CARDIFF METROPOLITAN UNIVERSITY

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CARDIFF SCHOOL OF SPORT

DEGREE OF BACHELOR OF SCIENCE (HONOURS)

SPORT AND PHYSICAL EDUCATION

2015-6

THE INFLUENCE OF RECOVERY MODE ON PHYSIOLOGICAL STRESS AND PERFORMANCE DURING A REPEATED SPRINT PROTOCOL

(Dissertation submitted under the Physiology and Health area)

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Acknowledgements

Firstly, I would like to thank everyone who volunteered to participate in this study, allowing me to complete my data collection. Additionally, I would also like to thank my family and friends who supported me and encouraged me during the process of writing this dissertation. Furthermore, I would like to thank Cardiff Metropolitan University for providing the use of all lab equipment as well as the Physiology Technicians who were more than willing to help if a problem arose. Finally, I would like to thank Dr Paul Smith for his constant support and guidance throughout this study.

Abstract

The purpose of this study was to compare the influence of active recovery (AR) compared to passive recovery (PR), on physiological stress and performance, during a repeated sprint protocol. Additionally, an attempt was made to evaluate the relationship between aerobic capacity and anaerobic performance. Ten male team sport athletes (20.4 (1) y, 183.9 (3.5) cm), 79.3 (7.2) kg) from Cardiff Metropolitan University performed a preliminary VO_{2max} test along with 8 x 6-s sprints separated with 24-s of either AR (cadence of 80 rpm against a resistive load of 1 kg) or PR (stationary) on a Monark cycle ergometer. Maximal oxygen uptake ($VO_{2max)}$ was recorded from the VO_{2max} test. Mean peak power output (PPO), mean average power output (APO), oxygen uptake (VO_2) carbon dioxide uptake (VCO_2), minute ventilation volume (VE) and heart rate (HR) were recorded for each recovery condition. Compared to AR, PPO and APO was greater (952 (118) *vs.* 833 (100) W; $p<0.05$) during the PR. Mean VO_2 (3302 (195) *vs.* 2908 (209) $ml \cdot min^{-1}$, $p<0.05$) was significantly higher during the AR, compared to the PR. A significant relationship was not observed with regard to VO_{2max} and the total work done involving PPO and APO (r (df 8) = 0.403, $p>0.05$; r (df 8) = 0.359, $p>0.05$). In conclusion, during a repeated sprint cycling protocol, AR was associated with a decline in repeated sprint ability (RSA) and higher muscle deoxygenation. Furthermore, individuals with a greater VO_{2max} do not have a significantly greater RSA ($p>0.05$). Future research should look into the effects of different time periods involving AR to identify when it proves advantageous, compared to PR.

CHAPTER 1: INTRODUCTION

1.0 Introduction

Repeated sprint ability (RSA), according to Girard *et al.* (2011) and Thebault *et al.* (2011), refers to the completion of multiple short duration sprints (5-8-s) combined with a brief recovery period. From a performance perspective, performing such exercise is essential within a team sport environment (Brown and Glaister, 2014). Research published by Bishop, Girard and Mendez- Villanueva (2011) defined brief recovery as 60-s or less. When performing repeated sprints, fatigue develops from the onset of exercise, therefore an individuals' capacity to produce peak anaerobic power becomes gradually impaired. This is due to limitations within the body regarding muscular factors including the accumulation of metabolites within muscle fibres, as well as neural changes, such as insufficient motor commands located in the motor cortex (Girard *et al.,* 2011).

1.1 Recovery Mode

Recovery mode is instrumental when performing repeated bouts of high intensity exercise. Most sports provide athletes with natural breaks in play during which time passive or active recovery can take place. Dupont, Bondel and Berthoin (2003) defined passive recovery (PR) as a rest period where little or no movement is involved. In contrast to this, active recovery (AR) is classified as the completion of exercise between 20-60% of maximal aerobic power (Dupont *et al*., 2007; Zavorsky *et al*., 2014).

1.2 Cardiovascular Parameters and Performance: Active vs Passive

When exercising various acute physiological changes occur such as increased heart rate (HR) and changes involving oxygen uptake kinetics (Spencer *et al.,* 2005). Kenney *et al*. (2012) identified maximal oxygen consumption (VO_{2max}) as the best physiological determinant of an individuals' cardiorespiratory endurance capacity. Although sprinting is largely fuelled by the ATP-PCr system, as performance continues a greater emphasis is placed on the aerobic system (McArdle, Katch and Katch, 2006). Once this occurs the rate of VO_2 will increase in order to provide a greater oxidative phosphorylation to resynthesis ATP (Bailey *et al.,* 2009; Thebault et al., 2011). Tomlin and Wenger (2001) suggested that a greater VO_2 when sprinting leads to a decreased reliance on anaerobic glycolysis and consequently a better maintenance of power.

The comparison between active and passive recovery has been well documented with regards to the effect on physiological parameters as well as performance. From a performance perspective, studies have shown that AR is advantageous as it promotes blood lactate clearance, therefore improving power output recovery (Signorile *et al.,* 1993; Thiriet *et al.,* 1993; Bogdanis *et al.,* 1996; Connolly *et al.,* 2003). However, more recent research conducted by Spencer *et al.* (2006) identified AR to be detrimental in the context of peak power production, compared to a PR.

In relation to physiological stress, Buchheit *et al.* (2009) established that when undergoing an AR, cardiovascular parameters (HR, VO_2, VCO_2 and VE) were significantly higher compared to a PR. An investigation published by Ben Abderrahman *et al.* (2013) reported that following a seven week, high intensity interval training programme involving two training groups (one participating in AR, the other PR), those who took part in an AR improved VO_{2max}.

1.3 Relationship between Aerobic and Anaerobic Performance

Various physiologists have conducted research around the area involving the relationship between aerobic peak power and RSA with varied findings. Castagna *et al.* (2007) identified that during repeated sprints both aerobic and anaerobic energy systems are used, contributing in varying proportions at different stages of performance.

Cipryan and Gajda (2011) concluded that the level of VO_{2max} did not influence performance indices such as peak anaerobic power, therefore contradicting previous research established by Tomlin and Wenger (2001). Despite positive research characteristics such as a large sample size, a limitation to this study was the fact that a straight running sprint test (RAST) was used. This methodology clearly does not account for multidirectional movement which is often associated with team sports (Wragg *et al.,* 2000). Additionally, participants were required to run less than 40 m which has previously been identified to show no correlation with VO_{2max} (da Silva *et al.,* 2010).

Findings published by Jones *et al.* (2013) confirmed that aerobic capacity is an important factor when recovering from RSA. Furthermore, Bishop and Edge (2006) identified significant correlations between VO_{2max} and RSA performance indices. Findings highlighted that those with a greater VO_{2max} were able to maintain a greater repeated sprint performance. Bishop and Edge (2006) proposed that the greater amount of oxygen

consumed and utilised by the muscle during recovery decreased the anaerobic contribution to performance and enhanced PCr resynthesis. A limitation of Jones *et al.* (2013) work, however, was that the relationship between anaerobic capacity and RSA was not assessed.

1.4 Rationale

To summarise, the purpose of the proposed study will be to examine and explore the influence of recovery mode on physiological stress and performance, following a repeated sprint protocol. Additionally, an attempt will be made to evaluate the relationship between peak aerobic power (VO_{2max}) and RSA. The rationale behind this study is that it has the potential to identify scientific training programmes, therefore preventing injury and optimising performance (Pote and Christie, 2014). With regards to team sport, data may induce the development and implementation of playing strategies allowing players to recover on a rotating basis (Padulo *et al.,* 2015). Ben Abderrahman *et al.* (2013) further proposes that findings may prove beneficial to middle and long distance running and cycling coaches attempting to evoke physiological adaptations within athletes, as well as providing relevant training intensities and associated recovery methods to optimise exercise performance.

The research question proposed includes whether an AR strategy was detrimental to performance, and influenced associated physiological responses during a repeated sprint cycling protocol, when compared to PR. Additionally, a secondary objective was to evaluate whether VO_{2max} impacted upon RSA. The hypotheses generated state; that an AR will have a detrimental effect on performance and will elicit higher physiological responses; and those individuals who have a greater VO_{2max} will demonstrate a better RSA.

CHAPTER 2: LITERATURE REVIEW

2.0 Literature Review

2.1 Demands of Repeated Sprint Ability (RSA)

Repeated sprint ability (RSA) is predominantly an anaerobic activity requiring athletes to produce maximal or near maximal efforts separated with short recovery periods (McArdle *et al.,* 2006; Girard *et al.,* 2011; Thebault *et al.,* 2011). Despite the majority of exercise being of an anaerobic nature, as the amount of sprints and subsequently the time period of performance increases, an increased aerobic contribution becomes evident (Castagna *et al.*, 2007). Furthermore, according to Tomlin and Wenger (2001) the aerobic system is key in relation to the recovery process following repeated sprints.

Regarding team sport performance, repeated sprints are thought to account for up to 10% of the total distance covered (Spencer *et al.,* 2004; Spencer *et al.,* 2005; Stolen *et al.,* 2005; Buchheit *et al.,* 2010). This is due to athletes experiencing fatigue leading to decreases in maximal power (cycling) and speed (running). Girard *et al.* (2011) identified this primarily occurs due to muscular and neural changes, although Thøgersen-Ntoumani *et al.* (2016) identified that intrinsic motivation was greater in fitter individuals when participating in exercise.

2.2 Muscular and Neural Factors effecting RSA

In relation to muscular changes, phosphocreatine (PCr) availability influences the onset of fatigue. Adenosine triphosphate (ATP) is utilized during high intensity exercise and therefore requires PCr during rephosphorylation to resynthesise (Girard *et al.,* 2011). Phosphocreatine availability, as demonstrated by Gaitanos *et al.* (1994) and Dawson *et al.* (1997), can reach as low as 35-55% of resting levels, following a six second maximal sprint. Karatzaferi *et al.* (2001) acknowledged that muscle fibre types determine PCr availability as fast twitch fibres are associated with a greater PCr reduction. This is because fast twitch fibres are responsible for power production. With respect to team sport, ATP and PCr stores fail to replenish fully from the onset of exercise as usually there is an insufficient recovery time (Bogdanis *et al.,* 1996; Dawson *et al.,* 1997).

