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THE INFLUENCE OF SPRINT DURATION ON THE ACUTE PHYSIOLOGICAL RESPONSES DURING SPRINT INTERVAL TRAINING SESSIONS

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THE INFLUENCE OF SPRINT DURATION ON THE ACUTE PHYSIOLOGICAL RESPONSES DURING SPRINT INTERVAL TRAINING SESSIONS

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ABSTRACT

The purpose of this study was to examine the acute physiological responses which occur throughout a sprint interval training (SIT) session and a modified SIT session. Assessment of cardiorespiratory and muscle oxygenation responses and performance were compared. Nine male sport students (age 20 ± 0.6 years; height 1.75 ± 0.1 m; body mass 75.9 ± 5.3 kg; mean ± SD) performed a VO_2max test and two SIT sessions on separate days. The SIT session consisted of 6 x 30s 'all out' cycling sprints interspersed with 4 minutes recovery. The modified SIT session consisted of 6 x 10s 'all out' cycling sprints interspersed with 4 minutes recovery. Cardiorespiratory variables, muscle oxygenation (tissue oxygenation index, TOI) and muscle deoxygenation were recorded at the vastus lateralis using near infrared spectroscopy (NIRS) during both sessions. Participants were unable to complete six 30s sprints during the SIT session and so three consecutive sprints performed during SIT and modified SIT were taken forward for analysis. The SIT session elicited a significantly greater cardiorespiratory response in comparison to modified SIT (44.7 ± 5.5 and 34.4 ± 3.7 ml kg^{-1} min^{-1}, respectively; $P < 0.05$). Peak power outputs were greater during modified SIT than in SIT (15.7 ± 2.1 and 13 ± 2.9 $W.Kg^{-1}$, respectively; $P < 0.05$) and were maintained throughout sprint trials. No significant difference was observed between muscle oxygenation values (TOI) and muscle deoxygenation for SIT and modified SIT ($P > 0.05$). The reliability of TOI assessed via NIRS was moderate ($r = 0.68$). These data indicate that modified SIT elicits similar degrees of peripheral stress in comparison to SIT. It can also be suggested that the attainment of high cardiorespiratory responses is not responsible for previously reported improvements in VO_2max. Peak power generation may therefore be a more important stimulus for eliciting physiological adaptations. It can be suggested from the present study that SIT and modified SIT predominantly promote peripheral rather than central adaptations. Modified SIT could therefore be an effective alternative to SIT and moderate intensity continuous training.

CHAPTER ONE

INTRODUCTION

1.0 Introduction

High-volume low-intensity exercise is an essential component within aerobic training programmes (Midgley et al., 2007). Performed continuously at relatively low intensities, high-volume low-intensity exercise has been shown to induce adaptations in both central and peripheral aspects of endurance (Daussin et al., 2007; Gormley et al., 2008; Scharhag-Rosenberger et al., 2009). Recent evidence however suggests that increases in factors which contribute to aerobic performance, can be achieved with reduced time commitment (Burgomaster et al., 2005). Although there is no clear definition, low-volume high-intensity interval training is characterised by a low work to rest ratio (1:8) (Bailey et al., 2009) consisting of intermittent 'all out' efforts, dispersed with periods of rest (Gibala and McGee, 2008). Applied practically, this type of training is commonly referred to as sprint interval training (SIT) in which four to six bouts of 30 second 'all out' sprints cycling are performed separated by four minutes of passive rest (Bayati et al., 2011).

Although SIT is characterised by a low training volume, recent studies have reported similar adaptations to those which occur from high volume exercise programmes, in a variety of physiological and health-related markers (Gibala et al., 2012). Increased glycolytic enzyme concentration (Burgomaster et al., 2005), increased muscle glycogen content at rest, improved hydrogen buffering (Barnett et al., 2004; Gibala et al., 2006), enhanced insulin sensitivity (Hood et al., 2011), as well as increased exercise tolerance (Bailey et al., 2009) and skeletal muscle oxidative capacity (Burgomaster et al., 2005; Burgomaster et al., 2008; Bayati et al., 2011) have all been consistent adaptations from a total of 15 minutes 'all out' cycling over a two week period.

Considering that these improvements in aerobic performance and fitness occur with little time commitment, SIT would not only be beneficial to sport performers, but also to the general public (Burgomaster et al., 2005). This is important considering that a large percentage of the general public, currently fail to reach the recommended public health guidelines of 30-60 minutes of moderate intensity exercise five days a week (Gibala and McGee, 2008). However, the SIT protocol has been deemed as unsafe, impractical and intolerable for general populations, due to maximal efforts and the symptoms which occasionally occur from the sessions such as sickness and dizziness (Bayati et al., 2011). As a result, greater investigation into modified versions of the SIT protocol would seem to be a valuable approach, not only to make SIT more accessible to general populations, but also to assess whether similar physiological adaptations occur with less time commitment (Talanian et al., 2007). Hazell et al. (2010) reported that modification of sprint duration to 10 second intervals with four minutes active recovery, elicited similar adaptations over a two week period as SIT. It has been suggested therefore that peak power generation during the first 10s of each sprint, is a greater training stimulus than attempted power maintenance over the remaining 20s (Hazell et al., 2010). This therefore highlights that performance adaptations can be gained with even smaller time commitments.

Although research with regards to SIT has grown, investigations have predominantly focused on training induced changes, failing to assess the acute physiological responses which occur throughout sessions (Buchheit et al., 2012). Muscle oxygenation trends using near infrared spectroscopy (NIRS) have previously been examined during incremental exercise (Grassi et al., 1999; Belardinelli et al., 1995) and during exercise above and below the lactate threshold (Chuang et al., 2002). However, muscle oxygenation trends during high intensity anaerobic exercise have been poorly examined (Bhambhani et al., 2001). To our knowledge only one study has examined the time course of muscle oxygenation, cardiovascular responses and performance throughout a single SIT session indicating greater muscle deoxygenation throughout a series of sprinting bouts (Buchheit et al., 2012). Insight into the degree of muscle deoxygenation which occurs during SIT, is therefore important as it is possible that the metabolic adaptations reported following SIT, are the result of a cascade of signals which occur due to localised O_2 availability and extraction (Coffey and Hawley, 2007). Measures of muscle oxygenation could therefore provide an insight into peripheral changes which result in skeletal muscle remodelling (Neary et al., 2002). Muscle oxygenation however is yet to be examined during modified SIT sessions and could therefore indicate whether, it is the achievement of peak power or attempted power maintenance contributing to the training adaptations (Hazell et al., 2010). In addition, the determination of the physiological variables which cause SIT and modified SIT to elicit performance and physiological improvements could be valuable in identifying adaptation mechanisms (Buchheit et al., 2012).

The purpose of the current study therefore is to assess the acute responses caused by a single session of SIT and modified SIT with regards to cardiorespiratory responses, muscle oxygenation, muscle deoxygenation and performance throughout sprint intervals. From this it may be possible to gain greater understanding into why adaptations from SIT occur within short periods of time and why modified versions of SIT lead to similar adaptations.

It is therefore hypothesised that:

1) Performance will be maintained throughout a modified SIT session
2) Acute physiological responses will be greater during SIT in comparison to modified SIT

CHAPTER TWO

LITERATURE REVIEW

2.0 Literature Review

2.1 Aerobic Training

2.1.1 Continuous Endurance Training

Training to elicit adaptations beneficial to performance and health are dependent upon frequency, duration and intensity (Daussin et al., 2007). Moderate intensity continuous training (MICT) is performed at an intensity below the lactate threshold, marking the limit of nearly exclusive aerobic metabolism (Faude et al., 2009). Such training has been shown to induce both central and peripheral adaptations (Daussin et al., 2007). Improved maximal oxygen consumption (VO_2max) has been a consistent training adaptation following MICT (Daussin et al., 2007; Gormley et al., 2008; Scharhag-Rosenberger et al., 2009). Considering VO_2max is closely related with enhanced cardiac output and stroke volume, VO_2max contributes to a central cardiovascular adaptation (Daussin et al., 2007). Improvements in arteriovenous oxygen (O_2) differences, skeletal muscle oxidative capacity and fibre type proportions have also been observed following MICT contributing to peripheral adaptations (Daussin et al., 2007). Considering the variety of health and fitness benefits from this type of training, it is recommended that individuals should perform 150 minutes of MICT each week (Haskell et al., 2007). However, for trained individual's MICT programmes fail to provide a large enough stimulus to promote adaptations (Scharhag-Rosenberger et al., 2009). In addition, a frequently identified barrier to exercise adherence for general populations is lack of time (Booth et al., 1997). Therefore an alternative strategy to improve health and fitness could be to

identify the minimum volume of exercise required to elicit health benefits whilst providing a training stimulus greater than that achieved through MICT (Metcalfe et al., 2012).

2.1.2 Sprint Interval Training

High-intensity interval training (HIIT) is characterised by brief bursts of vigorous exercise, interspersed with rest periods or low-intensity exercise (Gibala et al., 2012). The most recognised form of high-intensity interval training and most commonly used is Sprint Interval Training (SIT) (Gibala et al., 2012). SIT interventions involve four to six 30 second Wingate tests performed on a cycle ergometer (Gibala and McGee, 2008). Each sprint is a maximal effort and is separated with four minutes passive or active (unloaded cycling) rest (Burgomaster et al., 2005). As a result, a total of two-three minutes of very intense exercise is performed within each session (Gibala and McGee, 2008). Despite a low training volume, SIT has been reported to induce both central and peripheral adaptations, comparable to those which occur following MICT (Gibala et al., 2006; Burgomaster et al., 2008; Gibala et al., 2012). Although the mechanisms responsible for improvements in health and fitness resulting from SIT are unclear, it is suggested adaptations predominantly occur peripherally as improvements in VO_2max are not consistently reported (Burgomaster et al., 2005; Gibala and McGee, 2008). As a result, it is suggested that due to the short duration of SIT, the cardiorespiratory system is not stressed to a sufficient level to stimulate central adaptations (Buchheit et al., 2012).

2.2. Physiological Adaptations Promoted by SIT

SIT has been reported to induce similar physiological adaptations comparable to those achieved during MICT (Gibala et al., 2006; Burgomaster et al., 2008). Improvements in aerobic capacity, skeletal muscle oxidative capacity and insulin sensitivity have all been reported, highlighting the benefits SIT could have not only for sporting populations but also for general populations with a reduced time commitment (Burgomaster et al., 2005; Babraj et al., 2009).

