INVESTIGATION INTO THE EFFECT OF WARM-UP ON INTERMITTENT SPRINT PERFORMANCE

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STATEMENT OF CANDIDATE CONTRIBUTION

The work involved in designing and conducting the studies described in this thesis was performed primarily by Pongson Yaicharoen (candidate). The research experiments were planned and developed by the candidate under the guidance of Professor David Bishop and Professor Alan Morton, who were the candidate's original supervisors. When Prof Bishop left the University of Western Australia, he was replaced by Dr Karen Wallman as a supervisor. Subject recruitment, data collection, and data analysis were carried out solely by the candidate. The candidate was solely responsible for the organisation and implementation of the experiments.

Assistance in writing the studies was given by Dr Karen Wallman, Professor Alan Morton and Professor David Bishop. The candidate drafted the thesis, and the papers which are currently being considered for publication with Dr Karen Wallman, Prof Alan Morton and Prof David Bishop. Dr Karen Wallman and Prof Alan Morton provided feedback on the thesis draft.

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THESIS ABSTRACT

This PhD thesis consists of three separate but linked studies that focus on the concept of warm-up (WUP). While WUP is regularly performed prior to exercise by many athletes, its effect on subsequent exercise performance is equivocal. While there are many reasons for varying results between studies, it is possible that the intensity of WUP plays an important role in the outcome of subsequent exercise performance. Therefore, the aim of the first study was to investigate the effect of various WUP intensities (all based around individual lactate thresholds) on subsequent intermittent sprint performance (ISP), as well as the first sprint of ISP. A second aim of this first study was to determine which temperature (muscle; T_{mu}, rectal; T_{re} or body; T_b) best correlated with exercise performance (total work, power output of the first sprint and percentage work and power decrement). Results from this first study found no significant differences ($P > 0.05$) between any of the WUP conditions for any performance variable assessed. There was however, a tendency ($ES \geq 0.5$) for improved first sprint and ISP after a WUP that was performed at an intensity midway between lactate inflection (LI) and anaerobic threshold (also known as lactate threshold: LT). Further, there were no significant correlations between T_{mu}, T_{re}, or T_b assessed immediately after each WUP condition and any of the performance measures.

The second study aimed to assess the effect of an active WUP (using the optimal WUP intensity determined in study 1), compared to a no WUP trial, on single sprint performance, as well as on prolonged ISP, where the sprints simulated those performed in a typical team-sport game (i.e., 80 min in duration). The first sprint performance of the prolonged ISP was also compared between the WUP and no WUP trial, as well as to the single sprint trials. Results from this study demonstrated that active WUP, compared to a no WUP condition, improved

single sprint ability, but had no significant effect on prolonged ISP. Furthermore, work performed during the first sprint of prolonged ISP was significantly greater following an active WUP, compared to first sprint results of ISP in the no WUP trial. Conversely, first sprint performance of ISP (WUP and no WUP conditions) was significantly impaired compared to a single sprint performance that was preceded by an active WUP. It is possible that similar prolonged ISP following both an active WUP and a no WUP trial may be due to: (1) the use of a pacing strategy; (2) the initial sprints of the prolonged ISP providing a WUP effect in the no WUP condition resulting in similar overall exercise performance; or (3) the possibility that benefits associated with WUP on ISP are negated over time due to the metabolic impact of prolonged exercise performance. Of relevance, use of a pacing strategy was supported by the significant improvement in single sprint performance following active WUP, compared to the first sprint performance of prolonged ISP that was also preceded by an active WUP. Further, the significant impairment in the first sprint of prolonged ISP in the no WUP trial compared to the active WUP trial suggests that even though subjects may have adopted a pacing strategy, that active WUP still imparted some temperature and/or non-temperature related benefits on subsequent initial sprint performance.

The third study aimed to investigate the effect of an active WUP (performed at an intensity determined from study one) on prolonged ISP (80 min), as well as the first sprint of prolonged ISP, performed in hot and humid environmental conditions (35^{o}C, 50% RH), compared to cooler conditions (~20-25^{o}C, 20-40% RH). This study also assessed the effects of an active WUP compared to a passive WUP on 80 min of ISP undertaken in the heat (35^{o}C, 50% RH). The only significant result for this study was represented by significantly improved peak power for the first sprint of prolonged IPS following passive WUP, compared to both active WUP conditions. Results from this study suggest that the main benefits of

WUP are derived from temperature-related effects. Moreover, similar results for ISP performance following active compared to passive WUP may be explained by the following: (1) subjects used a pacing strategy throughout the exercise protocol; (2) the initial sprints performed following passive WUP provided similar effects to an active WUP over the period of prolonged exercise; (3) the effects of active and passive WUP diminish in a similar manner over the course of prolonged ISP, or (4) the metabolic and energy consequences of prolonged ISP override any benefits associated with WUP. Finally, environmental conditions did not have an effect on prolonged ISP or the first sprint of ISP that was preceded by an active WUP. These results may be related to core temperature values that did not reach critical levels proposed to impair exercise performance during exercise in hot and humid environmental conditions.

Further studies are needed to investigate the effect of different WUP intensities (based on lactate thresholds) to those used in these studies on subsequent ISP in order to determine if a significant effect can be elicited. Of importance, a power analyses needs to be determined in order to make sure that participant numbers are adequate.

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Chapter 1

INTRODUCTION

1.1 *The Problem*

Warm-up (WUP) is considered by many coaches, sports scientists, competitive and recreational athletes to be an essential practice that needs to be performed prior to participation in training sessions and sporting activities. Competitive and recreational athletes typically perform a WUP to prepare their body for the extra strain of strenuous physical activity. The purpose of WUP is to enhance physical performance and to reduce the incidence of sports-related musculoskeletal injuries (Bishop, 2003). Benefits associated with WUP are proposed to be due to temperature and non-temperature related effects that ultimately prime the body for subsequent exercise performance. These benefits are described in detail in the following literature review. However, despite its ubiquitous nature, there have been very few well-controlled studies investigating the effects of WUP on performance in team-sports athletes (Bishop, 2003).

Further, while there are a number of studies that have investigated the effect of WUP intensity on single sprint performance, there are few studies that have assessed the effects of WUP intensity on intermittent sprint performance (ISP). This lack of research is surprising, as in many countries the most popular sports, and those with the highest participation levels, are team sports (i.e. soccer, rugby, field hockey, basketball, etc.), which require athletes to sprint intermittently throughout the match.

Therefore, this thesis consists of three studies that focused on the effects of WUP on ISP. The aims and hypotheses are described in the following section.

1.2 AIMS and HYPOTHESES

1.2.1 Study One

The aim of the first study was to investigate the impact of varying WUP intensities on intermittent sprint performance (ISP) in order to determine which intensity resulted in better performance (i.e. total work, work and power output for the first sprint and % work decrement). This study incorporated WUP intensities based around an individual's lactate threshold (i.e. lactate threshold (LT), lactate inflection (LI), half way between LT and LI, half the difference between LT and LI below LI and half the difference between LT and LT above LT), rather than percentages of $\dot{V}O_{2max}$, as this method ensures that all subjects have similar changes in blood lactate concentration following the different WUP protocols. This study also investigated whether increases in specific body temperatures (muscle, body or rectal) induced by the various WUP strategies were correlated with performance.

It was hypothesised that a WUP intensity that was mid-way between lactate inflection (LI) and anaerobic threshold (described in this study as lactate threshold: LT) would result in better intermittent sprint performance, as this intensity should result in temperature related benefits associated with WUP, while at the same time, avoiding large increases in lactate concentration.

1.2.2 Study Two

The aim of the second study was to investigate the effects of active WUP (compared to no WUP) on single sprint performance, as well as on prolonged ISP, where the sprint and recovery periods and the duration of the exercise protocol equated to those used in a full team-sport game. The effect of active WUP on the first sprint of the ISP was also assessed.

It was hypothesised that both single sprint performance and prolonged ISP would be improved after an active WUP performed midway between the lactate inflection and the lactate threshold (previously described as AT), compared to a no WUP condition. It was further hypothesised that, due to the possibility of a conscious or subconscious pacing strategy, the first sprint of a prolonged ISP would be impaired when compared to single sprint performance.

1.2.3 Study Three

The aim of the third study was to investigate the effect of active WUP (based on lactate thresholds) on 80 min of ISP (equivalent to a full team sport game), as well as the first sprint of the ISP in hot and humid conditions (35^{o}C, 50% RH) compared to cooler environmental conditions (~20-25^{o}C, 20-40% RH). A second aim was to compare the effects of active versus passive WUP on 80 min of ISP performed in a hot and humid environment (35^{o}C, 50% RH).

It was hypothesised that prolonged ISP, and the first sprint of ISP, would be impaired in hot and humid conditions, compared to a thermoneutral environment, due to the extra heat load. Secondly, it was hypothesised that there would be no significant difference in ISP, or the first sprint of ISP, in hot and humid conditions between the active and the passive WUP conditions.

1.3 Unique Aspects Associated With These Studies

There are numerous aspects of the studies undertaken in this PhD project that are unique to the field of WUP. These aspects are as follows:

1) Many previous studies that investigated the effect of WUP intensity on performance used intensities that were either self-paced or based on individual percentage of $\dot{V}O_{2max}$. The current study used the lactate inflection and lactate threshold level (also described by others as aerobic threshold and anaerobic threshold, respectively) in order to determine the most appropriate WUP intensity for each subject. Use of lactate thresholds to determine WUP intensities was selected in preference to that based on a percentage of $\dot{V}O_{2max}$, as it represents a better means of imposing an equal physiological strain on each subject. For instance, if 70% $\dot{V}O_{2max}$ was used as the WUP intensity, this may result in some subjects working at their lactate threshold, while others may have a higher lactate threshold, as is common in athletes with higher aerobic capacities.

2) Typically, the majority of studies have assessed the effects of WUP on short-term, maximal-sprint and ISP protocols, in which sprint duration and recovery times were not reflective of that which typically occurs in team-sport games (Spencer et al., 2004). Of importance, varying sprint durations and recovery periods will result in different percentages of energy utilisation from the three different energy systems, i.e. aerobic, glycolytic and ATP-PC systems, which in turn can be impacted by the WUP protocol employed. The present studies used an intermittent sprint protocol based on recent time motion analyses of team-sport games described by Spencer et al. (2004), which reported that the average maximal sprint duration

was 4.1 ± 2.1 s, while recovery times between sprints ranged between 60 – 121 s. While this test was performed on a cycle ergometer, a strong correlation has been reported between intermittent sprint cycling and running performance (Bishop, Spencer, Duffield, & Lawrence, 2001). Further, this cycle sprint test has previously been used in studies by Bishop and Maxwell (2009), Bishop and Claudius (2004) and Schneiker, Bishop and Dawson (2006) in order to simulate intermittent sprints performed during a team-game. Employment of a protocol that uses these sprint and recovery times can give more accurate information on the impact of WUP (or no WUP) on exercise performance that simulates a typical team-sport game.

3) In addition to the lack of published protocols that have simulated sprints used in team-sport games sports, there have been very few studies to date that have assessed the impact of WUP on ISP performed over a time period that equates to that of a typical team-sport game (approximately 80-90 min). Assessment of WUP on an ISP protocol that simulates a full team-sport game can provide more accurate information on the overall benefits (if any) of performing a WUP prior to this type of performance.

4) The effect of WUP on intermittent sprints performed over the course of time that equates to a team-sport game played in hot and humid environmental conditions is an important consideration based on the effect that environmental heat can have on exercise performance and physical well-being. To date, there has been only one study known to the author that assessed the effect of WUP on ISP in hot environmental conditions, where the sprints were similar to that performed in a team-sport game (Bishop & Maxwell, 2009). However, the

duration of the exercise performance was only 36 min, which is equivalent to 'half' a team-sport game. Secondly, the WUP intensity was based primarily on % $\dot{V}O_{2max}$. Therefore, the present study may be the first to assess the effects of both passive and active WUP (based on lactate thresholds) on intermittent exercise in a hot environment over the extended time of a full team-sport game.

1.4 SIGNIFICANCE OF STUDIES

Warm-up is a popular technique that is proposed to improve subsequent exercise as well as to assist in injury prevention. To date, the effect of WUP on subsequent exercise performance has been equivocal. Therefore this series of studies will investigate the use of varying WUP intensities on subsequent exercise that simulates sprint patterns and recovery periods appropriate for team-sport games. The effect of WUP on subsequent intermittent sprint exercise performed in different environmental conditions will also be investigated. These investigations are novel and it is hoped that the results of these studies will provide a scientific rationale to underpin recommended WUP strategies in order to improve the performance of team-sport athletes playing in differing environmental conditions.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Introduction

Warm-up (WUP) is a well accepted practice that almost all competitive and recreational athletes perform before every training session and game in order to prepare their bodies for the extra strain of strenuous physical activity. Yet, interestingly, not all scientific studies have reported benefits associated with WUP on subsequent exercise performance (Asmussen & Boje, 1945; De Bruyn-Prevost & Lefebvre, 1980; de Vries, 1959; Gray & Nimmo, 2001; Grodjinovsky & Magel, 1970; Mathews & Snyder, 1959; Stewart & Sleivert, 1998), with some researchers even reporting impairment in subsequent exercise performance (De Bruyn-Prevost & Lefebvre, 1980; Genovely & Stamford, 1982; Massey, Johnson & Kramer, 1961). Reasons for lack of benefit of WUP on subsequent exercise performance may be related to the intensity or duration of the WUP performed, the inclusion and timing of a recovery period, as well as the intensity and duration of the subsequent exercise, with these issues being addressed later in this literature review. Further, according to Bishop (2003a), assessing the outcomes of these earlier studies is difficult, as many of these studies were poorly controlled, had very small cohorts, or simply did not include statistical analyses. Nonetheless, WUP still remains a popular practice for many athletes and warrants further investigation using well controlled trials.

The proposed purpose of WUP is to optimise physical performance and to reduce the incidence of sports-related musculoskeletal injuries (Bishop, 2003a; Karvonen, Lemon, & Iliev, 1992;

Shellock & Prentice, 1985). Benefits associated with subsequent exercise performance can be physiological and/or psychological (Bishop, 2003a; Karvonen et al., 1992), with the most common benefits of WUP being attributed to temperature related mechanisms (Bishop, 2003a).

2.2 TYPES of WARM-UP

Typically, WUP can be either active or passive, with passive WUP related to the local and global use of hot showers, shortwave diathermy, steam baths, heat pads and similar devices that are used to increase body temperature (Ingjer & Stromme, 1979). Generally, these procedures are not practical for use by many athletes due to the lack of facilities. Conversely, active WUP involves exercise that employs the major muscle groups of the body in the performance of repetitive activities such as swimming, jogging and cycling, with these activities inducing greater metabolic and cardiovascular changes than passive WUP. Active WUP can further be classified as being either general or specific in focus (Bishop, 2003a; Karvonen et al., 1992; Safran, Seaber & Garrett, 1989; Shellock & Prentice, 1985). A general active WUP involves any non-specific active movement of the major working muscle groups such as jogging, cycling or callisthenics (Bishop, 2003b; Safran et al., 1989), while a specific WUP utilises activities and muscle movements that are specific to the sport/activity about to be performed (Safran et al., 1989; Shellock & Prentice, 1985). Of relevance, Woods, Bishop and Jones (2007) claimed that the most effective WUP technique appeared to be the specific WUP, most likely due to the fact that it mimics the activity to be performed. For the purpose of this review, unless otherwise noted, active WUP will refer to specific WUP practices without the inclusion of stretching.

2.3 PROPOSED BENEFITS OF WARM-UP

The benefits of an active WUP on subsequent exercise performance are proposed to be related to both temperature and non-temperature related mechanisms (Bishop, 2003a). In relation to passive WUP, proposed benefits on subsequent exercise performance relates to temperature related mechanisms only, apart from a possible psychological benefit that participation in the process of a WUP (albeit a passive WUP) may elicit. The following section will briefly describe both temperature and non-temperature related benefits associated with WUP.

2.3.1 Temperature Related Benefits of Warm-Up

Physiologically, the majority of benefits associated with WUP have been attributed to temperature related mechanisms. This is consistent with the conclusion made by Asmussen and Boje (1945) who noted that a higher temperature in the working organism facilitated the performance of work. Active WUP increases muscle temperature (T_{mu}) and mean body temperature (T_b) due to an increased production of heat in the working muscle (Asmussen & Boje, 1945). Further, an increase in rectal temperature (T_{re}) during exercise has been found to be dependent on the rate of work, but independent of the environmental temperature, humidity and air movement (Nielsen & Nielsen, 1962). Interest to date relates to which specific temperature increase (i.e., T_{mu}, T_{re} or T_b), that occurs as a result of WUP, is the most important for improvement in subsequent exercise performance. To date the answer to this question remains equivocal as many studies have only assessed either T_{re} or T_{mu}, with comparison between studies made difficult due to the different depths that T_{mu} measurements have been taken (Saltin, Gagge, & Stolwijk, 1968; Sargeant, 1987). Further studies are needed in order to determine which temperature is the best indicator for positive effects on subsequent exercise performance.

An increase in T_{mu}, T_{re} and T_b, as a result of WUP, is proposed to improve performance via numerous factors that include: decreased muscle and joint viscous resistance, decreased stiffness of muscle fibres during contraction, increased unloading of oxygen from haemoglobin and myoglobin (Barcroft & King, 1909; McCutcheon, Geor, & Hinchcliff, 1999), increased speed of rate-limiting oxidative reactions (Koga, Shiojiri, Kondo, & Barstow, 1997), increased anaerobic metabolism (Fink, Costill & Van Handel, 1975), as well as increased nerve conduction rates (Karvonen et al., 1992). Each of these mechanisms is briefly described below.

2.3.1.1. Decreased Viscous Resistance

An increase in T_{mu} has been reported to decrease the viscous resistance of joints and muscles (Wright & Johns, 1961), as well as decrease the stiffness of muscle fibres during muscle contraction (Asmussen, Bonde-Petersen, & Jorgensen, 1976; Buchthal, Kaiser & Knappeis, 1944). This is demonstrated by Buchthal and colleagues (1944) who measured the rate of tension development and relaxation during voluntary maximal isometric contractions and found that while maximal isometric tension changed by less than 1% per degree, the rate of tension development and relaxation increased by 3-5% and 5% per degree, respectively, when T_{mu} increased from 30-40^{o}C. While this temperature effect in the muscle's elastic properties may be considered small, this may still provide an altered physical state for improvement in exercise performance (Bishop, 2003a).

2.3.1.2 Increased Oxygen Delivery to Muscle

As T_b increases, oxygen unloading from haemoglobin and hence delivery to working muscles increases via a rightward shift in the oxygen dissociation curve (known as the Bohr effect:

McArdle, Katch & Katch, 2001). An early study by Barcroft and King (1909) using rabbits as subjects, demonstrated that haemoglobin, at an oxygen tension of 30 mmHg, gave up nearly twice as much oxygen at a temperature of 41^{o}C compared to 36^{o}C. Further, an increase in T_b has been reported to result in vasodilation of blood vessels, which in turn results in greater blood flow and hence oxygen delivery to the working muscles (Barcroft & Edholm, 1943). However, the question arises of whether or not this increase in the availability of oxygen improves aerobic exercise performance. Studies by Burnley, Jones and Carter (2000) and Koppo and Bouckaert (2001) using active WUP, as well as a study by Koga et al. (1997) using a passive WUP, reported no benefit associated with either type of WUP on oxygen kinetics in healthy, young adults during exercise performed at a moderate intensity (below anaerobic threshold: AT) and high intensity (above AT but below maximal oxygen uptake). Interestingly, oxygen kinetics after an active WUP have only shown to be improved in elderly subjects participating in moderate intensity exercise (80% of ventilatory threshold: Scheuermann, Bell, Paterson, Barstow & Kowalchuk, 2002). According to a review by Bishop (2003a), lack of improvement in oxygen kinetics found in some studies may be due to the possibility that muscle perfusion and/or oxygen delivery is adequate in young healthy adults, and/or that the exercise intensity of the active WUP was not high enough to adequately increase blood flow in order to sufficiently increase oxygen kinetics.

2.3.1.3 Speeding of Rate-limiting Oxidative Reactions

Koga et al. (1997) reported that a higher T_{mu}, as a result of active or passive WUP, accelerated rate-limiting reactions associated with oxidative phosphorylation. This in turn has been proposed to also improve oxygen kinetics, allowing for more initial work to be completed aerobically. This can result in deferring energy contribution from anaerobic sources until later in the task, consequently improving overall exercise performance (Bishop, 2003a). However, as previously noted, neither a moderate intensity WUP nor passive heating performed prior to exercise has been reported to speed up oxygen kinetics in healthy, young adults (Burnley et al., 2000; Koppo & Bouchaert, 2001, Koga et al., 1997). According to Bishop (2003a), studies that reported a lack of an increase in oxygen kinetics after either active or passive WUP (Burnley et al., 2000; Koga et al., 1997; Koppo & Bouckaert, 2001) may not have raised T_{mu} sufficiently in order to affect oxidative phosphorylation and hence oxygen kinetics. Consequently, the intensity of WUP on subsequent exercise performance represents an important issue that requires further investigation.

2.3.1.4 Increased Nerve Conduction Rates

A study by Karvonen et al. (1992) reported that increased T_{mu} improved central nervous system (CNS) function and increased the transmission speed of nerve impulses. This finding is supported in part by Stewart, Macaluso and De Vito (2003), who reported higher power output during squat jumps following an active cycling WUP (70% ventilatory threshold), compared to a control condition (3324 ± 866 W vs. 3569 ± 919 W; $P < 0.05$). Of relevance, T_{mu} measured from the vastus lateralis was 33.8 ± 0.4°C in the control condition compared to 36.8 ± 0.5°C in the WUP condition ($P < 0.05$). Increased power output after this active WUP was further indicated by higher surface EMG activity, which was proposed by the researchers to be related to greater impulse conduction velocity, which may have resulted in the faster activation of the muscle fibres, thus partly explaining the increase in power output.

2.3.1.5 Increased Anaerobic Metabolism

An increase in T_{mu} has been found to increase muscle glycogenolysis, glycolysis, and high-energy phosphate degradation during exercise (Febbraio, Carey, & Snow, 1996; Edwards et al., 1972). Specifically, an increase in T_{mu} from 35ºC (resting T_{mu}) to 40ºC has been shown to increase the rate of anaerobic ATP supply by 40% above normal levels (Febbraio et al., 1996). While the availability of muscle glycogen is critical during long-term aerobic performance, an increase in anaerobic metabolism, as a result of WUP, may be beneficial for subsequent short-term sprint performance (Bishop, 2003a).

2.3.2 Non-Temperature Related Benefits of Warm-Up

Active WUP has also been proposed to result in a number of non-temperature related benefits to subsequent exercise performance. These effects include increased blood flow and oxygen delivery to the muscles, elevation of baseline oxygen consumption, post-activation potentiation, reduced muscle stiffness and psychological benefits, which together prime the body for the ensuing task. These benefits are briefly described in the following section.