Dupont *et al.* (2005) recognised that when performing a single 6-s sprint, anaerobic glycolysis provided almost 40% of total energy, and glycolysis was prohibited following subsequent sprints. However, Girard *et al.* (2011) identified that increasing a glycogenolytic rate may not result in an enhanced RSA. This is because athletes with a greater glycogenolytic rate from an initial sprint are associated with increased decrements in power

output due to a greater production of hydrogen ion's (H^+; Bishop *et al.,* 2004). It appears that further research must be undergone to identify whether initial and mean performance will be enhanced through an increase in anaerobic contribution.

Research published by Spencer *et al.* (2008) discussed that acidosis within the working muscle was responsible for inhibited RSA. The study by Spencer *et al.* (2008) employed moderately trained athletes performing three sprint protocols consisting of six, 4-s sprints with 25-s rest. Results highlighted that increases in H^+ accumulation led to an enlarged decrement in power and work. Spencer *et al*. (2008) attributed this to a decrease PCr levels and mitochondrial ATP, subsequently leading to a reduced PCr resynthesis. However, despite these findings there is much disparity within the literature regarding acidosis as a main cause of fatigue. A study conducted by Matsuura *et al.* (2007) involving sodium bicarbonate ingestion, concluded that an enhanced cellular buffering capacity failed to improve RSA.

During repeated sprint exercise, the body experiences a reduction in neural drive to the working muscles. This is largely associated with a decrement in performance due to decreased contracting musculature (Racinais *et al.,* 2007; Perrey *et al.,* 2010). Racinais *et al.* (2007) identified that although participants within their study experienced a progressive muscular deoxygenation, they were able to preserve and utilise oxygen throughout ten, 6-s sprints. Therefore, Racinais *et al.* (2007) proposed that the maximal voluntary force decreased due to a lack of neural drive. Results showed significant decreases in both the percentage of voluntary activation and surface electromyogram (EMG). Racinais *et al.* (2007) concluded that this was the first time neural drive failure had been confirmed within repeated sprints. Consequently, further research must be undertaken to identify a cause for activation failure as it may lead to the development of training procedures to suspend the failure and subsequently enhance repeated sprint performance.

Further work published by Mendez-Villaneuva *et al.* (2008) agreed with the findings of Racinais *et al.,* (2007). Mendez-Villaneuva *et al.* (2008) discussed that a reduced neuromuscular activation led to fatigue within repeated sprints. Data identified a parallel decline regarding power output and EMG amplitude within the *m. vastus lateralis*. In additon, the central nervous systems drive to the working musculature decreased along with alterations in the neuromuscular activation of contracting muscles. It is uncertain whether the decline in EMG was due to the progressive inhibition of the motor units, however, as surface EMG is unable to differentiate between motor unit recruitment as well as rate coding. Therefore, it is not possible to identify the mechanisms contributing to a decreased EMG

activity. Moreover, EMG readings can be altered through excessive sweating and changes in fibre membranes. Additionally, Hunter *et al.* (2003) highlights the range of movement from the working muscle can decrease the validity and reliability of the EMG signal (cycling produces a more reliable reading than running). Furthermore, Mendez-Villaneuva *et al.* (2008) gave credit to the potential fatigue of fast-twitch fibres with respect to impaired performance. Fast twitch fibres are known to control supramaximal power production and provide increased susceptibility to fatigue when compared to slow twitch muscle fibres (Karatzaferi *et al.,* 2001).

2.3 Cardiovascular Parameters: Active (AR) *vs.* Passive recovery (PR)

Nakumara *et al.* (2009) documented that when performing repeated supramaximal sprints there are various alterations regarding metabolic homeostasis. Consequently, it is imperative to enhance recovery from a training and competition perspective in order to improve performance and minimise the risk of injury (Argus *et al.,* 2013). Dorado *et al.* (2004) suggested that an AR was likely to enhance performance through an increase in O_2 delivery to the working muscles, therefore, leading to an enhanced PCr resynthesis. Data published by Brown and Glaister (2014) involving the use of 10 male recreational athletes, however, identified a significant difference ($p \leq 0.05$) with regard to mean heart rate recovery (HR_{rec}) ($b \cdot min^{-1}$) during 45-s and 180-s AR periods (164 (10); 150 (16)) compared to a PR (156 (12); 133 (19)). Active recovery (AR) was shown to prevent the immobility of the blood within the formerly active muscle and enhance blood flow. Brown and Glaister (2014) further argued that this delayed haemodynamic effect only proved beneficial to performance during recovery periods of 180-s as opposed to 45-s. These findings supported previous work, identifying that the haemodynamic effect of AR was only apparent after a 2-min period (Crisafulli *et al.,* 2004; Draper *et al.,* 2006; Buchheit *et al.,* 2009; Barak *et al.,* 2011).

In contrast to the findings of Brown and Glaister (2014), work produced by Wahl *et al.* (2013) included junior triathletes who were separated into an active and passive recovery group. Wahl *et al.* (2013) found alternate verdicts with respect to HR during periods of recovery. Both groups participated in a 14 day high-intensity shock microcycle. Before and after the 14 day programme, participants performed a Wingate, time trial and ramp test. Data illustrated that the AR individuals demonstrated lesser maximum heart rates (HR_{max}) during a 20-min time trial, both pre- and post-training interventions (Pre: 180 (10); Post: 179 (7) $b \cdot min^{-1}$), compared to the PR group (Pre: 183 (5); Post: 181 (7) $b \cdot min^{-1}$). This contradicted reports by Hoff *et al.* (2002) who reported a greater HR during AR and further claimed this to be beneficial from a training perspective as it allowed participants to reach their intended

HR (90-95% of HR_{max}) in subsequent bouts of exercise. Wahl *et al.* (2013) on the other hand, argued that PR was advantageous. Figures identified an enhanced endurance performance, with regard to the time trial and performance indices VO_2/ power output. Wahl *et al*., 2013 proposed that a PR led to longer lasting metabolic alterations, thus greater muscle fibre adaptations and an improvement in performance.

Strengths of Wahl *et al.* (2013) research design included the matching and distribution of participants to an AR and PR group based on age and performance. This helped the prevention of possible anomalies occurring within the data as physiological responses such as HR are known to decrease with age (McArdle *et al.,* 2006). In comparison, limitations of Wahl *et al.* (2013) study included the lack of metabolic measures. As a result, lactate and pH levels were not identified within the muscle tissues, which are known to have negative effects on performance. Therefore, further research must be conducted to determine the different physiological responses observed between AR and PR. Furthermore, due to the small sample size used for the study (16 participants: 12 male, 4 female) further research must be carried out to reinforce the data produced as this study is not representative of a population with regard to training status and gender.

With regard to VO_2 kinetics, information provided by Buchheit *et al.* (2009) found that AR increased participants' achieved VO_2 during repeated sprints, compared to PR. More recent findings presented by Brown and Glaister (2014) reinforced information published by Buchheit *et al.* (2009), highlighting a significantly greater oxygen uptake recovery (VO_{2rec}) during AR. However, Brown and Glaister (2014) reported an accompanied elevated metabolic cost, which according to Richardson *et al.* (2006) and Dupont *et al.* (2007) can lead to the depression of muscle tissue oxygenation, which resulted in a decreased intramuscular partial pressure of oxygen (PO_2). Research produced by Buchheit *et al.* (2009) used 10 male team sport athletes. These participants were required to perform two running based sprint protocols, each consisting of four, 6-s sprints with a 21-s rest period (one AR, the other PR). Their findings, presented as mean (±SD) demonstrated a significantly greater (p<0.001) cardiorespiratory stress during AR compared to a PR (HR: 160 (8) *vs*. 155 (8) $b \cdot min^{-1}$; VO_2: 3.64 (0.44) *vs*. 2.91 (0.47) $l \cdot min^{-1}$; VCO_2: 3.89 (0.60) *vs*. 2.96 (0.60) $l \cdot min^{-1}$). The study by Buchheit *et al.* (2009) was relevant to the exercise modality of running through the use of a non-motorised treadmill. However, this data does not account for sports such as track cycling, involving events such as the Kiernin and the omnium which involves six different disciplines in two days (Argus *et al.,* 2013; De Pauw *et al.,* 2014). Therefore,

additional investigations should be undertaken to examine if the same responses occur during a different exercise modality.

Data regarding cardiovascular parameters was later reinforced by Ben Abderrahman *et al.* (2013) who conducted a seven week, high-intensity interval training programme (SWHITP) combined with two recovery modes (active and passive). Ben Abderrahman *et al.* (2013) identified a significant enhancement (p<0.01) regarding VO_{2max} ($ml \cdot min^{-1}\ kg^{-1)}$ following an AR throughout the SWHITP (Pre-test: 59.37; Post-test: 62.85). Furthermore, the 30-s AR proved more efficient when maintaining a high percentage of $VO_{2max.}$ However, a significant difference was not observed with respect to the amount of time spent at 90% and 95% of individuals VO_{2max}. Due to the subjects involved within the study, Ben Abderrahman *et al.* (2013) identified that VO_{2max} was enhanced within individuals who were deemed untrained. However, it is not certain whether the same applies to moderately or endurance trained individuals. This is because trained populations may have already experienced the adaptations explained regarding the respiratory system and therefore, may not elicit any differences following an AR.

2.4 Performance Parameters: Active *vs*. Passive

Padulo *et al.* (2015) explained that athletes with a greater RSA are likely to sustain a greater level of performance than those of a reduced capability; therefore, RSA is viewed as a crucial fitness component within team sports. Performance within repeated sprints as detailed by Gaitanos *et al.* (1993) is largely affected by the intensity, duration and delivery of work periods. If one of these factors is overloaded then performance is impaired through the onset of fatigue (Granatelli *et al.,* (2014).

Early investigations conducted by Thiriet *et al.* (1993) proposed AR to be advantageous when participating in high intensity exercise. Work conducted by Thiriet *et al.* (1993) involved participants performing four exhaustive bouts of exercise, each lasting up to 2-min interspersed with 20-min of recovery (Passive, Leg Active and Arm active). Results identified a decreased decrement with regard to pedal duration for both active recoveries. Therefore, proving beneficial by preserving performance and promoting an enhanced clearance of blood lactate, compared to the PR. Limitations of the work by Thiriet *et al.* (1993) was that each exercise was distributed 20-min apart. From this, it was unlikely a significant difference would have been observed as there was a sufficient recovery time allowing the replenishment of PCr stores and lactate removal, preventing the accumulation of H^+ (Tomlin and Wenger, 2001).

