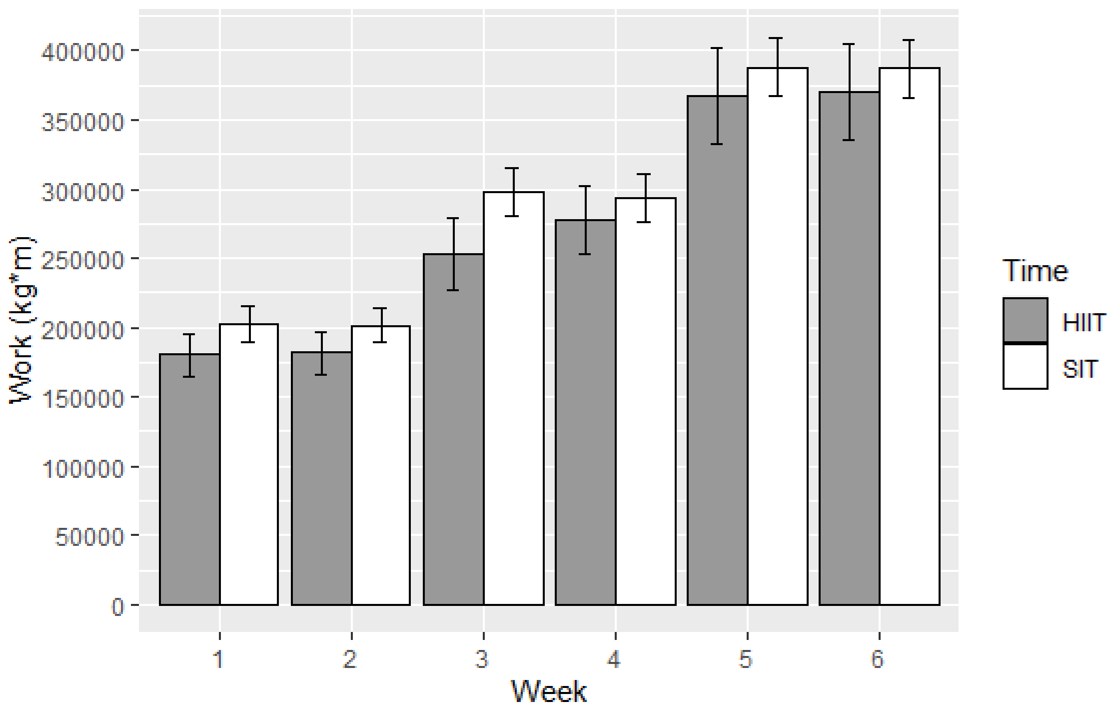

Figure 3: Distances covered during interval sets for both HIIT and SIT groups during Week 4 Day 3 of the training intervention.

4.4 VO_{2max} Measurement

Hypothesis 1: Following six weeks of training there will be significant increases in Aerobic Capacity (VO_{2max}) in both training groups, as indicated by a time main effect.

Table 7: VO2max Measurements for both Intervention Groups

Group	Time Point	Group Average and Standard Deviation
HIIT	Pre Post	48.93 +/- 6.76 mL/kg/min 52.70 +/- 6.45 mL/kg/min
SIT	Pre Post	50.12 +/- 4.75 mL/kg/min 52.74 +/- 7.83 mL/kg/min

From the measure for VO_{2max} there was no significant main effects for Time (W=27, p = 0.220, or Group (W= 81, p = 0.900. The interaction effect (W= 26, p = 0.534) was observed. The VO_{2max} measurement during testing for both training groups and timepoints are presented in figure 4.

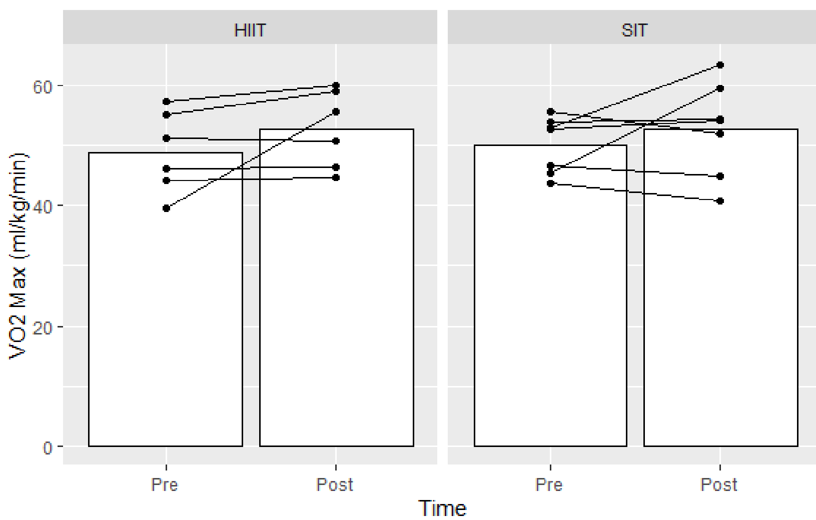

Figure 4: VO2max, in milliliters/kilogram/minute, during aerobic capacity treadmill test for both the HIIT and SIT groups pre and post six week training.

4.5 VO_2 at Ventilatory Threshold Measurements

Hypothesis 2: Following six weeks of training there will be a significant increase in VO2 at VT in both training groups, (represented as an absolute volume of VO2) as indicated by a time effect.

Table 8: VO2 at Ventilatory Threshold Measurements for both Intervention Groups

Group	Time Point	Group Average and Standard Deviation
HIIT	Pre Post	30.12 +/- 2.94 mL/kg/min 32.79 +/- 2.73 mL/kg/min
SIT	Pre Post	29.85 +/- 2.02 mL/kg/min 32.14 +/- 3.49 mL/kg/min

The measure of VO_2 at Ventilatory Threshold demonstrated a significant main effect for Time (W=12, p= 0.017, *d=0.89*). The measure for Group (W= 91, p = 0.740) and the interaction effect (W= 22, p = 0.950) were both non-significant. The VO_2 at ventilatory threshold measurement during VO_2 testing for both training groups and timepoints are presented in figure 5.

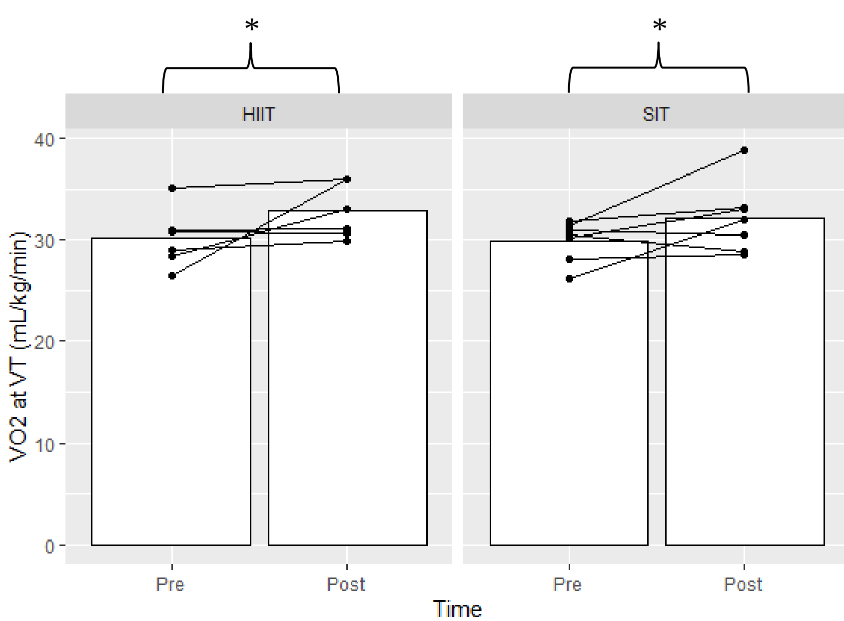

Figure 5: VO2 at Ventilatory threshold, in milliliters/kilogram/minute during aerobic capacity treadmill test for both the HIIT and SIT groups pre and post six week training. * represents a significant different between time points as seen by a time effect.