2.2.1. Endurance Capacity

SIT interventions performed over a two week period have been reported to enhance endurance capacity (Burgomaster et al., 2005; Burgomaster et al., 2006; Gibala et al., 2006). Assessment of time trial performance has indicated a 9.6% decrease in 10 km cycling time (Burgomaster et al., 2006). This was also demonstrated by Gibala et al. (2006) who reported a 10.1% decrease in 750 KJ time trial performance. In addition, increases in VO_2max following four to eight weeks SIT have been reported (Barnett et al., 2004; Burgomaster et al., 2008; Trilk et al., 2011). However, this has not been a consistent finding providing support for SIT predominantly eliciting peripheral, rather than central adaptations (Burgomaster et al., 2005).

SIT has also been shown to improve peak and average power outputs achieved throughout training sessions. Barnett et al. (2004) reported increased peak and average power outputs following an eight week SIT programme. Improved power outputs (5.4%) were also observed following a two week intervention (Burgomaster et al., 2006). It seems therefore that SIT not only promotes adaptations to increase aerobic endurance capacity, but also the ability to sustain power outputs during fixed work rates. However Burgomaster et al. (2005) reported no difference in average power outputs when SIT sessions from the beginning and end of the two week programme were compared. The mechanisms which control endurance capacity therefore seem to be multifactorial (Burgomaster et al., 2005). Despite this however, SIT has been shown to improve endurance capacity to the same extent as MICT despite approximately one third of the time commitment (Burgomaster et al., 2008).

2.2.2 Skeletal Muscle Oxidative Capacity

Muscle oxidative capacity is frequently assessed through monitoring changes in enzyme concentration and maximal enzyme activity (da Silva Pimenta et al., 2007). Increases in the maximal activity of citrate synthase (CS) are suggested to increase proportionally to increases in mitochondrial enzymes (Wang et al., 1999). Increases in cytochrome c oxidase (COX) are also often measured to assess the capacity of the respiratory chain to generate energy (Brzezinski and Ädelroth, 1998).

SIT has been shown to increase the maximal activity of CS following training (MacDougall et al., 1998; Barnett et al., 2004; Burgomaster et al., 2005). Burgomaster et al. (2008) observed increased maximal activity of CS following six weeks SIT. It is suggested therefore that SIT improves the ability to produce energy through oxidative metabolism of pyruvate instead of lactate (Barnett et al., 2004). Increases in COX have also been reported following two weeks SIT (Gibala et al., 2006). It appears therefore that changes in mitochondrial content occur early within the training process (Burgomaster et al., 2008). In addition, changes in oxidative capacity following SIT are comparable to those which occur following MICT (Gibala et al., 2006; Burgomaster et al., 2008). As a result, 15 minutes of SIT over a two week period is effective in improving muscle oxidative capacity (Burgomaster et al., 2005; Burgomaster et al., 2006).

2.2.3 Insulin Sensitivity

SIT performed over two weeks has also been reported to improve insulin sensitivity within healthy and overweight individuals (Babraj et al., 2009; Richards et al., 2010; Whyte et al., 2010). Although the mechanism behind this is unclear, increased insulin sensitivity could be the result of skeletal muscle adaptations (Richards et al., 2010). Despite increased insulin sensitivity being reported following two weeks SIT, it is unclear as to whether these finding are the result of the training imposed or due to the last SIT session performed (Richards et al., 2010). It is also important to note that Whyte et al. (2010) reported improvements in insulin sensitivity to be short lasting. Nonetheless, improvements in insulin sensitivity indicate the

potential for SIT to provide an alternative mode of exercise to improve vascular and metabolic health for general populations (Whyte et al., 2010).

2.3 Common Concerns of SIT

It is evident that SIT has the ability to promote a variety of physiological adaptations within a short time period (Burgomaster et al., 2005; Gibala et al., 2006; Whyte et al., 2010). These would not only be beneficial to sport performers but also to general populations. However, the demanding nature of SIT may not be safe or practical for some individuals (Little et al., 2010). SIT sessions can induce severe feelings of fatigue, often resulting in symptoms such as sickness and dizziness (Hood et al., 2011; Bayati et al., 2011). The use of 30s 'all out' sprints as a form of training is therefore often dismissed (Bayati et al., 2011). For these reasons, the use of HIIT has become widely used within sporting and general populations due to its reduced difficulty and time effectiveness (Hood et al., 2011; Gibala et al., 2012).

2.4 Physiological Adaptations promoted by HIIT

HIIT programmes have primarily focused on reducing the intensity of exercise intervals (McKay et al., 2009; Little et al., 2010; Hood et al., 2011). Bayati et al. (2011) suggested reducing interval intensity to 125% of power at VO_2max whilst performing 6-10 30s bouts. Little et al. (2010) on the other hand implemented 8-12 1 minute intervals performed at 100% of peak power. Although psychological variables were not measured, individuals showed greater tolerance to HIIT (Little et al., 2010).

Due to this, HIIT has been implemented within individuals suffering from chronic disorders as well as within healthy individuals (Little et al., 2010).

2.4.1 Aerobic Capacity

HIIT programmes have been reported to enhance VO_2max to a similar level as SIT and MICT (Helgerud et al., 2007; Gormley et al., 2008; Bayati et al., 2011). Helgerud et al. (2007) reported improvements in VO_2max of 5.5% and 7.2% following 15s and 4 minute running intervals at 90-95% of heart rate maximum (HR*max*) over an eight week period. McKay et al. (2009) also reported that eight HIIT sessions improved VO_2max by 4.5%. In addition, 10 x 4 minute bouts at 90% VO_2peak increased VO_2peak by 13% following a two week HIIT programme performed by women (Talanian et al., 2007).

2.4.2 Insulin Sensitivity

Improvements in insulin sensitivity following SIT have also been reported following HIIT programmes (Hood et al., 2011; Little et al., 2011). Hood et al. (2011) reported that two weeks of 10 x 60s cycling intervals at 80-95% of maximal heart rate (HR) reduced fasting insulin concentrations by 16% and improved insulin sensitivity by 35% ($P < 0.05$). This was supported by Little et al. (2011) who implemented the same HIIT protocol and observed reduced hyperglycaemia and lowered 24 hour blood glucose concentrations. These data support the promotion of mitochondrial biogenesis which is needed to reduce the risk of insulin resistance (Hood et al., 2011).

2.4.3 Cardiac Pathology

Compliance with cardiac rehabilitation consisting of MICT is relatively low (Currie et al., 2012). Due to the reduced time commitment, HIIT programmes have been implemented to increase cardiac rehabilitation adherence (Rognmo et al., 2004; Warburton et al., 2005). In comparison to 'all out' sprints performed during SIT, modification of sprint intensity to 90% HR/VO_2 reserve or 80-90% of VO_2*peak* with intervals lasting 2-4 minutes has resulted in increased aerobic capacity and cardiac function (Warburton et al., 2005; Rognmo et al., 2004). In addition, measures of endothelial function before and after acute HIIT in comparison to low intensity exercise indicated similar increases in brachial artery flow-mediated dilation (Currie et al., 2012). However, there is a concern that cardiac rehabilitation patients have an increased risk of cardiac arrest during vigorous exercise (Fletcher et al., 2001). Despite this, the chance of cardiac arrest is similar to that expected by chance alone (Fletcher et al., 2001). As a result, HIIT appears to be a useful training strategy within cardiac rehabilitation.

2.5 Issues with HIIT programmes

It is apparent that HIIT programmes stimulate a variety of performance and health related benefits (Bayati et al., 2011; Warburton et al., 2005; Whyte et al., 2010). However, the optimal prescription of exercise intensity, duration of work and rest as well as number of intervals to provide these adaptations remains unclear (Gosselin et al., 2012).

In addition although HIIT is more practical than SIT due to reduced interval intensity, interval durations have increased (McKay et al., 2009; Little et al., 2010; Hood et al., 2011). HIIT is therefore now longer in terms of total exercise duration in comparison to SIT. Also the area has become saturated with a range of HIIT protocols (Helgerud et al., 2007; Gormley et al., 2008; Little et al., 2011). As a result, reduction of sprint interval duration as opposed to intensity could provide a standard modified protocol, where individuals are not confused with different training intensities and varying sprint and rest durations.

2.6 Modification of Sprint Duration

It has been identified that SIT is characterised by peak power generation during the initial phase of the sprint (5-10s) followed by the attempted maintenance of peak power over the remaining sprint duration (10s-30s) (Hazell et al., 2010). When assessed, two weeks modified SIT (6 x 10s 'all out' sprints separated by four minutes rest) improved time trial performance by 3.5% and increased VO_2max by 9.2% (Hazell et al., 2010). These improvements were comparable to those reported following SIT, as time trial performance improved by 5.2% and VO_2max increased by 9.3% (Hazell et al., 2010). As a result, reduced sprint interval duration can elicit similar adaptations as those from SIT (Hazell et al., 2010).

Considering the ‘all out’ nature of 10s sprints, the short duration of these bouts resulted in reduced difficulty, improving the tolerance to the programme (Hazell et al., 2010). It has therefore been suggested that peak power generation is an important training stimulus and is more responsible for SIT adaptations (Hazell et al., 2010). However, the acute physiological responses and mechanisms responsible for these similar adaptations during SIT and modified SIT remain unclear (Buchheit et al., 2012).

2.7 Acute Physiological Responses to SIT

Considering the growing interest regarding SIT, the majority of studies have been concerned with training induced changes in comparison to MICT and modified SIT sessions (Burgomaster et al., 2008; Hazell et al., 2010). To our knowledge only one study has examined the acute physiology responses which occur throughout a single SIT session (Buchheit et al., 2012). Assessment of the physiological responses which occur throughout SIT are important to identify the physiological variables responsible for the adaptations reported (Buchheit et al., 2012). In addition, assessment of the responses during a modified SIT session would provide a greater insight into why suggested peak power generation is a greater training stimulus in promoting adaptations than power maintenance (Hazell et al., 2010). In turn this will also allow for greater understanding into the optimal strategies for modifying SIT (Gosselin et al., 2012) and may provide insight into adaptation mechanisms (Buchheit et al., 2012).