2.3.2.1. Increased Blood flow and Oxygen Delivery

Performance of an active WUP can result in a number of metabolic changes, such as increased potassium concentration (Kiens, Saltin, Walloe, & Wesche, 1989), reduced oxygen tension (McComas, 1996) and increased hydrogen ion concentration (Guyton, 1986), which have all been reported to cause vasodilatation and increased muscle blood flow in the working muscles (Bishop, 2003a). Further, increases in hydrogen ion concentration, 2,3-diphosphoglycerate and PCO_2, as a result of active WUP, have also been proposed to increase the unloading of oxygen from haemoglobin, as reflected by a rightward shift of the oxyhaemoglobin dissociation curve (Boning, Hollnagel, Boecker, & Goke, 1991).

2.3.2.2 Elevated baseline Oxygen Consumption

Another proposed benefit of WUP on exercise performance is that it allows subsequent exercise tasks to begin with an elevated baseline oxygen consumption (Bishop, 2003a). This effect suggests that there will be a reduced energy contribution required from anaerobic metabolism at the start of exercise, which can then be utilised later in the exercise performance (Bishop, 2003a). According to Bishop (2003a), this should result in increased time to exhaustion and hence improved exercise performance in tasks that require significant energy contribution from anaerobic sources. The premise of an elevated baseline oxygen level post WUP is supported by numerous studies that have reported a decreased oxygen deficit or a greater aerobic energy contribution to the exercise task when it was preceded by an active WUP (di Prampero, Davies, Cerretelli, & Margaria, 1970; Gollnick et al., 1995; Gutin, Stewart, Lewis, & Kruper, 1976; McCutcheon et al., 1999). Of importance, a reduced energy contribution from anaerobic metabolism at the start of subsequent exercise will only be realised if the time period between WUP and the start of exercise does not allow oxygen consumption to return to resting levels (Bishop, 2003a), with this time period proposed to be approximately 5 min (Ozyener, Rossiter, Ward & Whipp, 2001).

2.3.2.3 Post-activation Potentiation

Active WUP has been proposed to improve muscle contractile activity due to post-activation potentiation, which is purported to prime the muscles for subsequent performance (Vandervoort, Quinlan, & McComas, 1983). Consequently, according to Bishop (2003a), an active WUP that includes a sprint or a maximum muscle voluntary contraction (MVC) may improve subsequent strength and power performance by increasing muscle contractile performance. This suggestion is supported by studies by Gullich and Schmidtbleicher (1996) and Young, Jenner, and Griffiths (1998) that reported increased power output of both the upper and lower extremities 3 – 5 min following the performance of MVCs.

2.3.2.4 Reduction in Muscle Stiffness

It has been proposed by researchers that the performance of physical activity may reduce muscle stiffness by the breaking of any stable bonds that may have formed between actin and myosin filaments (Proske, Morgan, & Gregory, 1993; Wiegner, 1987) as a result of previous inactivity (Enoka, 1994). Therefore, performance of an active WUP may reduce any residual stiffness in the muscle fibres of the working muscles, hence priming the body for further exercise. According to Bishop (2003a), this in turn may improve power output during short-duration exercise.

2.3.2.5 Psychological Effects of Warm-Up

It is possible that the performance of either a passive or an active WUP may improve performance via psychological mechanisms that allow the athlete to perceptially prepare for the ensuing exercise task. In this respect, WUP can be considered as part of a pre-performance routine that allows the athlete time to concentrate and prepare for the task ahead (Shellock & Prentice, 1985). This suggestion is supported by an early study by Malarecki (1971) that reported improved results in some sporting activities that were preceded by an imagined WUP.

2.3 Further Benefit of Warm-Up

Many of the associated benefits of WUP, particularly temperature related benefits, are proposed to provide a protective mechanism against muscle damage. This is demonstrated in a study by Bixler and Jones (1992) that assessed the impact of a 3 min active WUP and stretching routine performed at half time during 55 high school football games, as opposed to a no WUP condition. These investigators reported that the intervention teams sustained significantly fewer third-quarter musculotendinous injuries (sprains and strains) per game, suggesting a positive association between half-time WUP and stretching and reduced injury.

2.4 PROPOSED NEGATIVE EFFECTS OF WARM-UP

While WUP is generally associated with positive effects on exercise performance, WUP has also been reported to impair subsequent exercise due to potential deleterious effects on core temperature (T_c), metabolism and energy stores.

During exercise, T_b increases rapidly due to heat generated from skeletal muscle contraction (Asmussen & Boje, 1945). Consequently, the more intense the muscle work, the higher the T_b (Asmussen & Boje, 1945). Of relevance, it has been previously reported that fatigue, which in turn will impair exercise performance, occurs when the body reaches a critical core temperature (T_c; Kozlowski et al., 1985), that is proposed to be approximately 39.4 – 40.0ºC for prolonged intermittent exercise (Drust, Rasmussen, Mohr, Nielsen & Nybo, 2005, Morris, Nevill, Lakomy, Nicholas & Williams, 1998) and 40ºC for prolonged continuous exercise in the heat (Gonzalez-Alonso & Coyle, 2001). Attainment of a critical T_c has been proposed to be the main limiting factor for continuous performance in hot environments (Cheung & McLellan, 1998; Gonzalez-Alonso et al., 1999; Nielsen, Hales, & Strange, 1993; Nielsen, Strange, Christensen, Warberg, & Saltin, 1997). While the existence of a critical T_c and its effects on fatigue and hence exercise performance has recently been challenged in one study (Ely et al., 2009), these researchers concluded that heat stress and fatigue were dependent upon a complex interplay of multiple physiological systems, which included T_c. Further studies are needed to verify this research by Ely et al. (2009), considering the many studies that describe a critical T_c associated with impaired exercise performance (see below).

Of further issue, is that team-sport players are reported to expend large amounts of energy during an entire game. For example, Spencer et al. (2004) reported that the total sprint distance covered by team players during a 70-90 min field-based game was approximately 700-1000 m. This high energy expenditure can result in the earlier attainment of a critical T_c, particularly if performance is undertaken in hot and humid ambient conditions, due to the extra heat load placed on the body by the environmental conditions. According to a number of researchers, elevations in T_c have been reported to affect metabolic (Febbraio, Snow, Stathis, Hargreaves & Carey, 1994), cardiovascular (Gonzalez-Alonso, Mora-Rodriguez, Below, & Coyle, 1995), and physiological (Brooks, Hittelman, Faulkner, & Beyer, 1971) responses to exercise. Further, the attainment of a critical T_c can also result in heat injury, which includes heat cramp, heat syncope and heat exhaustion, as well as the life threatening condition of heat stroke (McArdle et al., 2001). While the mechanisms of hyperthermia which impair performance are still unclear, Drust et al. (2005) proposed that premature fatigue during exercise appeared to be related to the influence of a high T_c on the function of the central nervous system. This premise is supported by numerous studies that have reported the occurrence of fatigue occurring during exercise without the depletion of muscle glycogen (Febbraio, 1999), or the accumulation of metabolic waste products (Drust et al., 2005; Gonzalez-Alonso et al., 1999; Morris, Nevill & Williams, 2000; Nybo & Nielsen, 2001). The role of reduced heat storage capacity in impairing prolonged exercise is further demonstrated by the use of cooling methods designed to lower body temperatures either prior to or during exercise performed in the heat (Castle et al., 2006; Lee & Haymes, 1995), which in turn can delay the attainment of a critical T_c and result in improved exercise performance compared to control conditions.

In addition, the performance of either an active or passive WUP prior to prolonged exercise, particularly if exercise is performed in hot ambient conditions, may further reduce heat storage capacity in the body, resulting in a critical T_c being achieved even sooner (Nadel & Horwarth, 1977). This was demonstrated in a study by Gregson, Drust, Batterham and Cable (2002a) that assessed the effects of an active and passive WUP, as well as a no WUP condition, on prolonged steady rate exercise (70% $\dot{V}O_{2max}$) performed in thermoneutral environmental conditions (21.7 ± 2.1° C and 36.7 ± 54% RH) until volitional exhaustion. Exercise time to exhaustion was significantly reduced following both the active and passive WUP compared to no WUP (47.8 ± 14.0 min vs 39.6 ± 16.0 min vs 62.0 ± 8.8 min, respectively), with the effect being related to a significantly higher T_{re} and mean T_b associated with both WUP conditions. The researchers proposed that the higher body temperatures achieved in these two WUP conditions compromised heat storage capacity and hence exercise performance. Importantly, the test protocol used in the above study did not mimic that used during team-sport games, while the results reflect the assessment of a small cohort of only six subjects.

Of further consideration, is that an active WUP performed in hot environmental conditions can contribute to reduced hydration levels which have been proposed to impair subsequent exercise performance (Fortney, Wenger, Bove, & Nadel, 1984).

The impact of metabolic and environmental heat on the body are important issues when deciding on the inclusion of a WUP prior to exercise, considering that a primary reason to employ a WUP is to induce temperature (active or passive WUP) and non-temperature (active WUP) related benefits on subsequent exercise performance. Studies that have assessed the impact of WUP on prolonged exercise performance in both hot and normal environmental conditions will be described later in this literature review.

A further consideration when deciding on the inclusion of a WUP prior to exercise is that an active WUP results in the depletion of energy substrates, as well as the accumulation of metabolic waste (Bishop, 2003a), which may impact subsequent exercise performance. This issue needs to be weighed up against the proposed benefits of employing an active WUP, with the duration and the intensity of the active WUP used representing important factors that can affect subsequent exercise performance (see later discussion). This prompts the question of whether the use of a passive WUP may be preferential to an active WUP prior to prolonged exercise, particularly team-sport performance where energy requirements are predominantly from anaerobic sources, with this issue being addressed in the following section.

2.5 PASSIVE VERSUS ACTIVE WARM-UP ON SUBSEQUENT EXERCISE

Both active and passive WUP can increase T_b, which in turn may have temperature-related benefits on subsequent exercise performance (Bishop, 2003a). Of further consideration is that passive WUP allows T_b to increase without a concomitant decrease in high energy substrates or increases in metabolic wastes, while active WUP provides benefits for subsequent exercise performance via temperature and non-temperature-related mechanisms, such as those described earlier in this literature review. Further, active WUP is more commonly used by athletes due to its more practical application in that various facilities used for passive WUP, such as steam baths or hot showers, may not be readily available. To date, a number of studies have compared the effects of an active versus a passive WUP on subsequent exercise performance (see below).

Results from studies that have assessed the effects of an active compared to a passive WUP on subsequent exercise performance have been equivocal. For example, in respect to the positive benefits on subsequent exercise performance following either type of WUP, an early study by Asmussen and Boje (1945) assessed the effects of an active WUP, a passive WUP and a no WUP condition on time to complete 956 kg/m (~12 – 15 s) and 9,860 kg/m (~4 – 5 min) of work in four subjects. While formal statistical analyses were not performed, results showed that both WUP conditions resulted in improved performance of between 2.7 and 8.0%, compared to the no WUP condition. Further, results between the two WUP conditions were similar, suggesting that temperature related benefits associated with WUP played an important role in the improvement of subsequent exercise. Similar results were also reported by Muildo (1946), who reported that both active and passive WUP resulted in improved swim times (50 and 400 m) compared to a no WUP condition in three subjects. Another study by Dolan, Greig and Sargeant (1985) also assessed cycling exercise performance following either active, passive or no WUP in four healthy males. These researchers reported that while there was no significant difference between the active and passive WUP conditions, both resulted in significantly improved short-term maximal peak power ($P < 0.01$) on a cycle test compared to the control condition. Of relevance, active and passive WUP resulted in a 2.7 and a 2.3% increase in maximal power per 1ºC increase in T_{mu}, respectively. Finally, Carlile (1956) reported a significant improvement in 40 yd (36.6 m) swim times when the swim was precede by an 8 min hot shower compared to 0.5 min luke-warm shower in 10 male and female subjects. These results by Carlile (1956) highlight temperature related benefits associated with a passive WUP, while results from Asmussen and Boje (1945), Muildo (1946) and Dolan et al. (1985) demonstrate the positive effects of temperature related mechanisms associated with both passive and active WUP.

Conversely, Gray and Nimmo (2001) reported no difference in subsequent exercise performance following an active, passive or no WUP condition. In this study, the effects of an active, passive and a no WUP condition on 30 s of intense exercise followed one min later by a cycle test to exhaustion (120% maximal power output) were examined in eight male subjects. Results showed significantly greater oxygen consumption during the 30 s exercise bout after both active and passive WUP, compared to the control condition ($P < 0.05$; 1017 ± 22, 943 ± 53 and 838 ± 45 ml O_2, respectively). However, there were no significant differences in exercise time to exhaustion between the two WUP conditions or between the WUP conditions and the control condition, suggesting that the WUP protocols used in this study had little effect on exercise performance.

Interestingly, some studies have reported that no WUP was preferential to either an active or a passive WUP on subsequent exercise performance. For example, Gregson et al. (2002a; study details described earlier) found that exercise time to exhaustion (70% $\dot{V}O_{2max}$) was significantly reduced following both active WUP (47.8 ± 14.0 min) and passive WUP (39.6 ± 16.0 min) compared to a no WUP condition (62.0 ± 8.8 min). This observed decrease in performance was related to the significantly higher T_{re} and mean T_b associated with both active and passive WUP. It was proposed that the higher T_{re} values recorded compromised heat storage capacity and hence exercise performance. Of additional interest, Gregson et al. (2002a) reported that exercise to exhaustion was decreased by 8.2 min (not significant) after passive WUP compared to active WUP, suggesting possible benefits associated with non-temperature related mechanisms of active WUP on subsequent performance. In another study, Gregson, Batterham, Drust and Cable (2002b) reported that a passive WUP that raised pre-exercise T_{re} to 38ºC, significantly decreased intermittent (30 s at 90% $\dot{V}O_{2max}$ separated by 30 s passive rest) run time to exhaustion compared to an active WUP (treadmill running at 70% $\dot{V}O_{2max}$ until the attainment of T_{re} of 38ºC; 38.5 ± 11.1 min vs 51.8 ± 7.2 min, respectively) when performed in moderate ambient conditions (21.5 ± 0.6ºC and 35.7 ± 5.4% RH). In addition, both active and passive WUP resulted in significantly slower run times compared to a no WUP condition (38.5 ± 11.1 min vs 51.8 ± 7.2 min vs 72.0 ± 17.2 min, respectively). Again the researchers suggested that the slower performance associated with the two WUP conditions reflected the significantly higher mean T_b and T_{re} recorded in these two trials, that resulted in a decreased heat storage capacity (passive 67.3 ± 17.2 $W \cdot m^{-2}$, active 70.7 ± 21.0 $W \cdot m^{-2}$, control 83.8 ± 21.2 $W \cdot m^{-2}$, $P < 0.05$) and hence premature fatigue. Furthermore, the researchers suggested that the difference in performance results between the two WUP conditions may have been due to the lower heat storage capacity reported for passive WUP.

It can be further speculated that the better run times associated with active WUP compared to passive WUP may reflect non-temperature related benefits associated with this form of WUP.

A study that reported improved subsequent exercise performance associated with active rather than passive WUP was performed by O'Brien, Gastin, Payne, and Burge (1997). These researchers reported greater average and peak power output and $\dot{V}O_{2peak}$ during the initial 30 s and the overall duration of 60 s of a supramaximal cycle sprint following active WUP compared to passive WUP. These researchers proposed that the improved performance was the result of greater oxygen consumption during the initial stages of exercise, highlighting the importance of non-temperature related benefits associated with active WUP. Further, while, Ingjer and Strømme (1979) did not assesses whether WUP resulted in improved subsequent exercise performance, they reported that standard work resulted in a significantly higher oxygen uptake and lower lactate concentration when preceded by an active WUP compared to a passive WUP or no WUP condition, again highlighting the importance of non-temperature related benefits associated with active WUP. Further, these researchers suggested that these physiological changes may be of benefit to subsequent athletic performance.

Of interest, apart from the studies by Gregson et al. (2002a), Gregson et al. (2002b) and Gray and Nimmo (2001), all the other studies described above reported benefits associated with an active and/or a passive WUP on subsequent exercise performance when compared to a no WUP condition, emphasising the positive temperature and non-temperature effects of both WUP conditions. Of relevance, both studies that reported improved subsequent exercise performance following a no WUP condition compared to an active and passive WUP condition, used either prolonged intermittent or prolonged submaximal exercise that resulted in higher T_{re} values in both WUP conditions prior to exercise, that in turn resulted in a reduced heat storage capacity and impaired performance (Gregson et al., 2002a, Gregson et al., 2002b). Further, Gray and Nimmo (2001) suggested that the benefit of WUP on power output, reported in their study, may have been overridden by the duration of the subsequent exercise period (58 – 112 s). This conclusion however, is contentious when considering the results of studies by Asmussen and Boje (1945) and Muildo (1946) that both reported benefits associated with passive and active WUP on subsequent exercise that consisted of longer durations than that used in the study by Gray and Nimmo (2001). However, neither Asmussen and Boje (1945) nor Muildo (1946) assessed their results using statistical significance, leaving their outcomes open to debate.

Lastly, an issue associated with most of the afore-mentioned studies relates to the recruitment of small cohorts (3 – 8 subjects) which most likely resulted in a lack of power, and that the performance protocols used were not relevant to team-sport performance. To date, the effect of passive WUP compared to active WUP has not yet been assessed on prolonged intermittent-sprint capacity that simulates a full team-sport game. Consequently, further investigation into this area is warranted.

2.6 INTENSITY, DURATION & RECOVERY OF ACTIVE WARM-UP

Subsequent exercise performance has been shown to be affected by the intensity and duration of the prior active WUP, as well as the recovery period used in between the WUP and subsequent exercise. The following section will address these issues.

2.6.1 Recovery Period between Warm-Up and Subsequent Exercise Performance

The duration of the recovery period between WUP and subsequent exercise can impact the proposed benefits associated with both passive and active WUP. In addition, the recovery period plays an important role in allowing energy systems, specifically the phosphocreatine (PCr) energy system, to recover if the intensity of the preceding WUP was high.

Of importance, determination of the recovery period needs to consider the proposed temperature related benefits associated with either active or passive WUP on subsequent exercise performance. Importantly, the post-WUP recovery period should not be too long, as any temperature related benefits associated with WUP may be reduced. For example, Saltin et al. (1968) reported that, based on WUP intensity and environmental conditions, T_{mu} is likely to decline significantly after a ~15-20 min rest period. Furthermore, a decrease in T_{mu} results in the diminishment of temperature-related factors that result in increased muscle contractility, potentially harming ensuing exercise performance.

Further, proposed non-temperature related benefits associated with active WUP can also be diminished if the recovery period is too long. For example, a study by Ozyener et al. (2001) reported that elevated baseline oxygen consumption, as a result of active WUP, returned to resting levels after approximately 5 min. This may explain why a study by Bishop, Bonetti and Dawson (2001) reported no initial sparing of anaerobic capacity as a result of elevated baseline oxygen consumption, when a 5 min recovery period was employed between a moderate intensity WUP and a 2 min sprint kayak performance. In addition, the duration of the recovery period may also affect the proposed beneficial effect of post-activation potentiation associated with active WUP. This is demonstrated in studies by Gullich et al. (1996) and Young et al. (1998) that both cited post-activation potentiation as a contributing factor to improved dynamic performance following a 3 – 5 min rest period that was preceded by an active WUP that included maximal voluntary contractions (MVC). It is reasonable to speculate that a longer recovery period may have diminished the effects of this particular benefit of active WUP. Conversely, a shorter recovery period (15 s) between a WUP that consisted of a MVC and subsequent dynamic knee extension performance resulted in no benefit being found in power output in a study by Gossen and Sale (2000). This particular study also highlights how the recovery time between WUP and subsequent exercise can affect energy system replenishment and hence exercise performance. Specifically, the lack of benefit of WUP on exercise performance in the study by Gossen and Sale (2000) most likely reflects the inability of phosphocreatine (PCr) stores to replete to a level necessary for optimal subsequent exercise performance. Of relevance, Dawson et al. (1997) reported that PCr stores took 3 min to almost fully replete following a single 6 s cycle sprint, while PCr stores were only 83% recovered 3 min following 5 x 6 s sprints separated by 30 s. In support of this premise, Sargeant and Dolan (1987) reported a 32% decrement in subsequent maximal power output compared to control values following a high intensity WUP (87% $\dot{V}O_{2max}$) when no rest period was included. However, when a rest period was introduced, subsequent peak power increased as the duration of the recovery period was lengthened. Therefore, the time required for complete PCr repletion needs to be considered when determining the optimal recovery period between an active WUP and subsequent exercise that both require high intensity efforts.

In summary, the recovery period between WUP and subsequent exercise should not be too long as to allow the proposed benefits associated with temperature and non-temperature related mechanisms of WUP to return to baseline levels, nor be too short as to prevent the restoration of PCr stores, particularly if the WUP and subsequent exercise performance are dependent on this particular energy system. Furthermore, if the WUP intensity is such that it does not negatively impact energy reserves, metabolic waste or heat storage capacity, then it may be astute to use a shorter recovery period (< 5 min), or even no recovery period, in order to maximise the proposed benefits of non-temperature related benefits associated with WUP on subsequent exercise performance.

2.6.2 Duration of Active Warm-Up

The duration of WUP needs to be long enough to promote both temperature and non-temperature related benefits proposed to improve subsequent exercise performance (as described earlier), while not be so long as to result in an excessive rise in metabolic and / or thermal responses that can induce premature fatigue. According to Saltin et al. (1968), T_{mu} rises rapidly within the first few minutes of exercise performed in thermoneutral conditions, reaching a plateau after approximately 10 – 20 min. Further, it has been reported that active WUP needs to be approximately 5 – 10 min in duration in order for a steady state in oxygen consumption to be reached (Ozyener et al., 2001). This would suggest that WUP duration should be at least 10 min in order to achieve these benefits. This premise is supported in a study by Franks (1983), that reported improved exercise performance following WUPs of ~10 min duration that were performed between 60 – 80% $\dot{V}O_{2max}$. Further, a study by Stewart and Sleivert (1998) reported significantly improved subsequent exercise performance (maximal run to exhaustion on a treadmill at a 20% grade and 13 km/h velocity) when the exercise was preceded by slightly longer WUP's of 15 min of treadmill running performed at 60% $\dot{V}O_{2max}$ and 70% $\dot{V}O_{2max}$.

Conversely, WUP duration should not be too long as to seriously deplete energy substrates or reduce heat storage capacity, particularly when subsequent exercise is performed in hot and humid conditions and/ or is prolonged (Bishop, 2003b). These issues are further compounded by a WUP intensity that is too high. While the partnership of WUP intensity and duration will be referred to briefly in this section, WUP intensity will be further considered later on in this review.