4.6 Percent VO_{2max} at Ventilatory Threshold Measurement

Hypothesis 3: Following six weeks of training there will be a significant increase in Ventilatory Threshold (VT) in both training groups, (represented as a percentage of VO_{2max}) as indicated by a time effect.

Table 9: Percentage of VO2max at Ventilatory Threshold Measurements for both Intervention Groups

Group	Time Point	Group Average and Standard Deviation
HIIT	Pre Post	62.08 +/- 6.19 % 62.57 +/- 4.39 %
SIT	Pre Post	59.80 +/- 4.59 % 61.68 +/- 7.95 %

The measure of Percentage of VO_{2max} at Ventilatory Threshold showed no significant differences for the main effects of Time (W=23, p =0.840), Group (W=37, p= 0.590). The interaction effect (W=21, p= 1.000) for Time x Group was non-significant as well. The Percentage of VO_{2max} at ventilatory threshold measurement during VO_{2max} testing for both training groups and timepoints are presented in figure 6.

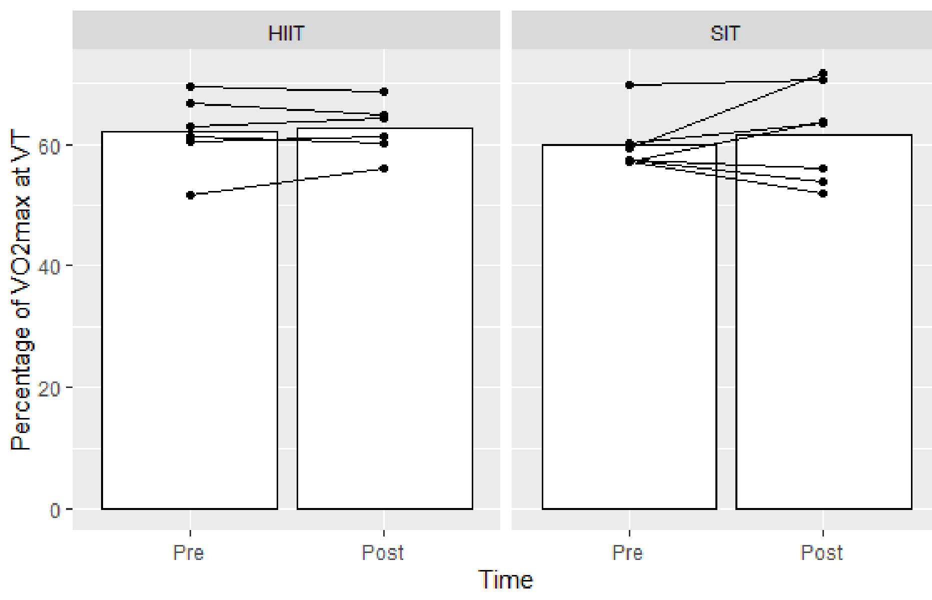

Figure 6: Percentage of VO2max at Ventilatory threshold, during aerobic capacity treadmill test for both the HIIT and SIT groups pre and post six weeks training.

4.7 Excessive Post Exercise Oxygen Consumption Measure

Hypothesis 4: Following six weeks of training there will be a significant decreases in Fatigue Index, measured as a decrease in Fast Slope of Excessive Post Exercise Oxygen Consumption post VO_{2max} *test in both groups, as indicated by a time main effect.*

Table 10: Excessive Post Exercise Oxygen Consumption Measurements for both Intervention Groups

Group	Time Point	Group Average and Standard Deviation
HIIT	Pre Post	21.97 +/- 3.14 mL/kg/min 23.03 +/- 1.90 mL/kg/min
SIT	Pre Post	21.45 +/- 3.98 mL/kg/min 24.00 +/- 5.04 mL/kg/min

The measure of Recovery Rates using an EPOC demonstrated a significant main effect for Time (W= 12, p = 0.021, *d=0.5*). The main effects for Group (W=88, p =0.860) and the interaction effect (W = 14, p= 0.370) of Time x Group were both non-significant. The Recovery measurement during VO_{2max} testing for both training groups and timepoints are presented in figure 7.

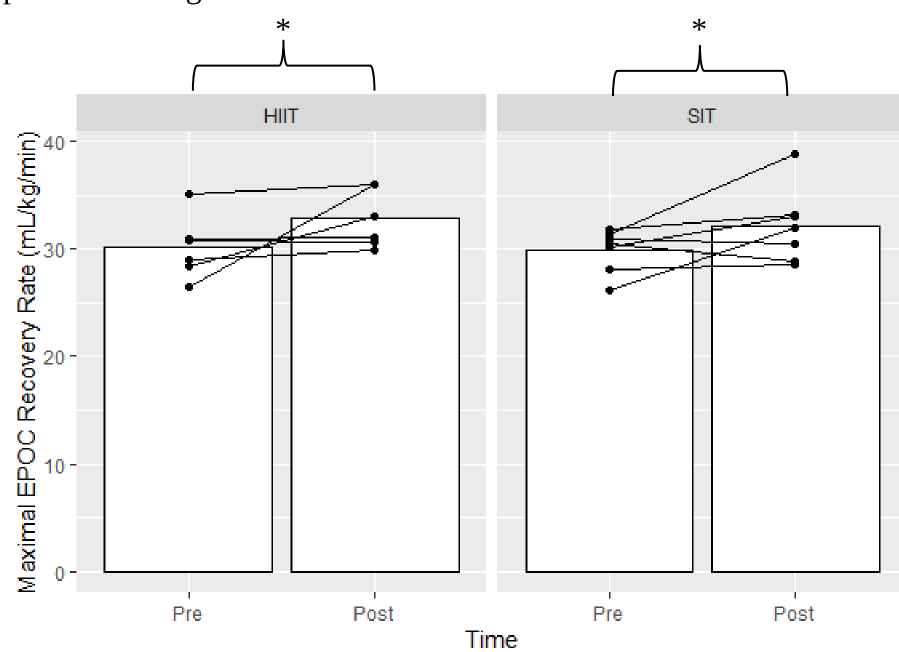

Figure 7: Excessive Post Exercise Oxygen Consumption measure, in milliliters/kilogram/min, during aerobic capacity treadmill test for both the HIIT and SIT groups before and after training. * represents a significant different between time points as seen by a time effect.

Table 11: Total Oxygen Consumption during Excessive Post Oxygen Consumption Measurements for both Intervention Groups

Group	Time Point	Group Average and Standard Deviation
HIIT	Pre Post	5.30+/- 0.70 L 5.45 +/- 0.76 L
SIT	Pre Post	5.68 +/- 0.60 L 5.84 +/- 0.67 L

The measure of O_2 consumption during EPOC demonstrated a significant main effect for Time (W= 13, p = 0.021, *d=0.61*). The main effects for Group (W=76.5, p = 0.720) and the interaction effect (W= 19, p = 0.840) of Time x Group, were both non-significant. The oxygen consumption measurement during VO_{2max} testing for both training groups and timepoints are presented in figure 8.