Thiriet *et al.* (1993) data was supported by research findings presented by Bogdanis *et al.* (1996) and Connolly *et al.* (2003). The research design of Connolly *et al.* (2003) study involved seven male cyclists performing six, 15-s sprints with either an AR (80 rpm for 3-min between each bout) or PR. Data illustrated significant differences (p<0.05) regarding mean peak power output (PPO) and average power output (APO) during both protocols. In addition, significantly greater decreases were observed for both PPO and APO during the PR. Connolly *et al.* (2003) identified that a greater performance may have been sustained through the increased contribution of aerobic metabolism. Moreover, potential performance maintenance may have been due to AR, as low intensity exercise is known to reduce the amount of circulating lactate following high intensity exercise (Connolly *et al.,* 2003). Conversely, the methodology used did not represent any significant differences with respect to lactate concentrations between recovery procedures. This may be due to the minimal sample size. According to Tomlin and Wenger (2001), full restoration of PCr requires more than 5-min. Although a 3-min recovery prevented the full replenishment of PCr, the use of 15-s sprints interspersed with 3-min rest periods does not replicate typical team sport performance. Therefore, the data was not relevant to repeated sprints within sports such as football, hockey or rugby.

Adversely, Spencer *et al.* (2006) reported alternate outcomes linked to a study which involved nine males performing four repeated sprint cycle tests (six, 4-s sprints, every 25-s): two with an AR (~32% VO_{2max}) and two with a PR. Results illustrated AR resulted in a greater power decrement than PR (7.4 (2.2*) vs*. 5.6 (1.8)%, p=0.01). Furthermore, a reduced final peak power was reported with regard to AR, when compared to PR (14.9 (1.5*) vs*. 15.3 (1.5) $W \cdot kg^{-1}$, p=0.02). During performance, muscle biopsies were taken from the *m. vastus lateralis*. Spencer *et al.* (2006) concluded that the biopsy analysis suggested performance had decreased during the AR due to decreased PCr levels, resulting in an impaired ability to sustain performance. Spencer *et al.* (2006) further explained that the reduced PCr resynthesis could have been due to limited oxygen as it is reliant on oxidative processes. Previous work by Yoshida *et al.* (1996) supported this by detailing a reduction in muscle oxygenation, during AR, following knee flexion exercises within long distance runners. A Weakness of Spencer *et al.* (2006) study was that cardiovascular parameters were not monitored. Therefore it was not possible to identify whether or not performance was inhibited due to a lack of oxygen. As a result, future investigations should be carried out to record how physiological responses (VO_2, VCO_2, VE and HR) correspond with performance.

Leading on from Spencer *et al.* (2006) research, a study published by Castagna *et al.* (2008) considered the effect of recovery mode on RSA within 16 male basketball players who were 16.8 (1.2) years old. Participants engaged in two repeated sprint protocols (10, 30 m shuttle run sprints) with 30-s of active and passive recovery between shuttles. Castagna *et al.* (2008) identified that AR was detrimental to performance as it resulted in a greater total sprint time and fatigue index (FI), when compared to PR. This agreed with preceding investigations carried out by Dupont *et al.* (2003) and Spencer *et al.* (2006), who concluded that AR reduced blood lactate concentrations during short intermittent sprints, but also illustrated detrimental effects on performance. Dupont *et al.* (2004) suggested performance was reduced through a decline in oxyhaemoglobin, preventing the re-oxygenation of myoglobin (Dupont *et al.*, 2004). Previously, Dupont *et al.* (2003) underpinned this statement, suggesting that PR not only induced a greater myoglobin re-oxygenation, but also a greater PCr resynthesis. Further knowledge provided by Buchheit *et al.* (2009) reiterated that PR was beneficial when preventing muscle deoxygenation. Buchheit *et al.* (2009) proposed this was due to a higher oxygen cost of exercise as well as an insufficient delivery of oxygen to the working muscles.

2.5 Aerobic Contribution to RSA

The relationship between aerobic peak power and RSA has been an area which has produced mixed findings and associated conclusions. Exercise consisting of <10-s, such as sprinting is primarily fuelled through the ATP-PC system. However, when performing repeated sprints the duration of exercise increases, leading to a gradual, but greater contribution from the aerobic system to aid performance (Bishop and Edge, 2006). Jones *et al.* (2013) suggested the ability to perform repeated sprints, at similar levels to initial performance, was likely to allow team sport athletes to perform at a higher standard for a prolonged period of time.

Previous work by Aziz *et al.* (2000) and Tomlin and Wenger (2002), detailed that an individuals' aerobic capacity was a limiting factor during RSA. Findings illustrated moderate correlations between VO_{2max} and total time sprinting. However, Bishop and Edge (2006) posed the question of whether or not a greater RSA may only be associated with a lower initial peak power rather than VO_{2max}? This is because previous research had identified a decreased RSA among those with a larger initial peak power due to a greater proportion of fast twitch muscle fibres (Bishop *et al.,* 2003).

Bishop and Edge (2006) investigated the relationship between VO_{2max} and RSA using females who were matched according to aerobic fitness (low and moderate). Participants performed a VO_{2max} test accompanied by five, 6-s repeated sprints every 30-s. Data highlighted that those of a moderate VO_{2max} demonstrated lesser work decrements across the five sprints (11.1 (2.5*) vs.* 7.6 (3.4*)%; p*=0.045), therefore, in agreement with previous work (Tomlin and Wenger, 2002). Bishop and Edge (2006) credited this to the fact that moderately trained individuals are able to consume and utilise a greater amount of oxygen during recovery spells, meaning there is a reduced anaerobic contribution to exercise. Furthermore, the addition of a greater oxygen supply to the muscle resulted in an enhanced rate of PCr resynthesis. Despite these findings, due to a minor difference in work decrement, Bishop and Edge (2006) suggest that VO_{2max} is not the sole contributor to an enhanced RSA.

Further inquiries into the influence of aerobic power on anaerobic exercise were carried out by Cipryan and Gajda (2011) and subsequently found adverse data to that of Bishop and Edge (2006). Cipryan and Gajda (2011) concluded that VO_{2max} was not associated with an individuals' RSA. Regardless of the data produced, participants' VO_{2max} were derived from a 20 m multi-stage fitness (MSFT) test which had the potential to be inaccurate by as much as 10-15% (Jones *et al.,* 2013). Therefore, preventing a true reflection of the individuals' capability. Moreover, the repeated sprint test consisted of a RAST. As a result participants were running less than 40 m, which as previously reported by da Silva *et al.* (2010) showed no correlation with VO_{2max}.

In contrast to Cipryan and Gajda (2011) research, Jones *et al.* (2013) testified that VO_{2max} was an important factor with respect to recovery between repeated sprint bouts. Maximal oxygen consumption was determined through an incremental treadmill run to fatigue with RSA evaluated over six, 40 m sprints with 20-s active recovery. Figures indicated significant negative correlations between relative VO_{2max} and RSA_{mean} ($r = -0.655$, $p<0.01$) and RSA_{total} ($r = -0.0591$, $p<0.01$). Jones *et al.,* (2013) explained that an enhanced oxygen consumption increased the muscles ability to remove and/or buffer H^+. This provided an efficient restoration of PCr and ATP stores from inorganic phosphate, and subsequently prolonged repeated sprint performance. Limitations of the work conducted by Jones *et al.* (2013) included the lack of assessment between anaerobic capacity and its relationship with RSA. By including such an evaluation the authors would have been able to identify the association between anaerobic and aerobic capacity as well as RSA in order to understand which factor is a better predictor of RSA.

In agreement to work previously discussed by Cipryan and Gajda (2011), Dardouri *et al.* (2014) conducted research into the relationship between RSA and both anaerobic and aerobic performance indices. With regard to determining VO_{2max}, a MSFT was used. Anaerobic speed reserve (AnSR) was calculated from the difference between maximal anaerobic speed (MAnS) and the maximal speed reached during the MSFT. MAnS was established through a 30 m sprint test. Dardouri *et al.* (2014) results elicited that AnSR was the only predictor of RSA in relation to total time (TT) and peak time (PT) (r =-0.68, *p*= 0.001 and r =-0.70, *p*=0.001). Similarly to Cipryan and Gajda (2011) findings, the RSA performance indices failed to show a significant affiliation with the estimated $VO_{2max.}$ This may be through the use of MSFT to estimate a $VO_{2max,}$ which has been previously discussed to be an inaccurate measure of an individual's aerobic fitness.

Whilst it has been discussed that RSA is affected by oxidative metabolism, to this date it appears only one study has looked at the relationship between an individual's VO_{2max} and the VO_2 consumed during isolated maximal sprints. McGawley and Bishop (2015) established individuals' VO_{2max} through a graded exercise test to exhaustion. A repeated sprint test then followed (five, 6-s sprints) which was performed twice with 5-min passive recovery between tests. Individuals' VO_2 were recorded for the first and last sprint of each test. Findings illustrated that participants' VO_2 increased from the first to the 10^{th} sprint with significant differences identified regarding the individuals VO_{2max} and the VO_2 consumed from the fifth, sixth and 10^{th} sprint. McGawley and Bishop (2015) concluded that those with a greater VO_{2max} were likely to be more efficient at resynthesising PCr and could contribute a greater amount of aerobic metabolism to latter sprints.

2.6 Summary

To summarise, limitations regarding the influence of recovery on physiological stress and performance during repeated sprints, include the large use of running based protocols (Buchheit *et al.,* 2009; Brown and Glaister, 2014). Whilst the evidence produced is accurate, it is not relevant to all exercise modalities such as cycling. Additionally, studies have often incorporated more than sufficient recovery periods which allow the replenishment of PCr stores, therefore not reflecting the nature of repeated sprints within team sport environments (Thiriet et al., 1993; Connolly *et al.,* 2003). Recent work conducted by Spencer *et al.* (2006) involved the use of a cycle ergometer which identified a decrement in power output following an AR, compared to a PR strategy; however, cardiovascular parameters were not measured, therefore, no information was provided on physiological responses. Overall, there is much disparity whether AR possesses advantages to performance as studies have

identified enhanced power output recovery credited to lactate removal (Thiriet *et al.,* 1993; Bogdanis *et al.,* 1996; Connolly *et al.,* 2003) as well decrements to power output (Spencer *et al.,* 2006; Castagna *et al.,* 2008).