2.8 Cardiorespiratory Responses

A central adaptation reported following SIT is improved VO_2max (Barnett et al., 2004; Burgomaster et al., 2008; Trilk et al., 2011). Improvements in VO_2max are therefore likely to occur through increases in O_2 delivery and/or O_2 utilization at the active muscle (Bayati et al., 2011). It has been reported that individuals reach close to 90% of their VO_2max and HR during 30s 'all out' sprints (Buchheit et al., 2012). Improvements in O_2 delivery have therefore been attributed to increased stroke volume, as maximal HR remains unchanged following SIT interventions (Buchheit et al., 2012). However, limited time is spent at this intensity indicating that this is not a long enough stimulus to promote central adaptations (Buchheit et al., 2012). MacDougall et al. (1998) therefore suggests that training at an intensity near to VO_2max may be more important than training volume to increase muscle oxidative potential.

It has also been reported that sprints performed at the latter end of a SIT session have a greater correlation with VO_2peak than sprints performed at the beginning (Mclester et al., 2008). Buchheit et al. (2012) also reported that sprint two through five resulted in a greater mean sprint HR than for sprint one. Considering VO_2peak is significantly correlated with HR (Mclester et al., 2008) this suggests there is a greater reliance on aerobic metabolism with each sprinting bout, possibility indicating why oxidative capacity is a commonly reported adaptation (Bogdanis et al., 1998; Mclester et al., 2008).

2.9 Muscle Oxygenation Responses

2.9.1 Near Infrared Spectroscopy

NIRS is a non-invasive, direct technique used to determine changes in tissue haemodynamics (Van Beekvelt et al., 2001). Due to the sensitivity of NIRS, measures have been able to identify both normal and pathological states within individuals (Van Beekvelt et al., 2001). Measures of oxygenation are achieved through passing non-harmful levels of light through the muscle (McCully and Hamaoka., 2000). The light absorption characteristics (700-1000 nm) of haemoglobin and myoglobin therefore change depending on their relative O_2 saturation (Belardinelli et al., 1995). However it is important to note that NIRS is unable to measure localised blood flow which makes it difficult to quantify absolute muscle oxygenation (Bhambhani et al., 2001). Despite this, NIRS measures have been shown to indicate localised differences in muscle O_2 extraction, which are undetectable by the established Fick Method (Van Beekvelt et al., 2001).

2.9.2 NIRS Investigations

Muscle oxygenation trends indicate the balance between localised O_2 delivery and O_2 utilisation and therefore the extent of O_2 extraction (McCully and Hamaoka., 2000). Although muscle oxygenation using NIRS has primarily been assessed within incremental exercise (Grassi et al., 1999; Belardinelli et al., 1995) and during exercise above and below the lactate threshold (Chuang et al., 2002), muscle oxygenation trends can provide insight into peripheral changes which cause skeletal

muscle remodelling (Neary et al., 2002; Austin et al., 2005). Investigations assessing muscle oxygenation trends in relation to SIT have primarily assessed post exercise changes. Bailey et al. (2009) reported that following a four to five week SIT programme, O_2 extraction assessed using NIRS was greater and more rapid at the onset of exercise. McKay et al. (2009) also reported that two SIT sessions resulted in a 20% reduction in O_2 utilisation at the muscle. As a result, understanding the signals responsible for metabolic adaptations, due to localised O_2 extraction is important in order to identify why these adaptations occur following SIT and modified SIT (Coffey and Hawley, 2007).

2.9.3 Muscle Deoxygenation

To our knowledge, only one study has investigated the time course of muscle oxygenation throughout a single SIT session (Buchheit et al., 2012). Buchheit et al. (2012) reported that muscle deoxygenation decreased gradually through the series of sprint trials. Rather than reduced muscle O_2 demand, decreased muscle deoxygenation has been suggested to be the result of enhanced O_2 delivery at the start of exercise, resulting in a priming effect (Tordi et al., 2003). In addition, increased blood lactate during incremental exercise has been reported to cause a rightward shift of the oxyhaemoglobin curve (Grassi et al., 1999). It is therefore possible that increased blood lactate accumulation during high intensity exercise drives muscle deoxygenation (Billaut and Smith, 2010). As a result, blood acidosis may reduce the affinity of haemoglobin to O_2 and induce vasodilation in the active muscle (Chuang et al., 2002; Tordi et al., 2003; Billaut and Smith, 2010).

Muscle deoxygenation is also reported to rapidly decrease as soon as each sprint commences (Buchheit et al., 2012). This is suggested to be the result of the recruitment of fast twitch muscle fibres, which have a greater fractional O_2 extraction in comparison to slow twitch muscle fibres (Behnke et al., 2003). In addition, rapid muscle deoxygenation at the start of the sprint would imply significant aerobic metabolism (Bhambhani et al., 2001). Although Wingate tests are anaerobic in nature, when used within SIT the attempt to generate maximal power output with declines in phosphocreatine (PCr) availability, should stimulate both glycolysis and oxidative phosphorylation (Hazell et al., 2010). It is not surprising therefore that adaptations resulting from SIT, are comparable to those which occur following MICT programmes.

2.9.4 Tissue Oxygenation Index

In addition to muscle deoxygenation, changes in the tissue oxygenation index (TOI) have been suggested to provide a better indication of muscle oxygenation status when blood flow is not constant (Buchheit et al., 2012). The TOI therefore provides a reliable estimation of O_2 extraction (Spencer et al., 2012). It has been reported that during a single SIT session, TOI increases progressively throughout sprints performed (Buchheit et al., 2012). The TOI for sprint six has therefore been reported to be significantly greater than that for sprints one and two (Buchheit et al., 2012). When related to peak and average power, it appears that a greater decline in power, results in greater increases in TOI (Billaut and Smith., 2010). This would explain why peak and average power also progressively declined throughout the SIT session (Buchheit et al., 2012). However, Buchheit et al. (2012) stated that sprint

VO_2 was maintained throughout the series of sprints, therefore fatigue was unlikely to have affected the attainment of the responses observed.

2.9.5 Muscle Reoxygenation

Determinants of repeated-sprint performance are dependent upon metabolic factors which occur during recovery periods (Buchheit and Ufland, 2011). Faster reoxygenation rates between sprints would therefore increase O_2 supply aiding recovery (Buchheit and Ufland, 2011). When muscle reoxygenation was assessed in relation to VO_2 during sprint recovery, a significant correlation was reported (Buchheit et al., 2012). Reoxygenation between sprints would therefore indicate possible muscle PCr recovery (Buchheit and Ufland, 2011). However, when muscle reoxygenation was assessed through a series of sprint trials in relation to VO_2 the relationship became dissociated (Buchheit et al., 2012). It therefore seems that measurements of local and systemic responses are not easy to compare (Buchheit et al., 2012). It is also important to add that lactate removal during rest periods is dependent upon O_2 availability (Bassett et al., 1991). Therefore, the oxidative capability to remove lactate is an important factor for performance throughout progressive sprints (Mclester et al., 2008).

2.10 The Importance of NIRS

The use of NIRS within SIT investigations is therefore valuable to assess peripheral changes, in order to identify the mechanisms responsible for skeletal muscle remodelling (Neary et al., 2002; Austin et al., 2005). In addition, muscle oxygenation responses which occur during SIT and modified SIT, may provide insight into why both protocols elicit similar adaptations.

2.11 Literature Review Summary

SIT has been shown to elicit similar adaptations to training as MICT despite one third of the time commitment (Burgomaster et al., 2008). Considering lack of time is a frequently stated barrier to participation and adherence in exercise, this could prove to be an effective alternative to training (Booth et al., 1997). However the nature of SIT makes it unsafe, impractical and intolerable for general populations (Bayati et al., 2011). HIIT programmes have been reported to promote a variety of physiological adaptations and are more accessible to general populations (Bayati et al., 2011). However, total exercise duration is now longer in comparison to SIT and the area has become saturated with a range of HIIT protocols (Helgerud et al., 2007). Therefore modification of the SIT protocol would be beneficial in order to make this form of training more accessible. Hazell et al. (2010) reported that 10s sprints elicited similar adaptations to SIT, indicating that the generation of peak power is a greater stimulus for adaptations than power maintenance. However, the underlying mechanisms responsible for these adaptations are unclear. Therefore insight into the acute physiological responses which occur throughout a SIT and modified SIT

session would be advantageous to identify the physiological variables responsible for improvements in health and performance (Buchheit et al., 2012).

CHAPTER THREE

METHODOLOGY

3.0. Methodology

3.1 Subjects

Nine physically active males (age 20 ± 0.6 years; height 1.75 ± 0.1 m; body mass 75.9 ± 5.3 kg; mean ± SD) participated in the study. Participants were all recreationally active and assessed as healthy based upon completion of the physical activity readiness questionnaire (Appendix A). Participants were instructed not to perform strenuous exercise 48 hours prior to exercise testing. Participants were also asked to abstain from caffeine and alcohol for 24 hours and not to eat anything heavy three hours prior to testing. Due to the intense exercise involved in the study, participants were informed of the procedures and potential risks of the study prior to giving written informed consent (Appendix B). Ethical approval was granted by the University Research Ethics Committee.

3.2 Experimental Overview

Participants were required to visit the laboratory on three separate occasions. Visit one involved basic anthropometric measurements and a maximal incremental cycling test to determine maximal oxygen uptake (VO_2max). Visit two and three involved completion of either a SIT session or modified SIT session. During both SIT protocols, power outputs, respiratory gas exchange data (VO_2), heart rate (HR), muscle oxygenation (HbO_2) and muscle deoxygenation (HHb) of the vastus lateralis measured via near infrared spectroscopy (NIRS) were recorded.

3.3 VO_2max Test

VO_2max was determined using an incremental test to exhaustion on a cycle ergometer (Excalibur Sport, Groningen, The Netherlands). Following a five minute warm up at 25 W, the test began at a workload of 25 W increasing by 25 W every minute (5 W every 12s) until the participant was unable to continue. To ensure participants completed the test until exhaustion, verbal encouragement was given. Gas exchange data was collected using an online breath by breath gas collection system (Oxycon CPX, Warwick, Warwickshire) determining VO_2max as the highest value averaged over 30s collection periods. HR was collected at 5s intervals using non-invasive telemetry (Polar Electro, RS4000, Kemple, Finland). Attainment of VO_2max was confirmed when two out of three of the following criterion were met: 1) a plateau in VO_2 despite increased work load 2) a respiratory exchange ratio (RER) above 1.2 3) peak heart rate equal to 90% of age predicted maximum (Bayati *et al.,* 2011).