The effects of a prolonged WUP on exercise performance are demonstrated in a study by Genovely and Stamford (1982). These researchers reported that a 60 min WUP performed at either below anaerobic threshold (AT: 40% $\dot{V}O_{2max}$) or above AT (68% $\dot{V}O_{2max}$) resulted in no benefit or impairment to subsequent exercise that consisted of 2 x 40 s bouts of 'all out' cycle sprints that required pedalling against a 5.5 kg resistance, that was separated by 5 min of rest. Of relevance T_{re} and blood lactate concentration increased significantly from baseline to the end of WUP in both conditions, but were both significantly higher in the higher intensity WUP condition after 30 min of exercise. These results highlight the impact of exercise intensity on physiological parameters. The researchers proposed that the negative effect of prolonged WUP performed above AT on subsequent exercise may have been a result of glycogen levels falling below a proposed 'required threshold' speculated by the researchers to be necessary to maintain maximal intensity performance. However, it is likely that this possible effect, combined with the significantly higher T_{re} and blood lactate concentrations recorded during and immediately after this higher intensity WUP, may have all contributed to impaired exercise performance. Elevated blood lactate concentration associated with prior exercise has been previously reported as a contributing factor towards fatigue (Karlsson, Bonde-Peterson, Henriksson & Knuttgen, 1975; Klausen, Knuttgen & Forster, 1972), while a study by Gollnick et al. (1973) reported that 60 min of cycling at 67% $\dot{V}O_{2max}$ resulted in over 50% of muscle glycogen depletion. Further, while glycogen depletion would not have occurred to the same extent in the lower intensity prolonged WUP condition, it still may also have resulted in glycogen levels being below this proposed 'required threshold' (noted earlier), necessary for optimal maximal performance. Hence the longer WUP resulted in a glycogen depleted state, resulting in poorer exercise performance.

When deciding on the duration of an active WUP, consideration must also be given to environmental conditions. This is demonstrated in a study by Bishop and Maxwell (2009) that assessed the effects of a 10 min, 20 min and a no WUP condition on a subsequent prolonged (36 min) intermittent sprint test that also included two repeated sprint bouts comprising of 5 x 2 s sprints separated by ~20s. Warm-up intensity consisted of 5 min or 10 min of cycling at 50% $\dot{V}O_{2peak}$, followed by 2 x 30 s efforts at 70% $\dot{V}O_{2peak}$ separated by 30 s of passive rest, with this then followed by 2 x 4 s 'all out' sprints separated by 2 min cycling at 35% $\dot{V}O_{2peak}$. All trials were performed in hot environmental conditions (35.5 ± 0.6ºC, 48.7 ± 3.4% RH). Results showed that the longer 20 min active WUP resulted in a higher T_{re} than the other conditions, and was associated with a significant decrease in short-term intermittent sprint ability. Consequently, it would appear that the combined effects of a hot environment and prolonged WUP (20 min) can significantly raise T_{re} and be detrimental to intermittent sprint performance.

In summary, as can be seen by the above studies, a prolonged 60 min WUP performed above AT, as well as a 20 min low-moderate intensity WUP performed in hot environmental conditions resulted in impaired subsequent exercise performance, while a 60 min WUP performed below AT resulted in no benefit to subsequent exercise. A further consideration that needs to be made when determining the duration of WUP relates to the important role of the intensity of WUP on heat storage capacity, energy depletion and metabolic waste accumulation. Therefore, if WUP intensity is not so high as to result in detrimental effects on subsequent exercise performance, then a 10 - 15 min WUP should be long enough to optimally increase T_{mu} and steady-state oxygen consumption, as well as to induce other temperature and non-temperature related benefits associated with active WUP. Further, a low to moderate intensity WUP of 10 – 15 min duration should have minimal impact on heat storage capacity, metabolic waste accumulation and anaerobic energy reserves.

2.6.3 Intensity of Active Warm-Up

Numerous studies have compared the effects of intensity specific WUP protocols, as well as a no WUP condition, on subsequent exercise performance, with equivocal results. Varying effects of WUP on subsequent exercise performance most likely relates to the energy and metabolic consequences of the WUP intensity, as demonstrated in the following studies.

An early study by Grodjinovsky and Magel (1970) reported that both a ‘regular’ WUP (5 min jogging and eight callisthenic exercises), as well as a ‘vigorous’ WUP (regular WUP plus a 176 yd run at near maximum speed) resulted in significant improvement to running performance during 60 yd and 440 yd runs compared to no WUP, with there being no significant difference between the two WUP conditions. Unfortunately, WUP intensity was neither constant between subjects nor reported, however regular WUP most likely equated to low to moderate intensity exercise as it is unlikely that the subjects would have run above their AT when asked to perform a jog prior to exercise. Further, the vigorous WUP protocol was the same as the regular WUP, apart from a single additional 176 yd sprint, which would have lasted ~20 - 25 s, suggesting that the overall WUP intensity was moderate rather than high. While the single sprint would have increased muscle and blood lactate concentrations (not reported), levels were not so high as to impair subsequent exercise performance. A positive effect of moderate intensity WUP protocols on subsequent performance was also noted by Stewart and Sleivert (1998), who reported that active WUP protocols consisting of 15 min of running at either 60 or 70% $\dot{V}O_{2max}$ resulted in significantly improved running times associated with a treadmill run to exhaustion. Further support for these results is found in a study by Sargeant and Dolan (1987) that reported a 10% increase in maximal power output during exercise that was preceded by a 6 min WUP that was performed at an intensity of ~50% $\dot{V}O_{2max}$. In contrast to the positive benefits reported above for moderate intensity WUP protocols on subsequent exercise performance, Genovely and Stamford (1982) reported no benefit on maximal performance after an active WUP performed at 68% $\dot{V}O_{2max}$. However, it can be speculated that this result is most likely due to the 60 min WUP period that resulted in significantly higher blood lactate concentration and a possible reduction in glycogen levels below a proposed required 'threshold' necessary to maintain maximal performance (Genovely & Stamford, 1982).

Studies that assessed higher intensity WUP on subsequent exercise have generally reported impaired exercise performance. For example, a high intensity WUP (80% $\dot{V}O_{2max}$ treadmill running performed for 15 min) performed in the same study noted earlier by Stewart and Sleivert (1998), resulted in reduced subsequent exercise performance (time to exhaustion). The investigators reported that this higher intensity WUP was associated with significantly higher lactate accumulation and a concomitant decrease in muscle and blood pH, which in turn has been shown to negatively affect metabolic processes and exercise performance (Stewart & Sleivert, 1998). Similar results, as previously described for moderate and high intensity WUP, were also demonstrated in a study by Bishop et al. (2001) where the effects of three different 15 min WUP intensities were assessed on a 2 min 'all-out' kayak ergometer test. Results showed either significant or near significant improvement in average power following WUP intensities that equated to individual AT, as well as midway between aerobic and AT, while no benefit was associated with a WUP intensity performed at AT. The WUP performed at AT was associated with a significantly higher blood lactate concentration and lower blood pH, which was proposed by the researchers as the main reason for impaired subsequent exercise performance (Bishop et al., 2001).

The negative effects of high intensity WUP was also demonstrated in a study by Sargeant and Dolan (1987), who reported that a WUP intensity of 98% $\dot{V}O_{2max}$ performed for 3 - 6 min immediately prior to subsequent exercise resulted in decreased maximal short-term power output, with final results equating to 70% of control values. These authors also reported that WUP intensities performed at 74% and 80% $\dot{V}O_{2max}$ for 6 min immediately prior to subsequent exercise, resulted in a substantial and progressive decline in subsequent exercise power output. Impaired performance was proposed to be directly related to the intensity of the WUP protocol and the lack of recovery period, which not only inhibited PCr repletion and hence subsequent maximal power output, but also resulted in high lactate concentrations (Sargeant & Dolan, 1987). These results not only demonstrate the negative effects of a high WUP intensity but also support the need for an adequate recovery time between exercise performance and prior high intensity WUP. In support of this, De Bruyn-Prevost and Lefebvre (1980) reported impaired short-term maximal cycle performance that was immediately preceded by a 5 min WUP performed at 75% $\dot{V}O_{2max}$ in four male and five female physically active subjects. Conversely, the same authors assessed a lower intensity WUP (5 min at 30% $\dot{V}O_{2max}$) performed immediately prior to exercise and reported improved performance, further highlighting the impact of WUP intensity on performance.

While a WUP intensity that is too high can impair subsequent exercise performance, it would also appear that a WUP intensity that is too low (or too low overall when a variety of intensities and rest periods are used), is of little benefit to subsequent exercise performance. For example, a study by Pyke (1968) required subjects to perform a variety of exercises (sit ups, push ups, squats and dorsal raises) prior to a 60 yd dash and reported no benefit associated with this form of WUP. While this study did not use a constant paced, single mode exercise format for WUP, it could be speculated that the overall intensity of this general WUP protocol was too low to induce subsequent performance benefits. Another study by Gray and Nimmo (2001) compared the effects of a no WUP condition to an active WUP (5 min at 40% of maximal power followed by a 1 min rest and then 4 x 15 s sprints at 120% max power separated by 15 s rest) on a cycle test (120% maximal power) to exhaustion in eight healthy male subjects and reported no significant differences between the two conditions. These investigators suggested that the proposed benefits associated with active WUP may have been overridden by the duration of the exercise period (58

– 112 s). However, it is also possible that the overall WUP intensity was not high enough to induce temperature related performance benefits. Differences in the outcomes between this study and that by De Bruyn-Prevost and Lefebvre (1980) (described earlier), who reported subsequent exercise benefits associated with a WUP intensity of only 30% $\dot{V}O_{2max}$, may be due to variances in subject characteristics (i.e., number, gender, activity levels) and subsequent exercise protocols, as well as the inclusion (or lack of) of a recovery period.

When deciding on the most appropriate WUP intensity that would benefit subsequent exercise (or even the use of a WUP protocol at all), athletes should also consider the impact of a high T_{re} on subsequent performance. The negative association of a high T_{re} on subsequent submaximal (70% $\dot{V}O_{2max}$) and intermittent (30 s bouts of running at 90% $\dot{V}O_{2max}$ separated by 30 s static recovery) exercise performed until exhaustion is demonstrated in studies by Gregson et al. (2002a and 2002b). These investigators reported that an active WUP performed at 70% of $\dot{V}O_{2max}$ until the attainment of a T_{re} of 38ºC resulted in impaired prolonged subsequent performance, compared to a no WUP condition, and proposed that these results were due to the earlier development of a high internal body temperature, which resulted in reduced heat storing capacity.

Results from the studies described above demonstrate that a WUP performed at high intensity (i.e., AT or above) can impair subsequent exercise. This observation most likely relates to increased levels of blood lactate concentrations and lower pH that may interfere with metabolic processes, as well as the depletion of high energy substrates that do not recover in time to be available for subsequent high intensity performance. In addition, it is important that WUP intensity does not contribute to a decreased heat storage capacity that can consequently result in premature fatigue during subsequent prolonged exercise, particularly if exercise is performed in hot environmental conditions. Further, it would appear that a WUP intensity that is too low may not induce temperature or non-temperature related benefits associated with WUP on subsequent exercise performance.

A further consideration is the use of a % of $\dot{V}O_{2max}$ as a guide for WUP exercise intensity. A review by Bishop (2003b) proposed that a WUP intensity of approximately 70% $\dot{V}O_{2max}$ represented the optimal intensity for improving intermediate performance in moderately trained athletes. However, a WUP intensity of 70% of $\dot{V}O_{2max}$ is likely to be greater than AT in untrained subjects, but below the AT in well-trained subjects (Hawley, Williams, Hamlin & Walsh, 1989). Of issue is that a WUP intensity above AT can result in high-energy phosphate depletion, as well as increased metabolic acidosis, which in turn can impair subsequent performance (Bishop, 2003b; McKenna, Green, Shaw, & Meyer, 1987; Pyke, 1968). Importantly, it has been previously shown that heart rate and plasma lactate concentrations differed between subjects of different fitness levels when exercise was performed at the same individual percent of $\dot{V}O_{2max}$, but were similar during exercise performed at a percent of the AT (Baldwin, Snow, & Febbraio, 2000). This suggests that WUP intensity should be based around an individual's lactate thresholds rather than $\dot{V}O_{2max}$ in an effort to standardise the metabolic stress experienced by the athlete, particularly if a group of subjects are to be tested. To the author's knowledge, only one other published study to date has employed WUP intensities based on lactate accumulation, as opposed to % $\dot{V}O_{2max}$, in order to assess the impact of these intensities on subsequent performance (Bishop et al., 2001). Further studies are needed to determine the optimal WUP intensity that results in improved subsequent exercise performance.

2.7 WARM-UP AND SUBSEQUENT EXERCISE PERFORMANCE

The primary purpose of performing a WUP is to improve subsequent exercise performance. As described earlier, factors such as WUP intensity and duration, the recovery period between performance and WUP, as well as environmental conditions, all combine to affect the overall metabolic status of the individual. This in turn can impact subsequent exercise performance. Research to date has generally focused on the effects of WUP on short bursts of exercise, such as single sprint performance and/or prolonged continuous exercise, while there has been a paucity in the research on intermittent sprint performance.

2.7.1 Warm-up and Single Sprint and First Sprint of Intermittent Sprint Performance

Numerous studies have reported improved single sprint performance following a moderate intensity WUP, compared to a no WUP condition (Dolan et al., 1985; Grodjinovsky & Magel, 1979; McKenna, et al., 1987; Thompson, 1958). Therefore, it is surprising that active WUP, compared to no WUP, has not been found to benefit subsequent initial sprint performance when the first sprint formed part of an overall, prolonged intermittent-sprint performance (ISP) (Bishop & Claudius, 2004; Bishop & Maxwell, 2009). An explanation proposed in both studies was that the results for the first sprint of prolonged ISP (36 – 72 min) may have reflected the adoption of a pacing strategy (despite being told to sprint as fast as they could), used by athletes in an attempt to sustain a high power output during the prolonged ISP. Pacing, in this context, is defined as the conscious or subconscious regulation of work and power output in order to maximise performance (Abbiss & Laursen, 2008). It has previously been proposed that a subconscious "controller" determines the overall pacing strategy during exercise by matching the rate of energy expenditure and the current energy reserves with the predicted energy cost of the exercise (Ulmer, 1996). Furthermore, this ‘controller’ takes into consideration the duration of the planned effort and calculates the pacing strategy on the basis of previous experience (Abbiss & Laursen, 2008; Lambert, Gibson & Noakes, 2005). Thus, the use of a pacing strategy may prevent the full benefits of an active WUP on initial sprint performance to be realised when the first sprint forms part of an overall prolonged ISP. This is an intriguing hypothesis that could be tested by assessing the effects of WUP on both single and ISP. Furthermore, the measurement of surface muscle EMG of the major active muscle groups could assist in determining whether any differences in exercise performance could be attributed to changes in muscle recruitment. This form of assessment may provide important information regarding the use of pacing strategies, in that EMG quantifies the electrical manifestation of the neuromuscular activation associated with a contracting muscle and is commonly used as a global indicator of muscle fibre excitation and recruitment (Farina, Merletti, & Enoka, 2004).

2.7.2 Warm-Up and Prolonged Intermittent Sprint Performance

While the majority of studies have reported improvement in prolonged, continuous exercise performance following a moderate intensity WUP, compared to a no WUP condition (Atkinson, Todd, Reilly, & Waterhouse, 2005; Grodjinovsky & Magel, 1970; Thompson, 1958), only a few studies have assessed the impact of WUP on ISP (Bishop & Claudius, 2004; Bishop & Maxwell, 2009; Drust et al., 2005; Mohr, Krustrup, Nybo, Nielsen & Bangsbo, 2004; Morris et al., 1998; Morris et al., 2000). This lack of research is surprising as intermittent sprinting represent an important component of many team sports, with team sports representing a popular pastime in many countries, as well as having the highest participation levels (i.e. soccer, rugby, field-hockey, basketball, etc.). Of relevance, team sports typically require athletes to perform intermittent, short-duration sprints throughout an extended period of competition (80-90 min), with this important exercise component being termed intermittent or repeated-sprint ability (Dawson, Fitzsimmons, & Ward, 1993). Intermittent sprint ability has also been referred to as ISP throughout this review, with both terms being interchangeable.

Many studies that have assessed the effects of WUP on ISP (Ball, Burrows, & Sargeant, 1999; Drust et al., 2005; Mohr, Rasmussen, Drust, Nielsen & Nybo, 2006), used ISP protocols, i.e., sprint duration and recovery times, that were not reflective of what typically occurs in a team-sport game. For example, time-motion analysis of elite field hockey players by Spencer et al. (2004) reported a frequency of 20 – 60 sprints during field-based team games of 70 - 90 min duration. Further, the average maximal sprint duration was reported as 4.1 ± 2.1 s, with recovery time between sprints being longer than 60 s for over 50% of the time, while 30% of recovery periods were longer than 121 s (Spencer et al., 2004). In contrast, a study by Drust et al. (2005) employed an ISP protocol consisting of 15 s sprints with 15 s of recovery in between. The assessment of WUP on different sprint and recovery durations to those used in team games is pertinent, as varying sprint durations and recovery periods will result in different percentages of energy utilisation from the three different energy systems (aerobic, glycolysis and phosphocreatine), which in turn can be impacted by the WUP protocol employed. For example, exercise performance that consists of 5 x 6 s sprints with 30 s of recovery in between bouts will result in greater reliance on anaerobic energy systems and may not receive the same benefits associated with enhanced oxygen kinetics (as a result of a prior active WUP), compared to longer subsequent (i.e. 60 s) sprints that place greater reliance on aerobic metabolism.

To date, only two studies known to the author have assessed the impact of WUP on ISP, where the sprints and the duration of the performance were similar to that performed in a team sport game. One study employed an ISP protocol that was equivalent to only 'half' a team game (36 min; Bishop & Maxell, 2009), while the second study used an ISP protocol that equated to an entire match (i.e., ~ 80 - 90 min; Bishop & Claudius, 2004). While both studies have been described in detail previously in this review, briefly, Bishop and Maxwell (2009) reported no benefit associated with active WUP (10 and 20 min duration), compared to no WUP on 36 min of ISP undertaken in hot and humid conditions (35.5 ± 0.6ºC, 48.7 ± 3.4% RH). Moreover, Bishop and Claudius (2004) reported no benefit associated with an active WUP, compared to no WUP, on subsequent ISP that equated to a full team-sport game duration (80 min. Importantly, WUP intensities used in both studies were not based around the subject's lactate thresholds and may have been inappropriate to benefit subsequent ISP. Consequently, further investigation into this area is warranted in order to provide further insight into the effects of WUP intensities, based on lactate thresholds, on intermittent sprints and recovery periods that simulate those used in team-sport games.

2.8 WARM-UP & SUBSEQUENT EXERCISE PERFORMED IN HOT ENVIRONMENTAL CONDITIONS

Exercise undertaken in hot environmental conditions provides an extra challenge to athletes attempting to achieve optimal performance. As described earlier in this review, WUP increases T_b, which when combined with hot environmental conditions and/or prolonged exercise can raise T_{re}, thus reducing the body's heat storage capacity, which in turn can lead to premature fatigue.

This process has been demonstrated in studies that reported premature fatigue during exercise in hot environments in the presence of adequate muscle glycogen stores (Febbraio, 1999) or without the accumulation of metabolic waste products (Drust et al., 2005; Gonzalez-Alonso et al., 1999; Morris et al., 2000; Nybo & Nielsen, 2001). Consequently, the added effect of WUP (either active or passive) on T_{re} during hot environmental conditions is an important consideration due to the increased thermoregulatory strain that WUP induces.

While a number of studies have investigated the effects of an elevated T_b on prolonged continuous exercise performance (Gonzalez-Alonso et al., 1999; Nielsen et al., 1993; Saltin, Gagge, Beigh & Stolwijk, 1972), there is little information regarding the effects of heat on prolonged ISP. Prior research has reported impaired (Drust et al., 2005), unchanged (Backx, McNaughton, Crickmore, Palmer, & Carlisle, 2000) or improved (Ball et al., 1999) ISP as a result of heat exposure. However, in the three studies described above, the duration of the sprints (15 – 30 s), as well as the recovery periods (15 s – 240 s) and the number of sprints performed (< 6), were different to that encountered in a team-sport game (Spencer et al., 2004).

To date, only three studies have investigated the effects of elevated T_b on prolonged ISP that consisted of bursts of all-out, short-duration (< 10 s) sprinting (similar to team sports) that was preceded by an active WUP (Morris et al., 1998; Morris et al., 2000; Bishop & Maxwell, 2009). Studies by Morris et al. (1998) and Morris et al. (2000) reported a significant decrease in prolonged ISP in hot (~ 30 ºC) compared to moderate (~ 17 ºC) conditions following a 15 min WUP that consisted of jogging, stretching and faster pace running. However, closer analysis of the data in this study revealed that the major performance differences between environmental conditions occurred in ‘part B’ of the performance test, which required subjects to alternate 60 s of running (at $\dot{V}O_{2peak}$ pace) with 60 s of rest until fatigued, with this protocol representing a very different activity pattern to that performed in team-game sports. In the third study, Bishop and Maxwell (2009) reported no significant detriment in ISP after a 10 min WUP in temperate conditions that significantly raised T_{re}. Rectal temperatures in this study was recorded as 37.3 ± 0.3ºC following 10 min of WUP compared to 37.0 ± 0.3ºC for the no WUP condition, with these values increasing to 38.7ºC and 38.3ºC, respectively, by the end of the ISP. Importantly, the research protocol used by Bishop and Maxwell (2009) only involved ISP that lasted for ‘half’ of a simulated team-sport game (i.e., 36 min). Further, T_{re} did not reach a critical level (~40ºC), which has previously been proposed to be the main limiting factor for prolonged continuous performance in hot environments (Cheung et al.,1998; Nielsen et al.,1993; Gonzalez-Alonso & Coyle, 2001). In addition, none of these three studies used WUP intensities based on individual lactate thresholds. Further research is required to investigate the effects of WUP (based on lactate thresholds) on prolonged ISP approximating the duration of a full team sport game (i.e., ~90 min), performed in hot, humid conditions (typical of those experienced by team-sport athletes in the summer months). Of further interest would be the assessment of a passive WUP compared to an active WUP in order to determine the role of temperature and non-temperature related mechanisms associated with WUP, on subsequent prolonged ISP performed in hot and humid conditions.

2.9 CONCLUSION

The preceding review has raised many questions regarding the effect of WUP (passive or active) on subsequent exercise performance. Results from previous studies suggest that the intensity and duration of WUP needs to be able to induce temperature and non-temperature related benefits, but not be too high or too long as to result in high hydrogen ion concentration (plasma and muscle), depleted anaerobic energy stores, or a high T_{re} that compromises heat storage capacity that can then impair subsequent exercise performance. In addition, the majority of previous studies used WUP intensities based on % $\dot{V}O_{2max}$ rather than on individual lactate thresholds. This is an important consideration, as LT is different in trained and untrained people, with further variability occurring within both these populations.

Another important question regarding WUP relates to which mechanism, namely T_b, T_{mu} or T_c, represents the best indicator for temperature related benefits associated with WUP. Further, there has been no research to date regarding the effect of WUP (based on lactate thresholds) on ISP that equates to a full team sport game (~80 min), as well as on the initial sprint performance of this prolonged ISP protocol. Finally, there have been no studies to date that have assessed the effect of passive and active WUP (where active WUP was based on lactate thresholds) on ISP, where the sprint and recovery pattern used and the duration employed simulated those of a full team-sport game performed in hot compared to cool environmental conditions. Results from studies that attempt to address these questions and short-comings in the literature could provide athletes and coaches with important information regarding the impact of temperature and non-temperature related benefits associated with WUP on subsequent ISP undertaken in different environmental conditions. Therefore, this PhD project aims to examine the issues noted above, with the specific aims and hypotheses associated with each study described in the introduction.