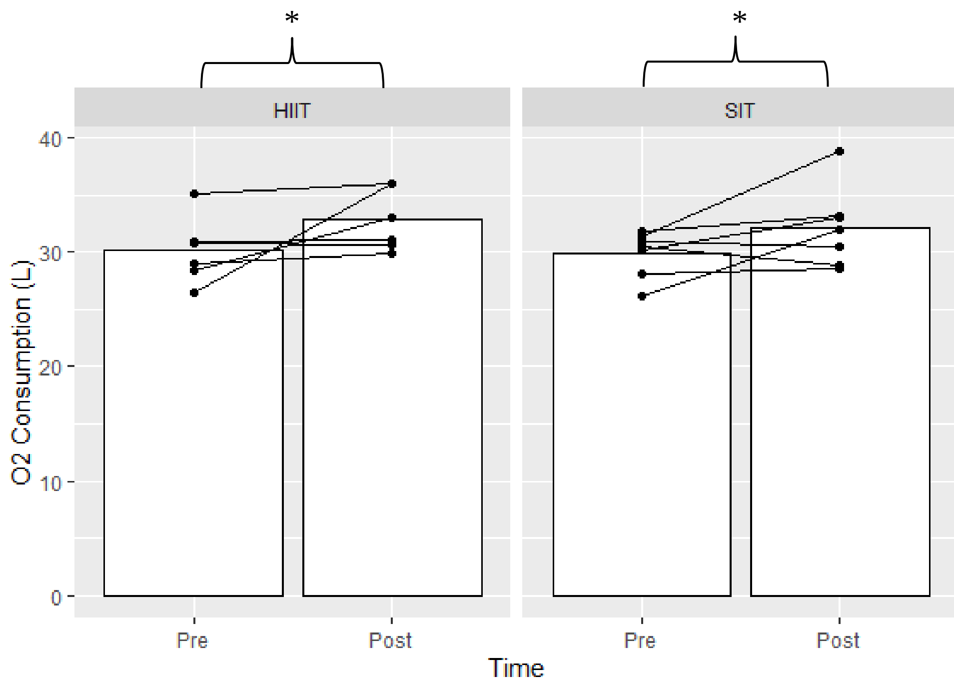

Figure 8: Oxygen Consumption measure, in liters, during aerobic capacity treadmill test for both the HIIT and SIT groups before and after training. * represents a significant different between pre and post testing for both groups as seen by a time effect.

Chapter 5 Discussion

The purpose of this study was to assess the changes in aerobic capacity and recovery rates in an athletic population comparing HIIT and SIT methods when matched for duration of exercise and sets. The findings of this study suggest that there is no significant difference in aerobic performance measures or recovery rate when comparing the two intervention methods over a six week intervention period. Based on the results of this study there was a significant time effect for VO_2 at Ventilatory Threshold and Recovery Rates during EPOC. Both of these variables improved over the duration of the intervention in both groups. However, neither VO_{2max} nor the percentage of VO_{2max} at Ventilatory Threshold demonstrated an improvement in performance. The increase in VO_2 at Ventilatory Threshold and the lack of improvement in VO_{2max} may be explained by the training status of the participants involved in this intervention. The participants were trained athletes at the Canadian Collegiate Athletics Association or University Sport level with 3.6 +/- 0.9 years of competitive experience. With this, the participants had well established aerobic systems represented by high VO_{2max} scores during initial testing (49.0 +/- 5.5 mL/kg/min). Although statistically absolute VO_{2max} values did not change over the duration of the intervention, the participants ability to manage a higher work rate prior to achieving VT was improved. This is a common finding in studies that used training at intensities at or near VO_{2max} (Esfarjani & Laursen, 2007; Stöggl & Sperlich, 2014). Regarding the increased recovery rate during EPOC, all participants trained at a work to rest ratio of 1:1 during the intervention. Previous literature has suggested that this work to rest ratio can result in significant improvements in recovery rate (Esfarjani & Laursen, 2007; Cicioni-Kolsky, Lorenzen, Williams & Kemp, 2013; Stöggl & Sperlich, 2014). The work to rest ratios in this research was set to closely mimic an aerobic training interval (1:1) as compared to traditional SIT work to rest (1:4-8) (Baechle & Earle, 2008). This research set out to have the same total volume of work between the compared intensities to see if the difference in muscle recruiting strategies influenced the metabolic adaptations. As outlined by Potvin & Fuglevand (2017) sustained recruitment during high intensity activity will fatigue high threshold muscle fiber types resulting in a reduction in overall force production and as one would speculate, a reduction in sprinting speed. The HIIT group recruited low and moderate threshold motor units to develop the force needed to maintain the running pace. As fatigue in the moderate intensity fibers set in, high threshold fibers would then be recruited to help sustain the force output, allowing the participant to maintain their running speed over the duration of the interval. Figure 1 gives a breakdown of a training session for all participants in week four of the training intervention to see the trends of both groups. The HIIT group stays relatively consistent due to their pacing strategy. However, the SIT group had a decreasing trend as sets going on. Total distance covered for each participant was recorded every day for every interval completed and summary work data can be found in Figure 2. It was found that only a time main effect was found for total work performed, which makes sense as the interval programming was designed to increase every two weeks to continue challenging the participants. For the HIIT group in this research it seems as though the work rate was more manageable as total work rate did not change drastically during the sets within a specific a specific training day. Once participants became accustomed to their designated distance requirement, they were able to hold their pace times consistently from set to set. As for the SIT group the work rate was much different in that participants were expected to fatigue throughout each session. In the SIT group with the added interval in later weeks there was a drop off in work rate within the interval due to fatiguing nature of this style of training, as seen in Figure 1. However, from figure 2 there was only a time effect change in total work performed between these two interval groups. The program was set up to increase intensity for both group simultaneously, but the amount of work performed by both groups was not statistically different.

It was hypothesized that there would be an increase in VO_{2max} following six weeks of training, however this was not supported as there were no changes following the intervention. There was potential of no change due to the training status of the participants prior to performing the intervention because of their already established aerobic capacities. It has been well documented that collegiate level athletes have high levels of VO_{2max} and despite varying training interventions often result in no significant changes in aerobic capacity following these interventions (da Silva et al, 2015; Fernandez-Fernandez, Zimek, Wiewelhove, Ferrauti, 2012; Machperson and Weston 2005).

Da Silva et al (2015) did a similar study with seventeen soccer athletes (VO_{2max} = 59.1+/- 2.7 ml/kg/min) where groups were split as either 10x 12 second shuttle runs with 12 seconds rest or 20x 6 second shuttle runs with 6 seconds rest both at 100% of peak running speed. Each group ran for 4 minute intervals dispersed with 3 minute rests in between intervals twice a week for five weeks. They concluded that there were no significant changes in VO_{2max} both between their intervention groups and over the training period but saw improvements in peak running velocity and lactate threshold. They concluded that the lack of improvements in VO_{2max} was due to the trained nature of the participants but that they still had changes in supporting systems like running velocity due to the repeated nature of the training. Unlike traditional aerobic training da Silva et al's (2015) study had more stop and start, rest and recover moments that more closely mimicked an actual soccer game. This study was performed during preseason which may have been a better timeline as most athletes would be coming in lacking injuries and have a block of time where competition may not occur.

Esfarjani & Laursen (2007) had similar findings with seventeen moderately trained runners (VO_{2max}: 51.3 +/- 2.4 mL/kg/min) that were split into two HIIT groups and a control group to assess changes following the two different HIIT protocols. The first HIIT group ran at the speed they reached VO_{2max} on the pretest for five to eight sets two times per week. Esfarjani & Laursen's (2007) intervention was different than this research in that participants ran for three and a half minutes during each interval with the same amount of rest five to eight times per session. Training was compared to a second HIIT Group that performed thirty second runs at 130% of their VO_{2max} speed with four and a half minutes of recovery for seven to twelve sets twice a week. Both HIIT groups were compared to a control group that ran at 75% of their VO_{2max} speed four times per week for sixty minutes of continuous running. Both HIIT groups performed two recovery runs that were similar to the intensity of the control group each week, which would have accounted for more total training volume to match the control group. They observed improvements in VO_{2max} (HIIT 1 - 9.1% and HIIT 2 - 6.2% change) and velocity at which VO_{2max} was obtained (HIIT 1 - 6.4% and HIIT 2- 7.8% change) in both HIIT groups compared to the control group. Discrepancies between the results found in the current research and the research listed above could have been due to the amount of training as participants were running four times per week for longer durations each day compared to the participants in our research. For Esfarjani & Laursen's (2007) intervention participants conditioning workouts lasted sixty minutes in total, where as in our research, participants were only doing conditioning work for a maximum of sixteen minutes. Both the total volume per week and the within session volume could account for the improvement observed in this study. Perhaps the utilization of higher volumes of work could have improved the adaptations in our study and should be considered in the future.