In relation to aerobic contribution to anaerobic exercise, a key limitation within the literature, as discussed previously, is the use of MSFT in order to estimate an individual's $VO_{2max.}$ For example, research has reported no significant differences regarding the relationship between aerobic and anaerobic performance through the use of a MSFT (Cipryan and Gajda, 2011; Dardouri *et al.,* 2014). In addition to this, RSA has been determined through protocols consisting of <40 m sprints, which as previously recorded by da Silva *et al.,* (2010) did not identify a correlation with $VO_{2max.}$ In comparison, significant differences have been found when adopting other VO_{2max} tests, such as an incremental treadmill run. This highlights uncertainty within the literature and therefore justifies an investigation into the relationship between VO_{2max} and RSA through the use of a more accurate method.

To conclude, the main objective of this research study was to examine whether an AR strategy was detrimental to performance, and influenced associated physiological responses during a repeated sprint cycling protocol, compared to PR. A secondary objective was to evaluate whether VO_{2max} impacted upon RSA. The hypotheses generated state that; an AR will have a detrimental effect on performance and will elicit higher physiological responses; and those individuals who have a greater VO_{2max} will demonstrate a better RSA.

CHAPTER 3: METHODOLOGY

3.0 Methodology

3.1 Participants

The study involved 11 athletes from Cardiff Metropolitan University Sports Teams. All participants volunteered, were non-smokers, free from any health implications and were between the ages of 19-22 years (20.4 (1) y; 183.9 (3.5 cm); 79.3 (7.2 kg)). A participant information sheet summarising the study's main aims and all approved testing protocols were provided, along with informed consent forms and a physical activity readiness questionnaire. These were all completed prior to testing. The option to withdraw from the study was available to participants throughout testing. To ensure participants were not fatigued each protocol took place in a different week, beginning with a preliminary VO_{2max}, followed by an active recovery sprint protocol, finished with a passive recovery sprint protocol. As a result, the order of trials was not counterbalanced.

3.2 Experimental Overview

Participants took part in three test protocols consisting of a preliminary VO_{2max} test and two repeated sprint protocols. All tests were performed using a resistance-braked cycle ergometer (Lode, Excalibur Sport, Lode B.V., Gronigen, The Netherlands) and an online, breath by breath analysis system (Oxycon, Pro, Jeager, Warwick, Warwickshire, UK) in order to measure respiratory data throughout each test. Participants were also required to wear a heart rate (HR) monitor (Polar Electro, RS4000, Polar Electro, Kemple, Finland) throughout all testing procedures. All protocols were completed within a three month period and participants were verbally encouraged throughout all test protocols.

3.3 Preliminary VO_{2max} Protocol

Participants completed a low intensity (less than 120 Watts (W)) warm up on the Excalibur cycle ergometer for a minimum of 4-min. This allowed time to make any final adjustments to the set-up of the ergometer. Expired air was analysed throughout the duration of the test to determine minute ventilation volume (VE), oxygen consumption (VO_2), carbon dioxide uptake (CO_2) and the respiratory exchange ratio (RER). The test began at 120 W and increased progressively throughout until the participant reached voluntary exhaustion. The power output requirement was automatically increased by 30 W every minute using Lode software. Participants were required to cycle at 80 revolutions per minute (rpm) throughout. If the participant's cadence dropped below 10 rpm of their target cadence then the test was stopped and volitional exhaustion deemed to have occurred. Once the test had been completed the Oxycon mask was removed from the participant and the external resistive

load of the cycle ergometer was reduced to a value equivalent to, or lower than the initial warm-up intensity. Participants then cycled at this intensity to aid recovery of the cardio-respiratory systems for a minimum of 5-min. Once the cool-down had been competed the participant removed themselves from the ergometer when they felt they had fully recovered; however, the test administrator ensured that the participant had made a full recovery before they left. During testing, all participants' physiological responses such as VO_2 ($ml \cdot ^{-1}kg \cdot min^{-1}$); VO_2 ($ml \cdot min^{-1}$); CO_2 ($ml \cdot min^{-1}$); VE ($l \cdot min^{-1}$); RER and HR ($b \cdot min^{-1}$) were recoded every 30-s along with each participants' peak aerobic power.

3.4 Generic Sprint Protocol

During both sprint protocols, participants were required to cycle all-out, with no pacing against a test load equivalent to 7.5% of their body mass on a Monark cycle ergometer (Monark, 824E, Monark Exercise AB, Varberg, Sweden). Body mass was calculated to the nearest 0.1 kg using a set of digital scales (SECA, 770, Vogel & Halke, Hamburg, Germany). A free standing stadiometre (SECA, 321, Vogel & Halke, Hamburg, Germany) was used to measure stature to the nearest 0.01 m. Once a participant started to sprint, the test load was automatically engaged with the ergometer flywheel using commercially available Wingate testing software (Cranlea, Wingate 4.0, Cranlea & Company, Bournville, Birmingham, UK).

3.5 Passive Recovery Protocol

The passive protocol took place two weeks later. Prior to testing a standardised warm-up was performed on a Monark cycle ergometer consisting of two 30-s periods of submaximal cycling at 85 rpm and 115 rpm against a resistance of 1.5 kg with 60-s recovery between each period. This was then followed by eight, 6-s sprints (Signorile *et al.,* 1993) against a standard resistive load (7.5% of each participant's body mass; Suzuki *et al.,* 2002) with 24-s passive recovery. During the recovery period the participant remained stationary (Ohya, Aramaki and Kitagawa, 2013). Participants were required to remain seated at all times. After testing all participants were required to complete a 3-min cool-down and were monitored for a further 10-min for health and safety reasons. During testing, participants' physiological responses such as VO_2 ($ml \cdot ^{-1}kg \cdot min^{-1}$); VO_2 ($ml \cdot min^{-1}$); CO_2 ($ml \cdot min^{-1}$); VE ($l \cdot min^{-1}$); RER and HR ($b \cdot min^{-1}$) were recorded every 30-s, along with peak anaerobic power (PPO; W) and average anaerobic power (APO; W) regarding performance.

3.6 Active Recovery Protocol

The final sprint protocol took place one month after the completion of the preliminary VO_{2max} protocol. Prior to testing, a standardised warm-up was performed on a Monark cycle ergometer consisting of two 30-s periods of submaximal cycling at 85 rpm and 115 rpm against a resistance of 1.5 kg with 60-s recovery between each period. This was then followed by eight, 6-s sprints (Signorile *et al.,* 1993) against a resistive load (7.5% of the participant's body mass; Suzuki *et al.*, 2002) with 24-s active recovery. During the recovery period participants cycled at a resistance of 80 W (Robertson, Watt and Galloway, 2004). This was achieved using a cadence of 80 rpm and a resistive load of 1 kg. Participants were required to remain seated at all times. Following the completion of the test, participants were required to participate in a 3-min cool-down and further monitored for an additional 10-min for health and safety reasons. During testing, participants' physiological responses such as VO_2 ($ml \cdot {}^{-1}kg \cdot min^{-1}$); VO_2 ($ml \cdot min^{-1}$); CO_2 ($ml \cdot min^{-1}$); VE ($l \cdot min^{-1}$); RER and HR ($b \cdot min^{-1}$) were recoded every 30-s, along with PPO and APO regarding performance.

3.7 Data Analysis

All statistical analysis was completed using the Statistical Package for the Social Sciences (SPSS). Results are presented in Tables and Figures as mean values (±SD). A separate 2-way, repeated measures, ANOVA test (recovery strategy * sprint number) was used to identify if there was a significant difference between recovery strategies when highlighting physiological responses such as VO_2, VCO_2, VE and HR along with PPO and APO regarding performance. Sphericity checks were carried out for all ANOVA tests. If sphericity was not assumed then the Huynh-Feldt measurement was taken. When a significant main effect was found a *post-hoc* (least significant difference) was performed. Furthermore, a Pearson's product-moment correlation was used to explore the relationship between measures of aerobic capacity (VO_{2max}) and anaerobic performance (RSA). A value of $p<0.05$ was set to determine whether data proved significant. All data is provided as mean values (±SD).

CHAPTER 4: RESULTS

4.0 Results

4.1 Preliminary VO_{2max} Test

Table 1 summarises mean (±SD) values of cardiorespiratory and performance values achieved during the preliminary VO_{2max} test.

VO_{2max} ($ml \cdot min^{-1}$)	3912 (495)
VCO_{2max} ($ml \cdot min^{-1}$)	4756 (693)
VE ($l \cdot min^{-1}$)	146.5 (38)
HR_{max} ($b \cdot min^{-1}$)	178.7 (14.9)
RER	1.2 (0.1)
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	50.1 (7)
Peak aerobic power (W)	315 (45)

4.2 Performance Parameters during both Sprint Protocols

In relation to the AR protocol, mean performance values for PPO (Fig 1) and APO (Table 2) were 833 (100) W and 704 (91) W, respectively. With regard to the PR protocol mean performance values, PPO (Fig 1) and APO (Table 2) were 952 (118) W and 821 (105) W. In relation to APO, no main effect (p>0.05) was observed for the interaction between recovery mode and sprint repetition.

4.3.1 Peak Power Data during both AR and PR Sprint Protocols

Figure.1 shows that PPO (W) was significantly lower (p<0.05) from sprints two to eight during the AR condition compared to the PR condition. With regard to overall repeated sprint performance, there was a significant (p<0.05) main effect for recovery mode for all values of PPO presented in Table 2.