CHAPTER 3

3.0 STUDY ONE

3.1 TITLE: Effects of warm-up intensity on intermittent sprint performance and selected thermoregulatroy parameters.

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3.2 ABSTRACT

Background: This study aimed to investigate the effect of various warm-up (WUP) intensities that were based around individual lactate thresholds on subsequent intermittent sprint performance, as well as to determine which temperature (muscle; T_{mu}, rectal; T_{re} or body; T_b) best correlated with performance (total work, work and power output of the first sprint and % work decrement). **Methods**: Nine male team-sport subjects performed five 10 min WUP protocols consisting of different exercise intensities on five separate occasions, separated by a week, in a random counter-balanced order. Each WUP protocol was followed by 2 min of passive rest and a 6 x 4 s intermittent sprint test performed on a cycle ergometer with 21 s of recovery between sprints. T_b, T_{mu} and T_{re} were monitored throughout the test. **Results**: There were no significant differences ($P > 0.05$) between any of the WUP conditions for any performance variable assessed. However, moderate to large effect sizes (> 0.5; Cohen's *d*) suggested a tendency for improvement following a WUP performed at an intensity midway between lactate inflection and lactate threshold for every performance variable assessed. While T_{mu}, T_r , T_b heart rate, ratings of perceived exertion and blood lactate increased significantly during the exercise protocol ($p < 0.05$), these changes did not affect intermittent sprint performance between WUP conditions. Further, there were no significant correlations between T_{mu}, T_r, and T_b assessed immediately after each WUP condition for any of the performance measures. **Conclusions**: A WUP performed at an intensity midway between lactate inflection and lactate threshold may elicit optimal performance during an intermittent sprint test. Significant increases in T_{mu}, T_{re} and T_b during the intermittent sprint test did not affect performance between WUP conditions.

Keywords: muscle temperature, rectal temperature, lactate threshold, lactate inflection

3.3 INTRODUCTION

Active warm-up (WUP) is a well-accepted practice and considered by many athletes and coaches to be an essential part of any training session or as a precursor to competition. There are many proposed benefits of WUP, these being either physiological or psychological (Bishop, 2003; Karvonen, Lemon, & Iliev, 1992). Physiologically, the main benefits of WUP have been attributed to an increase in muscle temperature (T_{mu}), rectal temperature (T_{re}) and body temperature (T_b) achieved as a result of active movements of the major working muscle groups (Asmussen & Boje, 1945; Nielsen & Nielsen, 1962; Saltin, Gagge, & Stolwijk, 1968; Shellock & Prentice, 1985). An increase in temperature, as a result of WUP, is proposed to improve performance via decreased muscle and joint viscous resistance (Asmussen & Boje, 1945), greater unloading of oxygen from haemoglobin and myoglobin (Barcroft & King, 1909; McCutcheon, Geor, & Hinchcliff, 1999), the speeding of oxygen kinetics (Koga, Shiojiri, & Kondo, 1997), increased anaerobic metabolism (Febbraio, Carey, & Snow, 1996; Fink, Costill, & Van Handel, 1975), as well as an increase in nerve conduction rates (Karvonen et al., 1992; Stewart, Macaluso, & De Vito, 2003). An active WUP has also been proposed to impart non-temperature related benefits on subsequent exercise performance, such as: increased blood flow and oxygen delivery to the working muscles (Bishop, 2003; McComas, 1996); elevation of baseline oxygen consumption (McCutcheon,et al., 1999); post-activation potentiation (Vandervoort, Quinlan, & McComas, 1983); and reduced muscle stiffness (Proske, Morgan, & Gregory, 1993).

While many researchers have reported improved performance following an active WUP (Asmussen & Boje, 1945; Bishop, Bonetti, & Dawson, 2001; Grodjinovsky & Magel, 1970;

McCutcheon et al., 1999; Sargeant & Dolan, 1987; Stewart & Sleivert, 1998), some researchers have found no beneficial effect of an intensity-specific WUP on performance compared to no WUP (Bruyn-Prevost & Lefebvre, 1980; Gray & Nimmo, 2001; Mitchell & Huston, 1993; Stewart & Sleivert, 1998). Lack of consensus regarding the effects of WUP on performance may be due to the use of different exercise protocols, the lack of well-controlled studies, and also to the recruitment of small cohorts (Bishop, 2003). In addition, conflicting results may be due to the use of $\dot{V}O_{2max}$ to determine WUP intensity. For example, a WUP intensity of 70% of $\dot{V}O_{2max}$ is likely to be greater than the lactate threshold (LT: also known as anaerobic threshold) in untrained subjects, but below the LT in well-trained subjects (Wilmore & Costill, 1994). Furthermore, if the WUP intensity is greater than the LT, it can result in high-energy phosphate depletion, as well as an increase in lactate accumulation, which in turn may impair subsequent exercise performance (Bishop et al., 2001; Kozlowski et al., 1985; Sargeant & Dolan, 1987). This suggests that the optimal WUP intensity should raise body temperature, while at the same time avoid too great an increase in lactate accumulation or the depletion of high energy substrates.

Additionally, while a number of studies have investigated the effect of WUP intensity on single sprint performance (Bishop et al., 2001; Sargeant & Dolan, 1987; Stewart & Sleivert, 1998), there is no published research, to the author's knowledge, describing the effects of WUP on intermittent sprint ability, where the WUP intensity was based on lactate thresholds. This lack of research is surprising, as in most countries the most popular sports, and those with the highest participation levels, are team sports (i.e. soccer, rugby, hockey, basketball), which require athletes to sprint intermittently throughout the match.

Therefore the aim of this study was to investigate the impact of varying WUP intensities on intermittent sprint ability in order to determine which intensity resulted in better exercise performance (i.e. total work, work and power output for the first sprint and % work decrement). This current study used WUP intensities based around an individual's LT, rather than percentages of $\dot{V}O_{2max}$, as this proposed method ensures that all subjects have similar changes in blood lactate concentration following the different WUP conditions. A second aim of this study was to also investigated whether the temperature (T_{mu}, T_b or T_{re}) induced by the various WUP strategies was correlated with performance. It was hypothesised that a WUP intensity that was performed mid-way between LI and LT would result in better intermittent sprint performance, as this intensity should produce an increase in temperature while at the same time avoid a large increase in lactate concentration or a large decrease in phosphocreatine stores.

3.4 METHODS

3.4.1 Subjects

Nine male subjects (mean ± SD age: 26.1 ± 4.4 y, body mass: 86.9 ± 11.4 kg, $\dot{V}O_{2max}$: 49.6 ± 6.1 $mL \cdot kg^{-1} \cdot min^{-1}$) were recruited from The University of Western Australia Rugby Football Club and from the School of Sport Science, Exercise and Health. All subjects were currently-competing, team-sport athletes and were moderately well trained (7.6 ± 2.7 $h \cdot wk^{-1}$). Subjects were informed of the study requirements, benefits and risks before giving written informed consent. The Research Ethics committee of the University of Western Australia granted approval for the study's procedures.

3.4.2 Experimental Overview

Subjects were required to complete three preliminary sessions and five experimental trials over a seven-week period. During the first preliminary visit, subjects performed a familiarisation session of both the graded exercise test (GXT) and the intermittent sprint test. During this visit, height was determined (to the nearest 0.1 cm) using a stadiometer, while body mass was measured (to the nearest 0.01 kg) using Sauter scales (model ED3300, Ebingen, West Germany). The GXT was then performed on the second preliminary visit in order to determine the subject's LT and $\dot{V}O_{2max}$. On the third preliminary visit, subjects performed a second familiarisation of the intermittent sprint test. Subjects then performed each of the five experimental trials over a five week period. Subjects were asked to maintain their normal diet and training throughout the study and were required to consume no food or beverages (other than water) during the 2 h period prior to testing. Subjects were requested to keep a diary of their food and drink intake during the 48 hr period prior to exercise and to replicate this intake prior to each exercise trial. This diary was checked by the researchers to ensure conformity. Additionally, subjects were asked not to consume alcohol or to perform vigorous exercise in the 24 h prior to testing.

All exercise tests were performed on a calibrated, front-access cycle ergometer (Model EX-10, Repco, Australia) that had been modified using a shield cover over the back wheel so to prevent the subject being cooled by the flywheel. This ergometer was interfaced with an IBM-compatible computer system to allow for collection of data for the calculation of work and power generated during each flywheel revolution (Cyclemax, The University of Western Australia, Perth, Australia). This ergometer required subjects to pedal against an air resistance caused by rectangular vanes attached perpendicular to the axis of rotation of the flywheel. The power output of the air-braked cycle ergometer is proportional to the cube of the flywheel velocity. An optical sensor monitored the velocity of the flywheel at a sampling rate of 80 pulses per pedal revolution. Before testing, the ergometer was dynamically calibrated on a mechanical rig (Western Australia Institute of Sport, Perth, Australia) across a range of power outputs (100-2000 W).

3.4.3 Graded Exercise Test (GXT)

The GXT, a multi-stage discontinuous test, consisted of graded exercise steps (3 min stages), using an intermittent protocol (1 min rest between stages) performed on the same cycle ergometer described earlier. The test commenced at 70 W and thereafter, intensity was increased by 30 W every 3 min. Subjects were required to maintain the set power output, which was displayed on a computer screen in front of them, with the test being terminated when the subject could no longer maintain the required power output (volitional exhaustion). Strong verbal encouragement was provided to each subject during the latter stages of the test. Both LT and $\dot{V}O_{2max}$ were determined from data collected during the GXT. Lactate threshold was calculated using the modified Dmax method (Bishop, Jenkins, & Mackinnon, 1998). This is determined by the point on the polynomial regression curve that yields the maximal perpendicular distance to the straight line connecting the first increase in lactate concentration above the resting level (LI) (Yoshida, Chida, Ichioka, & Suda, 1987) and the final lactate point.

3.4.4 Gas Analysis

During the GXT, expired air was continuously analysed for O_2 and CO_2 concentrations using Ametek gas analysers (Applied Electrochemistry, SOV S-3 A/1 and COV CD-3A, Pittsburgh, PA), while ventilation was recorded every 15 s using a turbine ventilometer (Morgan, 225A, Kent, England). The gas analysers were calibrated immediately before and verified after each test using three certified gravimetric gas mixtures (BOC Gases, Chatswood, Australia), while the ventilometer was calibrated pre-exercise and verified post-exercise using a one-litre syringe in accordance with the manufacturer's instructions. The ventilometer and gas analysers were connected to an IBM personal computer that measured and displayed variables every 15 s. The sum of the four highest consecutive 15 s $\dot{V}O_2$ values was recorded as the subject's $\dot{V}O_{2max}$.

3.4.5 Experimental Trials

The five experimental trials were conducted at the same time of day, approximately a week apart in a randomised counter-balanced order. The WUP intensities were either:

1) WUP 1 - half the difference between LT and LI, [(LT-LI)/2] below LI level
2) WUP 2 - at LI level
3) WUP 3 - midway between LI and LT level
4) WUP 4 - LT level
5) WUP 5 - half the difference between LT and LI, [(LT-LI)/2] above LT level

An example of the selected WUP intensities used is shown in Figure 3.1. This range of intensities was chosen in order to determine the effects of various levels of blood lactate on subsequent intermittent sprint performance. Warm-up 1 represented a very low intensity WUP that would produce minimal blood lactate levels, while WUP 5 represented a very high intensity WUP that would produce high levels of blood lactate level, with various intensities selected between these two points. It was thought that the analysis of this range of WUP intensities would provide information on how metabolic acidosis affected subsequent exercise performance. Furthermore, a control group was not included as it was thought that an extra laboratory visit would deter subjects from participating in the study.

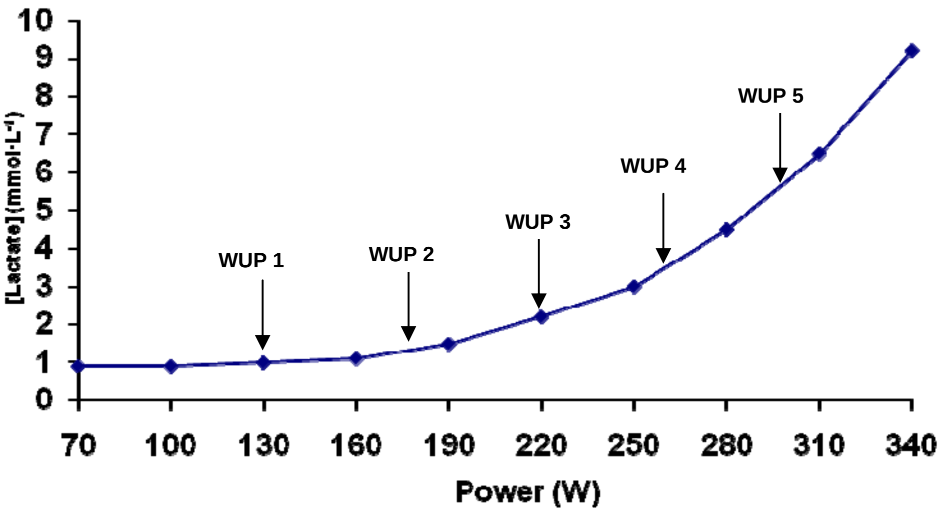

Figure 3.1. An example of warm-up intensity levels used in this study based on a subject's lactate accumulation (LI = lactate infliction, LT = lactate threshold). WUP 1 = LI - [(LT-LI)/2)]; WUP 2 = LI; WUP 3 = LI + [(LT-LI)/2)]; WUP 4 = LT); WUP 5 = LT + [(LT-LI)/2)].

3.4.6 Intermittent Sprint Test

The intermittent sprint test involved 6 x 4 s sprints separated by 21 s of active recovery performed at an intensity that equated to WUP 1 (Figure 2). While this test was performed on a cycle ergometer due to ease in assessing power and work, a strong correlation has been reported between intermittent sprint cycling and running performance (Bishop, Spencer, Duffield, & Lawrence, 2001). Further, this cycle sprint test has previously been used in studies by Bishop and Maxwell (2009), Bishop and Claudius (2004) and Schneiker, Bishop and Dawson (2006) in order to simulate intermittent sprints performed during a team-sport game. Subjects were requested to sprint as fast as they could during each sprint. An active recovery was chosen as it has previously been reported that 95% of the recovery periods during intermittent sprint bouts in field hockey were active (Spencer et al., 2004). Total work for the six sprints, work done and power output for the first sprint, and % work decrement were calculated. Percent work decrement was determined using the method described by Fitzsimons, Dawson, Ward, & Wilkinson, (1993), i.e. 100-[(total time/ [best time x 6]) x 100]. Subjects completed a 10 min WUP and then passively rested for 2 min prior to the beginning of the intermittent sprint trial (Figure 3.2). Heart rate (HR: Polar Electro Oy, Kempele, Finland) and ratings of perceived exertion (RPE) based upon the Borg (1982) scale (6-20) were assessed pre-WUP, immediately post-WUP, pre bout and post bout.

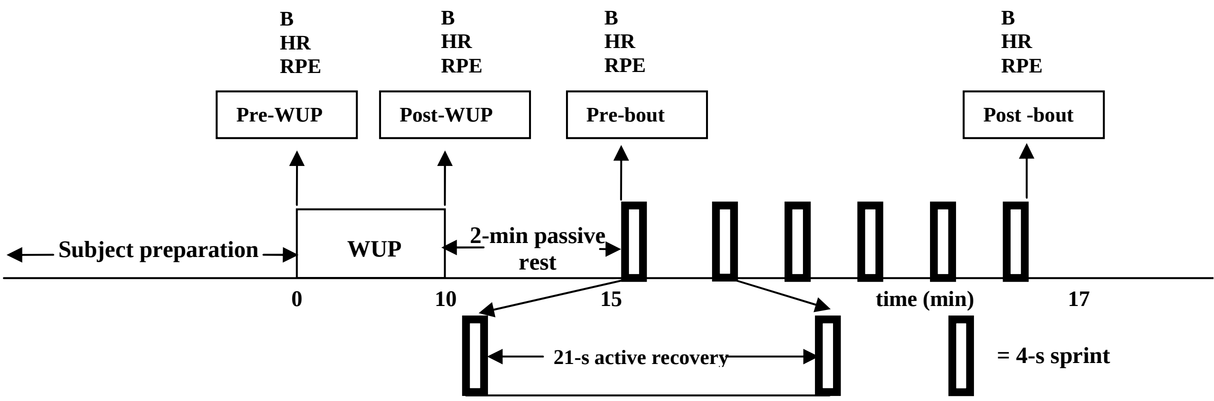

Figure 3.2. Schematic of the intermittent sprint test. Six x 4 s sprints separated by 21 s of active recovery (performed at WUP 1 intensity). B = Blood sample (lactate concentration), WUP = warm-up, RPE = rating of perceived exertion, HR = heart rate. Rectal temperature (T_{re}) and muscle temperature (T_{mu}) were measured continuously throughout the experimental trials.

3.4.7 Capillary Blood Sampling and Analysis

A hyperaemic ointment (Finalgon, Boeringer Ingelheim, Germany) was applied to the earlobe 5-7 min prior to the initial blood sampling. Glass capillary tubes were used to collect 35 µL of blood during the GXT (D957G-70-35, Clinitubes, Radiometer Copenhagen) and 2 x 125 µL of blood during the intermittent sprint test (D957G-70-125, Clinitubes, Radiometer Copenhagen). Capillary blood samples were taken at rest and immediately following each 3 min stage of the GXT, as well as at rest and throughout the experimental trials (Figure 3.2). Plasma lactate concentrations were determined using a blood-gas analyser (ABL625, Radiometer, Copenhagen). The blood-gas analyser was regularly calibrated using precision standards and routinely assessed by external quality controls.

3.4.8 Temperature Measurements

Rectal temperature (T_{re}) was measured using a thermistor (Model RET-1, Physitemp Instruments Inc., Clifton, NJ, USA) from a site 10 cm beyond the external anal sphincter. Skin thermistors (Model SST-2, Physitemp Instruments Inc., Clifton, NJ, USA) were attached to four sites: 1) the upper chest on the sternum, just below the sternal notch; 2) left mid forearm - midway between the elbow and wrist joint on the anterior surface with the subject in the anatomical position; 3) left upper thigh – next to the insertion point of muscle temperature electrode (see below); and 4) left calf – posterior surface, midway between the parallel lines drawn through the junction of the femur and the tibia and the inferior border of the medial malleolus. Mean skin temperature (T_{sk}) was calculated using the formula $T_{sk} = 0.3 \cdot (T_1+T_2) + 0.2 \cdot (T_3+T_4)$, where T_1 is chest, T_2 is upper arm, T_3 is thigh and T_4 is calf temperature (Burton, 1934). Mean body temperature (T_b) was calculated as $0.87 \cdot T_{re} + 0.13 \cdot T_{sk}$ (Lee & Haymes, 1995).

One hour prior to arriving at the laboratory, subjects were asked to apply a topical anaesthetic (Emla, Astra Zeneca, North Ryde, Australia) onto a 2 cm^2 area of the thigh that covered the site where T_{mu} would be recorded. A dressing was then affixed directly over the cream. T_{mu} was monitored via a needle thermistor probe (Model T-204A, Physitemp Instruments Inc., Clifton, NJ, USA) inserted 4 cm into an anaesthetised area of the vastus lateralis, half-way between the anterior superior iliac spine and the superior border of the patella. This technique involved a sterile needle piercing the skin to introduce the sterile probe. The needle was then removed, leaving the flexible probe in the muscle. The probe was then covered and securely fixed to the subject's thigh to allow for movement and continual measurement of T_{mu}. Temperature measurements were taken to the nearest 0.1^{o}C from all thermistor sites.

3.4.9 Data Analyses

All values are reported as mean ± SD. Differences in performance between conditions, including total work ($J \cdot kg^{-1}$), power output ($W \cdot kg^{-1}$) and work of the first sprint, and % work decrement were analysed using a one-way ANOVA with repeated measures for condition (one group x five conditions). Blood lactate concentrations, HR, ratings of perceived exertion (RPE: Borg Scale: Borg, 1982), T_{mu}, T_{re} and T_b were analysed using a two-way ANOVA with repeated measures for condition (four measurements x five conditions). Peak power output and work for each of the six sprints were analysed using a two-way ANOVA with repeated measures for conditions (six sprints x five conditions). A Newman Keuls post-hoc test was applied whenever significance was found. Statistical significance was accepted at the level of $P \leq 0.05$. In addition, performance variables were compared between WUP intensities using Cohen's *d* effect sizes

(ES) and thresholds (< 0.5, small; 0.5-0.79 = moderate; > 0.8, strong; Cohen, 1969). Only effect sizes ≥ 0.5 are reported. Further, Pearson correlation coefficients were used in order to assess the relationship between T_{re}, T_{mu}, T_b, assessed immediately after each WUP, and performance variables (i.e., total work, first sprint work, first sprint power output and % work decrement). All statistical analyses were conducted using the SigmaStat statistical package (Version 3.1, SigmaStat, Richmond, California, USA).

3.5 RESULTS

3.5.1 Performance

There were no statistical differences between each WUP condition for total work ($J \cdot kg^{-1}$; P = 0.442), first sprint work ($J \cdot kg^{-1}$; P = 0.769), power output of the first sprint ($W \cdot kg^{-1}$; P = 0.189), or % work decrement (P = 0.136), respectively (Table 3.1). However, moderate to large effect sizes were evident between various WUP intensities for total work (WUP 2 vs 3, *d* = -0.6; WUP 3 vs 5, *d* = 0.5; WUP 4 vs 5, *d* = 0.5), first sprint work (WUP 1 vs 3, *d* = -0.5), power output of the first sprint (WUP 3 vs 5, *d* = 0.7; WUP 4 vs 5, *d*= 0.6) and % work decrement (WUP 1 vs 3, *d* = 0.8; WUP 1 vs 4, *d* = 0.7; WUP 1 vs 5, *d* = 0.5; WUP 2 vs 3, *d* = 1.0; WUP 2 vs 4, *d* = 0.9; WUP 2 vs 5, *d* = 0.7; WUP 3 vs 5, *d* = -0.6).

Table 3.1. Total work (W_{tot}), first sprint work (W_{1st}), power output of first sprint (P_{1st}) and % work decrement (W_{dec}) recorded during a 6 x 4 s intermittent sprint test (mean ± SD).

	W_{tot} (J·kg^{-1})	W_{1st} (J·kg^{-1})	P_{1st} (W·kg^{-1})	W_{dec} (%)
WUP 1	261.1 ± 38.3	44.9 ± 6.3	15.9 ± 2.1	10.6 ± 5.3
WUP 2	257.5 ± 26.0	46.3 ± 4.9	16.0 ± 1.7	10.7 ± 3.9
WUP 3	272.4 ± 22.6	47.5 ± 5.5	16.6 ± 1.5	6.5 ± 4.2
WUP 4	258.8 ± 38.9	47.0 ± 8.6	16.6 ± 1.5	7.7 ± 2.8
WUP 5	260.8 ± 28.9	45.1 ± 5.1	15.6 ± 1.7	8.6 ± 1.8

3.5.2 Peak Power of Each Sprint

There was a statistically significant difference ($P < 0.001$) in peak power values between the different sprint repetitions. Peak power was significantly lower in sprints 2 to 6 compared with sprint 1 ($P < 0.001$), sprints 3 to 6 compared with sprint 2 ($P < 0.001$) and in sprints 5 and 6 compared with sprints 1, 2 and 3, respectively ($P < 0.001$). Further, there was no significant difference ($P > 0.05$) in peak power among WUP conditions (Figure 3.3).