Cicioni-Kolsky, Lorenzen, Williams & Kemp (2013) had a similar research protocol in which recreationally active participants were randomly allocated to a HIIT group (100% running velocity, 10 males, 9 females) a second HIIT Group (130% of running velocity 7 males, 9 females) and a control group (75% running velocity 6 males, 14 females) for 6 weeks. All running velocities were determined from an average running velocity of a 3000 meter running trial which was also the main measure of aerobic capacity. The HIIT group ran 4x 4minutes on 4 minutes off (1:1 work to rest) twice a week ramping up to 6 sets in the final week. The second HIIT group ran 7x 30seconds running with 150seconds of rest (1:5 work to rest) twice per week, ramping up to 12 sets in the final week. The control group ran at 75% running velocity and covered 500 meters for a set time that was not disclosed. It is assumed that the volume for this continuous control group matched the work prescribed for their two HIIT groups. They found that the second HIIT group was the only group to have significant changes in the 3000 meter time trial and accounted for the greater utilization of the anaerobic system and not having an added recovery run as compared to Esfariani & Laursen (2007). Obtaining a VO_{2max} value from this could be useful as a timed running trial will always have a pacing strategy during the test but could be used as a supplementary test to accompany to a value form direct spirometry.

Similar trends with trained athletes show that absolute VO_{2max} does not always increase from a training intervention based on running velocities (Cicioni-Kolsky, Lorenzen, Williams & Kemp, 2013; da Silva et al, 2015; Fernandez-Fernandez, Zimek, Wiewelhove, Ferrauti, 2012). Our research study performed three training sessions per week whereas other studies assessing aerobic capacity used frequency ranges between two to four sessions per week. The total volume in our research study does seem to be less compared to previous studies, however participants did have a weight program associated with their training intervention as opposed to just conditioning exercises in our study to better replicate true sport training conditions. This was used as a means of controlling the total training load of the participants. This ensured that all participants were completing their training under the researcher's supervision and controlled as much outside stimulus as possible. Our research set out to set up a schedule very similar to a typical sport training intervention.

It was hypothesized that after six weeks of training there would be a change in VO_2 at VT due to a time effect, and this was seen and supported with a strong effect size of 0.89. This change lines up with research similar to this study as participants were training at intensities prescribed that were above maximal conditions based on their VO_{2max} (Edwards, Clark, & Macfadyen, 2003). For the HIIT group, intensity was based on running at 120% of the speed achieved during the aerobic capacity test which is very similar to how prescription of intensity is used for high level collegiate athletes (Iaia et al, 2015) and is the norm for aerobic style training as total work rate can be maintained. For the SIT group, intensity was set at "all-out pace" (Macpherson &Weston, 2015) in the hopes that participants total work rate decreased as intervals went on. The set intensity for this research is based on typical prescription methods for athletes with high VO_{2max} before training.

Edwards, Clark, & Macfadyen, (2003) assessed aerobic capacity changes from a 5 week block of light aerobic training (70-90% Heart Rate max) in twelve male soccer players (63.3 +/ 5.8 ml/kg/min). They only trained two times per week for twenty five minutes per session. They found no difference in VO_{2max} but a significant change in VT after 5 weeks of training (Pre: 50.73 +/- 4.83 to Post: 52.59 +/- 4.13 ml/kg/min). They attributed this to the highly trained status of the participants who already had a high VO_{2max} and that VT might be a better measure of training status. They also claim that the change in VT could have been merely a motivational factor of completing the testing again and or that their training regime was more aerobic long duration training and pushed the athletes in a different capacity than they were accustomed. Their training regime volume was minimal to begin with and typically this volume is used more to maintain capacities rather than improve capacity. This could account for nonsignificant changes in VO_{2max} scores and the minimal changes in VT. Adding in another training day per week or increasing the time of the intervention may yield better results in this study as well.

It was hypothesized that after six weeks of training there would be a change in the percentage of VO_{2max} at VT due to time effect. This is a similar situation to hypothesis 1 as VO_{2max} did not significantly change from training athletes with established aerobic capacities. Despite changes in absolute VT as seen in hypothesis 2, there was not a large enough difference in regards to VO_2 levels to observe a difference the Percentage of VO_{2max} at VT. There was a non-significant increase in VO_{2max} in both groups but not a large enough change to yield a significant change in overall percentage of VO_{2max} at VT. With more data this could potentially have a clearer distinction as it is very closely related to absolute VT.

As mentioned above Edwards, Clark, & Macfadyen, (2003) only saw small changes in traditional aerobic based exercises when looking at VT changes over a 5 week training intervention. They said that percentage of VO_{2max} at VT went from 50.73 +/-4.83 mL/kgmin to 52.59 +/- 4.13ml/kg/min) which is a minimal change, but still significant enough change compared to endurance athletes from different research who train regularly with intensity based on their respected VT. This should be used more as a reference to show that training only twice per week can maintain VO_{2max} values out of season when training these intensities. However only changing 1% may not be enough to warrant prescription as this could have just been fluctuations from day to day.

Laursen, Blanchard & Jenkins (2002) did a two week study with fourteen trained cyclists (at least VO_{2peak} 60ml/kg/min) in which they performed four HIIT sessions, 20x 1min at VO_{2peak} Peak Power Output with 2 mins recovery at 50 watts. They found that VT changed from 2.31 +/- 0.44 L/min to 2.81 +/- 0.51 L/min, but VO_{2peak} did not change. They also specifically looked at VT1 and VT2 during the VO_{2peak} test and found an improvement of +22% in VT1 and +15% in VT2. They accounted this change in both VTs for the training near maximal levels and thus improving peak power output on the bike in such a short time. This could just be a learning curve improvement as participants trained on the same bike they tested on and in a very short period of time between both testing and intervention. The volume in this study is quite high compared to most HIIT or SIT work which could also account for the training stimulus.

Sheykhlouvand, Gharaat, Khalili, & Agha-Alinejad (2016) look at HIIT training on VT changes in 21 trained canoe polo athletes (VO_{2peak} from a kayak ergometer: 38.1 +/- 4.7 ml/kg/min) three times a week for three weeks. They were split into groups, the HIIT groups either performed at the speed of VO_{2peak} or a percentage above VO_{2peak}, and then they were compared to a control group of 75% of VO_{2peak}. They found that only the HIIT group who trained below VO_{2peak} improved VT (pre: 69.2 ± 10.9%, post: 80.3 ± 2.4% of VO_{2peak}). Those that trained above VO_{2peak} and the control group did not see significant changes. Sheykhlouvand et al (2016) accounted the lack of changes in the control group and group who trained above VO_{2peak} due to their training status before the intervention. These values were generated from a kayak ergometer, meaning only the upper body was used which would account for the lower VO_{2peak} values of a “trained” athlete.

For most of the studies on VT and VO_2 at VT it seems that in trained individuals it is much harder to get a significant change in aerobic capacities. Due to their trained status and already developed aerobic systems, the potential for change becomes much harder. Training at these near maximal intensities or threshold training may be the key to changing some of the supporting mechanisms associated with VO_{2max} This is why VT measures may yield better understanding if the training is in fact working. In the current research, six weeks was enough time to see a change with three training sessions per week. Although compared to other research these changes can potentially be seen in a shorter time frame. Some of the research that was compared to had relatively higher aerobic capacity values (either peak or max VO_2) which could account for more significant changes in VT as they would have had greater ranges to work. Very little research was found of sprint type work on VT changes, instead most researchers are looking at repeated sprint ability in comparison to VT (Bishop, Girard, & Mendez-Villaneuva, 2011) which was not collected as part of this research but could be an avenue for future research. More research is required when looking at VT using interval training to give a clearer picture of what adaptations can occur with this intensity prescription.