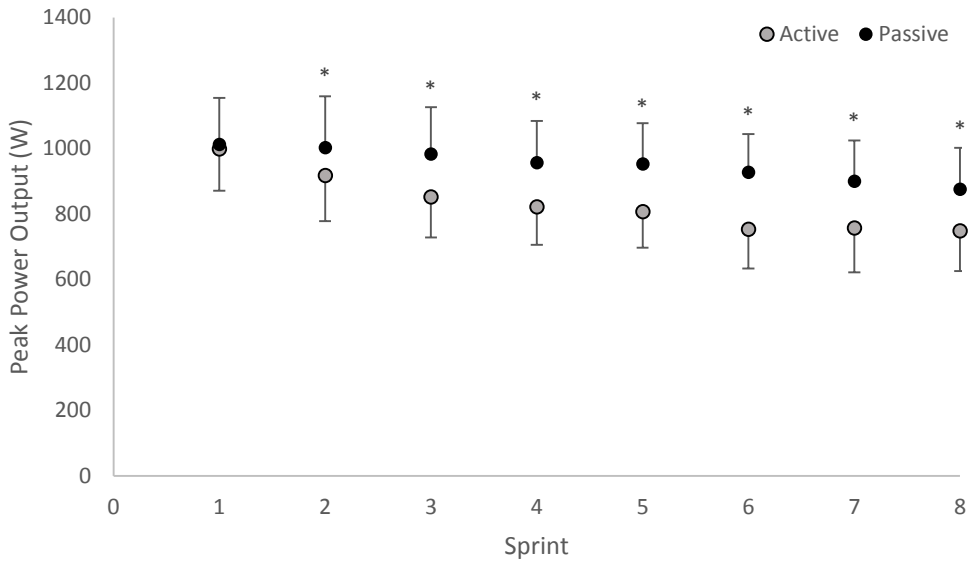

Figure. 1 Mean (+/-SD) values of peak power output (W) achieved during the repeated sprints protocol using an AR or PR strategy (n = 10).

* Denotes a significant difference (p<0.05) between protocols.

4.3.2 Comparison of PPO Values recorded during AR Protocol

With regard to PPO, values measured during the first and second sprint were similar (p>0.05); however, a reduction (p<0.05) in PPO was observed from the third sprint onwards. Furthermore, the third sprint was similar (p>0.05) compared to sprints four and five. Finally, PPO in sprint six was significantly lower (p<0.05) compared to sprint five, but no differences (p>0.05) were observed between sprints six, seven and eight. See Appendix A for *post hoc* raw data relating to PPO during AR protocol.

4.3.3 Comparison of PPO Values recorded during PR Protocol

With regard to PPO, values measured during the first sprint were significantly greater (p<0.05) when compared to sprints six to eight. Furthermore, sprints two, three and four were similar (p>0.05); however, all demonstrated a reduction (p<0.05) in PPO with sprints seven and eight. Peak power out was significantly greater (p<0.05) during sprint five when compared to sprints six to eight. Additionally, sprint six demonstrated a reduction (p<0.05) in PPO when compared to sprint eight. Finally, sprint seven was similar (p>0.05) to sprint eight. See Appendix A for *post hoc* raw data relating to PPO during PR protocol.

Table 2: Mean (+/-SD) values of APO (W) measured during each cycle sprint with AR or PR periods.

Sprint	1	2	3	4	5	6	7	8
APO (W)								
AR	894 (104)	796 (106)	702 (168)	698 (120)	670 (98)	629 (105)	625 (110)	618 (117)
PR *	902 (128)	889 (127)	839 (126)	837 (107)	804 (115)	786 (113)	759 (122)	752 (126)

* Denotes a significant difference *vs.* AR (p<0.05).

4.4.1 Cardiorespiratory Parameters during both Sprint Protocols

In relation to the AR protocol, mean cardiorespiratory values for VO_2 (Fig. 2), carbon dioxide uptake (VCO_2), minute ventilation (VE) and heart rate (HR) (Table 3) were 3302 (195) $ml \cdot min^{-1}$; 4043 (335) $ml \cdot min^{-1}$; 127 (24) $l \cdot min^{-1}$ and 169 (12) $b \cdot min^{-1}$. With regard to the PR protocol, mean cardiorespiratory values for VO_2 (Fig. 2); VCO_2; VE and HR (Table 3) were 2908 (209) $ml \cdot min^{-1}$; 3452 (310) $ml \cdot min^{-1}$; 102 (24) $l \cdot min^{-1}$ and 161 (11) $b \cdot min^{-1}$, respectively. In relation to VCO_2, VE and HR no difference (p>0.05) was found involving the interaction between recovery mode and sprint repetition.

4.4.2 Oxygen Consumption during both AR and PR Sprint Protocols

Figure.2 shows that VO_2 ($ml \cdot min^{-1}$) was significantly lower (p<0.05) across all sprints during the PR condition when compared to the AR condition. With regard to cardiorespiratory data, there was a significant (p<0.05) recovery mode effect for all cardiorespiratory parameters (VCO_2, VE, HR), as illustrated in Table 3.

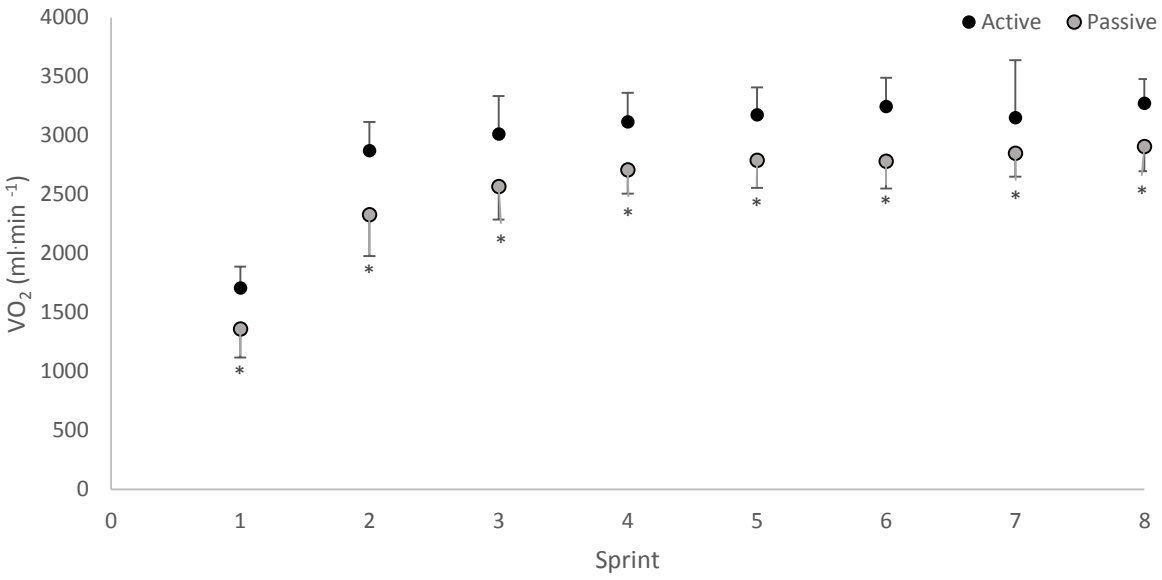

Figure. 2 Mean (+/-SD) values of oxygen consumption (ml·min^{-1}) during the repeated sprints protocol using an AR or PR strategy (n = 10).

* Denotes a significant difference (p<0.05) between protocols.

Table. 3 shows cardiorespiratory values during each cycle sprint with AR or PR periods. Comparison between AR and PR for mean (±SD) VCO_2, VE and HR during repeated sprint cycling.

Sprint	1	2	3	4	5	6	7	8
VCO_2 ($ml \cdot min^{-1}$)								
AR	1609 (258)	2814 (373)	3372 (530)	3782 (474)	3886 (439)	3937 (391)	3779 (627)	3819 (282)
PR *	1275 (233)	2250 (409)	2809 (521)	3143 (443)	3306 (407)	3311 (362)	3347 (290)	3372 (249)
VE ($l \cdot min^{-1}$)								
AR	48 (10)	80 (13)	94 (18)	109 (201)	115 (22)	121 (25)	117 (27)	122 (21)
PR *	36 (9)	62 (15)	79 (20)	89 (23)	95 (24)	97 (24)	101 (24)	102 (24)
HR ($b \cdot min^{-1}$)								
AR	116 (14)	140 (18)	152 (9)	158 (10)	161 (11)	164 (11)	167 (12)	169 (11)
PR *	114 (15)	138 (12)	145 (10)	149 (11)	154 (11)	157 (11)	158 (11)	160 (11)

* Denotes significant difference ($p<0.05$) between protocols.

4.5.1 Relationship between Average Total Work Done and VO_{2max}

A positive relationship was observed between the average total work done and the initial measurement of VO_2, however the correlation coefficient was not found to be significant, r (df 8) = 0.359, p>0.05. Furthermore, no significant correlation coefficient was found between average total work done and peak aerobic power, r (df 8) = 0.357, p>0.05.

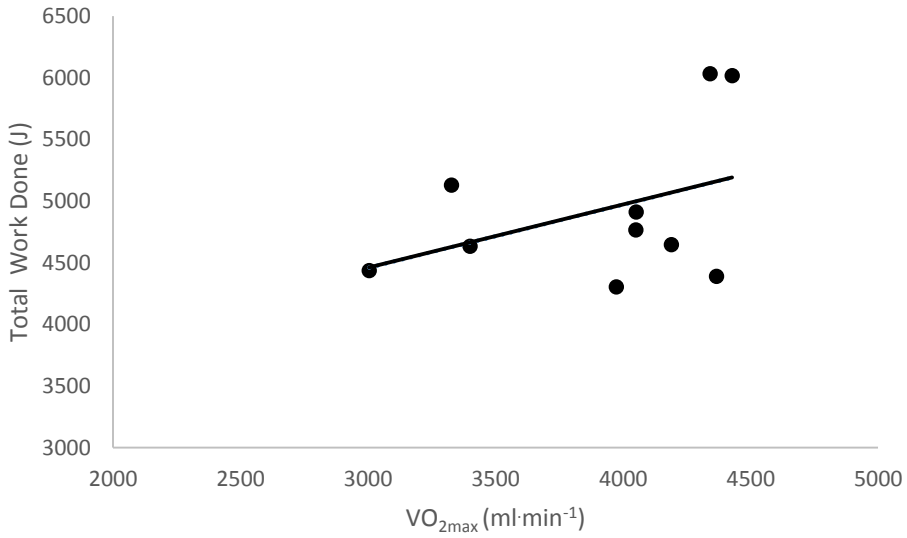

Figure.3 illustrates the relationship between an individuals' VO_{2max} ($ml \cdot min^{-1}$) and average total work done (J) during the eight sprints, during the PR protocol.

4.5.2 Relationship between Peak Total Work Done and VO_{2max}

A positive relationship was observed between the peak value of total work done during the eight sprints and the initial value of VO_{2max}; however, the correlation coefficient was relatively weak and was not found to be significant, r (df 8) = 0.403, p>0.05. Furthermore, there was a non–significant (p>0.05) correlation coefficient between peak total work done and peak aerobic power, r (df 8) = 0.402.