3.4 SIT Sessions

Following pre-experimental testing participants were required to perform a standard SIT protocol and a modified SIT protocol on two separate occasions, 3-7 days apart and more than two days after the VO_2max test. Both SIT sessions were adapted from previously used protocols and included a five minute warm up at 50 W. The standard SIT protocol (Burgomaster et al., 2005; Buchheit et al., 2012; Gibala et al., 2012) consisted of 6 x 30 second ‘all out’ sprints interspersed with 4 minutes active recovery (unloaded cycling). The modified SIT protocol (Hazell et al., 2010) consisted of 6 x 10 second ‘all out’ sprints interspersed with 4 minutes active

recovery (unloaded cycling). The order of testing was randomly assigned to the participants to reduce the effects of familiarisation. Both protocols were performed using a cycle ergometer (Excalibur Sport, Groningen, The Netherlands) where load was calculated based upon the participants weight. Participants were instructed to sprint from a seated position and as fast as possible throughout each sprint to reduce the chance of participants adopting a pacing strategy (Buchheit et al., 2012). Peak and average power outputs for the duration of each sprint in relation to participant body weights were determined.

3.5 Physiological Measures

3.5.1 Cardiorespiratory Measures

Throughout each SIT protocol, VO_2 and RER were continuously recorded via breath by breath analysis. Before each test, the VO_2 analysis system was calibrated as recommended by the manufacturer. VO_2 and RER values were averaged over 5s intervals. HR was collected at a sampling frequency of 1s throughout each protocol.

Peak and average VO_2 and HR were determined from each sprint with the subsequent four minute recovery. This was based on the assessment that participants did not return to baseline measures following each sprint interval. In order to assess the cardiorespiratory demand of SIT and modified SIT protocols, percentage of VO_2max was calculated.

3.5.2 Muscle Oxygenation Measures

Muscle oxygenation was assessed throughout each protocol with continuous wavelength NIRS (Oxiplex TS, Glasgow, United Kingdom) and was recorded at a sampling frequency of 1s on a computerised system. Prior to performing each test, the NIRS system was calibrated according to the manufacturer's specifications. Two wavelengths of 690 and 830 nm were used to assess changes in local oxygenated and deoxygenated haemoglobin concentrations. It should be noted that due to identical spectral characteristics, myoglobin and haemoglobin are undistinguishable.

The NIRS probe was positioned with participants seated on a cycle ergometer with their leg being in a position at the lowest pedal point. Due to the reported influence of adipose tissue thickness on NIRS measurements only participants with a BMI >32 were allowed to participate. The NIRS probe was positioned on the right vastus lateralis, mid-way between the patella and inguinal fold after the skin had been shaven. This point was recorded in order to reposition the probe in the correct place for the second protocol. The NIRS probe was secured using bandages to reduce movement during sprint intervals and to reduce the effect of ambient light (Bailey et al., 2009; McKay et al., 2009; Buchheit et al., 2012).

Muscle oxygenation was directly assessed through the Tissue Oxygenation Index (TOI) [TOI = HbO_2/ (HbO_2 + HHb) x 100] to indicate the balance between O_2 delivery and O_2 extraction. Peak and average values of muscle deoxygenation and TOI were determined through assessment of sprint duration with one minute of active recovery. This was identified as the time frame where all participants had returned back to baseline measures.

3.6 Statistical Analysis

The TOI and VO_2 data was assessed for reliability using an intraclass correlation coefficient (ICC). Data was continuously recorded during the five minute warm up prior to the SIT and modified SIT sessions. TOI and VO_2 data was averaged from 60s to 240s during this period. An overall average for visit one and visit two was then taken for analysis.

A paired t-test was performed to test for significant differences between percentage of VO_2*max* achieved during SIT and modified SIT. Peak VO_2 for each sprint trial were averaged. An overall average for SIT and modified SIT was then taken for analysis.

Two-way repeated-measures ANOVA (sprint duration x trial) was used to test for significant differences in cardiorespiratory measures, muscle oxygenation, muscle deoxygenation and performance between SIT and modified SIT. When significant effects were observed, a Bonferroni's post hoc test was performed to further explain the differences observed. The significance level was set at P <0.05. Statistical

analyses were performed using the Statistical Package for the Social Sciences (SPSS for Microsoft, SPSS inc., Chicago, IL). All data are presented as means ± standard deviation (SD).

CHAPTER FOUR

RESULTS

4.0 Results

All participants completed the modified SIT session. However six out of nine participants could only complete three of six 30s sprint intervals during the SIT session. Therefore data from three consecutive sprint intervals of SIT and modified SIT were taken for final analysis.

4.1 Performance

Relative peak power output was significantly greater during 10s sprint intervals (15.7 ± 2.1 $W.Kg^{-1}$) in comparison with 30s sprint intervals (13 ± 2.9 $W.Kg^{-1}$; $P < 0.05$). In contrast to 30s sprint intervals, there was no decline in peak power output during the series of 10s bouts ($P > 0.05$; Figure 1).

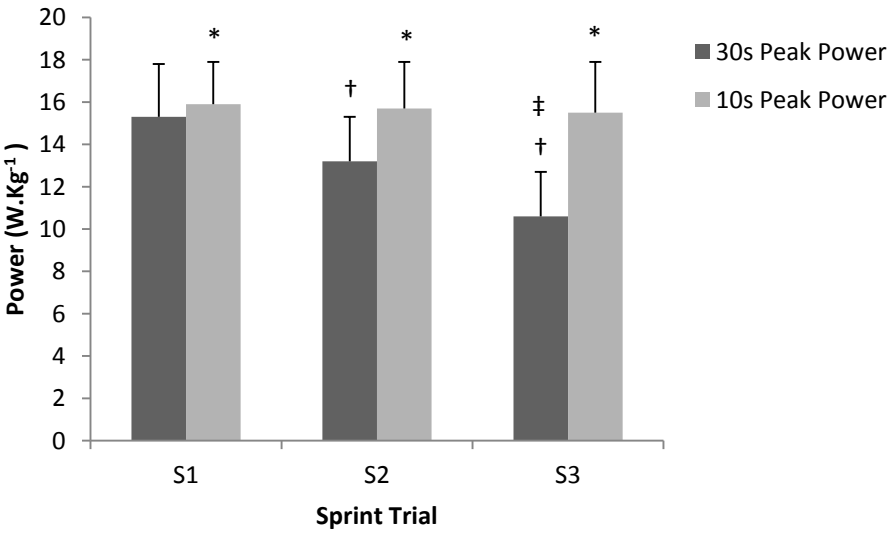

Figure 1. Mean (±SD) peak power output during 30s and 10s sprints performed during two individual sprint interval training sessions.

*Significant difference between 30s and 10s sprints ($P < 0.05$). †Significantly lower than sprint 1 (30s trial; $P < 0.05$). ‡Significantly lower than sprint 2 (30s trial; $P < 0.05$).

Relative average power outputs were 7.7 ± 1.4 W.Kg^{-1} for 30s sprints and 12.3 ± 1.1 W.Kg^{-1} for 10s sprints. As shown in Figure 2, relative average power output declined over the course of the 30s sprint intervals, but were maintained during 10s sprint intervals (P > 0.05).

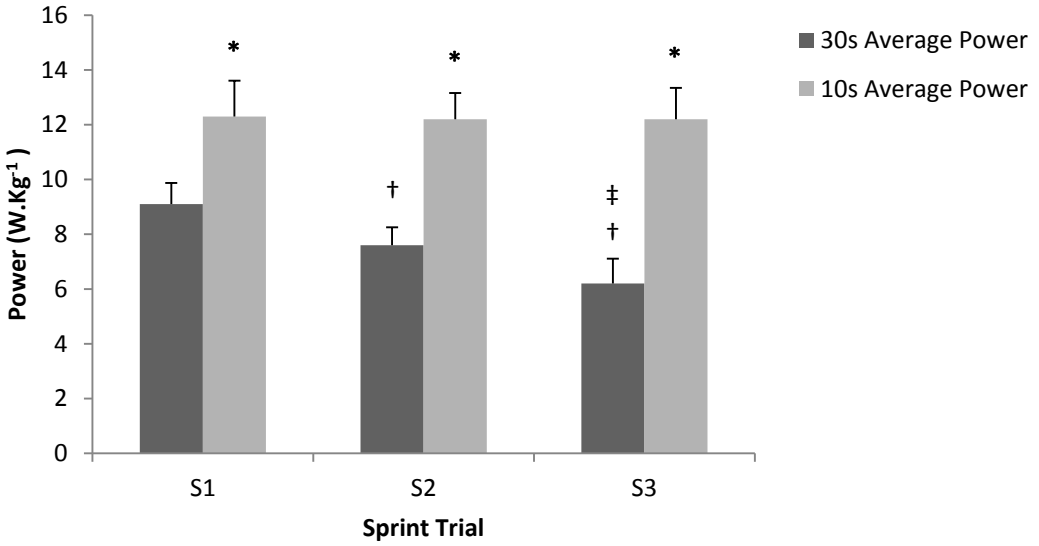

Figure 2. Mean (±SD) average power output during 30s and 10s sprints performed during two individual sprint interval training sessions.

*Significant difference between 30s and 10s sprints (P < 0.05). †Significantly lower than sprint 1 (30s trial; P < 0.05). ‡Significantly lower than sprint 2 (30s trial; P < 0.05).

4.2 Cardiorespiratory Responses

4.2.1 VO_2peak

The VO_2peak for 30s and 10s sprints is illustrated in Figure 3. Relative VO_2peak was greater during 30s sprint intervals (44.7 ± 5.5 ml kg^{-1} min^{-1}) than 10s sprint intervals (34.4 ± 3.7 ml kg^{-1} min^{-1}; $P < 0.05$). There was also a significant sprint duration x trial interaction ($P < 0.05$). During 30s trials, S2 was greater than S1 ($P < 0.05$) however there was no difference between S1 and S3 ($P > 0.05$). During 10s trials, S3 was greater than S1 ($P < 0.05$).