Hypothesis four, which looked at recovery rates based on excessive post exercise oxygen consumption recovery rate was supported with a time effect as a result of 6 weeks of training. Effect sizes were calculated for EPOC and O_2 consumption and were 0.5 and 0.61 respectively. Both values here show a medium effect size and with a small sample size from this research should be taken with caution. Participants from both groups were given one minute of rest after each interval which lines up with more aerobic based interval training guidelines (Haff & Triplett, 2015) but because of the changes of direction may elicit more of a reliance of the anaerobic systems for the acceleration and decelerations within each interval (Padulo et al, 2015). This will in turn yield a greater deficit during each interval and only increased with each succeeding interval. In the testing pre and post participants were given up to ten minutes to recover post VO_{2max} test which allows for a more proper recovery compared to the training methods. However, if the participants reached resting values of VO_2 before ten minutes there could take the gas exchange apparatus off. Therefore, oxygen consumption for five minutes post graded exercise test was also looked at to see if there was a difference from the training intervention. Similar to the fast slope of EPOC recovery there was a time effect seen from six weeks of training as participants utilized more oxygen in post testing as compared to pre testing. This could again be due to the allowance of more time to recover as compared to the training intervals in which the participants were accustom to or an improved buffering system which can only be assumed as no blood samples were taken in this research.

Dupont et al (2010) looked at recovery rates in twelve male collegiate soccer players (predicted VO_{2max} = 59.5 ± 6.8 mL/kg/min) by looking at VO_{2max} performed on a graded running test and then the effects of a repeated sprint test after on two separate days. Here they used the repeated sprint test speeds as well as the recovery in oxygen consumption post graded test to see how well these participants could recover. They found that participants with a faster recovery of oxygen consumption post graded test had better repeated sprint ability as they had better developed systems for PCR resynthesis. Also, they state that the training adaptations of increased mitochondrial volume density with associated oxidative capacity can play a major role in enhanced enzyme activity and muscular distribution of fibers. They stated that both the six minute time frame as well as the short periods of recovery in the repeated sprint test (20 seconds) were not enough time to fully recover the PCR system. Based on the training status of these participants, they were used to the demands needed to continue producing energy and performing the sprint based task. Also, having VO_{2max} levels above 50 mL/kg/min could account for the faster recovery and ability to continue producing energy when in a fatigued state.

Matsuo et al (2012) did a similar study by assessing recovery from three different bouts of exercise (“SIT”:7x30-s cycling at 120% VO_{2max}, 15-s rest between sets; “HIIT”: 3x3 -min cycling at 80~90% VO_{2max} with 2-min active rest at 50% VO_{2max} between sets;

Continuous aerobic training: 40 min of cycling at 60~65% VO_{2max}) with healthy male participants (VO_{2max} = 52.0 ± 9.2 mL/kg/min). Researchers kept direct spirometry on post testing to see how participants recovered from each specific bout of conditioning. They concluded that cardiorespiratory fitness level correlates negatively with the level of EPOC, especially when performing aerobic-type interval training. They suggest that this enhanced recovery may be due to better thermoregulatory systems and enhanced lactate metabolism in trained participants but did not measure either of these within their study. It should be noted that Matsuo et al classified their SIT group as 120% of $VO_{2max,}$ but this intensity is not "all out" as defined in the current research project. They found that the SIT group had the largest ratio of EPOC to net exercise $VO_{2,}$ which makes sense in that it was the most intense out of the three protocols chosen and would recruit the most fibers for energy production resulting in a greater deficit post activity.

Cannon, Rhodes & Langill (2003) looked at the effect of EPOC from a six week training intervention in untrained (VO_{2max} < 50ml/kg/min) males. They used speeds on a treadmill corresponding to certain percentages below VT ranging from 16 percent in the first week up to 3 percent in the final week. Participants ran at these speeds for thirty minutes three times per week for six weeks. They found that EPOC values significantly dropped post training (Pre-9.13±1.68 litres; Post- 7.49 ± 1.73 litres) as well as an increase in VO_{2max} (Pre- 46.4±3.7ml/kg/min, Post - 51.8 ± 5.2 ml/kg/min). They account the change in EPOC recovery to the enhancement in the aerobic system, greater oxygen delivery mechanism, greater oxygen consumption post training and a better established lactate removal system. Although these participants were classified as "untrained" their VO_{2max} levels are quite comparable to participants in our research study. They also saw similar improvements from six weeks of training and had a very similar sample size. The measurement of EPOC was different in that they measured for thirty minutes post graded test and used the total volume consumed during this time, rather than looking at the fast slope. This is an interesting value to measure as it could be looked at as complete rest following rigorous activity and gives a larger range for changes if the body comes back down to an actual resting value.

From these research articles it is clear that a higher aerobic capacity allows for a more efficient recovery post rigorous activity. Physiologically EPOC has a lot of factors that account for how much recovery occurs within the body, but PCR turnover and lactate removal seem to be two of the more predominant contributing mechanisms that help bring the body back to a resting state. Very few studies assess EPOC recovery rates following graded exercise tests. Reporting these values can be a very useful piece of information for determining optimal methods for enhancing recovery following bouts of High intensity work. Looking at the area under the curve of oxygen consumption post test can yield more information on EPOC, but will not give the full understanding as to get back to a full rested and energy replenished state can take up to a few hours (Cannon, Rhodes & Langill, 2003). Also adding in a blood lactate test could give additional information on recovery post test as well to see if there is a more developed lactate removal mechanism after a training intervention.

From this research it was clear that there were signs of change in aerobic capacity measures and recovery rate following training in both High Intensity or Sprint interval training. Looking at the two intensities prescribed and the utilization of muscle activity during each interval may yield more information as to why there was a lack of significant interaction effect. For the HIIT group it was hoped that participants were able to recruit lower threshold units and sustain force output by recruiting more high threshold units in later sets of the intervention. For the SIT group it was thought the “all out” pace would fatigue the high threshold units first and as fatigue set in the participants would rely more on the lower threshold units as they continue to produce force at a much lower rate and have not fatigued completely. For the sprint group this was found as within each session the total distance covered from start to finish was always a decreasing trend. The SIT participants were always advised to run as fast as they could and avoid a pacing strategy. For the HIIT group the distance covered within sets had minimal fluctuations from day to day and were predominantly maintained. This could mean that the intensity was not set high enough for them to recruit as many fibers as compared to the SIT group and ultimately not fatigue the system. Intensity was set at a manageable pace for the participants to complete the intervention, but from comparing to other HIIT style training the total volume may not have been enough to warrant a significant change. From the analysis on total work it shows that both groups did similar total work across each week. This could account for the lack of differences between either training group. In the future, potentially more sets can be used to elicit a change. For the SIT groups although the rest interval was unlike typical sprint training, the total volume was in line with most prescription as participants were working for a total of eight minutes. However, the intervals in this study were grouped much closer together and any additional volume may have been too fatiguing. Likely the participants would not have been able to continue with the intervention with the added volume.

Finally, the non parametric stats were chosen as analysis for this research due to the smaller sample size. A Mixed Model ANOVA would be a more appropriate test, but with a small sample size and a different number of participants in each group the strength of the outcomes would not be appropriate to draw conclusions. Adding in more participants to this intervention is key to finding stronger evidence. From prior power calculations a group size of 15 would be more appropriate for looking at these variables. Effect sizes were also calculated for variables that were statistically significant which were all from time main effects for VO_2 at VT, EPOC and O_2 Consumption during EPOC. VO_2 at VT had the strongest effect size, while EPOC and O_2 Consumption only showed moderate effect sizes. For all of these finding with a small sample size they should be taken with caution and used as potential avenues for future research and findings.

5.1 Limitations:

In order to strengthen the data obtained within this research having additional participants complete the intervention can give clearer distinctions of outcome variables. With only 13 participants completing the full intervention and testing a clear conclusion cannot be made and more data is needed. Due to issues with lack recruitment and participants dropping out the strength of this data is not high.

Due to the nature of measurement with the open circuit spirometry participants have to remain relatively stationary while attached to the breathing apparatus (i.e. on a cycle ergometer, treadmill, etc.). Having a portable metabolic cart in future during both testing sessions and interval training sessions could allow for a better assessment of the training intervention within each session rather than simply assessing total work performed. One foreseeable limitation with using this apparatus is the addition of the weight for the pack could alter running mechanics of the participants if they are not used to the additional weight. As well this is style of training would require multiple units or potentially only one participant being able to undergo the intervention at a time, which unfortunately is not feasible in typical university research settings.