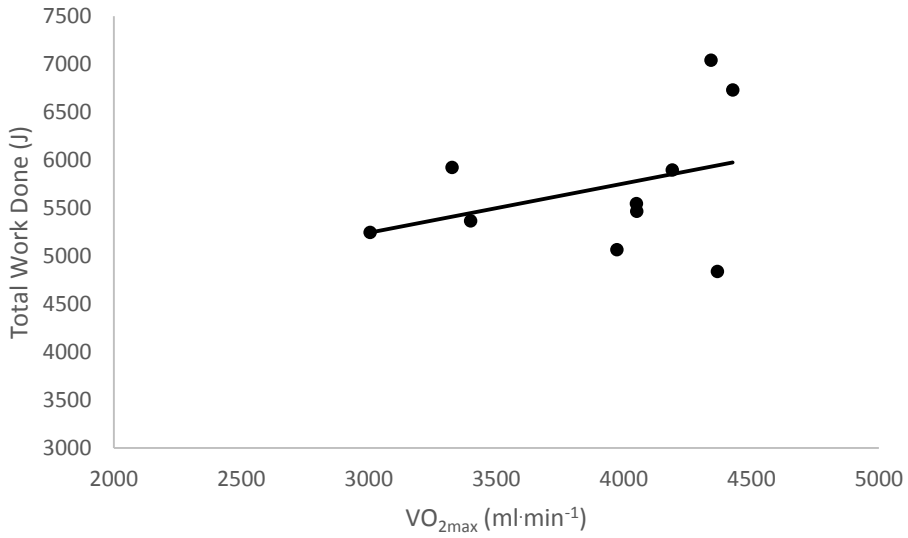

Figure.4 illustrates the relationship between an individuals' VO_{2max} ($ml \cdot min^{-1}$) and peak total work done (J) during the eight sprints performed, during the PR protocol.

CHAPTER 5: DISCUSSION

5.0 Discussion

The present study evaluated whether or not an active recovery (AR) was advantageous compared to a passive recovery (PR) in the context of performance and associated physiological stress experienced during a repeated sprint protocol. Findings reinforced the stated hypothesis as results showed RSA performance indices (PPO and APO) were significantly inhibited (p<0.05) when participating in an AR, compared to PR. Furthermore, this was accompanied by a significant increase (p<0.05) in VO_2, VCO_2, VE and HR during exercise and recovery, when an AR was performed. Secondly, an attempt was made to evaluate the relationship between aerobic capacity and anaerobic performance. Results showed no significant correlation (p>0.05) between VO_{2max} and the total work done (TWD) for PPO and APO, unfortunately these did not support the stated hypothesis.

5.1 Performance Parameters: Active *vs.* Passive

In relation to performance parameters, the main findings of this study supported previous work (Dupont *et al.,* 2004; Spencer *et al*., 2006; Castagna *et al*., 2008 and Buchheit *et al*., 2009), identifying that AR had a negative effect on RSA. Results highlighted that mean PPO was significantly greater (p<0.05) during the PR compared to the AR (Fig.2). Likewise, a similar relationship was observed for APO (Table 2).

It is likely that a more marked decline in power output was observed during the AR due to the impairment of oxygen availability (Spencer *et al*., 2006; Buchheit *et al.*, 2009). This led to a decrease in PCr resynthesis as it is an oxidative process. As a result, the individuals' PCr level would have progressively reduced, further decreasing the energy availability (Girard *et al*., 2011). Furthermore, Dupont *et al*. (2003; 2004) explained that AR would have prevented the re-oxygenation of myoglobin, hence a decrease in oxyhaemoglobin. This was because the energy needed to perform the relevant exercise during the recovery period led to a decrease in oxygen availability (Christmass *et al.,* 1999). Additionally, McAinch *et al.* (2004) speculated that an AR would have utilised a large proportion of the mitochondrial ATP production to maintain the activity in the muscle, reducing the amount of PCr resynthesis. However, this has only been reported involving 15-min of AR following a 20-min maximal cycling time trial, not within repeated sprint exercise *per se*.

In addition, Spencer *et al*. (2004) identified that post exercise, lactate concentrations were significantly greater following an AR, compared to a PR. Therefore, questioning whether or not an AR promotes the clearance of acidosis. With increased exercise, there is an increase

in muscle and blood H^+ accumulation (Ratel *et al.,* 2006; Spencer *et al.*, 2008). As a result, performance was reduced as the amount of ATP derived from glycolysis was inhibited. Similar work conducted by Thomas *et al.* (2005) suggested skeletal muscle monocarboxylate transporters (MCT1) had an influence on fatigue during repeated sprints. Thomas *et al.* (2005) reported an inverse correlation involving fatigue indices and MCT1, therefore, identifying that MCT1 encourages the removal of H^+ and lactate in the muscle. Despite this conclusion, however, Matsuura *et al.* (2007) challenges this theory of fatigue as at physiological temperatures the time period of recovery following maximal work occurs at a faster rate than that of pH.

It was also possible that as fatigue increased, RSA could have been impaired due to increased levels of inorganic phosphate (Pi; Girard *et al.*, 2011). Perrey *et al.* (2010) reported a decrease in peak twitch force in the plantar flexors during repeated sprint running, suggesting that as performance was prolonged contractile properties of the working muscles were less efficient. Therefore, as Pi built up, the amount of calcium released from the sarcoplasmic reticulum would become reduced, consequently decreasing the strong myofibril cross-bridges (Westerblad *et al.,* 2002).

5.2 Cardiorespiratory Parameters: Active *vs.* Passive

With regard to cardiorespiratory parameters, findings supported the stated hypothesis and previous research (Brown and Glaister, 2014; Buchheit *et al*., 2009). Data from the present study identified that cardiorespiratory responses were (mean VO_2, VCO_2, VE, HR) significantly higher (p<0.05) during the AR, compared to the PR protocol (Table 2, Fig.1)

Cardiorespiratory parameters increased during the AR, compared to the PR, due to an increase in VO_2 needed to cycle at 80 rpm throughout the recovery period (Fig.1; Buchheit *et al*., 2009). Furthermore, due to the recovery period being less than 30-s it was likely that VO_2 prior to each sprint would already be at an elevated level (Thevenet *et al.,* 2006). Buchheit *et al.* (2009) concluded that an AR increased the oxygen cost of exercise. Consequently, this increase, combined with an insufficient oxygen supply, resulted in an increased muscle deoxygenation. As a result, there was a competition between PCr resynthesis and lactate oxidation (Spencer *et al*., 2006; Castagna *et al*., 2008). According to Spencer *et al*. (2006), oxidation contributes 55-70% of the removal of lactate following maximal exercise. Earlier work produced by Thiriet *et al*. (1993) and Tomlin and Wenger (2001) explained that participation in low intensity exercise promoted an increased

clearance of blood lactate and prevented the accumulation of H^+ within the working muscles. Despite the fact blood lactate samples were not taken within the present study, previous work carried out by Spencer *et al.* (2006;2008) reported elevated levels of blood lactate clearance. This indicated an increase in lactate oxidation, which would have decreased the amount of PCr resynthesis. However, Buchheit *et al.* (2009) reiterated that lactate clearance reflects the balance between lactate removal and production, further outlining the difficulty in determining whether the values expressed were due to an increased lactate production and/or a decreased oxidative capacity.

Data regarding HR (Fig.1) was similar to the findings of Buchheit *et al.* (2009) (AR: 160 (8) vs PR: 155 (8) $b \cdot min^{-1}$). Crisafulli *et al.* (2003) attributed a lower HR during a PR due to the interruption of central commands from the cerebral motor cortex, which resulted in a decrease in stimuli from mechanoreceptors. Toubekis *et al*. (2008) noted that an increase in HR indicated a greater metabolic rate along with an elevated aerobic metabolism. Furthermore, research produced by Toubekis *et al.* (2008) demonstrated that an AR was beneficial when participants performed a repeated, 30-s Wingate test when separated by 4-min of recovery. An elevated heart rate led to an enhanced muscle blood flow, an improved resynthesis rate of PCr and a greater rate of lactate removal.

5.3 Aerobic Capacity and Anaerobic Performance

Despite the fact no significant correlation (p>0.05) was found between participants' VO_{2max} and both mean and peak total work done during the PR protocol, data did show a weak, positive correlation (r (df 8) = 0.359, p>0.05, r (df 8) = 0.403, p>0.05), as illustrated in Fig.3 and 4.

In contrast to previous findings, an individuals' VO_{2max} did not appear to be a significant factor with regard to RSA (Aziz *et al*., 2000; Tomlin and Wenger, 2002; Bishop and Edge, 2006). However, due to the positive correlation observed an individuals' VO_{2max} may still prevent a decline in performance during the latter stages of the RSA protocol. As performance is prolonged there is an increase in aerobic contribution to exercise. Therefore, during the final few sprints those who possessed a greater VO_{2max} appeared able to maintain a higher standard of performance as there was less competition for oxygen between PCr resynthesis, lactate oxidation and buffering of H^+. Subsequently, those individuals were able to restore PCr and ATP from Pi more efficiently (Bishop and Edge, 2006; Castagna *et al.,* 2008; Jones *et al.,* 2013).

Recent work produced by Cipryan and Gajda (2011) and Dardouri *et al.* (2014) concluded an individuals' VO_{2max} was not significantly correlated to RSA, however, these studies had used a MSFT in order to determine an individuals' $VO_{2max,}$ which is known to be inaccurate by up to 15% (Jones *et al.*, 2013). Consequently, any data produced could be questioned. However, as used in the present study, a breath by breath analyser was a more accurate and reliable method of collecting and analysing expired gases, which did not record a significant difference (p>0.05) when compared to RSA. This may be due to variations in the muscle fibre type proportions. Individuals who show a greater peak power output tend to show a larger decrement in power output as they possess a large amount of type II X muscle fibres which are known to fatigue easily. Moreover, individuals possessing more type II X fibres have a lower oxidative capacity, compared to those who have predominantly more type II A and type I muscle fibres. These fibres predominantly resynthesise ATP through aerobic energy transfer which is a preferred trait for prolonged exercise (McArdle *et al.,* 2006).

5.4 Limitations

Weaknesses of the current study include the lack of lactate samples taken. As a result, it was only possible to speculate and assume there was a build-up in lactate leading to fatigue based on findings from previous research. Furthermore, the sample size was small with only 10 participants (all male). According to Florey (1993), this can decrease the likelihood of finding a significant difference (p<0.05), and can restrict the reliability of the results.