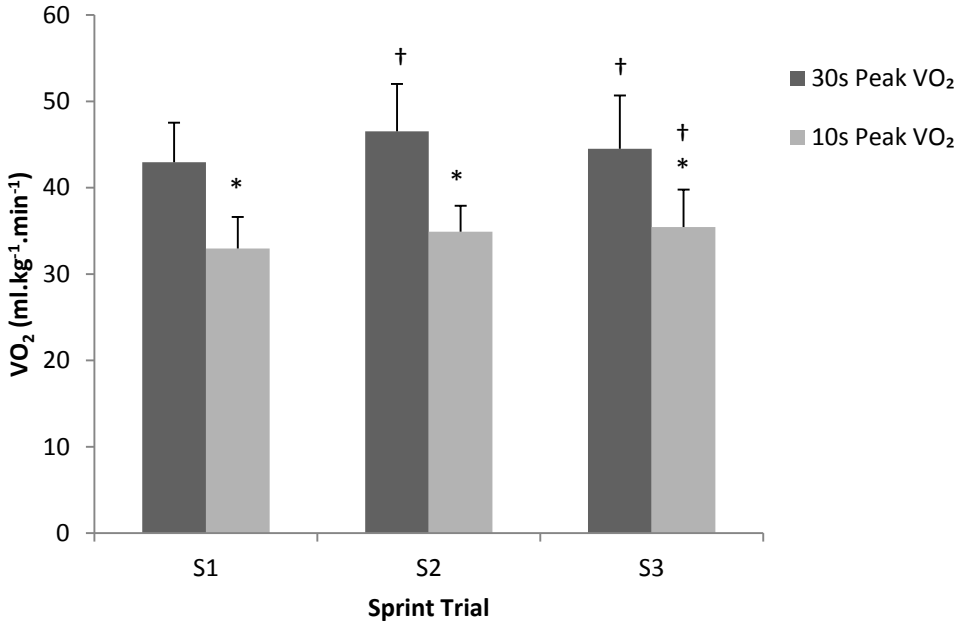

Figure 3. Mean (±SD) VO_2peak during 30s and 10s sprints performed during two individual sprint interval training sessions.

*Significant difference between 30s and 10s sprints ($P < 0.05$). †Significantly greater versus sprint 1 ($P < 0.05$).

Mean percentage of VO_2max during 30s and 10s sprint intervals were 93.3 ± 7.4% and 72.2 ± 6.9%, respectively. The mean percentage of VO_2max elicited during the 30s sprints was significantly greater than that elicited during 10s sprints (P < 0.05).

4.2.2 Average VO_2

Average VO_2 for 30s and 10s sprints are illustrated in Figure 4. Average VO_2 was significantly greater during 30s sprints than 10s sprints (P < 0.05). In the 30s trials there was no difference in average VO_2 (P > 0.05). However during 10s trials, S2 and S3 were greater than S1 (P < 0.05). S3 was also greater than S2 (P <0.05).

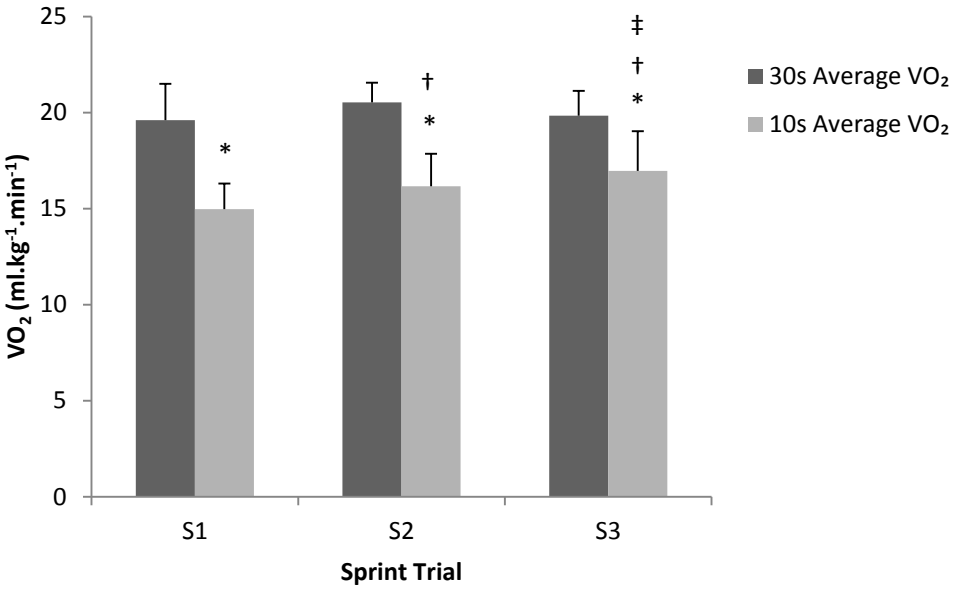

Figure 4. Mean (±SD) average VO_2 during 30s and 10s sprints performed during two individual sprint interval training sessions.

*Significant difference between 30s and 10s sprints (P < 0.05). †Significantly greater than sprint 1 (10s trial; P < 0.05). ‡Significantly greater than sprint 2 (10s trial; P < 0.05).

4.2.3 HR*peak*

HR*peak* was greater during 30s sprint intervals (181 ± 9 beat min^{-1}) in comparison to 10s sprint intervals (164 ± 13 beat min^{-1}; $P < 0.05$). During 10s sprint trials HR*peak* was greater in S2 and S3 than in S1 ($P < 0.05$). No sprint duration x trial effect was observed for 30s sprints ($P > 0.05$).

4.2.4 Average HR

Average HR was significantly greater for 30s sprint intervals (155 ± 12 beat min^{-1}) than 10s sprint intervals (127 ± 16 beat min^{-1}; $P < 0.05$). There was also a significant effect of sprint duration and trial with S2 and S3 being greater than S1 for both 30s and 10s protocols ($P < 0.05$). During 10s sprint trials, S3 was greater than S2 ($P < 0.05$). However, no difference was observed between S2 and S3 for 30s sprint trials ($P > 0.05$).

4.3 Muscle Deoxygenation

4.3.1 Peak Muscle Deoxygenation

Peak muscle deoxygenation was 43.8 ± 26.3 µM during 30s sprints and 44.7 ± 25.6 µM for 10s sprints. Peak muscle deoxygenation for 30s and 10s sprint trials are illustrated in Figure 5. There was no significant difference between 30s and 10s sprint peak deoxygenation ($P > 0.05$) and there was no sprint duration x trial effect for either SIT protocol ($P > 0.05$).

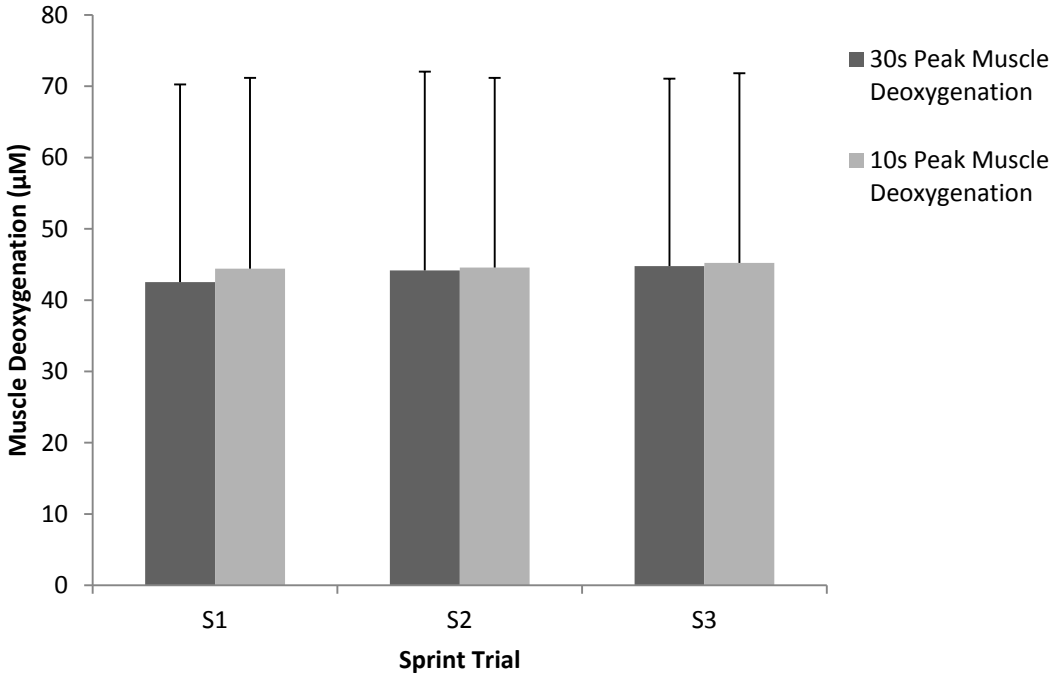

Figure 5. Mean (±SD) peak muscle deoxygenation during 30s and 10s sprints performed during two individual sprint interval training sessions.

4.3.2 Average Muscle Deoxygenation

Average muscle deoxygenation is illustrated for 30s and 10s sprints in Figure 6. Average muscle deoxygenation was not different between 30s and 10s sprint protocols ($P > 0.05$). However there was a significant effect of sprint duration on trial ($P < 0.05$). During 10s sprint trials, S3 was greater than S1 ($P < 0.05$). During 30s sprint trials, S3 and S2 were greater than S1 ($P < 0.05$). S3 was also greater than S2 ($P < 0.05$).