Participants were instructed to continue regular sport activity during the training intervention which unfortunately was a reason for certain participants dropping out due to injury. These issues were out of the control of the researcher and for a study of this nature it is near impossible to find a time that performance athletes have an extended period of time that they are completely off from training. In future finding the block of time right after their respected season has occurred might be the best time of year as sport specific training volume would be at the lowest volume.

The prescription of the intervention followed a very linear progression in a six week time frame, but potentially could have been too little volume to warrant change. Comparing to similar research (da Silva et al, 2015; Fernandez-Fernandez, Zimek, Wiewelhove, Ferrauti, 2012; Machpherson and Weston 2005) the volumes prescribed in the current research were less to start the intervention and could be why there was minimal change in the outcome variables. In future adding in more volume to the intervention through more training weeks or starting at a higher volume within the first few weeks can be done to match the work done in previous research.

A mental barrier was apparent in the SIT group in which there seemed to be a pacing strategy when the interval number increased to a point in which fatigue was becoming very apparent. The last interval on each training day usually had a larger distance covered than the previous intervals completed on this date. This is reflective of the participants utilizing a pacing strategy when performing repeated sprint tasks in order to continue with training. Looking at changing the distance or familiarization has been utilized to prevent this from occurring in other studies and should be considered in future assessments (Chaouachi et al, 2010, Spencer, M, Bishop, D, Dawson, B, and Goodman, 2005).

Finally, participants were given a resistance training program to go along with their condition work every day which was completed before the conditioning training occurred. This was used as a recruitment tool to both entice athletes to participate in the research as well as control as many aspects in regards to outside physical activity. Providing these participants with a workout program and conditioning, it was understood that they would not need to utilize the gym outside intervention times. Most research that was used as a comparison only did interval or conditioning work as part of their research project. This research set out to try and control as much of the physical training as possible and mimic more of a real life team or athlete training situation and the decision was made to put the weight training before to following basic strength and conditioning periodization guidelines.

5.2 Directions for Future Research

The primary goal of this research was to compare two different training intensities commonly used in sport. Most research typically looks at comparing closely related intensities/durations or vastly different training protocols that yield results that show similar changes in aerobic capacity measures (Edge, Bishop, Goodman and Dawson, 2005; Foster et al, 2015; Fernandez-Fernandez, Zimek, Wiewelhove, Ferrsauti, 2012; Gonzalez- Mohino et al, 2015) . Having similar intervals to this research but adding in a few more interval groups with varied intensity to include submaximal HIIT or at velocities at or near ventilatory threshold may give more evidence on changing metabolic capacities in trained athletes. Also potentially increasing the total volume or training of either a longer intervention or increased number of intervals from the beginning may have yielded better information. This increase in volume would also be more in line with similar research that this work was compared to (Da Silva et al 2015; Esfarjani & Laursen, 2007; Fernandez-Fernandez, Zimek, Wiewelhove, Ferrauti, 2012; Machperson and Weston 2005) Expanding on this piece would be key for future research, to see which protocols are superior for improving aerobic capacities. As well having participants do a crossover conditioning training schedule in which they do a block of either HIIT or SIT first followed by another block of the other training method. This could show if there are any advantages to training one first over the other in order to elicit a certain adaptation such as running at high speeds, establishing recovery patterns, or even just getting used to this style of training.

Next looking at supporting anaerobic systems or repeated sprint ability values in conjunction with aerobic capacity values can be looked at to see if there is significant changes from this training style. Due to the stop and start nature of the training, more reliance on the anaerobic system within intervals can occur (Buchheit & Mendez-Villanueva, 2014). Typical sprint training utilizes the anaerobic system as the primary energy producer but once fatigued out it will rely on the aerobic system and PCR recovery to replenish energy sources. Looking at maximal power production and fatiuge rate in a more anaerobic task such as a Wingate can be utilzed to see if there were improvements if there were no signficant changes in aerobic capacities. Next having an intervention looking at intervals with and without changes of direction can be used to see if the training is similar to a more classic linear metabolic training intervention. Here both groups would still have to work at the same intensity and duration, but one group would be changing directions at designated spots while covering a certain distance and the linear group would run in a straight line. This would shed more light on how much the anaerobic system helps with the constant stopping and starting as opposed to a consistent speed throughout the interval.

Next comparing outcomes to established predicted VO_{2max} measures such as the Beep Test or Yo-Yo Intermittent Test could be utilized in future as a comparison or in addition to open circuit spirometry. It could be argued that these intermittent tests are more sport specific mimicking a game like or training situation. This way both a predicted VO_{2max} can be obtained from these tests as well as compare total distance covered within the test pre vs post training intervention. Both measures have been seen in research involving field-based athletes when looking at aerobic training and even used as a training method (Delahunt et al, 2013). The distance covered in the field test can be compared to the VO_{2max} obtained from direct spirometry to see if there are significant differences in outcome measures. If similar values are obtained for VO_{2max} then looking at the distance covered from the field test can be utilized to see improvements likely from improved mechanisms of changing direction or buffering capacity from training.

Finally strengthening the data obtained in this research would be important moving forward. From the data collected in this research there was no clear difference in intensities which means either intervention method could be prescribed during a training block looking to improve aerobic metabolic function and EPOC recover rate. In future having a larger sample size can lead to more distinction between these two intensities and better answer the research question regarding the prescription for athletes looking to maximize aerobic capacity improvements.

5.3 Conclusions

The results of this study indicate that following, six weeks of training in an athletic population, both HIIT and SIT training methods resulted in similar improvements in aerobic capacity at ventilatory threshold and result in faster recovery after exercise performed at high intensity. Based on these results both intensities can be used in training field-based athletes, however HIIT may be more appropriate to use with an athletic population due to the added psychological strain that comes along with SIT. These results are important since they compared two field-based approaches with matched durations and work to rest ratios, yet employed drastically different exercise intensities, which controls for many of the limitations of previous work that has attempted to compare these two methods. Although we observed these results, they need to be interpreted with caution since our sample size was small and therefore more studies including a bigger sample size to confirm our observations.

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Appendix A: Interval and Workout Documents

Table 12: Interval Number through the Experiment Timeline for both HIIT and SIT Groups

Week	Interval Number	Interval	HIIT Pace	SIT Pace
1	4	1:1min	120% MAS	All Out
2	4	1:1min	120% MAS	All Out
3	6	1:1min	120% MAS	All Out
4	6	1:1min	120% MAS	All Out
5	8	1:1min	120% MAS	All Out
6	8	1:1min	120% MAS	All Out

Table 13: Guided Workout Program for the Participants within the study.*Designed by Mark Gifford, CSCS

Day 1			Week 1		Week 2		Week 3		Week 4		Week 5		Week 6	
	Warmup	Rest	Sets	Reps	Sets	Reps	Sets	Reps	Sets	Reps	Sets	Reps	Sets	Reps
A1	Straight Leg Lunge to High Hand Rotation		1	5/side	1	5/side	1	5/side	1	5/side	1	5/side	1	5/side
A2	Yoga Pushup		1	8	1	8	1	8	1	8	1	8	1	8
A3	Quad Stretch to Overhead Reach		1	6/side	1	6/side	1	6/side	1	6/side	1	6/side	1	6/side
A4	Band Separations Horizontal/Vertical	1min	1	10each	1	10each	1	10each	1	10each	1	10each	1	10each
B1	Bird Dog Holds		2	20secs/si	2	20secs/si	2	20secs/si	2	20secs/si	2	20secs/si	2	20secs/sid
B2	SL Athletic Stance Balance	1min	2	20secs/si	2	20secs/si	2	20secs/si	2	20secs/si	2	20secs/si	2	20secs/sid
	Weights													
A1	Squat		3	8	3	8	3	10	3	10	3	12	3	12
A2	TRX Row		3	8	3	8	3	10	3	10	3	12	3	12
A3	Plank Reaches	1min	3	8/side	3	8/side	3	10/side	3	10/side	3	12/side	3	12/side
B1	Deadlift		3	8	3	8	3	10	3	10	3	12	3	12
B2	Bench Press		3	8	3	8	3	10	3	10	3	12	3	12
B3	Deadbugs	1min	3	8/side	3	8/side	3	10/side	3	10/side	3	12/side	3	12/side
	ESD													
	Group Dependent													
	Stretching													
	Toe on Wall Hip Flexor Stretch		1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/sid
	Banded Hamstring Stretch		1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/sid
	Childs Pose		1	45secs	1	45secs	1	45secs	1	45secs	1	45secs	1	45secs
	Wall Pec Stretch		1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/sid
	Pidgeon Pose		1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/sid
	Windmills		1	6/side	1	6/side	1	6/side	1	6/side	1	6/side	1	6/side