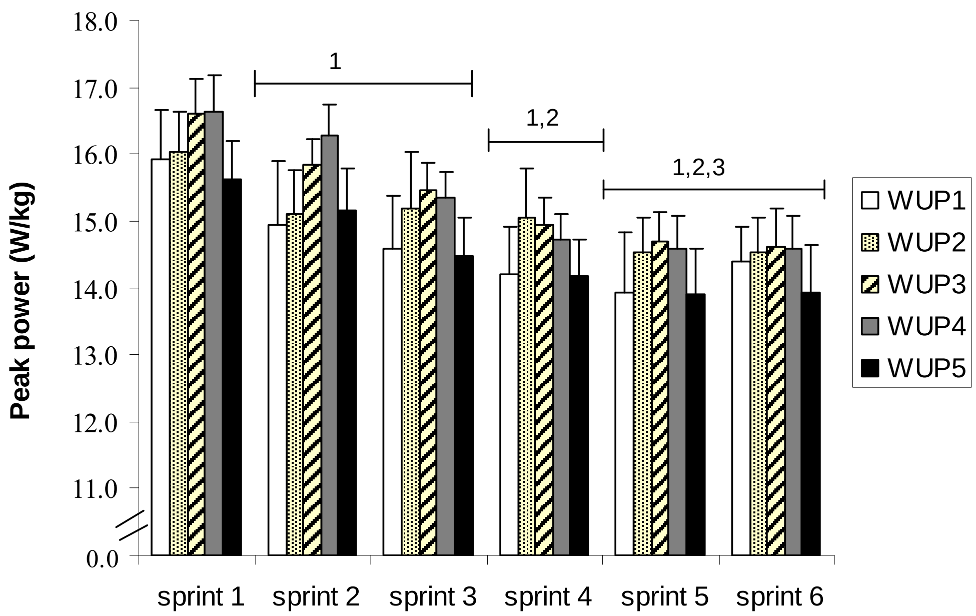

Figure 3.3. Mean peak power output of each sprint during the repeated-sprint test for the five WUP conditions. Values are mean ± SD (N = 9). 1, 2, 3 = significantly different from sprint 1, 2 and 3, respectively ($P < 0.05$).

3.5.3 Work of Each Sprint

There was a statistically significant difference (increase: $P < 0.05$) in the work done in the first sprint and that performed in sprints 2, 4, 5 and 6, following each WUP condition. No significant differences were observed for work done for each sprint among WUP conditions ($P > 0.05$; Figure 3.4).

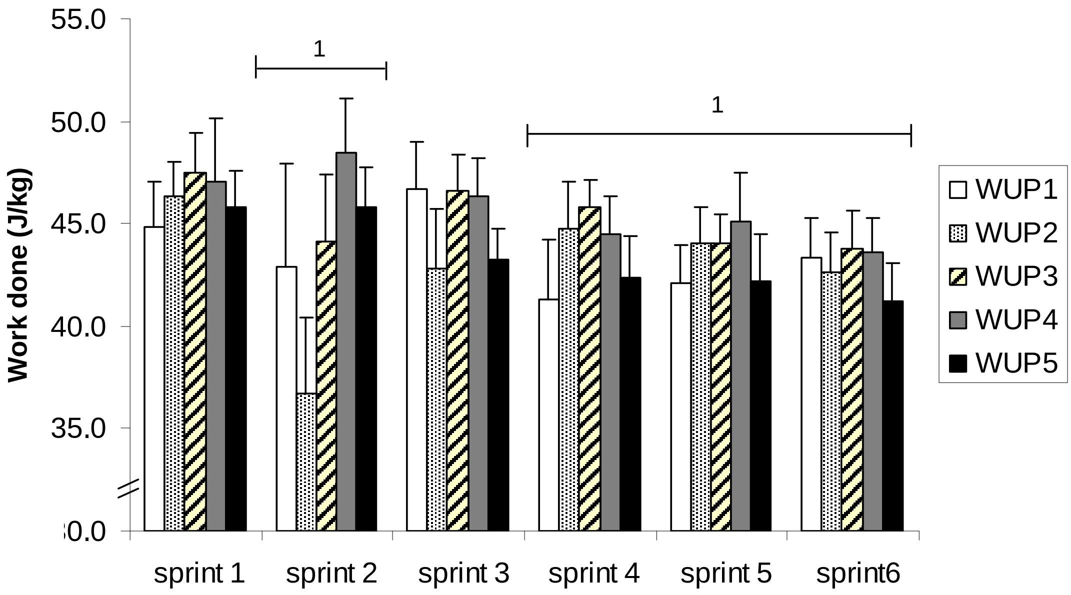

Figure 3.4. Mean work done for each sprint during the intermittent sprint test for the five WUP conditions. Values are mean ± SD (N = 9). 1 = Significantly different from sprint 1 ($P < 0.05$).

3.5.4. Blood Lactate Concentration

No significant differences were observed in blood lactate concentrations during the pre-WUP period for any of the WUP conditions ($P > 0.05$; Figure 3). At post-WUP, as well as at pre-bout, blood lactate concentrations were significantly higher after WUP 5 compared to all other conditions, while blood lactate levels were also significantly higher after WUP 4 compared to WUP's 1, 2, and 3 ($P < 0.05$). Finally, at post-bout, WUP 5 again resulted in significantly higher blood lactate concentrations compared to all other conditions ($P < 0.05$).

Changes in blood lactate concentrations over time were significantly higher ($P < 0.05$) post-WUP compared to pre-WUP after WUP's 3, 4, and 5. There were also significant increases in blood lactate concentrations at pre-bout compared to pre-WUP after WUP's 4 and 5 ($p < 0.05$). Further, all WUP conditions resulted in significantly higher blood lactate concentrations post-bout compared to pre-WUP. Finally, blood lactate concentrations increased significantly between post WUP and post-bout and pre-bout and post-bout for all conditions except for WUP 5 ($P < 0.05$) (Figure 3.5a).

3.5.5 Heart Rate (HR)

Heart rate measured prior to WUP was not significantly different between WUP conditions ($P > 0.05$). Heart rate increased significantly post-WUP compared with pre-WUP for every WUP condition ($P < 0.05$), except for WUP 1 ($P > 0.05$). At post WUP, there were significant differences in HR between every WUP condition ($P < 0.05$), i.e., the higher the WUP intensity, the higher the HR. After the 5-min rest period, HR decreased significantly for each WUP condition compared with post-WUP values ($P < 0.05$). Following the intermittent sprint test (post-bout), HR values for all WUP conditions were significantly higher compared with pre-bout values ($P < 0.01$), with significant differences resulting between WUP 5 and WUP's 1 and 3 (Figure 3.5b).

3.5.6 Rating of Perceived Exertion (RPE)

At rest (pre-WUP), there were no significant differences in RPE between any of the WUP conditions ($P > 0.05$). However, there were significant increases in RPE for all WUP conditions after 10 min of WUP compared with pre-WUP values ($P < 0.05$). After the 5 min rest period (pre-bout), RPE was significantly lower than post-WUP for all WUP conditions ($P < 0.001$) except for WUP 1 ($P > 0.05$). Following the intermittent sprint test (post-bout), RPE values for all WUP conditions were significantly higher than pre-bout values ($P<0.001$), with significant differences resulting between WUP 5 compared with WUP's 1, 2 and 3 (Figure 3.5c).

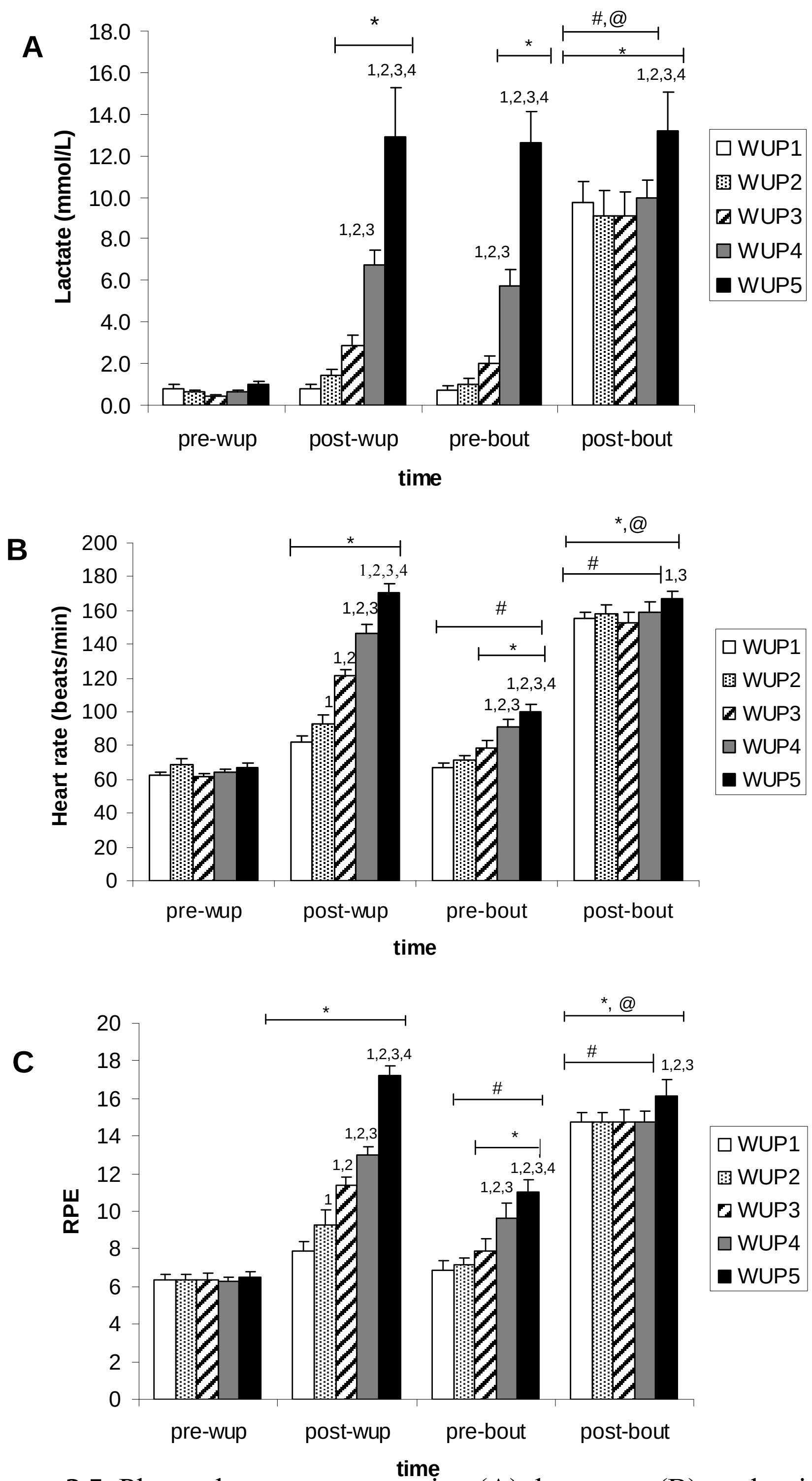

Figure 3.5. Plasma lactate concentration (A), heart rate (B), and rating of perceived exertion (RPE) values (C) for each WUP intensity during the experiment. * = significantly different from

pre-WUP ($P < 0.05$), # = significantly different from post-WUP, @ = significantly different ($P < 0.05$) from before intermittent sprint performance (pre-bout), 1 (2, 3, 4, 5) = significantly different ($P < 0.05$) from WUP 1 (2, 3, 4, 5).

3.5.7 Muscle Temperature (T_{mu})

No significant differences were found between WUP conditions for T_{mu} at pre-WUP ($P > 0.05$; Table 3.2). However, at post-WUP, T_{mu} for WUP's 2, 3, 4, and 5 was significantly higher than T_{mu} for WUP 1, while T_{mu} for WUP 5 was also significantly higher than those recorded for WUP's 2, 3, and 4. Further, T_{mu} recorded at pre-bout was significantly higher in WUP's 2, 3, 4, and 5 compared to WUP 1, whilst values for WUP 5 were also significantly higher than those recorded for WUP 3. Finally, post-bout T_{mu} was significantly higher in WUP's 2, 4 and 5 compared to WUP 1 ($P < 0.05$).

Changes in T_{mu} over time resulted in significant increases in T_{mu} between pre-WUP to post-WUP, pre-WUP to pre-bout, and pre-WUP to post-bout, in WUP's 1, 2, 3 and 4 ($P < 0.05$). Muscle temperature in WUP 5 also significantly increased from pre-WUP to post-WUP, however whilst there was no significant difference in T_{mu} between pre-bout and post-bout values for WUP 5, T_{mu} was significantly lower at pre-bout and post-bout when compared to post-WUP values. Finally, no significant correlations were found between T_{mu} assessed immediately after each WUP and any of the performance variables (i.e. total work, $r = -0.46$ to 0.65; first sprint work, $r = -0.49$ to 0.68; first sprint power output, $r = -0.44$ to 0.75; and % work decrement, $r = -0.49$ to 0.32).

Table 3.2. Muscle, rectal and body temperatures (T_{mu}, T_{re}, T_b) before warm-up (pre-WUP), after warm-up (post-WUP), after a five minute rest period (pre-bout) and after the intermittent sprint test (post-bout). * = significantly different from pre-WUP ($P < 0.05$); # = significantly different from post-WUP ($P < 0.05$); (1, 2, 3, 4) = significantly different from WUP (1, 2, 3, 4) ($P < 0.05$).

T_{mu} (°C)	**WUP 1**	**WUP 2**	**WUP 3**	**WUP 4**	**WUP 5**
Pre-WUP	36.3 ± 0.4	36.4 ± 0.5	36.2 ± 0.6	35.9 ± 0.7	36.4 ± 0.6
Post-WUP	37.1 ± 0.6*	37.9 ± 0.5* (1)	37.9 ± 0.4* (1)	38.1 ± 1.1* (1)	39.2 ± 0.7* (1,2,3,4)
Pre-bout	37.1 ± 0.5*	37.6 ± 0.6* (1)	37.5 ± 0.3* (1)	37.7 ± 0.8* (1)	38.4 ± 0.4* #, (1,3)
Post-bout	37.5 ± 0.4*	38.1 ± 0.4* (1)	37.9 ± 0.4*	37.9 ± 0.8* (1)	38.6 ± 0.5* #, (1)
T_{re} (°C)					
Pre-WUP	37.3 ± 0.3	37.2 ± 0.2	37.3 ± 0.4	37.3 ± 0.3	37.4 ± 0.2
Post-WUP	37.4 ± 0.3	37.4 ± 0.2*	37.5 ± 0.3*	37.6 ± 0.3*	37.8 ± 0.2* (1,2)
Pre-bout	37.5 ± 0.3	37.4 ± 0.2*	37.5 ± 0.2*	37.6 ± 0.3* (2)	38.0 ± 0.3* #, (1,2,3)
Post-bout	37.5 ± 0.3*	37.4 ± 0.2*	37.5 ± 0.2*	37.6 ± 0.3*	38.0 ± 0.3* #, (1,2,3,4)
T_b (°C)					
Pre-WUP	36.9 ± 0.3	36.6 ± 0.3	36.8 ± 0.3	36.8 ± 0.3	36.9 ± 0.3
Post-WUP	37.0 ± 0.3*	36.9 ± 0.2*	37.0 ± 0.4*	37.2 ± 0.3* (1,2)	37.5 ± 0.4* (1,2)
Pre-bout	37.0 ± 0.3	36. ± 0.2*	37.0 ± 0.3*	37.3 ± 0.3* (1,2)	37.7 ± 0.4* #, (1,2,3,4)
Post-bout	37.0 ± 0.3	36.86 ± 0.3*	37.0 ± 0.3*	37.2 ± 0.3* (1,2)	37.7 ± 0.4* #, (1,2,3,4)

3.5.8 Rectal Temperature (T_{re})

No differences were found between WUP conditions for T_{re} at pre-WUP ($P > 0.05$; Table 3.2). However, at post-WUP, T_{re} in WUP 5 was significantly higher than values recorded for WUP's 1 and 2 ($P < 0.05$). Additionally, pre-bout T_{re} was significantly higher after WUP 5 compared to WUP's 1, 2 and 3, while pre-bout T_{re} was significantly higher after WUP 4 compared to WUP 2 ($P < 0.05$). Finally, post-bout T_{re} were significantly higher in WUP 5 compared to all other WUP conditions ($P = 0.05$).

Further, analysis of T_{re} over time showed that post-WUP and pre-bout T_{re} values were significantly higher than pre-WUP temperatures ($P < 0.05$) for WUP's 2, 3, 4 and 5. Additionally, post-bout T_{re} was significantly higher than pre-WUP values for all WUP conditions. There were no further significant changes in T_{re} over time except for WUP 5, where pre-bout and post-bout values were significantly higher than post-WUP values.

No significant correlations were found between T_{re} assessed immediately after each WUP and any of the performance variables (i.e. total work, $r = -0.499$ to 0.490; first sprint work, $r = -0.234$ to 0.685; first sprint power output, $r = -0.663$ to 0.775; and % work decrement, $r = -0.524$ to 0.717).

3.5.9 Body Temperature (T_b)

No differences were found among WUP conditions for T_b at pre-WUP ($P > 0.05$; Table 3.2). However, T_b assessed post-WUP was significantly higher after WUP's 4 and 5 compared to values measured for WUP's 1 and 2. Additionally, pre-bout and post-bout T_b values were significantly higher after WUP 5 compared to all other WUP conditions, while pre-bout and post-bout T_b values after WUP 4 were significantly higher than those recorded for WUP's 1 and 2 ($P < 0.05$).

Body temperature increased significantly between pre-WUP and post-WUP for all WUP conditions ($P < 0.05$). Additionally, T_b increased significantly between pre-WUP and pre-bout, as well as between pre-WUP and post-bout after WUP's 2, 3, 4 and 5 ($P < 0.05$). There were no further significant increases in T_b over time, except for WUP 5 where T_b significantly increased from post-WUP to pre-bout and from post-WUP to post-bout ($P < 0.05$). Further, no significant correlations were found between T_b assessed immediately after each WUP and any of the performance variables (i.e. total work, r = -0.274 to 0.664; first sprint work, r = 0.118 to 0.492; first sprint power output, r = -0.609 to 0.658; and % work decrement, r = -0.597 to 0.250).

3.6 DISCUSSION

While the lack of a control (no WUP) condition in this study meant that impairment, improvement, or in fact, no change in subsequent exercise performance could be determined, comparison between the various WUP conditions and their effect on subsequent exercise performance could still be made. Results from this study showed that none of the WUP conditions resulted in a significant change in subsequent intermittent sprint performance as assessed by total work, first sprint work, power output of the first sprint or percent work decrement. There was however, a tendency ($ES \geq 0.5$) for improved first and overall intermittent sprint performance following WUP 3. Furthermore, while T_b, T_{mu}, and T_{re} all increased significantly post-WUP in all conditions, there were no significant correlations between these temperatures and any of the performance variables assessed.

This study employed WUP intensities based around each subject's LT in an effort to standardise the metabolic strain experienced by all subjects during the various WUP conditions. This is an important and novel aspect of this study as it has previously been shown that HR and blood lactate differed between subjects of different fitness levels when exercise was performed at a percent of $\dot{V}O_{2max}$, but were similar during exercise performed at a percent (%) of the LT (Baldwin, Snow & Febbraio, 2000). Importantly, a WUP intensity above the LT can deplete energy stores, particularly phosphocreatine reserves, needed for subsequent exercise performance (Dawson et al., 1997), as well as result in high levels of metabolic acidemia, which in turn can decrease muscle force, inhibit anaerobic glycolysis and impair subsequent performance (Sargeant & Dolan, 1987). Conversely, WUP intensity needs to be high enough to impart temperature related benefits on subsequent exercise performance. To our knowledge, only one other published study to date has employed WUP intensities based on lactate accumulation in order to assess the impact of these concentrations on subsequent exercise performance, with this exercise consisting of a 2 min 'all out' sprint effort performed on a kayak ergometer (Bishop, Bonetti & Dawson, 2001). Typically, previous studies have used WUP protocols consisting of sub-maximal intensities based on either a fixed power (Bogdanis, Nevill, Boobis & Lakomy, 1996; Dawson et al., 1997), fixed revolutions per min (Gaitanos, Williams, Boobis & Brooks, 1993), % $\dot{V}O_{2max}$ (Stewart & Sleivert, 1988), or not specified (Balsom, Seger, Sjoedin & Ekblom, 1992a; Balsom Seger, Sjoedin & Ekblom, 1992b). In addition, a number of these WUP protocols also included the performance of stretching and short sprints (Dawson et al., 1997; Gaitanos et al., 1993; Balsom et al., 1992a and 1992b). Consequently, this is the first study, known to the authors, to assess the effects of WUP intensities based around LT on subsequent intermittent sprint performance.

3.6.1 Warm-up and Intermittent Sprint Performance

The similarity in performance between the various WUP intensities for first sprint and intermittent sprint performance suggests that the significantly higher blood lactate concentrations reported pre-bout after WUPs 4 and 5 (5.8 ± 1.1 and 12.6 ± 2.3 $mmol \cdot L^{-1}$, respectively) compared to WUPs 1, 2 and 3 (all below 3 $mmol \cdot L^{-1}$) did not have a detrimental effect on exercise performance. These results differ to those by Bishop et al. (2000), who compared the effects of different WUP intensities on subsequent exercise, and reported impaired 2 min 'all-out' kayak ergometer performance following a 15 min WUP performed at anaerobic threshold (termed LT in the current study), which resulted in blood lactate concentrations of 5.1 ± 1.4 $mmoL^{-1}$ immediately post WUP. A possible explanation for the difference in results between the current study and that by Bishop et al. (2000) may relate to the exercise protocols employed following WUP. An example of this is that the predominant energy system for intermittent sprint performance has been reported to be high energy phosphates, followed by anaerobic glycolysis and then aerobic metabolism (Spencer, Bishop, Dawson & Goodman, 2005), while the 2 min 'all out' continuous kayak sprint would have relied more heavily on energy from anaerobic glycolysis (Bishop et al., 2000). A greater reliance on anaerobic glycolysis would most likely have resulted in a higher overall blood lactate concentration (not reported by Bishop et al., 2000), compared to the current study, which in turn may explain the impaired exercise performance. Nonetheless, it was still surprising that intermittent sprint performance in the current study was not impaired following WUP 5 where the mean pre-bout blood lactate level was 12.6 mmol·L^{-1}.