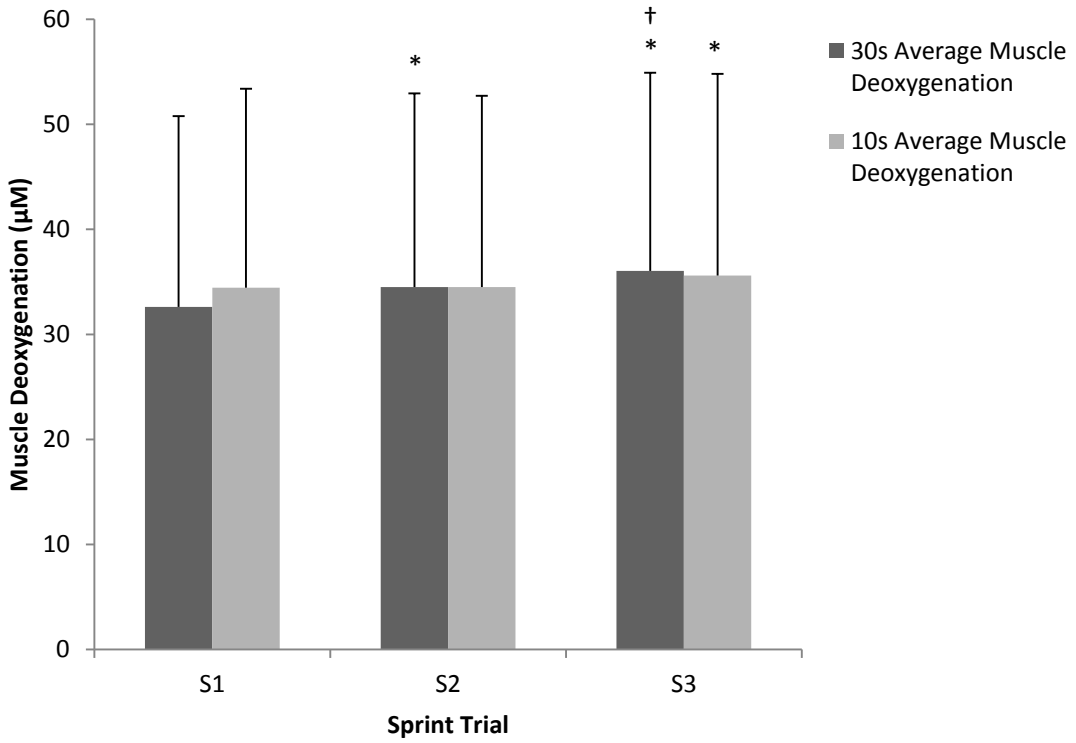

Figure 6. Mean (±SD) average muscle deoxygenation during 30s and 10s sprints performed during two individual sprint interval training sessions.

*Significantly greater than sprint 1 ($P < 0.05$). †Significantly greater than sprint 2 (30s trial; $P < 0.05$).

4.4 Muscle TOI

4.4.1 Peak Muscle TOI

Peak muscle TOI was not significantly different between 30s and 10s sprint intervals ($P > 0.05$). There was also no effect of sprint duration x trial for both sprint interval protocols ($P > 0.05$). Peak muscle TOI for 30s and 10s sprints are shown in Figure 7.

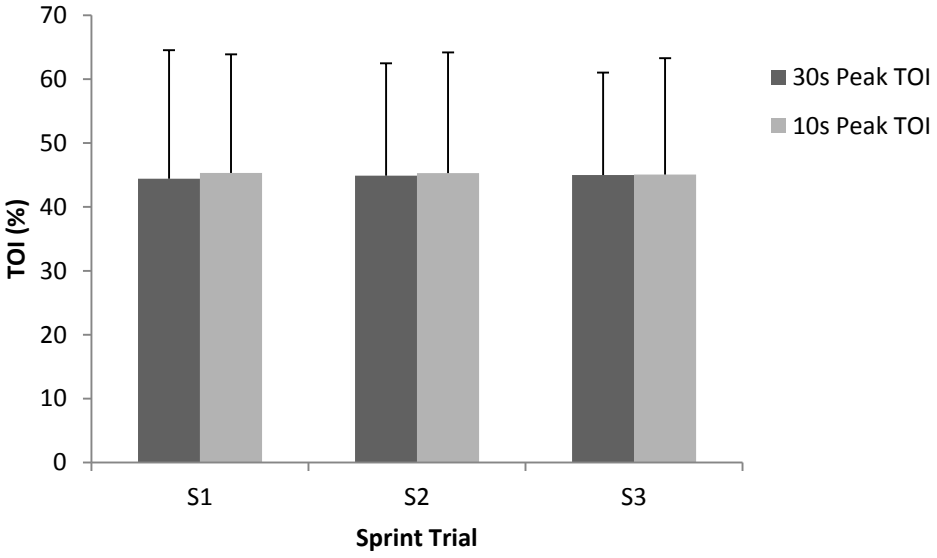

Figure 7. Mean (±SD) peak Tissue Oxygenation Index (TOI) during 30s and 10s sprints performed during two individual sprint interval training sessions.

4.4.2 Average Muscle TOI

Average muscle TOI for 30s and 10s sprints are shown in Figure 8. Average TOI was also not different between sprint interval protocols ($P > 0.05$). However during 30s sprint trials, S3 was greater than S1 ($P < 0.05$). There were no differences in average TOI for 10s trials ($P > 0.05$).

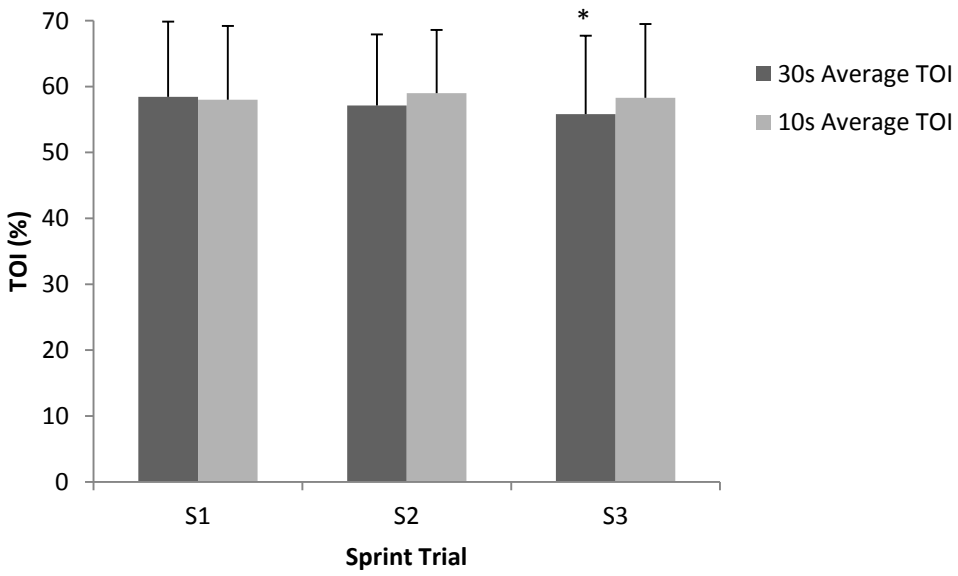

Figure 8. Mean (±SD) average Tissue Oxygenation Index (TOI) during 30s and 10s sprints performed during two individual sprint interval training sessions.

*Significantly lower than sprint 1 ($P < 0.05$).

4.5 NIRS and VO_2 Reliability

Mean VO_2 reliability data values were 14.7 ± 0.8 ml kg^{-1} min^{-1} for visit one and 14.5 ± 1.5 ml kg^{-1} min^{-1} for visit two and were not significantly different ($P > 0.05$). The intraclass correlation coefficient (ICC) based upon steady state VO_2 data was 0.96 suggesting excellent reliability (Weir, 2005).

Mean TOI reliability data values were 62.6 ± 6.4 % for visit one and 65.7 ± 4.1 % for visit two and were not significantly different ($P > 0.05$). Figure 9 illustrates a positive correlation between visit one and visit two TOI. The ICC based upon steady state TOI data was 0.68. The ICC suggests moderate reliability for the TOI data gained from NIRS (Celie et al., 2012).

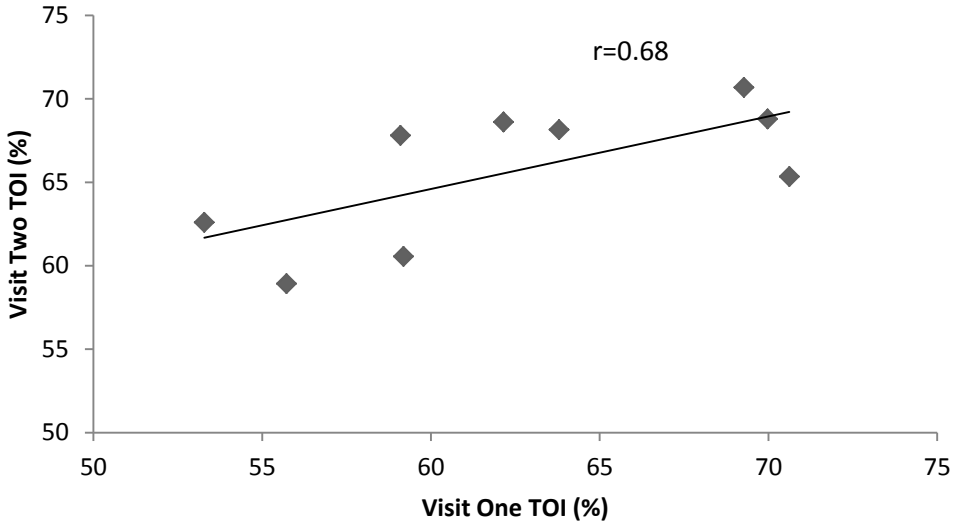

Figure 9. Relationship between mean Tissue Oxygenation Index (TOI) data recorded via NIRS during warm up periods for visits one and two prior to a sprint exercise.

The time course of VO_2*peak*, RER, HR, power and NIRS variables of a representative participant are illustrated for each 30s and 10s sprint in Figure 10.