Despite all participants' being team sport athletes and completing a participation, activity and readiness questionnaires (PARQ), it became apparent from the VO_{2max} protocol some participants' aerobic fitness was not as good as previously stated. This was because the approved VO_{2max} protocol used, should have lasted between 8-15-min. However, three participants failed to last at least 8-min. Although a breath by breath analyser was a more accurate way of measuring an individual's VO_{2max}, compared to a MSFT, it is not 100% reliable. Carter and Jeukendrup, (2002) reported that the use of a breath by breath analyser tended to overestimate expired gases when cycling above a steady state (150 W). This occurred throughout the present study. However, due to the overestimation being a constant (systematic) rather than a random error, data gathered and comparisons made can be considered as being valid. Furthermore, the reliability of a breath by breath analyser can be

altered by the amount of saliva which can potentially interfere with delay time when collecting the expired gases (Carter and Jeukendrup, 2002).

Despite the fact multiple, 6-s sprints are often used when assessing RSA, Bishop *et al.* (2001) suggested that a repeated sprint test should be modified to reflect appropriate sprint distances specific to individual sports. As Bishop *et al.* (2001) identified, a 5 x 6-s cycle test was similar to running 15 m repeatedly as opposed to 10 m or 5 m. In addition, although each participant was verbally motivated throughout each sprint, it was possible that the participant could have subconsciously held back effort for the final sprints. Moreover, the order of the repeated sprint protocols were not counterbalanced, therefore, an ordering effect could have occurred (Zavorsky *et al.,* 2014).

5.5 Practical Application

An AR appears beneficial from a training perspective if an individual is trying to improve their VO_{2max} as research and findings in the present study highlight an elevated VO_2 during AR, compared to PR. This may lend itself to middle and long distance coaches and athletes trying to optimise performance in training. Additionally, an AR may lead to muscle fibre adaptations such as an increase in type II A and type I fibres resulting in an increased oxidative capacity which will prove beneficial to endurance and team sport athletes (McArdle *et al.*, 2006).

With regard to performance within a sporting environment, it is advised that athletes do not take part in an AR when the rest interval available is 24-s or less, as performance is likely to be inhibited. However, Kappenstein *et al.* (2015) outlined that an AR will prove beneficial when rest periods are more prolonged as lactate oxidation will take place. Consequently, muscle soreness will be reduced preventing the likelihood of micro-injury to connective tissue and muscle fibres (Andersen *et al*., 2013).

With reference to the relationship between aerobic capacity and anaerobic performance, an increase in the amount of type I muscle fibres will likely prevent a drop in fatigue during latter sprints due to an increased aerobic metabolism. However, initial sprint performance will not be as great due to a reduction in type II X muscle fibres. Therefore, initial power output will decrease but can be repeated to a similar standard as performance is continued.

5.6 Future Research

Although the present study has added to previous literature, identifying that an AR was detrimental to performance compared to a PR, when participating in repeated sprints every 30-s, it is recommended that further research explores various time periods of AR. Therefore, this would determine the length of time in which an AR is advantageous over a PR. Additionally, it is important to modify a repeated sprint test specific to a set of individuals depending on their sport. Furthermore, future research should avoid using a VO_{2max} when exploring the relationship between aerobic capacity and anaerobic performance. Jones *et al.* (2013) advised that it was worth researching other performance indices to identify limiting factors of RSA such as anaerobic capacity, as determined by means of measuring peak power output and associated fatigue index during a repeated sprint effort.

5.7 Conclusion

To conclude, the present study has identified that an AR is detrimental to performance when compared to a PR, during a repeated sprint protocol ($p<0.05$). An AR demonstrated greater physiological stress (mean VO_2, CO_2, VE and HR), resulting in an increased competition for oxygen between PCr resynthesis and lactate oxidation. This led to an increased muscle deoxygenation which resulted in a decrease in PPO and APO, compared to the PR protocol. With regard to the relationship between aerobic capacity and anaerobic performance, an individuals' VO_{2max} does not show a significant difference ($p<0.05$) with RSA. However, due to a positive correlation observed, a greater VO_{2max} may aid latter performance due to an increased oxidative metabolism. Future research should look into different time periods of AR to identify when it becomes more advantageous than a PR in a performance and training scenario. With regard to the relationship between aerobic capacity and anaerobic performance, research should avoid using a VO_{2max} as an indicator of RSA. Therefore, additional performance indicators should be assessed in order to identify potential limiting factors of RSA, such as anaerobic capacity (Jones *et al.,* 2013).

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APPENDICES

Appendix A – Peak power *output Post Hoc* data

Pairwise Comparisons

Measure: MEASURE_1

recovery	(I) sprint	(J) sprint	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
						Lower Bound	Upper Bound
1	1	2	81.431	36.537	.053	-1.222	164.084
		3	146.833*	43.267	.008	48.955	244.711
		4	177.594*	48.976	.006	66.803	288.385
		5	192.101*	41.717	.001	97.729	286.473
		6	245.948*	54.382	.001	122.927	368.969
		7	241.889*	63.579	.004	98.064	385.714
		8	250.252*	60.060	.002	114.386	386.118
	2	1	-81.431	36.537	.053	-164.084	1.222
		3	65.402*	15.343	.002	30.694	100.110
		4	96.163*	28.521	.008	31.645	160.681
		5	110.670*	27.962	.003	47.416	173.924
		6	164.517*	33.454	.001	88.839	240.195
		7	160.458*	47.762	.008	52.413	268.503
		8	168.821*	47.222	.006	61.997	275.645
	3	1	-146.833*	43.267	.008	-244.711	-48.955
		2	-65.402*	15.343	.002	-100.110	-30.694
		4	30.761	21.475	.186	-17.820	79.342
		5	45.268	22.785	.078	-6.275	96.811
		6	99.115*	24.783	.003	43.053	155.177
		7	95.056*	40.975	.045	2.364	187.748
		8	103.419*	40.946	.032	10.792	196.046
	4	1	-177.594*	48.976	.006	-288.385	-66.803
		2	-96.163*	28.521	.008	-160.681	-31.645
		3	-30.761	21.475	.186	-79.342	17.820
		5	14.507	13.233	.301	-15.428	44.442
		6	68.354*	8.994	.000	48.009	88.699
		7	64.295*	24.001	.025	10.000	118.590
		8	72.658*	23.647	.013	19.164	126.152
	5	1	-192.101*	41.717	.001	-286.473	-97.729
		2	-110.670*	27.962	.003	-173.924	-47.416
		3	-45.268	22.785	.078	-96.811	6.275
		4	-14.507	13.233	.301	-44.442	15.428
		6	53.847*	17.950	.015	13.242	94.452
		7	49.788	26.843	.097	-10.934	110.510

		8	58.151	31.071	.094	-12.136	128.438
	6	1	-245.948*	54.382	.001	-368.969	-122.927
		2	-164.517*	33.454	.001	-240.195	-88.839
		3	-99.115*	24.783	.003	-155.177	-43.053
		4	-68.354*	8.994	.000	-88.699	-48.009
		5	-53.847*	17.950	.015	-94.452	-13.242
		7	-4.059	19.252	.838	-47.611	39.493
		8	4.304	22.454	.852	-46.490	55.098
	7	1	-241.889*	63.579	.004	-385.714	-98.064
		2	-160.458*	47.762	.008	-268.503	-52.413
		3	-95.056*	40.975	.045	-187.748	-2.364
		4	-64.295*	24.001	.025	-118.590	-10.000
		5	-49.788	26.843	.097	-110.510	10.934
		6	4.059	19.252	.838	-39.493	47.611
		8	8.363	23.176	.727	-44.064	60.790
	8	1	-250.252*	60.060	.002	-386.118	-114.386
		2	-168.821*	47.222	.006	-275.645	-61.997
		3	-103.419*	40.946	.032	-196.046	-10.792
		4	-72.658*	23.647	.013	-126.152	-19.164
		5	-58.151	31.071	.094	-128.438	12.136
		6	-4.304	22.454	.852	-55.098	46.490
		7	-8.363	23.176	.727	-60.790	44.064
2	1	2	9.198	11.912	.460	-17.748	36.144
		3	29.395	20.067	.177	-16.000	74.790
		4	54.938	35.618	.157	-25.636	135.512
		5	59.224	39.796	.171	-30.801	149.249
		6	84.441*	36.433	.046	2.023	166.859
		7	112.025*	42.612	.027	15.630	208.420
		8	136.283*	47.409	.018	29.035	243.531
	2	1	-9.198	11.912	.460	-36.144	17.748
		3	20.197	18.124	.294	-20.802	61.196
		4	45.740	35.662	.232	-34.934	126.414
		5	50.026	41.568	.259	-44.008	144.060
		6	75.243	37.325	.075	-9.192	159.678
		7	102.827*	44.192	.045	2.859	202.795
		8	127.085*	48.760	.028	16.782	237.388
	3	1	-29.395	20.067	.177	-74.790	16.000
		2	-20.197	18.124	.294	-61.196	20.802
		4	25.543	20.391	.242	-20.585	71.671
		5	29.829	30.807	.358	-39.862	99.520

	6	55.046	25.863	.062	-3.461	113.553
	7	82.630*	30.042	.022	14.670	150.590
	8	106.888*	33.480	.011	31.152	182.624
4	1	-54.938	35.618	.157	-135.512	25.636
	2	-45.740	35.662	.232	-126.414	34.934
	3	-25.543	20.391	.242	-71.671	20.585
	5	4.286	18.457	.822	-37.466	46.038
	6	29.503	14.472	.072	-3.236	62.242
	7	57.087*	12.293	.001	29.278	84.896
	8	81.345*	19.070	.002	38.206	124.484
5	1	-59.224	39.796	.171	-149.249	30.801
	2	-50.026	41.568	.259	-144.060	44.008
	3	-29.829	30.807	.358	-99.520	39.862
	4	-4.286	18.457	.822	-46.038	37.466
	6	25.217*	8.536	.016	5.906	44.528
	7	52.801*	17.345	.014	13.563	92.039
	8	77.059*	20.595	.005	30.470	123.648
6	1	-84.441*	36.433	.046	-166.859	-2.023
	2	-75.243	37.325	.075	-159.678	9.192
	3	-55.046	25.863	.062	-113.553	3.461
	4	-29.503	14.472	.072	-62.242	3.236
	5	-25.217*	8.536	.016	-44.528	-5.906
	7	27.584	15.766	.114	-8.082	63.250
	8	51.842*	18.458	.020	10.086	93.598
7	1	-112.025*	42.612	.027	-208.420	-15.630
	2	-102.827*	44.192	.045	-202.795	-2.859
	3	-82.630*	30.042	.022	-150.590	-14.670
	4	-57.087*	12.293	.001	-84.896	-29.278
	5	-52.801*	17.345	.014	-92.039	-13.563
	6	-27.584	15.766	.114	-63.250	8.082
	8	24.258	14.326	.125	-8.150	56.666
8	1	-136.283*	47.409	.018	-243.531	-29.035
	2	-127.085*	48.760	.028	-237.388	-16.782
	3	-106.888*	33.480	.011	-182.624	-31.152
	4	-81.345*	19.070	.002	-124.484	-38.206
	5	-77.059*	20.595	.005	-123.648	-30.470
	6	-51.842*	18.458	.020	-93.598	-10.086
	7	-24.258	14.326	.125	-56.666	8.150

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Appendix B – Information Form

Information Form

Ethics Approval Reference Number: 15/5/205U

Title of Project: The influence of recovery mode on performance and physiological responses during a repeated sprint exercise protocol.