Further, significantly higher T_{mu} recorded post-WUP for WUPs 2, 3, 4, and 5, but not for WUP 1, demonstrates that increased temperature did not have an important role in performance outcomes. This premise is further supported by significant increases in T_{re} and T_b pre-bout compared to pre-WUP in all WUP conditions, apart from WUP 1 without ensuing performance effects. It is feasible to suggest however, that an increase in temperature does not have to be statistically significant for temperature-related benefits of WUP to be still imparted on subsequent exercise performance. Inclusion of a control condition in this study would have clarified this summation. Of relevance, there was no significant decrease in T_{mu} during the post-WUP and pre-bout period in all WUP conditions, while T_{re} and T_b either did not decrease or slightly increased (ns). This suggests that the recovery period of 2 min was not too long as to negate any possible benefits associated with temperature related mechanisms associated with WUP on intermittent sprint performance. It is also possible that a shorter recovery period, or in fact, no recovery period at all, may have resulted in a greater effect of non-temperature related benefits associated with WUP on subsequent exercise performance following WUP's 1, 2 and 3. This premise is based on the fact that blood lactate concentrations were all below 3 mmol·L^{-1} in these three WUP conditions immediately post-WUP, as well as pre-bout, suggesting minimal impact of this variable on subsequent intermittent sprint performance. In addition, these lower intensity WUP conditions were unlikely to seriously deplete phosphocreatine stores required for subsequent exercise performance. Further studies are needed to assess this premise.

Similar results for first sprint and intermittent sprint performance in this study may be due to subjects adopting a pacing strategy - where pacing is defined as the conscious or subconscious regulation of work and power output in order to maximise performance (Abbiss & Laursen, 2008). It has previously been proposed that a subconscious "controller" determines the overall pacing strategy during exercise by matching the rate of energy expenditure and the current energy reserves with the predicted energy cost of exercise (Abbiss & Laursen, 2008; Ulmer, 1996). Thus, the use of a pacing strategy may not have allowed the proposed benefits of WUP on initial and intermittent sprint performance to have been fully realised. Another explanation for similar results between WUP conditions may relate to the recruitment of nine subjects. While this number is typical of many published studies in sport science, a larger cohort may have resulted in statistically significant results between WUP conditions.

While non-significant, results for total work were highest after WUP 3 (4.3%, 5.8%, 5.2% and 4.4% higher than WUP's 1, 2, 4 and 5, respectively), whilst percent work decrement values were the lowest (4.0%, 4.2%, 1.2% and 2.1% lower than WUPs 1, 2, 4 and 5, respectively), with these differences supported by moderate to large effect sizes. Further, there was a tendency (ES > 0.5) for improved work and greater power output for the first sprint following WUP 3 compared to the other WUP conditions. The moderate to large effect sizes associated with WUP 3 and these performance measures suggest that this intensity may be the most appropriate for eliciting optimal 6 x 4 s (separated by 21 s) intermittent sprint performance. Interestingly, WUP 3 was of similar intensity (~55% $\dot{V}O_{2max}$) to the WUP protocols used in other studies that have resulted in improved single sprint performance (Sargeant & Dolan, 1987; Stewart & Sleivert, 1988).

3.6.2 Temperature and Performance

While T_b has been shown to be dependent upon environmental conditions (Nielsen & Nielsen, 1962; Saltin, Gagge & Stolwijk, 1968), T_{mu} and T_{re} have been reported to be directly proportional to the relative workload (Saltin et al., 1968). Further, T_{mu} has been reported to increase rapidly within 5 – 10 min of the initiation of exercise, while T_{re} increases gradually over a longer period (Saltin et al., 1968). This temperature pattern was demonstrated in the current study where T_{mu} and T_{re} increased significantly immediately following WUP's 2 to 5, with T_{mu} rising at a higher rate compared to T_{re}. While T_{mu} was also significantly higher after WUP 1, it remained below T_{re} reflecting the lower workload employed. Consistent with the previously reported relationship between exercise intensity and temperature, the greater the WUP intensity employed in the present study the higher the T_b, T_{mu} and T_{re} values.

Asmussen and Boje (1945) have previously reported that sprint cycling performance showed the greatest improvement when T_{mu} increased markedly and core temperature increased minimally, concluding that T_{mu} was the most important factor influencing performance. However, this current study found no significant correlations between T_{mu}, T_{re} or T_b and any of the performance variables assessed. Reasons for these results are speculative and may be related to the small cohort used in this study and the previously mentioned possibility of pacing by our subjects. In addition, the relationship between T_b and performance may have been confounded by the large increase in blood lactate concentrations following WUP performed at intensities above the LT.

3.7 CONCLUSION

In conclusion, there were no significant differences in performance results between varying WUP intensities based around individual LT on subsequent exercise performance consisting of either the first sprint or 6 x 4 s sprints, separated by 21 s. These results may be due to subjects adopting a pacing strategy in order to maximise overall exercise performance or to the low cohort used in this study. However, moderate to large effect sizes associated with performance results suggest that a WUP that is performed at an intensity midway between LI and LT (i.e., WUP 3), as indicated by an RPE of ~11 and a HR of ~55% of HR_{max}, may represent the best intensity for improving subsequent first sprint and intermittent sprint performance. This tendency for improvement in intermittent sprint performance following WUP 3 may be important in team-sport games where seconds can be the difference between a successful or non-successful sporting manoeuvre.

3.8 Key Points

- There were no statistically significant differences between any of the WUP trials for total work, first sprint work, power output of the first sprint or % work decrement, despite WUP intensity being different for each trial.
- Subsequent exercise performance was similar between all five WUP trials despite there being significant differences in T_{mu}, T_{re}, heart rate and blood lactate concentrations between various WUP trials post-WUP.
- There was a tendency (i.e., moderate to large effect sizes) for improved subsequent exercise performance following WUP 3 (exercise performed midway between lactate inflection and lactate threshold), compared to the other WUP trials.

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CHAPTER 4

4.0 STUDY TWO

4.1 TITLE: The effect of warm-up on single and intermittent sprint performance.

This paper is in the process of being submitted to the Journal of Sports Medicine and Physical Fitness

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4.2 ABSTRACT

Aim: To investigate the effects of warm-up (WUP), compared to no WUP, on both single sprint performance and prolonged intermittent sprint performance (ISP). The first sprint of ISP was also assessed in both trials (WUP vs no WUP) and compared to single sprint performance (WUP vs no WUP). **Methods**: Twelve male subjects, who participated in team sports, performed four experimental trials on a cycle ergometer. These trials consisted of either an 80 min (2 x 40 min 'halves') ISP, or a single, all-out, 4 s sprint, following either no WUP or a 10 min WUP performed at an intensity midway between the lactate inflection point and the lactate threshold. **Results:** There were no significant interaction effects between trials for prolonged ISP for total work ($J \cdot kg^{-1}$), work decrement and power decrement ($P = 0.59$, $P = 0.50$, and $P = 0.37$, respectively). In contrast, work done for the first sprint of ISP (no WUP trial) was significantly less ($P < 0.001$) than work done during the first sprint of ISP (WUP trial) and to both single sprint trials (WUP and no WUP). Further, peak power output ($W \cdot kg^{-1}$) during the single sprint trial following WUP was significantly higher ($P < 0.05$) than peak power output during the single sprint trial without WUP, and to the first sprint of both ISP trials (WUP and no WUP). **Conclusion:** WUP improved single sprint performance and the first sprint of prolonged ISP. Improved single sprint performance (WUP trial) compared to the first sprint of prolonged ISP (WUP and no WUP trials) may be due to the adoption of a pacing strategy employed during prolonged ISP. Pacing may also explain similar ISP between the WUP and no WUP trials. Alternatively, the initial sprints of ISP in the no WUP trial may have provided a WUP effect, or else benefits associated with WUP may be negated over time by the metabolic costs of prolonged ISP, resulting in similar performance between trials.

Keywords: pacing, lactate threshold, lactate inflection, team-sport game, soccer, football

4.3 INTRODUCTION

Warm-up (WUP) is a popular practice, considered by many to be an essential part of any training session or team-sport competition due to its proposed ability to improve subsequent exercise performance and to reduce the incidence of sports related musculoskeletal injuries (Shellock & Prentice, 1985). As implied by its name, WUP is associated with temperature related benefits on subsequent exercise performance (Bishop, 2003). In order to achieve these temperature related benefits, WUP can be either active or passive. Passive WUP uses external methods such as hot baths and heat blankets to raise core or muscle temperature (Dolan, Greig & Sargeant, 1985), while active WUP involves movements that activate the body's major muscle groups, such as jogging, cycling and walking (Bishop, 2003).

An increase in body temperature, as a result of either active or passive WUP, is proposed to improve exercise performance via various mechanisms, such as decreased muscle and joint viscous resistance (Asmussen & Boje, 1945), greater release of oxygen from haemaglobin and myoglobin (Barcroft & King, 1909) and the speeding of oxygen kinetics (Koga, Shiojiri, & Kondo, 1997). In addition, there are also various non-temperature related benefits associated with active WUP, which include increased blood flow and oxygen delivery to the working muscles (McComas, 1996); elevation of baseline oxygen consumption (McCutcheon, et al., 1999). etc (see Bishop, 2003 for a review). Overall, these factors prime the body for the ensuing task.

While many studies have reported improvement in prolonged, continuous exercise performance following an active WUP, compared to a no WUP condition (Atkinson, Todd, Reilly, &

Waterhouse, 2005; Grodjinovsky & Magel, 1970; Thompson, 1958), the effects of WUP on intermittent sprint performance (ISP) are less clear. This is largely because only a few studies to date have assessed the impact of WUP on ISP (Bishop & Claudius, 2004; Bishop & Maxwell, 2009; Drust, Rasmussen, Mohr, Nielsen, & Nybo, 2005; Mohr, Krustrup, Nybo, Nielsen, & Bangsbo, 2004; Morris, Nevill, Lakomy, Nicholas, & Williams, 1998; Morris, Nevill, & Williams, 2000). Of these studies, only two (Bishop & Claudius, 2004; Bishop & Maxwell, 2009) used an intermittent sprint protocol based on the movement patterns of team-game sports (Spencer et al., 2004). Furthermore, only Bishop and Claudius (2004) assessed the impact of active WUP, compared to no WUP, on ISP that continued for the duration of a typical team-sport game (2 x 36 min 'halves).

In contrast to the typical observation of an ergogenic effect associated with an active WUP on continuous exercise performance, the limited research to date has reported no significant difference in ISP preceded by a 10 min active WUP, compared to a no WUP trial (Bishop & Claudius, 2004; Bishop & Maxwell, 2009). It was proposed that these results may have been due to subjects adopting a pacing strategy, which may have resulted in similar prolonged ISP between WUP trials (Bishop & Claudius, 2004; Bishop & Maxwell, 2009). A pacing strategy is defined as the conscious or subconscious regulation of work and power output in order to maximise performance (Ulmer, 1996). It has previously been proposed that a subconscious 'controller' determines the overall pacing strategy required during exercise by attempting to match the rate of energy expenditure and the current energy reserves with the predicted energy cost of the exercise (Abbiss & Laursen, 2008; Ulmer, 1996). Thus, the use of a pacing strategy may not have allowed the proposed benefits of WUP on both initial sprint performance and prolonged ISP to have been fully realised. One way to assess this hypothesis would be to assess the effects of an active WUP on single sprint performance compared to the first sprint of ISP.

An alternative explanation for similar results between the active WUP and no WUP trials in the studies by Bishop and Claudius (2004) and Bishop and Maxwell (2009), may be that the overall WUP intensity (50 – 70 % $\dot{V}O_{2peak}$, and an 'all out' sprint, with rest periods interspersed), used in both studies, may not have been appropriate to improve subsequent ISP. Results from previous studies suggest that WUP intensity needs to be high enough to induce temperature related benefits associated with WUP (Bishop, 2003), but not be too high as to result in a large decrease in pH (Bishop, Bonetti & Dawson, 2001), depleted anaerobic energy stores (Bishop, 2003), or reduced heat storage capacity (Gregson, Drust, Batterham & Cable, 2002), which may impair subsequent exercise performance. Of relevance, we recently determined that a WUP performed at an intensity that was midway between an individual's lactate inflection (LI) and lactate threshold (LT) resulted in a significant increase in both muscle and core temperature, but only a moderate increase in blood lactate concentration (2.01 ± 0.91 $mmol \cdot L^{-1}$; unpublished study). Furthermore, a 10 min WUP performed at an intensity that is midway between LI and LT should not deplete high energy phosphocreatine stores to levels that impair subsequent ISP, particularly when followed by a 2 min passive recovery period (Spencer et al., 2005). Use of a WUP intensity based on individual lactate thresholds, rather than % $\dot{V}O_{2max}$, ensures that all subjects are performing under a similar metabolic strain when participating in exercise. For example, it has previously been shown that heart rate (HR) and blood lactate differed between subjects of different fitness levels when exercise was performed at a percent of $\dot{V}O_{2max}$, but were similar during exercise performed at a percent (%) of the LT (Baldwin, Snow & Febbraio, 2000). Of importance, there have been no studies to date known to the authors that have assessed the impact of a WUP on prolonged ISP where the WUP intensity was based around individual lactate thresholds.

Therefore, the aim of this study was to investigate the effects of an active WUP (compared to no WUP) on prolonged ISP, where the sprint patterns and the total duration of the protocol closely replicated those of a team-sport game. A second aim was to investigate the effects of active WUP (compared to no WUP) on single sprint performance and the first sprint of prolonged ISP. It was hypothesised that single sprint performance, prolonged ISP and the first sprint of ISP would be improved after an active WUP performed midway between LI and LT, compared to a no WUP condition. It was further hypothesised that, due to the adoption of a conscious or subconscious pacing strategy, the first sprint of prolonged ISP would be lower when compared to single sprint performance.

4.4 METHODS

4.4.1 Subjects

Twelve male subjects (mean ± SD age: 24.5 ± 6.7 y, body mass: 86.9 ± 12.8 kg, $\dot{V}O_{2max}$: 47.4 ± 8.0 $mL \cdot kg^{-1} \cdot min^{-1}$), who participated in team-game sports (Australian rules football, soccer and rugby), were recruited from the School of Sport Science, Exercise and Health and The University of Western Australia Rugby Football Club. Subjects were informed of the study requirements, benefits and risks before giving written informed consent. The Research Ethics Committee of the University of Western Australia granted approval for the study's procedures.

4.4.2 Experimental Overview

Subjects were required to complete two preliminary sessions and four experimental trials over a six-week period. During the first preliminary visit, subjects performed a familiarisation session of both the graded exercise test (GXT) and the intermittent sprint test. During this visit, height was determined using a stadiometer (to the nearest 0.1 cm), while body mass was measured (to the nearest 0.01 kg) using Sauter scales (model ED3300, Ebingen, West Germany). The GXT was then repeated during the second preliminary visit to determine the lactate threshold (LT), $\dot{V}O_{2max}$ and maximal power output at $\dot{V}O_{2max}$. Subjects then performed each of the four experimental trials in a randomised, counter-balanced order. Subjects were asked to maintain their normal diet and training throughout the study and were required to consume no food or beverages (other than water) during the 2 h period prior to testing. Subjects were requested to keep a diary of their food and drink intake during the 48 hr period prior to exercise and to replicate this intake prior to each exercise trial. This diary was checked by the researchers to ensure conformity. Additionally, subjects were asked not to consume alcohol or to perform vigorous exercise in the 24 h prior to testing. All exercise tests were performed on a calibrated, front-access, air-braked cycle ergometer (Model EX-10, Repco, Australia) that had been modified to include a cover over the back wheel so as to prevent the subject being cooled by the flywheel. This ergometer was interfaced with an IBM compatible computer system to allow for the collection of data for the calculation of work and power generated during each flywheel revolution (Cyclemax, The University of Western Australia, Perth, Australia). Before testing, the ergometer was dynamically calibrated on a mechanical rig (Western Australia Institute of Sport, Perth, Australia) across a range of power outputs (100-2000 W).

4.4.3 Graded Exercise Test

The GXT was a multi-stage, discontinuous test performed on the same cycle ergometer described earlier, that consisted of graded exercise steps (3 min stages), using an intermittent protocol (1 min passive rest between stages). The test commenced at 70 W, and intensity was increased by 30 W every 3 min. Subjects were required to maintain the set power output, which was displayed on a computer screen in front of them. The test was stopped when the subject could no longer maintain the required power output (volitional exhaustion). Strong verbal encouragement was provided to each subject during the latter stages of the test. The LT was calculated using the modified Dmax method (Bishop, Jenkins & MacKinnon, 1998). This is determined by the point on the polynomial regression curve that yields the maximal perpendicular distance to the straight line connecting the first increase in lactate concentration of more than 0.4 mM above the resting level (lactate inflection: LI; Yoshida, Chida, Ichioka, & Suda, 1987) and the final lactate point. The GXT results (LI, LT and maximum power output) were used to calculate WUP intensity, and the active recovery workload between each sprint of ISP for each individual subject.

During the GXT, expired air was continuously analysed for O_2 and CO_2 concentrations using Ametek gas analysers (Applied Electrochemistry, SOV S-3 A/1 and COV CD-3A, Pittsburgh, PA). Ventilation was recorded every 15 s using a turbine ventilometer (Morgan, 225A, Kent, England). The gas analysers were calibrated immediately before and verified after each test using three certified gravimetric gas mixtures (BOC Gases, Chatswood, Australia), while the ventilometer was calibrated pre-exercise and verified post-exercise using a one-litre syringe, in accordance with the manufacturer's instructions. The ventilometer and gas analysers were connected to an IBM PC that measured and displayed variables every 15 s. The sum of the four highest consecutive 15 s $\dot{V}O_2$ values was recorded as the subject's $\dot{V}O_{2max}$.

4.4.4 Experimental Trials

Each subject performed the four experimental trials in a randomised, counterbalanced order, at the same time of day, approximately one week apart, over a four week period. The four trials consisted of prolonged ISP (2 x 40 min exercise bouts, separated by 10 min), or a single 'all out' 4 s sprint that was preceded by either no WUP or a 10 min WUP. All sprints were performed in a standing position, on a cycle ergometer that was fitted with toe clips and heel straps. The active WUP was performed at an intensity midway between the LI and the LT level, which equated to ~55 % $\dot{V}O_{2max}$. This selected WUP intensity was based on the results of a previous study by the authors (submitted for publication) that demonstrated that this intensity elicited the best subsequent ISP (effect sizes > 0.5), when compared to four other WUP intensities assessed. Subjects completed a 10 min WUP and then passively rested for 2 min prior to the beginning of the performance tests. In both of the no WUP trials, subjects sat quietly on the cycle ergometer for 10 min prior to the performance tests.

4.4.5 Single and Intermittent Sprint Performance

The intermittent sprint protocol used in this study was based on a time-motion analysis of international men's field hockey by Spencer et al. (2004) and was designed to mimic the sprint and recovery durations of a typical team-sport game. While this test was performed on a cycle ergometer, a strong correlation has been reported between intermittent sprint cycling and running performance (Bishop, Spencer, Duffield, & Lawrence, 2001). Further, this cycle sprint test has been used in previous studies in order to simulate intermittent sprints and recovery periods performed during a team-sport game (Bishop & Claudius, 2004, Bishop & Maxwell, 2009, Schneiker, Bishop & Dawson, 2006). The protocol consisted of 40 min of intermittent sprint exercise which was divided into ~2-min blocks consisting of a 4 s sprint (in a standing position) and 100 s of active recovery (at an intensity that equated to individual LI) and 10 s of passive rest (Figure 4.1). Subjects were advised to sprint as fast as they could for each sprint. The protocol was completed twice so as to simulate the duration of a typical full team-sport game and included a 10 min passive rest between each 'half'.

Peak power ($W \cdot kg^{-1}$) and work ($J \cdot kg^{-1}$) were calculated for both the single sprint tests and the first sprint of ISP. In addition, total work performed and the work and power decrement during ISP were calculated for each of the two 40 min exercise bouts (halves), as well as for the full 80 min protocol. Percent work and power decrement were determined using a method modified from that described by Fitzsimmons, Dawson, Ward and Wilkinson, (1993), i.e., 100-[(total performance/ [best performance x 20]) x 100]. In addition, electromyographic activity (EMG) for selected muscles, Heart rate (HR: Polar Electro Oy, Kempele, Finland), blood lactate concentrations and ratings of perceived exertion (RPE), as determined by the Borg 6-20 scale (Borg, 1982) were assessed (Figure 1).

4.4.6 Capillary Blood Sampling and Analysis

A hyperaemic ointment (Finalgon, Boeringer Ingelheim, Germany) was applied to the subject's earlobe 5-7 min prior to the initial blood sampling. Glass capillary tubes were used to collect 35 µL of blood during the GXT and ISP (D957G-70-35, Clinitubes, Radiometer Copenhagen).

Capillary blood samples were taken at rest and immediately following each 3 min stage of the GXT. Capillary blood samples were also taken immediately prior to and after WUP, immediately after the final (20^{th}) sprint of both halves of the exercise protocol, as well prior to the 1st sprint of the second half of the protocol (following the 10 min rest period). Blood lactate concentration was determined using a blood-gas analyser (ABL625, Radiometer Copenhagen). The blood-gas analyser was regularly calibrated using precision standards and was routinely assessed using external quality controls.

4.4.7 Muscle Electromyography

Electromyography (EMG) activity of the vastus lateralis, gluteus maximus and biceps femoris muscles of the right leg was recorded using bipolar Ag-AgCl surface electrodes at an inter-electrode distance of 20 mm. These muscles were chosen because they had previously been used to assess muscle activation (using EMG) during cycling performance (MacIntosh, Neptune & Horton, 1999; Marsh & Martin, 1994; Saunders et al., 2000). Before placing the electrodes on the body, the overlying skin was carefully prepared. The hair was shaved, the skin lightly abraded to remove the outer layer of epidermal cells and thoroughly cleansed with alcohol to reduce the skin-electrode interface impedance to below 2 k-ohms. Electrodes were fixed lengthwise, parallel to a line bisecting the proximal and distal tendons over the middle of the muscle belly. The electrodes were taped down with cotton wool swabs to minimise sweat-induced interference. The EMG reference electrode was then placed over the right patella. In order to prevent movement artifact, wires between the electrodes and the computer were secured to the skin with adhesive tape and the leads braided to minimise electromagnetic-induced interference. The EMG signal was amplified (x 1000) (P511, Grass Instrument Division, West

Warwick, RI) and sampled at a rate of 2048 Hz using a custom-written data acquisition program (Lab VIEW, National Instruments Corp., Austin, TX). Before sampling, the EMG signals were analogue band-pass filtered (high-pass 35 Hz, low pass 1000 Hz) to remove unwanted noise and possible movement artifacts in the low frequency region, as well as to eliminate aliasing and other artifacts in the high-frequency region (Karlsson, Larsson, Eriksson, & Gerdle, 2003). A root mean square (RMS) value was calculated for each sprint. Root mean squared data for each muscle were normalised to the mean maximum value recorded over 100 ms in any of the trials undertaken by each subject in any one test (Heiden & Burnett, 2003).