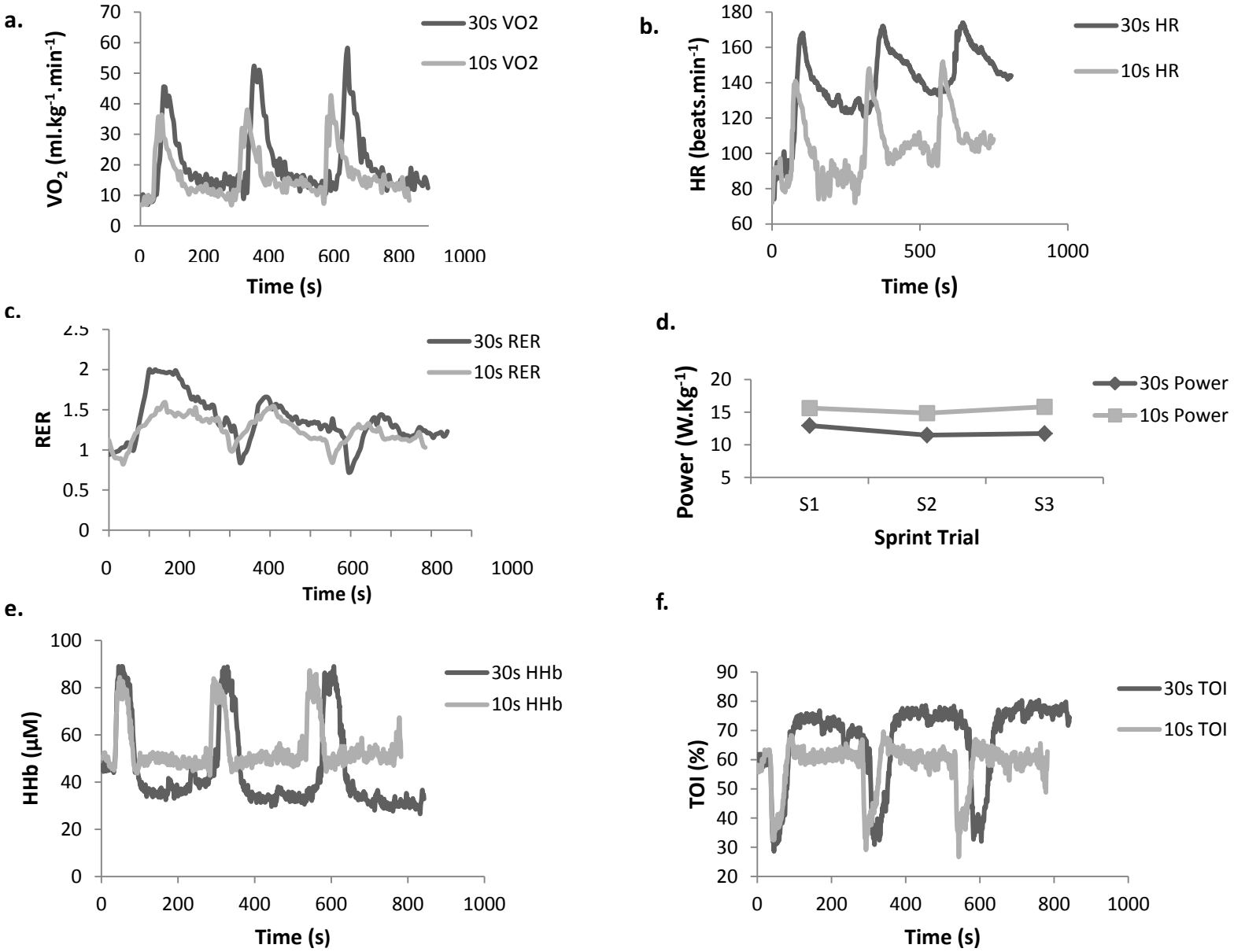

Figure 10. Cardiorespiratory, muscle oxygenation and performance variables during 30s and 10s sprint interval training sessions in a representative participant. a. Changes in oxygen uptake (VO_2). b. Changes in heart rate (HR). c. Changes in RER. d. Changes in power output. e. Changes in muscle deoxygenation (HHb). F. Changes in tissue oxygenation index (TOI).

CHAPTER FIVE

DISCUSSION

5.0 Discussion

The present study was undertaken to assess the acute physiological responses which occur during a SIT and modified SIT session. Assessing the acute physiological responses which occur during SIT and modified SIT may allow an insight into adaptation mechanisms and whether it is peak power generation or power maintenance which results in training adaptations (Hazell et al., 2010). The main findings of the present study were that: (1) performance declined during SIT but was maintained during modified SIT, (2) cardiorespiratory responses were significantly greater during SIT intervals in comparison to modified SIT intervals, (3) muscle oxygenation responses were not significantly different during SIT and modified SIT sessions.

5.1 Performance

As expected and in line with our hypothesis, peak and average power outputs were greater during modified SIT in comparison to SIT. Although peak power output has not been assessed during a single session of modified SIT, peak power outputs reported during consecutive Wingate tests (10.2 ± 0.8 $W.Kg^{-1}$; Mclester et al., 2008) or six 30s sprint intervals (9.2 ± 1.0 $W.Kg^{-1}$; Buchheit et al., 2012) were lower than those achieved during the SIT session in the current study (13 ± 2.9 $W.Kg^{-1}$). We can suggest therefore that participants were highly motivated and did not adopt pacing strategies throughout the SIT protocol.

Peak and average power outputs also decreased over the series of 30s sprint intervals but were maintained during 10s sprint intervals. This is in line with Buchheit et al. (2012) who reported peak and average power outputs to decrease over a series of 30s sprint intervals. SIT therefore has a higher exercise volume in comparison to modified SIT. However due to the ability to maintain peak power output the intensity of the modified SIT session was greater than that of the SIT session. It is not surprising therefore that improvements in peak power output are similar following SIT and modified SIT (Burgomaster et al., 2005; Burgomaster et al., 2006; Hazell et al., 2010).

It is also important to note that although perceived exertion was not quantified during the SIT and modified SIT sessions, subjectively participants found the 10s sprints less demanding and easier to perform in comparison to the SIT session. This is also supported by six of the nine participants only being able to complete three out of six 30s sprints.

5.2 Cardiorespiratory Responses

Our results demonstrate that VO_2*peak* and HR*peak* responses were significantly greater during SIT in comparison to modified SIT. The results of the current study agree with earlier work demonstrating that during 30s sprint intervals, individuals reach close to (or above) 90% of their VO_2*max* (Buchheit et al., 2012). An important finding of the current study was that during modified SIT, participants only attained peak VO_2 of 72.2 ± 6.9% of maximum. It can be suggested therefore that the attainment of high cardiorespiratory responses may

not be responsible for improvements in VO_2max. In addition, considering limited time is spent at 90% VO_2max during SIT and approximately 70% VO_2max during modified SIT, the cardiorespiratory system may not be stressed to a sufficient level to stimulate substantial central adaptations (Buchheit et al., 2012). Taken together, these data possibly indicate that improvements in exercise capacity following SIT and modified SIT, are the result of enhanced O_2 utilisation at the muscle rather than enhanced O_2 delivery through increased stroke volume. It could be deduced that improvements in VO_2max are therefore due to an increase of the arteriovenous oxygen difference, rather than increased maximal cardiac output. It can therefore be suggested that enhanced exercise capacity reported following SIT and modified SIT programmes is the result of peripheral rather than central adaptations (Buchheit et al., 2012).

In addition, our findings indicate VO_2peak and mean HR to be greater in sprints two and three when compared to sprint one during 30s sprint intervals. Buchheit et al. (2012) also reported VO_2peak and mean HR to be greater for sprints two through to sprint five than sprint one. With respect to modified SIT, VO_2peak was greater in sprint three than sprint one and mean HR was greater in sprint three than sprint two. Due to the requirement to generate maximal power output with declines in PCr availability it can be inferred that both glycolysis and oxidative phosphorylation are required throughout sprint intervals (Hazell et al., 2010). It is therefore likely that aerobic metabolism becomes more important throughout the series of sprint bouts (Bogdanis et al., 1998; Mclester et al., 2008).

5.3 Muscle Oxygenation Responses

An important aspect of the current study was the assessment of the reliability of the TOI generated from NIRS during the warm up period prior to SIT and modified SIT. Although there have been reports of good to excellent reliability for NIRS variables generated from exercise at the lactate threshold, muscular contractions or cuff occlusions, our study is the first to assess reliability prior to SIT or modified SIT sessions (Austin et al., 2005; Celie et al., 2012; Crenshaw et al., 2012). The results of the ICC (r = 0.68) indicated moderate reliability. Considering the reliability of VO_2 data was excellent (r = 0.96) caution should be taken when assessing the muscle oxygenation findings within the current study

The degree of muscle deoxygenation and TOI is important in gaining insight into peripheral changes causing skeletal muscle remodelling (Neary et al., 2002). Improvements in muscle oxidative capacity have commonly been reported following SIT (Burgomaster et al., 2005; Burgomaster et al., 2006). Fluctuations in O_2 consumption at the muscle have therefore been reported to act as an important stimulus in promoting muscular oxidative capacities (Buchheit et al., 2012).

An important finding of the current study was that there was no difference in peak muscle deoxygenation or peak TOI during SIT and modified SIT sessions. Considering muscle deoxygenation and TOI reflect localised O_2 delivery and O_2 utilisation, the extent of O_2 extraction caused by SIT and modified SIT were similar during both protocols despite differences in sprint duration. It is therefore not surprising that modified SIT has been reported to elicit similar adaptations as SIT, despite a reduced time commitment (Hazell et al., 2010).

Peak muscle deoxygenation assessed via NIRS during ramp exercise in active students has previously been reported at 33.2 ± 11.4 μM (Boone et al., 2012). In the present study peak deoxygenation was 43.8 ± 26.3 μM and 44.7 ± 25.6 μM in SIT and modified SIT sessions, respectively. The peripheral stress caused by SIT and modified SIT may therefore be greater than that which occurs during ramp exercise. Although blood lactate was not assessed in the current study, it can be speculated that similar increases in blood lactate occurred during 30s and 10s sprints, possibly causing a rightward shift of the oxyhaemoglobin curve driving muscle deoxygenation (Billaut and Smith, 2010).

The results of the current study also agree with earlier work demonstrating progressive declines in peak muscle deoxygenation throughout 30s sprint trials (Buchheit et al., 2012). Considering O_2 demand at the muscle would be similar for all sprint trials, it can be suggested that a priming effect caused by sprint one enhanced O_2 delivery to the muscle (Tordi et al., 2003). In addition, muscle deoxygenation rapidly decreased at the start of both 30s and 10s sprint intervals. It is therefore possible that both SIT and modified SIT stimulate glycolysis and

oxidative phosphorylation due to the need to generate maximal power output (Hazell et al., 2010).

With regards to the TOI, Buchheit et al. (2012) previously reported that 30s sprint peak average TOI values were 42.8 ± 5.8%. Our findings indicated a similar TOI value (44.8 ± 17.3% and 45.2 ± 17.8%) for 30s and 10s sprint intervals, respectively. Although oxidative capacity has not been assessed following a modified SIT programme, the results of the current study would imply that adaptations regarding enzyme concentrations and mitochondrial changes may occur to a similar extent as those reported following SIT programmes (MacDougall et al., 1998; Barnett et al., 2004; Burgomaster et al., 2005).

It has also been previously reported that declines in peak power output result in greater declines in TOI (Billaut and Smith., 2010; Buchheit et al., 2012). However, an interesting finding of the current study was that despite no declines in peak power output, TOI decreased to a similar level during modified SIT. In addition VO_2peak was maintained throughout SIT and modified SIT sprint trials, indicating that fatigue was unlikely to have affected the TOI response (Buchheit et al., 2012).