Day 2			Week 1		Week 2		Week 3		Week 4		Week 5		Week 6	
	Warmup	Rest	Sets	Reps	Sets	Reps	Sets	Reps	Sets	Reps	Sets	Reps	Sets	Reps
A1	Straight Leg Lunge to High Hand Rotation		1	5/side	1	5/side	1	5/side	1	5/side	1	5/side	1	5/side
A2	Yoga Pushup		1	8	1	8	1	8	1	8	1	8	1	8
A3	Quad Stretch to Overhead Reach		1	6/side	1	6/side	1	6/side	1	6/side	1	6/side	1	6/side
A4	Band Separations Horizontal/Vertical	1min	1	10each	1	10each	1	10each	1	10each	1	10each	1	10each
B1	Bird Dog Holds		2	20secs/si	2	20secs/si	2	20secs/si	2	20secs/si	2	20secs/si	2	20secs/sid
B2	SL Athletic Stance Balance	1min	2	20secs/si	2	20secs/si	2	20secs/si	2	20secs/si	2	20secs/si	2	20secs/sid
	Weights													
A1	Lunges		3	8/side	3	8/side	3	10/side	3	10/side	3	12/side	3	12/side
A2	Lat Pulldown or Pullup		3	8	3	8	3	10	3	10	3	12	3	12
A3	Pallof Presses		3	8/side	3	8/side	3	10/side	3	10/side	3	12/side	3	12/side
B1	Hamstring Curls on Ball		3	8	3	8	3	10	3	10	3	12	3	12
B2	DB Shoulder Press		3	8	3	8	3	10	3	10	3	12	3	12
B3	Alternating Supermans		3	8/side	3	8/side	3	10/side	3	10/side	3	12/side	3	12/side
	ESD													
	Group Dependent													
	Stretching													
	Toe on Wall Hip Flexor Stretch		1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/sid
	Banded Hamstring Stretch		1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/sid
	Childs Pose		1	45secs	1	45secs	1	45secs	1	45secs	1	45secs	1	45secs
	Wall Pec Stretch		1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/sid
	Pidgeon Pose		1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/sid
	Windmills		1	6/side	1	6/side	1	6/side	1	6/side	1	6/side	1	6/side

Day 3			Week 1		Week 2		Week 3		Week 4		Week 5		Week 6	
	Warmup	Rest	Sets	Reps	Sets	Reps	Sets	Reps	Sets	Reps	Sets	Reps	Sets	Reps
A1	Straight Leg Lunge to High Hand Rotation		1	5/side	1	5/side	1	5/side	1	5/side	1	5/side	1	5/side
A2	Yoga Pushup		1	8	1	8	1	8	1	8	1	8	1	8
A3	Quad Stretch to Overhead Reach		1	6/side	1	6/side	1	6/side	1	6/side	1	6/side	1	6/side
A4	Band Separations Horizontal/Vertical	1min	1	10each	1	10each	1	10each	1	10each	1	10each	1	10each
B1	Bird Dog Holds		2	20secs/si	2	20secs/si	2	20secs/si	2	20secs/si	2	20secs/si	2	20secs/sid
B2	SL Athletic Stance Balance	1min	2	20secs/si	2	20secs/si	2	20secs/si	2	20secs/si	2	20secs/si	2	20secs/sid
	Weights													
A1	Squat		3	8	3	8	3	10	3	10	3	12	3	12
A2	TRX Row		3	8	3	8	3	10	3	10	3	12	3	12
A3	Plank Reaches	1min	3	8/side	3	8/side	3	10/side	3	10/side	3	12/side	3	12/side
B1	Deadlift		3	8	3	8	3	10	3	10	3	12	3	12
B2	Bench Press		3	8	3	8	3	10	3	10	3	12	3	12
B3	Deadbugs	1min	3	8/side	3	8/side	3	10/side	3	10/side	3	12/side	3	12/side
	ESD													
	Group Dependent													
	Stretching													
	Toe on Wall Hip Flexor Stretch		1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/sid
	Banded Hamstring Stretch		1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/sid
	Childs Pose		1	45secs	1	45secs	1	45secs	1	45secs	1	45secs	1	45secs
	Wall Pec Stretch		1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/sid
	Pidgeon Pose		1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/si	1	45secs/sid
	Windmills		1	6/side	1	6/side	1	6/side	1	6/side	1	6/side	1	6/side

Appendix B: Statistical Analysis

Table 14 Shapiro Wilks Normality Test for Aerobic Variables

Value	Time Point	F Value	P value
VO_2max	Pre Post	0.9211 0.0071	0.3578 0.9342
Ventilatory Threshold (VT)	Pre Post	0.8054 2.2157	0.3887 0.1647
VO_2 at VT	Pre Post	0.7123 0.0301	0.4167 0.8653
Percent of VO_2max at VT	Pre Post	0.5705 2.0581	0.4659 0.1792
EPOC Fast Slope	Pre Post	0.3719 2.4905	0.5543 0.1428
Five minute Oxygen Consumption	Pre Post	0.8802 0.8398	0.2702 0.099

Table 15: Levenes Test for Homogeneity of Variance

Value	F-Value	P Value
VO_{2max} (3,22)	0.3749	0.7719
VO_2 at Ventilatory Threshold (3,22)	0.4626	0.7113
Percentage of VO_{2max} at Ventilatory Threshold (3,22)	1.1726	0.3428
EPOC Recovery (3,22)	0.9595	0.4293
Five minute Oxygen Consumption (3,22)	0.0448	0.9871

Table 16: Mixed Model ANOVA Results for Each Hypothesis

Hypothesis 1 – VO_{2max}		
Intercept	F (1,11) = 1059	p=2.74e-12
Group	F (1,11) =0.00393	p=0.846
Time	F (1,11) =3.086	p=0.109
Group: Time	F (1,11) =0.098	p=0.76
Hypothesis 2 – VO_2 at Ventilatory Threshold		
Intercept	F (1,11) = 2545	p=2.28e-14
Group	F (1,11) =0.139	p=0.716
Time	**F (1,11) =6.304**	**p=0.029**
Group: Time	F (1,11) =0.0379	p=0.849

Hypothesis 3 – Percent VO_{2max} at Ventilatory Threshold		
Intercept	F (1,11) = 1615.817	p=2.74e-13
Group	F (1,11) =0.271	p=0.613
Time	F (1,11) =0.776	p=0.397
Group: Time	F (1,11) =0.269	p=0.614

Hypothesis 4– Maximal EPOC		
Intercept	F (1,11) = 459.529	p=1.69e-10
Group	F (1,11) =0.012	p=0.915
Time	**F (1,11) =10.647**	**p=0.0076**
Group: Time	F (1,11) =1.82	p=0.204

Oxygen Consumption		
Intercept	F (1,11) = 984.96	p=4.08e-12
Group	F (1,11) =0.204	p=0.66
Time	**F (1,11) =6.84**	**p=0.024**
Group: Time	F (1,11) =0.00024	p=0.987