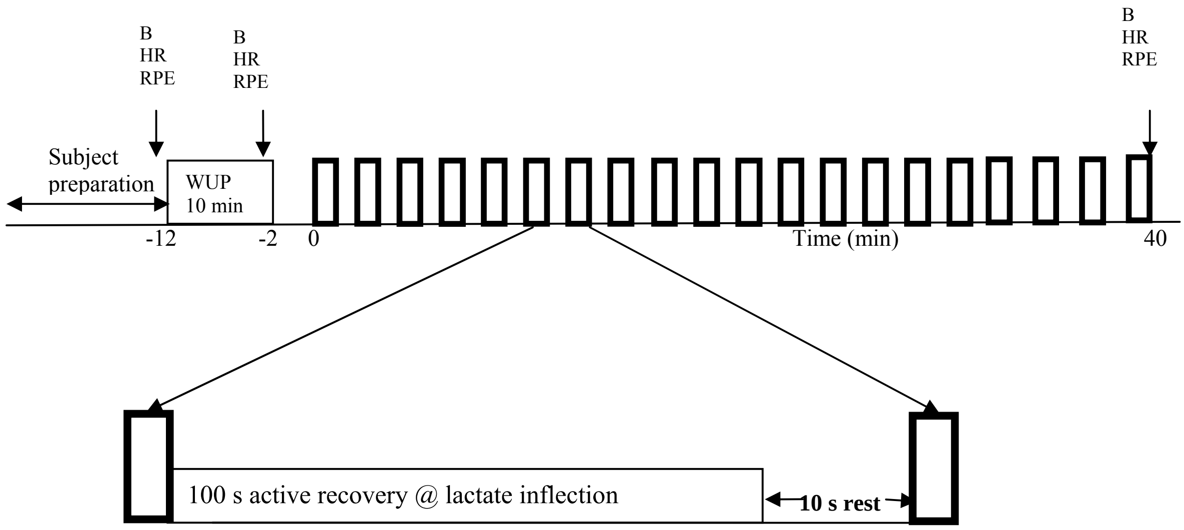

Figure 4.1. - Schematic of the first half of the intermittent sprint protocol. Each ~2-min block consisted of a 4 s maximal sprint, 100 s of active recovery performed at an intensity equivalent to individual lactate inflection, and 10 s passive rest.  = 4 s sprint, B = blood sample (lactate), RPE = rating of perceived exertion, HR = heart rate, WUP = warm-up. Electromyography was recorded for each sprint.

4.4.8 Data Analysis

All values were reported as mean ± SEM. Comparisons between single sprint performance and performance during the first sprint of the ISP were assessed using one-way, repeated-measures ANOVA (1 group x 4 trials). Total work ($J{\cdot}kg^{-1}$), work decrement, and power decrement for the prolonged ISP were assessed using a two-way, repeated-measures ANOVA (2 trials x 3 time points), while physiological variables (HR, RPE and blood lactate) were assessed using a two-way, repeated-measures ANOVA (2 trials x 5 time points). A Bonferroni t-test was applied whenever significance was found. Statistical significance was accepted at the level of $p < 0.05$. All statistical analyses were conducted using the SigmaStat statistical package (Version 3.1, SigmaStat, Richmond, California, USA).

4.5 RESULTS

4.5.1 Single Sprint and Intermittent Sprint Performance

There were no significant interaction effects between the WUP and the no WUP trials for total work ($J{\cdot}kg^{-1}$), work decrement, or power decrement ($P = 0.59$, $P = 0.50$, and $P = 0.37$, respectively; Table 4.1.). Accordingly, performance was similar between trials at the end of each 'half' of ISP, as well as for the entire intermittent sprint protocol. In contrast, work done for the first sprint of prolonged ISP in the no WUP trial, was significantly lower ($P < 0.001$) than that recorded for the first sprint of ISP following a WUP, and significantly lower than both single sprint trials (WUP and no WUP). In addition, peak power output ($W{\cdot}kg^{-1}$) for single sprint performance following WUP was significantly higher than single sprint performance following no WUP, as well as compared to the first sprint of ISP following either a WUP or no WUP ($P < 0.05$; Table 4.2).

Table 4.1. Total work (W_{tot}), work decrement (W_{dec}), and power decrement (P_{dec}) recorded during 80 min (2 x 40 min 'halves', with each half consisting of 20 x 4 s sprints with recovery) of intermittent-sprint performance (ISP) following active warm-up (WUP) and no WUP. Values are mean ± SEM, N=12.

	W_{tot} (J·kg^{-1})	%W_{dec}	%P_{dec}
WUP+ISP			
First 40 min half	860.7 ± 36.4	9.6 ± 1.1	6.7 ± 0.4
Second 40 min half	745.4 ± 71.0	10.0 ± 1.3	7.5 ± 0.7
Overall sprint performance	1606.1 ± 98.4	12.3 ± 1.3	8.4 ± 0.76
no WUP+ISP			
First 40 min half	859.8 ± 32.8	10.6 ± 1.1	7.3 ± 0.7
Second 40 min half	818.0 ± 71.0	10.2 ± 1.0	7.0 ± 0.9
Overall sprint performance	1677.8 ± 80.2	12.0 ± 0.8	9.1 ± 0.8

Table 4.2. Work done and peak power output for single sprint (SS) performance and the first sprint (FS) of the intermittent sprint protocol following either an active warm-up (WUP) or no WUP. Values are mean ± SEM, N=12.

	WUP+SS	WUP+FS	no WUP+SS	no WUP+FS
Work (J·kg^{-1})	44.2 ± 7.3 ^{d}	41.6 ± 7.0 ^{d}	42.5 ± 6.0 ^{d}	37.1 ± 8.2
Peak power (W·kg^{-1})	15.6 ± 2.4 ^{b,c,d}	14.6 ± 2.2 ^{a,d}	14.4 ± 2.1 ^{a,d}	13.2 ± 2.5 ^{a,b,c}

[a] = significantly different from WUP+SS ($P < 0.05$), [b] = significantly different from WUP+FS ($P < 0.05$), [c] = significantly different from no WUP+SS ($P < 0.05$), [d] = significantly different from no WUP+FS ($P < 0.05$).

4.5.2 Electromyographic Activity

Only EMG results for single sprint performance (WUP and no WUP trials) and the first sprint of ISP (WUP and no WUP trials) are presented due to the impact of sweating on EMG electrodes which resulted in their movement over the course of the prolonged exercise trials (Table 4.3). Results showed that root mean squared (rms) EMG data for gluteus maximus was significantly higher during single sprint performance preceded by a WUP, compared to the first sprint of ISP that was also preceded by a WUP ($P = 0.04$), but was not significantly different to first sprint and single sprint results that were not preceded by a WUP ($P = 0.08$ and $P = 1.0$, respectively). There were no significant interaction effects between any of the exercise conditions for vastus lateralis or biceps femoris rmsEMG values ($P = 0.25$ and $P = 0.24$, respectively).

Table 4.3. Electromyographic (EMG) activity for single sprint (SS) performance and the first sprint (FS) of intermittent sprint performance following either an active warm-up (WUP) or no WUP. rms = root mean squared. Values are mean ± SEM, N= 9.

	rmsEMG (% max)			
	WUP+SS	**no WUP+SS**	**WUP+FS**	**no WUP+FS**
Biceps femoris	45.4 ± 2.8	48.2 ± 2.8	42.4 ± 2.2	43.8 ± 2.9
Gluteus maximus	46.5 ± 3.6*	45.0 ± 3.2	32.0 ± 3.3	35.2 ± 1.9
Vastus lateralis	61.3 ± 1.4	58.2 ± 2.0	57.6 ± 1.5	54.5 ± 1.6

* = significantly different from WUP+FS. Significance = $P < 0.05$

4.5.3 Blood Lactate Concentration

There were no significant differences in blood lactate concentrations measured at any time point between any of the trials ($P > 0.05$), except post-WUP where blood lactate concentrations were significantly higher ($P < 0.05$) after both active WUP trials (ISP and single sprint), compared to the no WUP trials (ISP and single sprint). Further, post-WUP blood lactate concentrations were significantly higher ($P < 0.05$) compared to pre-WUP for single sprint and ISP following active WUP. In both ISP trials (WUP and no WUP), changes in blood lactate concentrations followed a similar pattern. This is demonstrated during the first half of the exercise protocol where blood lactate increased significantly ($P < 0.05$), compared to post-WUP values, and then decreased ($P > 0.05$) after the passive rest period. Finally, blood lactate increased during the second half in both ISP trials, with these changes not reaching significance. Values for blood lactate can be found in Tables 4.4 and 4.5.

Table 4.4. Blood lactate concentration (La^-), heart rate (HR) and ratings of perceived exertion (RPE) for single sprint (SS) performance following either a warm-up (WUP) or no WUP trial. Values are mean ± SEM, N = 12. [a] = significantly different from pre WUP (P < 0.001). [b] = significantly different from no WUP + SS (P < 0.001).

	WUP + SS La^- (mmol·L^{-1})	no WUP + SS La^- (mmol·L^{-1})	WUP + SS HR (bpm)	noWUP+SS HR (bpm)	WUP+SS RPE	noWUP+SS RPE
Pre WUP	1.1 ± 0.2	1.0 ± 0.1	72 ± 3	74 ± 3	6.5 ± 0.5	6.2 ± 0.1
Post WUP	2.7 ± 0.3 [a b]	1.1 ± 0.1	124 ± 6 [a b]	76 ± 2	9.8 ± 0.8 [ab]	6.3 ± 0.2

Table 4.5. Blood lactate concentration (La^-), heart rate (HR) and ratings of perceived exertion (RPE) at rest (pre-warm-up: WUP), immediately after WUP (post-WUP), as well as after the 20th sprint in both exercise 'halves' of 80 min of intermittent sprint performance (ISP), following a WUP or a no WUP trial. Values are mean ± SEM, N = 12. [a] = significantly different from pre-WUP (P < 0.001), [b] = significantly different from post-WUP (P < 0.05), [c] = significantly different from end of 1st 20 sprints (P < 0.05), [d] = significantly different from passive rest (P < 0.05), [e] = significantly different from no WUP+ISP at post-WUP (P < 0.001).

	WUP+ISP La^- (mmol·L^{-1})	noWUP+ISP La^- (mmol·L^{-1})	WUP+ISP HR (bpm)	noWUP+ISP HR (bpm)	WUP+ISP RPE	noWUP+ISP RPE
Pre WUP	1.0 ± 0.1	1.0 ± 0.1	72 ± 3	75 ± 3	6.2 ± 0.2	6.0 ± 0.0
Post WUP	2.6 ± 0.3[ae]	1.0 ± 0.1	127 ± 4[ae]	73 ± 4	9.8 ± 0.7[ae]	6.1± 0.1
1st 20 sprints	4.9 ± 0.7[ab]	5.0 ± 0.7[ab]	149 ± 3[ab]	149 ± 4[ab]	15.1 ± 1.0[ab]	15.8 ± 0.8[ab]
passive rest	3.2 ± 0.5[ab]	3.4 ± 0.5[ab]	97 ± 2[abc]	98 ± 2[abc]	9.7 ± 0.7[ac]	9.2 ± 0.9[abc]
2nd 20 sprints	3.8 ± 0.3[ab]	3.8 ± 0.6[ab]	149 ± 3[abd]	150 ± 5[abd]	15.1 ± 0.9[abd]	15.8 ± 0.7[abd]

4.5.4 Heart Rate

Heart rate increased significantly post-WUP, compared to pre-WUP, following the active WUP trial for single sprint performance and ISP. (Tables 4 and 5). Further, HR measured post-WUP for single sprint performance and ISP was significantly higher ($P < 0.05$) following a WUP compared to HR values recorded in the no WUP trials. By the end of the first 20 sprints (first half), HR values for both ISP trials (WUP and no WUP) were significantly higher ($P < 0.05$) than post-WUP values. Following a 10 min passive rest period, HR in both ISP trials (WUP and no WUP) decreased significantly compared to values recorded at the end of the first half of ISP. Heart rate values then increased significantly over the second bout (half) of 20 sprints in both ISP trials compared to values recorded following the passive rest period ($P < 0.05$: Table 5).

4.5.5 Rating of Perceived Exertion

Ratings of perceived exertion increased significantly post-WUP, compared to pre-WUP, for single sprint performance and ISP following a WUP, compared to the no WUP trial (Tables 4 and 5). In addition, RPE assessed post-WUP for ISP (WUP trial) was significantly higher ($P < 0.05$) compared to ISP (no WUP trial). By the end of the first 20 sprints (first half of the protocol), RPE values for both ISP trials (WUP and no WUP) were significantly higher ($P < 0.05$) compared to the post-WUP values. After a 10 min passive rest period, RPE in both ISP trials significantly decreased compared to values recorded at the end of the first half of the ISP ($P < 0.05$). Finally, RPE values then increased significantly over the next 20 sprints (second half) in both ISP trials ($P < 0.05$).

4.6 DISCUSSION

4.6.1 Overview

This is the first study to assess the effects of an active WUP intensity, based on individual lactate thresholds, on both single sprint performance and prolonged ISP (80 min). Of relevance, final values for blood lactate concentrations (~4 $mmol \cdot L^{-1}$) and HR (~ 150 $b \cdot min^{-1}$) recorded for ISP were similar to those previously reported following football (soccer) matches (Krustrup et al. 2006; Mohr et al. 2004) and suggests that the prolonged ISP used in this study was able to replicate, in part, some of the physical demands of team-game sports. Results demonstrated that active WUP, compared to a no WUP trial, improved single sprint ability, but had no significant effect on prolonged ISP. Furthermore, work done during the first sprint of prolonged ISP was significantly greater following an active WUP, compared to the no WUP trial. In addition, power output for the first sprint of ISP in both the WUP and no WUP trial was significantly impaired compared to single sprint performance that was preceded by an active WUP.

4.6.2 Single Sprint and First Sprint of Intermittent Sprint Performance

Compared to no WUP, single sprint performance was significantly improved following a 10 min active WUP. This is consistent with previous research which has reported improved single sprint performance following a moderate-intensity WUP (Dolan et al., 1985; Grodjinovsky & Magel, 1970; McKenna, Green, Shaw & Meyer, 1987; Pacheco, 1957; Sargeant & Dolan, 1987; Thompson, 1958). Mechanisms of active WUP that have been proposed to improve single sprint performance relate to temperature and non-temperature benefits, as described in the introduction. Assessment of core and muscle temperatures in this study would have allowed for this premise to have been confirmed.

As hypothesised, despite performing an identical active WUP, performance of the first sprint of prolonged ISP was significantly impaired compared to single sprint performance. This was demonstrated by significantly higher peak power output for single sprint performance (preceded by a WUP) compared to the first sprint of ISP in both trials (WUP and no WUP), as well as by significantly lower work done for the first sprint of ISP (no WUP trial) compared to the both single sprint trials (no WUP and WUP). It is possible that results for first sprint performance reflected the use of a pacing strategy by subjects so as to maximise overall prolonged ISP. The use of a pacing strategy would suggest that energy used during the first sprint of the prolonged ISP would be conserved (as opposed to that used during a single sprint effort), in an effort to evenly distribute energy reserves over the entire exercise protocol. Such a result is consistent with the recent results of Billaut et al. (2010), who observed the use of a pacing strategy when subjects were deceived as to the number of intermittent sprints they were required to perform. Evidence to support the use of a pacing strategy is provided, in part, by EMG data assessed during cycling, where muscle activation of the gluteus maximus was shown to be significantly lower for the first sprint of the ISP, when preceded by a WUP, compared to single sprint performance also following a WUP. Further, muscle activation of gluteus maximus for the first sprint of ISP (no WUP trial) was ~24% and 22% lower (ns) than both single sprint trials (WUP and no WUP, respectively), which would further support the use of a pacing strategy during prolonged ISP. EMG data for biceps femoris and vastus lateralis were also lower (ns) for first sprint performance (WUP and no WUP trials) compared to single sprint performance (WUP and no WUP trials). Anticipation of performing more sprints therefore seemed to influence the quantity of muscle mass that subjects were willing to recruit to perform the first sprint.

While EMG activity is considered by some to be limited due to the possibility that signals may be confounded by movement artefact and/or the conducted signals from other muscles (Saunders et al., 2000), it has still been employed in a number of studies as a tool to assess muscular effort (Martin & Martin, 1995; MacIntosh et al., 2000; Saunders et al., 2000). Relevant to the current study, Saunders et al. (2000) reported increased EMG activity in the vastus lateralis and rectus femoris during high intensity cycling compared to lower intensity exercise, while MacIntosh et al. (1999) reported increasing muscle activation associated with higher power output during incremental cycling using EMG analyses of various muscles that included biceps femoris and gluteus maximus. More importantly, Billaut et al. (2010) have recently reported a similar result, with less muscle activation (as assessed by EMG) during the first sprint when subjects were required to perform more sprints.

Results from this study also showed that the first sprint of prolonged ISP was significantly improved (more work performed) when preceded by an active WUP, compared to a no WUP condition. This suggests that while a pacing strategy may have been employed in both ISP trials, active WUP still imparted some initial performance benefits, which again may have been temperature and non-temperature related.

Our results differ to those by Bishop and Claudius (2004) and Bishop and Maxwell (2009), who reported similar first sprint performance during prolonged ISP following a 10 min active WUP and a no WUP trial. The lack of benefit observed following an active WUP on first sprint performance in both of these studies may have been due to the use of a WUP protocol that included moderate intensity exercise bouts (70% $\dot{V}O_{2peak}$), as well as an 'all out' sprint bout.

When combined with a brief 2 min recovery period, this may have resulted in incomplete phosphocreatine resynthesis prior to the first sprint of ISP. As it has previously been reported that phopshocreatine stores took 3 min to almost fully replete following a single 6 s cycle sprint (Dawson et al., 1997), and there is a close association between phosphocreatine resynthesis and sprint performance (Bogdanis et al., 1996), this may explain why there was no significant difference in first sprint performance in the previous studies.

4.6.3 Prolonged Intermittent Sprint Performance

Similar performance results for prolonged ISP between the WUP and no WUP trials for both exercise 'halves,' as well as for the entire protocol, were contrary to our hypothesis. However, these results are similar to those reported by Bishop and Claudius (2004) and Bishop and Maxwell (2009), respectively, who both reported no significant differences between an active WUP and a no WUP trial for prolonged ISP (similar ISP to that used in the current study), albeit that ISP was performed in the heat in the study by Bishop and Maxwell (2009). The similar results between trials may have been due to the initial sprints of the prolonged exercise protocol providing a warm-up stimulus in the no WUP trial, thereby making the need for a separate active WUP protocol superfluous. Alternatively, there may come a time point during prolonged exercise where temperature and non-temperature related benefits of active WUP reach their maximum potential, with no further advantage imparted on subsequent exercise performance. The attainment of this time point would be intrinsically linked to exercise intensity and duration, as well as ambient temperature, where hotter environmental conditions may negatively impact heat storage capacity and hence exercise performance (Gregson, Drust, Batterham & Cable, 2002). A similar explanation was provided by Gray and Nimmo (2001) to explain comparable subsequent performance results (30 s of intense cycling followed one min later by a cycle test to exhaustion) between an active and a no WUP trial. This would suggest that active WUP is more beneficial during the early stages of exercise, as demonstrated by improved first sprint results of ISP, compared to a no WUP trial, in the current study. In support of this concept is a study by Mohr et al. (2004) that reported that most soccer goals were scored in the first ten min of each game half following an active WUP. Linked to this explanation is the possibility that any ergogenic effects of an active WUP on subsequent ISP may be negated by physiological changes during the ISP (e.g., decreased phosphocreatine and glycogen stores and increases in lactate, hydrogen ions and other metabolites), as demonstrated in this study by significant increases in HR, RPE and blood lactate concentration over the course of both trials. Finally, it is possible that similar prolonged ISP between the WUP and no WUP trials may have been due to the use of a pacing strategy by subjects (despite being requested to sprint as fast as they could) that resulted in any long-term benefits associated with active WUP on ISP being of minimal or no consequence. Evidence that partially corroborates this premise relates to performance and EMG data that support the use of a pacing strategy during the first sprint of prolonged ISP, compared to single sprint performance that followed an active WUP.

Employment of an 80 min intermittent sprinting protocol, where energy contribution was predominantly from anaerobic sources (in particular, phosphocreatine), may explain the difference in results of this study to those that reported benefit associated with active WUP on long-term (< 25 min) continuous exercise (Atkinson et al., 2005; Grodjinovsky & Magel, 1970; Thompson, 1958). Results from this current study promote the idea of a ‘limited life-span’ for benefits associated with active WUP on subsequent ISP, with this information being important in team-game sports that use a player interchange protocol, such as in basketball.

4.7 CONCLUSION

Results from this study suggest that an active WUP, compared to no WUP, is beneficial for single sprint performance, as well as for the first sprint of prolonged ISP. However, active WUP was not able to improve prolonged ISP, compared to a no WUP trial. This may be due to the use of a pacing strategy by subjects, or the possibility that the initial sprints of prolonged ISP serve as a WUP stimulus in a no WUP trial, resulting in similar overall exercise performance. Alternatively, the benefits of WUP may be overridden by the metabolic consequences of prolonged ISP. Use of a pacing strategy also explains why performance of the first sprint of prolonged ISP was impaired to that of a single, isolated sprint.

4.8 KEY POINTS

- An active WUP improves single sprint performance compared to no WUP.
- The performance of the first sprint of an intermittent sprint protocol is improved following an active WUP, compared to no WUP; however, prolonged ISP is not improved following an active WUP.
- Single sprint performance is superior compared to the first sprint of an intermittent sprint protocol, suggesting that subjects may adopt a pacing strategy so as to maximise prolonged ISP.

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CHAPTER 5

5.0 STUDY THREE

5.1 TITLE: The effects of warm-up on intermittent sprint performance in a hot and humid environment.

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5.2 ABSTRACT

AIM: To investigate the effects of active warm-up (WUP) on 80 min of intermittent sprint performance (ISP) and first sprint performance performed in thermoneutral (~22^{o}C, 40% RH) or in hot and humid environmental conditions (35^{o}C, 50% RH). A second aim was to compare the effects of an active versus passive WUP on 80 min of ISP and first sprint performance performed in hot environmental conditions (35^{o}C, 50% RH). **METHODS:** Eleven male, team-sport athletes performed three experimental trials that consisted of 80 min (2 x 40 min 'halves') of ISP, performed on a cycle ergometer. The trials consisted of ISP preceded by either an active WUP (performed at an intensity midway between lactate inflection and lactate threshold), or a passive WUP (immersion in hot water) designed to achieve the same core temperature as active WUP. Active WUP followed by ISP was performed in both hot and thermoneutral environmental conditions, while passive WUP followed by ISP was performed in hot conditions only. **RESULTS:** There were no significant interaction effects between any of the WUP trials for ISP for total work (J·kg^{-1}), work decrement, and power decrement (P = 0.10, P = 0.42, P = 0.10, respectively). There were also no significant differences between any trials for work done for the first sprint of ISP (P = 0.22), however peak power was significantly higher after passive WUP compared to active WUP performed in either thermoneutral (P = 0.03), or in hot conditions (P = 0.02). **CONCLUSION:** Results are consistent with the notion that the main ergogenic effects of WUP, for first sprint performance, are derived from temperature related effects. Further, active WUP did not impair prolonged ISP in the heat compared to thermoneutral conditions. This can most likely be attributed to the moderate increase in temperature achieved by the intermittent sprint protocol.