With respect to muscle reoxygenation, all participants returned to baseline TOI within the first minute of recovery for both SIT and modified SIT sessions. It is also important to note that some participants elicited a hyperaemia effect during recovery, with TOI increasing above baseline values. Although no hyperaemia effect was reported by Buchheit et al. (2012) muscle oxygenation returned to pre-sprint levels during the two minute recovery period. Perhaps this was the result of

increased blood lactate accumulation inducing vasodilation in the active muscle (Chuang et al., 2002; Tordi et al., 2003; Billaut and Smith, 2010). However despite muscle reoxygenation returning to or above baseline values during SIT, peak power output decreased throughout the series sprints. It can therefore be implied that muscle reoxygenation is not a valid measures of a muscles metabolic recovery (Buchhiet et al., 2012). We can infer therefore that muscle reoxygenation is not a limiting factor of high intensity performance (Buchheit et al., 2012).

5.4. Summary of Acute Responses

Taken together, the acute responses observed in the present study provide further support for the conclusions made by Hazell et al. (2010). Peak power generation which occurs during 10s therefore appears to be an important stimulus for promoting physiological adaptations rather than attempting to maintain power output over the remaining 20s of each sprint (Hazell et al., 2010). It is not surprising therefore that SIT and modified SIT have been reported to elicit similar physiological adaptations despite a reduced time commitment (Hazell et al., 2010).

5.5 Practical Implications

To our knowledge this is the first study to assess the acute physiological responses during a SIT and modified SIT session. The findings of the current study provide support for the proposal of Hazell et al. (2010) in that peak power generation is a more important stimulus for eliciting physiological adaptations than power maintenance. As a result, modified SIT could be an effective alternative to MICT and SIT in gaining similar adaptations with reduced time commitment and reduced difficulty. This is important considering a large percentage of the general population fail to meet recommended health guidelines and report lack of time as a barrier to participation (Booth et al., 1997; Gibala and McGee, 2008). Modified SIT would also be an advantageous method for athletes who may have reductions in fitness during competitive seasons when there is an emphasis on skill development (Hazell et al., 2010).

The current study also suggests that SIT and modified SIT predominantly promote peripheral rather than central adaptations. Muscle oxygenation responses assessed via NIRS during SIT and modified SIT, indicate similarities in metabolic signalling despite differences in sprint duration (Coffey and Hawley, 2007). The reduced cardiorespiratory demand during modified SIT also highlights the possibility of modified SIT to be implemented, under supervision for the treatment of health related issues. As a result, modified SIT could be an effective, time efficient intervention within clinical settings.

5.6 Critique of the Methodology

NIRS is a useful tool providing insight into peripheral changes resulting from training (Austin et al., 2005). The use of NIRS in the current study allowed insight into localised O_2 extraction in order to gain understanding into the signals responsible for metabolic adaptations (Coffey and Hawley, 2007). NIRS has therefore been reported to be a reliable measure of muscle oxygen saturation (Austin et al., 2005). Previous investigations however have failed to assess the reliability of NIRS as a measure of muscle oxygenation during SIT (Bailey et al., 2009; Buchheit et al., 2012). In the current study the reliability of NIRS as a measure of the TOI was assessed as moderate (r = 0.68). Every effort was made to ensure the reliability of the NIRS data through calibration and reposition of the NIRS probe during subsequent visits. Although low signal noise during sprints could have affected the reliability of the NIRS data, it is possible that differences in blood flow between participants and visits to the laboratory affected the O_2 saturation readings (Boushel et al., 2001).

In addition to the reliability issues, it must also be remembered that NIRS light is absorbed by the skin and adipose tissue. Participants within the study all had a BMI >32. However it must be acknowledged that the NIRS signal may have been affected by variations in body fat (Boushel et al., 2001). The use of NIRS in the current study was also performed on one portion of the vastus lateralis. It must be assumed therefore that the portion of muscle investigated was representative of the whole muscle.

Regarding other aspects of methodology, the current study could have benefited from the use of a rating of perceived exertion (RPE) scale. Assessment of how participants felt during SIT and modified SIT sessions, would have given an objective measure of difficultly between the two sessions. This would have allowed for an indication of the practicality of the SIT sessions and whether the use of modified SIT could be implemented within populations with health issues.

5.7 Future Developments

To date and to our knowledge, only one study has assessed the training induced adaptations following two weeks of modified SIT (Hazell et al., 2010). However, it remains unclear as to how modified SIT would compare to MICT and SIT over longer training periods. Measures of skeletal muscle mitochondrial enzymes and health related variables such as insulin sensitivity are also yet to be compared following modified SIT in relation to those reported after SIT programmes. This would allow for a greater understanding into the peripheral adaptations elicited by modified SIT and whether there is the potential for the protocol to be implemented within clinical settings.

A further recommendation which could be suggested directly from the current study is the need for the assessment of the acute physiological responses, which occur during six 30s and six 10s sprint intervals. This assessment was intended within the current study however the demanding nature of SIT made this difficult, as participants were unable to complete the SIT protocol. It is therefore unknown

as to whether the effects observed in the current study would change with the inclusion of more sprint intervals.

CHAPTER SIX

CONCLUSION

6.0 Conclusion

SIT has been reported to elicit similar adaptations to those which occur from MICT in a variety of physiological and health-related markers despite approximately one third of the time commitment (Burgomaster et al., 2008; Gibala et al., 2012). Due to the reduced time commitment, SIT would not only benefit sport performers but also the general public (Burgomaster et al., 2005). However the current SIT protocol has been deemed unsafe, impractical and intolerable for general populations (Bayati et al., 2011). HIIT programmes are more accessible than SIT and have been reported to elicit similar adaptations (Bayati et al., 2011; Warburton et al., 2005; Whyte et al., 2010). However HIIT programmes are not as time efficient as SIT and the area has become saturated with a range of protocols (Helgerud et al., 2007; Gormley et al., 2008; Little et al., 2011). Modification of the SIT protocol to 10s intervals, has been shown to elicit similar adaptations over a two week period as SIT (Hazell et al., 2010). It has therefore been suggested that peak power generation is a more important training stimulus than attempted power maintenance (Hazell et al., 2010). Despite this the acute physiological responses which occur during SIT and modified SIT, have failed to be examined. Insight into the cardiorespiratory and muscle oxygenation responses which occur during SIT and modified SIT are important in order to gain insight into adaptation mechanisms and whether peripheral changes result in skeletal muscle remodelling (Neary et al., 2002; Buchheit et al., 2012).

The results of the current study indicate that cardiorespiratory responses were greater during SIT in comparison to modified SIT ($P < 0.05$). However, muscle oxygenation responses were not different between the two SIT protocols ($P > 0.05$). In addition, peak power outputs were greater during modified SIT in comparison to SIT ($P < 0.05$). It can therefore be concluded that peak power generation may act as an important stimulus for eliciting physiological adaptations (Hazell et al., 2010). It can also be suggested that SIT and modified SIT promote peripheral rather than central adaptations.

Modified SIT could therefore be an effective alternative to MICT and SIT in gaining similar physiological adaptations within reduced time commitment and reduced difficulty. Modified SIT also has the potential to be implemented within clinical settings for the treatment of health related diseases due to the reduced difficulty, reduced cardiorespiratory demand and reported physiological adaptations.

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APPENDICES

APPENDIX A

General Health Questionnaire

Your Name: ……

Your Date of Birth: ……

Male / Female (please circle)

Your Height: …… Your Weight: ……

Your Address: ……

……

……

Your Phone No.: ……

Name of person responsible for study: ……..

Please read the following carefully and answer as accurately as possible. The questions are designed solely to determine whether the proposed exercise is appropriate for you. Your answers will be treated as strictly confidential. If you have any doubts or difficulties with any of the questions please contact the person responsible for the study.

1.	**Have you seen your doctor in the last 6 months?**	YES	NO
2.	**Are you currently taking any prescription medications?**	YES	NO
3.	**Has a doctor ever said you have heart trouble?**	YES	NO
4.	Do you ever feel chest pain when you undertake physical activity?	YES	NO
5.	**Do you ever feel faint or have spells of dizziness?**	YES	NO
6.	Do you experience unreasonable breathlessness?	YES	NO
7.	Do you take heart medications?	YES	NO
8.	Has a doctor ever said you have epilepsy?	YES	NO
9.	Has a doctor ever said you have diabetes?	YES	NO
10.	Has a doctor ever said you have asthma or other lung disease?	YES	NO
11.	Do you have a bone, joint or muscular problem which may be aggravated by exercise?	YES	NO
12.	Do you have any form of injury?	YES	NO
13.	Has a doctor ever said you have high blood pressure?	YES	NO
14.	Has a doctor ever said you have high cholesterol?	YES	NO
15.	Do you have a close blood relative who had a heart attack or heart surgery before age 55 (father or brother) or age 65 (mother or sister)?	YES	NO
16.	Do you smoke, or have you quit smoking in the last 6 months?	YES	NO

17. Do you get more than 30 minutes of physical activity on at least 3 days per week?	YES	NO
18. If you are female, are you pregnant?	YES	NO

I have completed the questionnaire to the best of my knowledge and any questions that I have raised have been answered to my full satisfaction.

Signed: ……..

Date: ……

APPENDIX B

CARDIFF METROPOLITIAN UNIVERSITY
INFORMED CONSENT FORM

Title of the Research Project:

The influence of sprint duration on the acute physiological responses during sprint interval training sessions

Name of Researcher: Anna West

Participant to complete the section below:	**Initial**
I confirm that I have read and understand the participant information sheet with regards to the research project being conducted	
I have been able to discuss and ask questions with regards to the research project and participant information sheet, and have had these answered satisfactorily	
I understand that I am free to withdrawal from the research project at any time without giving a justification	
I understand that if I do withdrawal from the study, our relationships with the Cardiff Metropolitan University and our legal rights will not be affected	
I am aware that information obtained from the research project will be reported but that I will not be identified	
I therefore agree to voluntary take part in the research project outlined	
I have been given a copy of this consent form	

Name of Participant ……..

Participant Signature …… **Date:** ……

Name of Person taking Consent……

Signature of Person taking Consent…… **Date:**…….....