Appendix C: Values During Training

Table 17: Pace and Average Number of Touches Throughout Intervention

Participant Number	Group	Sex	Pace	Average	St Dev
1	HIIT	Male	10.5	10.78009	0.500838
2	HIIT	Male	11	11.05048	1.020648
3	SIT	Male	Allout	10.63194	0.861602
4	SIT	Female	Allout	9.61413	0.454545
5	SIT	Male	Allout	10.15404	0.927683
6	SIT	Male	Allout	11.05324	0.920972
7	HIIT	Female	10.5	10.28935	0.227137
9	SIT	Male	Allout	10.93878	0.962614
11	HIIT	Female	10	10.205	0.389865
12	HIIT	Male	11	10.94149	0.161585
13	HIIT	Male	11	11.21348	0.312046
14	SIT	Female	Allout	10.08424	0.435822
16	SIT	Male	Allout	11.19293	0.74872

Table 18: Work Calculations From each Week During the Training Intervention

Participant	Group	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
1	HIIT	750.0208	722.5104	740.3681	770.2917	734.0938	768.1198
2	HIIT	654.15	666.4	622.3	657.4167	655.375	649.25
11	HIIT	689.0625	735	735	771.75	768.6875	771.75
12	HIIT	833.8	833.8	833.8	833.8	822.7458	824.325
13	HIIT	1009.792	1017.5	1022.639	1040.625	1063.75	1063.75
7	HIIT	562.8646	562.8646	549.1181	550.6042	545.0313	544.474
9	SIT	914.125	900.4453	843.3125	805.76	825.6094	831.2422
14	SIT	749.7708	737.6042	734.0556	746.2222	719.7344	732.2813
16	SIT	931.5	885.9375	895.5	906.75	901.125	921.375
3	SIT	901.3125	940.5	951.1875	923.875	893.2969	870.1406
4	SIT	571.875	579.5	591.3611	585.4306	593.7969	590.9375
5	SIT	862.0208	868.7292	832.9514	778.1667	795.776	803.6583
6	SIT	982.8125	970.4167	950.3472	950.3472	923.4896	902.2396

Appendix D: Reference Documents

Canadian Society for Exercise Physiology "Get Active" Questionnaire:

CSEP | SCPE
THE GOLD STANDARD IN EXERCISE SCIENCE AND PERSONAL TRAINING

Get Active Questionnaire

CANADIAN SOCIETY FOR EXERCISE PHYSIOLOGY –
PHYSICAL ACTIVITY TRAINING FOR HEALTH (CSEP-PATH®)

Physical activity improves your physical and mental health. Even small amounts of physical activity are good, and more is better.

For almost everyone, the benefits of physical activity far outweigh any risks. For some individuals, specific advice from a Qualified Exercise Professional (QEP – has post-secondary education in exercise sciences and an advanced certification in the area – see csep.ca/certifications) or health care provider is advisable. **This questionnaire is intended for all ages – to help move you along the path to becoming more physically active.**

☐ I am completing this questionnaire for myself.

☐ I am completing this questionnaire for my child/dependent as parent/guardian.

PREPARE TO BECOME MORE ACTIVE

The following questions will help to ensure that you have a safe physical activity experience. Please answer **YES** or **NO** to each question before you become more physically active. If you are unsure about any question, answer **YES**.

YES	NO	
		1 Have you experienced **ANY** of the following (A to F) **within the past six months**?
○	○	**A** A diagnosis of/treatment for heart disease or stroke, or pain/discomfort/pressure in your chest during activities of daily living or during physical activity?
○	○	**B** A diagnosis of/treatment for high blood pressure (BP), or a resting BP of 160/90 mmHg or higher?
○	○	**C** Dizziness or lightheadedness during physical activity?
○	○	**D** Shortness of breath at rest?
○	○	**E** Loss of consciousness/fainting for any reason?
○	○	**F** Concussion?
○	○	**2** Do you currently have pain or swelling in any part of your body (such as from an injury, acute flare-up of arthritis, or back pain) that affects your ability to be physically active?
○	○	**3** Has a health care provider told you that you should avoid or modify certain types of physical activity?
○	○	**4** Do you have any other medical or physical condition (such as diabetes, cancer, osteoporosis, asthma, spinal cord injury) that may affect your ability to be physically active?

NO to all questions: go to Page 2 – ASSESS YOUR CURRENT PHYSICAL ACTIVITY

YES to any question: go to Reference Document – ADVICE ON WHAT TO DO IF YOU HAVE A YES RESPONSE

CSEP | SCPE Get Active Questionnaire

THE GOLD STANDARD IN EXERCISE SCIENCE AND PERSONAL TRAINING

ASSESS YOUR CURRENT PHYSICAL ACTIVITY

Answer the following questions to assess how active you are now.

1 During a typical week, on how many days do you do moderate- to vigorous-intensity aerobic physical activity (such as brisk walking, cycling or jogging)? ☐ DAYS/ WEEK

2 On days that you do at least moderate-intensity aerobic physical activity (e.g., brisk walking), for how many minutes do you do this activity? ☐ MINUTES/ DAY

For adults, please multiply your average number of days/week by the average number of minutes/day: ☐ MINUTES/ WEEK

Canadian Physical Activity Guidelines recommend that adults accumulate at least 150 minutes of moderate- to vigorous-intensity physical activity per week. For children and youth, at least 60 minutes daily is recommended. Strengthening muscles and bones at least two times per week for adults, and three times per week for children and youth, is also recommended (see csep.ca/guidelines).

GENERAL ADVICE FOR BECOMING MORE ACTIVE

Increase your physical activity gradually so that you have a positive experience. Build physical activities that you enjoy into your day (e.g., take a walk with a friend, ride your bike to school or work) and reduce your sedentary behaviour (e.g., prolonged sitting).

If you want to do **vigorous-intensity physical activity** (i.e., physical activity at an intensity that makes it hard to carry on a conversation), and you do not meet minimum physical activity recommendations noted above, consult a Qualified Exercise Professional (QEP) beforehand. This can help ensure that your physical activity is safe and suitable for your circumstances.

Physical activity is also an important part of a healthy pregnancy.

Delay becoming more active if you are not feeling well because of a temporary illness.

DECLARATION

To the best of my knowledge, all of the information I have supplied on this questionnaire is correct.
If my health changes, I will complete this questionnaire again.

I answered NO to all questions on Page 1

Sign and date the Declaration below

I answered YES to any question on Page 1

Check the box below that applies to you:

☐ I have consulted a health care provider or Qualified Exercise Professional (QEP) who has recommended that I become more physically active.

☐ I am comfortable with becoming more physically active on my own without consulting a health care provider or QEP.

Name (+ Name of Parent/Guardian if applicable) [Please print] ____ Signature (or Signature of Parent/Guardian if applicable) ____ Date of Birth ____

Date ____ Email (optional) ____ Telephone (optional) ____

With planning and support you can enjoy the benefits of becoming more physically active. A QEP can help.

☐ Check this box if you would like to consult a QEP about becoming more physically active.
(This completed questionnaire will help the QEP get to know you and understand your needs.)

Borg Scale for Rate of Perceived Exertion:

Rating	Perceived Exertion
6	No exertion
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

Curriculum Vitae

Candidate's full name: Mark Gerard Gifford

Universities attended (with dates and degrees obtained):

Trent University, BSc in Biochemistry and Molecular Biology, 2013

University of New Brunswick, BSc in Kinesiology, 2016

Publications: None

Conference Presentations:

1. Richards, B., Gifford, M. & Seaman, K. A., (2019). Bilateral and split stance isometric midthigh pulls equally predict change of direction ability. American College of Sports Medicine, Orlando, FL.

2. Richards, B. J., Gifford, M., Morrison, J. K., Willgress, S., Noble, J. & Seaman, K. A. (2018). Reliability of the force-velocity imbalance assessment in an athletic population. Canadian Society of Exercise Physiology, Niagara Falls, Ont.

3. Richards, B. J., Gifford, M., Morrison, J. K., Willgress, S., Noble, J. & Seaman, K. A. (2018). Controlling lower-body fatigue prior to the force-velocity imbalance assessment in an athletic population: An assessment of reliability. Canadian Society of Exercise Physiology, Niagara Falls, Ont.

4. Richards, B., Kashetsky, N., Gifford, M. & Seaman, K. (2018). A comparison of high velocity resistance loading and traditional strength loading methods on post activation potentiation. European College of Sport Science, Dublin, Ireland.