Through Cardiff Metropolitan University and as part of my final examination, I am required to undertake a research project. The aim of the research project is to determine the influence of recovery mode on performance and physiological stresses as well as identifying how aerobic peak power contributes to anaerobic peak power. You have been chosen because you are an endurance trained male who does not suffer from chronic or acute cardiac disease, aged between 18-25 years and are a non-smoker.

The following outlines key components of the study.

Why you?

You have been invited to take part in this experiment because it is thought that you are endurance trained, you are a non-smoker and you will benefit from this study. Data from participants will be gathered over a four month period beginning in November. You will be one of these.

What would happen if you agree to take part?

If you agree to join the study, there are six main things that will happen.

1. All laboratory testing will involve the use of either an Excalibur Sport or Monark cycle ergometer. You will be attached to an online, breath by breath analyser and heart rate monitor during all laboratory testing sessions.

2. You will attend three sessions, each will occur on a different day. Firstly you will be required to perform an approved preliminary VO^2 max protocol. To begin with a 4 minute warm up will be completed (less than 120 W). This will then be followed by the test itself. The protocol will begin at 120 W and will increase by 30 W every 60-s. The test will last

between 8-15 minutes. Once the test is complete you will be required to take part in a five minute cool down, therefore cycling against a resistive test load or equivalent to or lower than the warm up intensity (less than 120 W).

3. Secondly, height and weight measurements will be taken using a Stadiometre and a set of Scales. This is general information in order to quantify test loads for both repeated sprint protocols.

4. Thirdly, you will be required to perform a warm up consisting of two 30-s periods of submaximal cycling at 85 and 115 rpm against a resistance of 1.5kg with 60-s recovery between each period. This will then be followed by eight, 6-s all out maximal sprints on a cycle ergometer with a 24 second active recovery between each sprint. Active recovery consists of pedalling at 80 W of resistance. At all times there will be a first aid trained member of staff supervising testing. Once the test is finished you will be required to perform a two to three minute cool down and will be monitored for 10 minutes for health and safety reasons. The test will last no longer than 20 minutes.

5. The final session will consist of a warm up consisting of two 30-s periods of submaximal cycling at 85 and 115 rpm against a resistance of 1.5kg with 60-s recovery between each period. This will then be followed by eight, 6-s all out maximal sprints on a cycle ergometer with a 24 seconds passive recovery between each sprint. Passive recovery consists of remaining stationary through the rest period. At all times there will be a first aid trained member of staff supervising. Once the test is finished you will be required to perform a two to three minute cool down and will be monitored for 10 minutes for health and safety reasons. The test will last no longer than 20 minutes.

6. It is important you do not take part in any physical activity 24 hours prior to testing.

Are there any risks?

Injury is always a potential risk when taking part in physical activity. Other risks include the possibility of light headedness and vomiting. Therefore you will be monitored for a further 10 minutes in the presence of a first aider. Muscle soreness may be felt the following day hence why a cool down is provided. Additionally, breathing irregularities may be experienced when wearing a mouth piece.

What happens to the results of the testing?

The measurements that are taken at the start as well as the data produced during testing will be stored a laptop in which only the researcher will have access too. Names will be removed from the data recorded and referred to as a participant number, the results taken will be used for further analysis. Information will be presented in figures within a dissertation, however individuals will not be able to be identified. I don't intend to discuss the data produced with you, however if you are interested it is possible. You will not be identified in this piece of work.

I will present a dissertation to Cardiff Metropolitan University.

Are there any benefits from taking part?

Yes, from the approved VO^2 max protocol it will be possible to identify your peak aerobic power and your VO^2 max. From both sprint protocols it will be possible to identify the fluctuations of your oxygen consumption, carbon dioxide production, ventilation and heart rate through varied recoveries as well as your peak anaerobic power. You will be given an insight to how aerobic peak power contributes to anaerobic peak power during repeated sprint performance. Taking part in this study will cost you nothing.

What happens next?

With this information sheet there are two other forms to complete. One is an informed consent form giving yourself permission to participate in the study. Additionally, there is a PAR-Q form. This is to determine if you are eligible to take part in physical activity from a medical perspective. Both forms must be completed prior to testing.

Your rights?

No one is forcing you to take part; it is completely up to you. If you decide you do not want to carry on for any reason you can drop out. You will not be giving up any of your legal rights and in any very unlikely event of something going wrong Cardiff Metropolitan University fully indemnifies its staff, and participants are covered by its insurance.

Confidentiality:

During the study all participant information, names and address, will remain anonymous to all but my supervisor and myself. At the end of the study we will destroy the information we have gathered about you. We will only keep the consent forms with your name and address. We keep these for five years because we are required to do so by Cardiff Metropolitan University. Anonymity is a high priority as the information will only be used for research purposes and the participant's identities will not be identified.

I have enclosed for your attention, a consent form and a PAR-Q form. I hope that you will participate in this study. You're free to pull out from the investigation at any time. Should you require any further information please do not hesitate to contact myself or my supervisor through the contact details provided.

Any questions?

If you have any questions, please don't hesitate to ask me via email or telephone as I will respond as soon as possible. Contact details are listed below

Undergraduate Researcher: Alex Hunt
Email address: @outlook.cardiffmet.ac.uk
Contact number: 07812073402

Research Supervisor: Dr.Paul Smith
Email address: psmith@cardiffmet.ac.uk
Contact number: 02920416687

Appendix C – Consent form

Ethics Approval Reference Number: 15/5/205U

Title of Project: The influence of recovery mode on performance and physiological responses during a repeated sprint exercise protocol.

Name of Researcher: Alex Hunt

Name of Supervisor: Dr. Paul Smith

Please complete the following sections by placing your signature in each box as well as in the designated area.

1. I confirm that I have read and understand the information sheet for the above study.	
2. I have had the opportunity to consider the information, ask questions and have received a satisfactory answer.	
3. I understand that my participation is voluntary and that I have the right to withdraw at any time, without giving any reason.	
4. I agree to take part in an approved preliminary VO^2 max protocol, both repeated sprint protocols and to the data recorded from all laboratory testing sessions.	
5. I agree to the use of anonymised data being used within a dissertation and any publications.	
I agree to take part in the above study	

Name of participant:

Signature of participant:

Date (DD/MM/YEAR):

Name of person taking consent:

Signature of person taking consent

Date (DD/MM/YEAR):

****When completed, 1 copy for the participant and 1 copy for the researcher site file.**

Appendix D – Physical, Activity and Readiness Questionnaire

PAR-Q		Participant ID (staff only)	
Name		Date of birth	
Home address			
Post code			
Phone number			
Email address			
Health Screening			

	Yes	**No**
1. Has a doctor told you that you have a heart condition AND must seek medical advice before participating in regular exercise?	☐	☐
2. Do you feel pain in your chest when you do physical activity?	☐	☐
3. Do you lose your balance because of dizziness or do you ever lose consciousness?	☐	☐
4. Do you have a bone or joint problem?	☐	☐
5. Are you currently on any medication for high blood pressure?	☐	☐
6. Are you currently taking any medication for a heart problem	☐	☐
7. Do you have insulin dependent diabetes?	☐	☐
8. Do you consider yourself to have a disability? If YES please state:	☐	☐

9. Do you know of any other reason as to why you should not do physical activity?	☐	☐
10. Women Only: Are you pregnant at the moment or have recently given birth?	☐	☐

If you have answered YES to any question between 1, 2, 5 and 6, you will need to get a signature from your doctor to confirm it is safe for you to take part in physical activity **before** attending the laboratory for your exercise/fitness assessment. **If you have answered YES to any question between 3, 4, 7, 8, 9, 10 you will need to provide further detail about the condition** before participating in exercise**.** This may or may not exclude you from any further involvement. The judgement will be made by an experienced member of staff only.

Any other comments you feel are relevant:

Declaration, Terms & Conditions

I have read the statements above 1 and can confirm that the information I have provided is correct. I wish to participate in fitness and exercise assessment, which may include exercise to exhaustion and am aware that participation in these activities involves the risk of injury. I agree to inform a member of staff in the event of any change to either my personal or medical details.

Signature:		Date	

Health and Wellbeing			
Name		Participant ID (staff only)	
Occupation			
Do you smoke?	Never ☐ Socially ☐ Regularly ☐	How many cigarettes do you smoke per day?	
On average how often do you drink alcohol?	Never ☐ Rarely ☐ 1-2 times a week ☐ 3-5 days ☐ >5 days ☐		
Current fitness/training status			
Are you currently active?	Not Active ☐ Leisurely ☐ Recreational ☐ Competitive ☐		
How often do you train?	N/A ☐ 1-2session per week ☐ 3-5 sessions per week ☐ 5+ sessions per week ☐		
Any other information (e.g. Why do you want to complete a fitness assessment? Do you have an exercise goal or competition you are training for?)			

This form is to be completed prior to testing

Please answer the following questions, adding detail in the space provided

a) Do you consider that you have eaten well in the last 24 hours?

b) Have you eaten in the last 3 hours? (give details if so)

c) Have you exercised in the last 24 hours? (if so give details)

d) Are you currently performing your typical amount of exercise training?

e) Do you have any current health or injury concerns that may affect your performance in the tests today?