Keywords: active warm up, passive warm up, pacing strategy, first sprint performance

5.3 INTRODUCTION

Warm-up (WUP) is a well-accepted practice, considered by many to be an essential part of any training session or team-sport competition to prepare athletes both physically and mentally for performance, as well as to prevent sport-related injuries (Bishop 2003a; Shellock & Prentice 1985). As suggested by the name, the majority of positive effects of WUP on subsequent exercise performance are commonly attributed to temperature related mechanisms (Bishop, 2003a). An increase in temperature, as a result of WUP, is proposed to improve exercise performance via decreased muscle and joint viscous resistance (Asmussen & Boje, 1945), greater release of oxygen from haemaglobin and myoglobin (Barcroft & King, 1909), the speeding of oxygen kinetics (Koga, Shiojiri, & Kondo, 1997), increased anaerobic metabolism (Febbraio, Carey, & Snow, 1996), as well as an increase in nerve conduction rates (Karvonen & Ilev, 1992). Increases in body temperature (T_b) can be achieved through the use of either an active or passive WUP. Active WUP raises T_b using physical movements that activate the body's major muscle groups, such as jogging and cycling, whereas passive WUP uses external methods to warm the body, such as hot baths, heat blankets and diathermy (Bishop 2003b). Importantly, WUP intensity needs to be high enough to induce temperature related benefits associated with WUP (Bishop, 2003a), but not be too high as to result in a large decrease in muscle and blood pH (Bishop, Bonetti & Dawson, 2001), depleted anaerobic energy stores (Bishop, 2003a), or reduced heat storage capacity (Gregson, Drust, Batterham & Cable, 2002), that can consequently impair subsequent exercise performance.

Of relevance, we recently determined that a WUP performed at an intensity that was midway between an individual's lactate inflection (LI) and lactate threshold (LT) produced a significant increase in both muscle and core temperature, but only a moderate increase in blood lactate concentration (2.01 ± 0.91 mmol·L^{-1}; unpublished study). Of importance, use of a WUP intensity based on individual lactate thresholds, rather than % $\dot{V}O_{2max}$, ensures that all subjects are performing under a similar metabolic strain when participating in exercise (Baldwin, Snow & Febbraio, 2001). While this WUP intensity resulted in a tendency for improved intermittent sprint performance (ISP) in thermoneutral conditions (effect sizes > 0.5), it is not known whether such a WUP would also improve performance in hot and humid environmental conditions, where a reduced heat-storage capacity has previously been reported to impair ISP (Gregson et al., 2002).

While there have been numerous studies to date that have investigated the effects of an elevated T_b on prolonged, continuous exercise performance, there is little information regarding the effects of an elevated T_b on prolonged ISP. This lack of research is surprising, as in many countries the most popular sports, and those with the highest participation levels, are team-sports (i.e. soccer, rugby, field hockey, basketball, etc.), which require athletes to sprint intermittently throughout the match.

To date, only three studies are known to the authors that have investigated the effects of elevated T_b on prolonged, intermittent exercise with bursts of all-out, short-duration (< 10 s) sprinting (Bishop & Maxwell, 2009; Morris, Neville, Lakomy, Nicholas & Williams, 1998; Morris, Nevill, & Williams 2000). Studies by Morris et al. (1998) and Morris et al. (2000) reported significant impairment in prolonged ISP in hot (~ 30ºC) compared to cooler (~ 17ºC) conditions, while Bishop and Maxwell (2009) reported no significant detriment in ISP after an active WUP, compared to no WUP, performed in hot environmental conditions (~35ºC, RH ~49%). Of importance, the sprint protocols used in the studies by Morris et al. (1998) and Morris et al. (2000) consisted of only 5 x 15 m sprints spread over a 75 min exercise duration, which is very different to sprint patterns performed in a team-sport game (Spencer et al., 2004), while Bishop and Maxwell (2009) only assessed 36 min of ISP (equivalent to 'half' a team game). Additionally, none of these studies used WUP intensities based on lactate thresholds. Further research is therefore required to investigate the effects of WUP (where intensity is midway between LI and LT), on prolonged ISP, performed in hot, humid conditions (similar to conditions experienced by team-sport athletes in the summer months), where the pattern of sprinting and recovery, and the duration of the exercise protocol, more closely replicates that of a typical team-sport game.

If an active WUP is shown to affect ISP in the heat, it would be important to determine whether any such changes can be attributed to temperature related factors or to other causes. For example, active WUP is also associated with non-temperature related benefits on subsequent exercise performance which include: increased blood flow and oxygen delivery to the working muscles (Bishop, 2003a; McComas, 1996); elevation of baseline oxygen consumption (McCutcheon, et al., 1999); post-activation potentiation (Vandervoort, Quinlan, & McComas, 1983); reduced muscle stiffness (Proske, Morgan, & Gregory, 1993); as well as psychological benefits (Shellock & Prentice, 1985). Conversely, active WUP can also result in negative effects on subsequent exercise performance, as described earlier. In contrast, passive WUP results in an increase in T_b, but is not associated with non-temperature related benefits on subsequent exercise performance. Nor is passive WUP associated with a decrease in high-energy substrates or an increase in lactate and other metabolites (Bishop 2003a). Thus the use of a passive WUP condition would allow us to determine whether any changes in ISP in hot, humid conditions, can be attributed to increases in T_b or to other factors.

Therefore, the purpose of this study was to investigate the effect of active WUP on 80 min of ISP (where the duration and the sprint pattern used were similar to those in a typical team-sport game; Spencer et al., 2004) in either a thermoneutral environment (22^{o}C, 40% RH) or in hot and humid conditions (35^{o}C, 50% RH). A second aim was to compare the effects of active versus passive WUP on the performance of an 80 min intermittent sprint protocol performed in a hot and humid environment (35^{o}C, 50% RH). First sprint performance of each condition was also investigated. It was hypothesised that prolonged ISP, and the first sprint of ISP, following an active WUP, would be impaired in hot and humid conditions compared to a thermoneutral environment, due to the extra heat load. Secondly, it was hypothesised that there would be no significant difference in ISP, or the first sprint of ISP, in hot and humid conditions between the active and the passive WUP conditions.

5.4 METHODS

5.4.1 Subjects

Eleven male subjects (mean ± SD: age: 24.3 ± 4.0 y, body mass: 74.4 ± 10.1 kg, $\dot{V}O_{2max}$: 52.8 ± 7.5 $mL \cdot kg^{-1} \cdot min^{-1}$) who participated in team-sports (Australian rules football, soccer and rugby) were recruited from the School of Sport Science, Exercise and Health at the University of Western Australia (UWA). Subjects were informed of the study requirements, benefits and risks before giving written informed consent. The UWA Research Ethics Committee granted approval for the study's procedures.

5.4.2 Experimental Overview

Subjects were required to complete one preliminary session and three experimental trials over a five week period. During the first preliminary visit, subjects performed a graded exercise test (GXT) to determine their lactate threshold (LT), $\dot{V}O_{2max}$ and maximal power output at $\dot{V}O_{2max}$. A familiarisation trial of the intermittent sprint test was also performed. During this visit, height was determined using a stadiometer (to the nearest 0.1 cm), while body mass was measured (to the nearest 0.01 kg) using Sauter scales (model ED3300, Ebingen, West Germany). Subjects then performed each of the three experimental trials. Subjects were asked to maintain their normal diet and training throughout the study and were required to consume no food or beverages (other than water) during the 2 h period prior to testing. Subjects were requested to keep a diary of their food and drink intake during the 48 hr period prior to exercise and to replicate this intake prior to each exercise trial. This process was checked by the researchers to ensure conformity. Additionally, subjects were asked not to consume alcohol or to perform vigorous exercise in the 24 h prior to testing. All exercise tests were performed on a calibrated, front-access cycle ergometer (Model EX-10, Repco, Australia) that had been modified to include a shield cover over the back wheel so to prevent the subject being cooled by the flywheel. This ergometer was interfaced with an IBM compatible computer system to allow for the collection of data for the calculation of work and power generated during each flywheel revolution (Cyclemax, The University of Western Australia, Perth, Australia). Before testing, the ergometer was dynamically calibrated on a mechanical rig (Western Australia Institute of Sport, Perth, Australia) across a range of power outputs (100-2000 W).

5.4.3 Graded Exercise Test (GXT)

The GXT was a multi-stage, discontinuous test that consisted of graded exercise steps (3 min stages), using an intermittent protocol (1 min of passive rest between stages). The test commenced at 70 W, and intensity was increased by 30 W every 3 min. Subjects were required to maintain the set power output, which was displayed on a computer screen in front of them. The test was stopped when the subject could no longer maintain the required power output (volitional exhaustion). Strong verbal encouragement was provided to each subject during the latter stages of the test. The LT was calculated using the modified Dmax method (Bishop, Jenkins, McEniery & Carey, 2000). This is determined by the point on the polynomial regression curve that yields the maximal perpendicular distance to the straight line connecting the first increase in lactate concentration of more than 0.4 mM above the resting level (the lactate inflection: LI; Yoshida et al. 1987) and the final lactate point. The GXT results, LT and maximum power output were used to calculate WUP intensity and the active recovery workload between each sprint during the ISP for each individual subject.

During the GXT, expired air was continuously analysed for O_2 and CO_2 concentrations using Ametek gas analysers (Applied Electrochemistry, SOV S-3 A/1 and COV CD-3A, Pittsburgh, PA). Ventilation was recorded every 15 s using a turbine ventilometer (Morgan, 225A, Kent, England). The gas analysers were calibrated immediately before and verified after each test using three certified gravimetric gas mixtures (BOC Gases, Chatswood, Australia), while the ventilometer was calibrated pre-exercise and verified post-exercise using a one-litre syringe, in accordance with the manufacturer's instructions. The ventilometer and gas analysers were connected to an IBM personal computer that measured and displayed variables every 15 s. The sum of the four highest consecutive 15 s $\dot{V}O_2$ values was recorded as the subject's $\dot{V}O_{2max}$.

5.4.4 Experimental Trials

The three experimental trials were performed in a randomised, counter-balanced order, at the same time of day, approximately one week apart. The three trials consisted of (1) an active WUP followed by ISP (2 x 40 min exercise bouts/halves separated by 10 min) performed in normal room temperature conditions (22.9 ± 0.9^{o}C, 42.7 ± 9.9% RH), (2) an active WUP followed by ISP (2 x 40 min exercise bouts separated by 10 min) performed in hot and humid conditions as simulated by a climate chamber (35.8 ± 1.6^{o}C, 47.8 ± 2.5% RH), and (3) a passive WUP followed by ISP (2 x 40 min exercise bouts separated by 10 min) performed in hot and humid conditions (35.8 ± 1.6^{o}C, 47.8 ± 2.5% RH). The active WUP was performed for 10 min at an intensity midway between the LI and the LT level, which equated to ~ 55% $\dot{V}O_{2max}$. This selected WUP intensity was based on the results of a previous study by the authors (submitted for publication) that demonstrated that this intensity elicited the best subsequent ISP (effect sizes > 0.5), when compared to four other WUP intensities assessed. For passive WUP, subjects sat in a hot water bath immersed to their xiphoid process for approx 10-15 min until their core temperature (T_c) was the same value as that recorded after active WUP performed in hot and humid environmental conditions. After both the active or passive WUP, subjects then passively rested for a 2 min prior to the beginning of the prolonged intermittent sprint trial.

5.4.5 Intermittent Sprint Performance

The ISP used in this study was based on a time-motion analysis study of international men's field hockey (Spencer et al., 2004), and was designed to mimic the sprint and recovery durations of a typical team-sport game. While this test was performed on a cycle ergometer, a strong correlation has been reported between intermittent sprint cycling and running performance (Bishop, Spencer, Duffield & Lawrence, 2001). Further, this cycle sprint test has been previously used in other studies in order to simulate intermittent sprints and recovery periods performed during a team-sport game (Bishop & Claudius, 2004, Bishop & Maxwell, 2009, Schneiker, Bishop & Dawson, 2006). The protocol consisted of 40 min of intermittent sprint exercise which was divided into ~2 min blocks consisting of a 4 s 'all out sprint', 100 s of active recovery (performed at a pace equivalent to individual LI) and 20 s of passive rest (Figure 5.1). Subjects were advised to sprint as fast as they could for each sprint. The protocol was completed twice so as to simulate the duration of a typical full team-sport game and included a 10 min passive rest between each 40 min bout. In all conditions, subjects were required to continue cycling during the 100 s of active recovery at the LI intensity determined during the GXT. Sprints were performed in the standing position, on a front-access, wind-braked, cycle ergometer that was fitted with toe clips and heel straps.

During each experimental trial, total work performed ($J \cdot kg^{-1}$) and the percent of work and power decrement for ISP were calculated for each of the two 40 min exercise bouts ('halves'), as well as for the full 80 min protocol. Percentage work and power decrement were determined using a method modified from that described by Fitzsimmons, Dawson, Ward and Wilkinson, (1993), i.e., 100-[(total performance/ [best performance x 20]) x 100]. Further, peak power ($W \cdot kg^{-1}$) and work done for the first sprint of ISP were calculated for all trials. In addition, heart rate (HR; Polar Electro Oy, Kempele, Finland), blood lactate concentrations and ratings of perceived exertion (RPE), as determined by the Borg scale (6-20 scale; Borg, 1982) were assessed (Figure 1). During the exercise protocol, subjects consumed 3 $mL \cdot kg^{-1}$ body-mass of water every 20 min in order to standardise fluid intake.

5.4.6 Capillary Blood Sampling and Analysis

A hyperaemic ointment (Finalgon, Boeringer Ingelheim, Germany) was applied to the subject's earlobe 5-7 min prior to the initial blood sampling. Glass capillary tubes were used to collect 35 μL of blood during the GXT and ISP (D957G-70-35, Clinitubes, Radiometer Copenhagen). Capillary blood samples were taken at rest and immediately following each 3 min stage of the GXT. Capillary blood samples were also taken immediately prior to WUP, immediately after WUP, immediately after the final (20^{th}) sprint of both 'halves' of the experimental trials, as well as prior to the 1st sprint of the second half of the protocol (following the 10 min rest period). Blood lactate concentration was determined using a blood-gas analyser (ABL625, Radiometer Copenhagen). The blood-gas analyser was regularly calibrated using precision standards and was routinely assessed using external quality controls.

5.4.7 Core Temperature Measurement

Core temperature (T_c) was measured in the small intestine using a silicon-coated core temperature pill (CorTemp™, HQ Inc., Florida, USA). Each pill contained a crystal quartz oscillator which transmitted a low frequency radio wave to an external receiver. Data from the temperature pill was recorded with the use of a telemetric monitoring system (CoreTemp™ 2000 data recorder). The ingestible pill was swallowed ~6 h prior to the intermittent sprint test to ensure that it would be past the stomach, in the small intestine, and insensible to the drinking of cold fluids. Temperature readings by CoreTemp™ have been found to be highly correlated to rectal temperature ($r = 0.98$, $P < 0.01$; Easton, Fudge & Pitsiladis 2007). In order to comply with ethics guidelines, exercise was terminated at the subject's request or if T_c reached 39.5ºC. This situation occurred on two occasions; one where a subject asked to terminate the test after the 13th sprint of the second 'half' of the protocol during the passive WUP trial, while another subject's T_c reached 39.5ºC following sprint number 8 in the second 'half' of the protocol following active WUP (hot and humid environmental conditions). Both subject's data were included in all analyses. Core temperature was recorded pre-WUP, post-WUP, prior to the first sprint (both halves), and at the end of the last (20th) sprint of both halves.

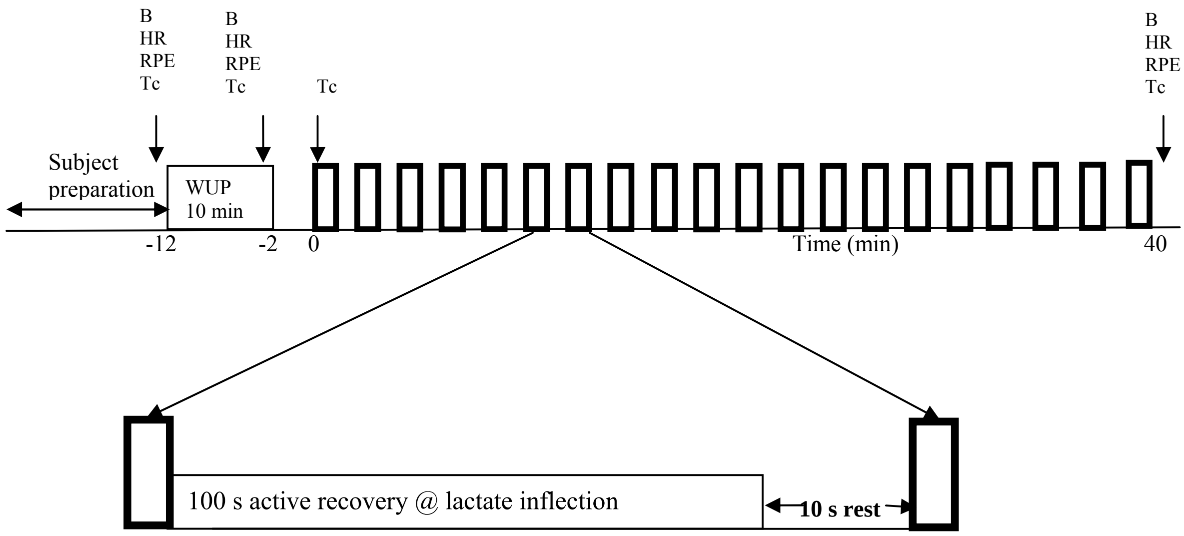

Figure 5.1. - Schematic of the first half of the intermittent sprint protocol. Each ~2-min block consisted of a 4 s maximal sprint, 100 s of active recovery performed at lactate inflection

determined during a graded exercise test, and 10 s passive rest. = 4 s sprint, B = blood sample (lactate), RPE = rating of perceived exertion, HR = heart rate, T_c = core temperature, WUP = warm-up.

5.4.8 Sweat Loss

Nude body mass, to the nearest 10 g, was measured both before and immediately after the exercise protocol using a digital platform scale (model ED3300; Sauter Multi-Range, Ebingen, West Germany). Sweat loss was calculated as the difference between pre- and post-exercise body mass, whilst accounting for the ingestion of water during the performance trial. Subjects towel dried their body prior to weighing, while toilet visits were postponed until after the final weighing.

5.4.9 Environmental Conditions

Ambient temperature and RH were measured during the exercise by a digital temperature and humidity meter (model 971; Fluke, Everett, WA). This device has a temperature range of -20 to 60°C with an accuracy of ± 0.5°C for temperatures between 0 to 45°C, while the humidity range is 5 to 95% with an accuracy of ± 2.5% for conditions between 10 to 90% RH (manufacturer details). Values provided by this device consistently matched temperature and humidity values that were recorded independently in the climate chamber.

5.4.10 Data Analysis

Differences in total work performed and % of work and power decrement between the three WUP trials during both 40 min 'halves' and the full 80 min exercise protocol were assessed using a two-way, repeated-measures ANOVA (3 trials x 3 time points). Differences in work and power output for the first sprint of ISP for the three different trials were assessed using a one-way, repeated-measures ANOVA (one group x 3 trials). Heart rate, RPE and blood lactate concentration was assessed using a two-way repeated measures ANOVA (3 trials x 5 time points), while T_c was also assessed using a two-way, repeated-measures ANOVA (3 trials x 6 time points). A Bonferroni t-test was applied whenever significance was found. Statistical significance was accepted at the level of $P < 0.05$. All statistical analyses were conducted using the SigmaStat statistical package (Version 3.1, SigmaStat, Richmond, California, USA).

5.5 RESULTS

5.5.1 Performance

There were no significant interaction effects between any of the WUP trials for total work ($J \cdot kg^{-1}$) or for percentage work and power decrement ($P = 0.10$, $P = 0.42$, $P = 0.10$, respectively). This meant that performance was similar between trials at the end of each 'half' of ISP, as well as for the entire intermittent sprint protocol. Further, percentage work and power decrement were significantly greater in the second half of the intermittent sprint protocol, compared to the first half, for active WUP performed in the heat ($P = 0.004$; Table 5.1).

Table 5.1. Total work (W_{tot}), work decrement (W_{dec}) and power decrement (P_{dec}) recorded during an 80 min intermittent sprint protocol (divided into 2 x 40 min halves; each half = 20 x 4 s plus recovery per half) following active warm-up (WUP) in thermoneutral conditions (active WUP neutral), active WUP in hot and humid conditions (active WUP hot) and passive WUP in hot and humid conditions (passive WUP hot). Values are mean ± SEM, n=11.

	W_{tot} (J·kg^{-1})	%W_{dec}	%P_{dec}
Active WUP neutral			
End 1st 40 min	939 ± 44	10.1± 0.9	7.4 ± 0.5
End 2nd 40 min	963 ± 47	11.0 ± 1.3	8.7 ± 1.5
End 80 min	1902 ± 92	13.0 ± 1.1	9.4 ± 1.1
Active WUP hot			
End 1st 40 min	989 ± 68	12.1 ± 1.3	7.4 ± 1.0
End 2nd 40 min	967 ± 55	15.0 ± 1.3†	11.2 ± 1.4†
End 80 min	1956 ± 138	14.8 ± 1.2	10.1 ± 1.4
Passive WUP hot			
End 1st 40 min	1004 ± 58	11.1 ± 1.4	8.4 ± 1.4
End 2nd 40 min	1009 ± 63	12.2 ± 1.5	9.3 ± 1.4
End 80 min	2013 ± 123	13.4 ± 1.4	10.4 ± 1.2

† = 2nd 'half' was significantly higher than 1st 'half' ($P < 0.05$).

There were no significant differences between any of the WUP trials for work done for the first sprint of the prolonged ISP ($P = 0.22$). However, peak power output for the first sprint was found to be significantly higher after passive WUP compared to active WUP performed in either thermoneutral or hot environmental conditions ($P = 0.03$, $P = 0.02$, respectively). In addition, peak power output for the first sprint of ISP was significantly higher in the first 'half' of the 80 min exercise protocol compared to the second 'half' following the passive WUP trial ($P < 0.05$; Table 5.2).

Table 5.2. Work done for the first sprint (1st W), and peak power output for the first sprint (1st P_{peak}) recorded during two x 40 min bouts (halves) of intermittent exercise (20 x 4 s sprints and recovery per half) following active warm-up (WUP) in thermoneutral conditions (active WUP neutral), active WUP in hot and humid conditions (active WUP hot) and passive WUP in a hot and humid condition (passive WUP hot). Values are mean ± SEM, N=11.

	Active WUP neutral		**Active WUP hot**		**Passive WUP hot**	
	1st half	**2nd half**	**1st half**	**2nd half**	**1st half**	**2nd half**
1st sprint work ($J \cdot kg^{-1}$)	40.6 ± 2.4	43.5 ± 2.2	42.5 ± 3.2	43.2 ± 2.9	46.4 ± 3.0	43.6 ± 3.7
1st sprint P_{peak} ($W \cdot kg^{-1}$)	14.7 ± 0.6	14.8 ± 0.7	14.8 ± 1.0	15.3 ± 0.8	16.0 ± 0.8 *†	15.1 ± 0.9

* = significantly higher than active WUP neutral and active WUP hot ($P < 0.05$), † = significantly higher than the second half ($P < 0.05$).

5.5.2 Core Temperature

Core temperature values were similar between all WUP trials prior to WUP, as well as after 10 min of either active or passive WUP ($P > 0.05$). At the end of the first half (40 min) of ISP, T_c increased significantly in all WUP trials, and then decreased significantly during the 10 min passive rest period in all WUP trials ($P < 0.05$). However, during the passive rest period, T_c was significantly higher ($P < 0.05$) after active WUP (hot conditions) compared to values recorded for passive WUP (hot conditions) and active WUP (thermoneutral conditions). By the end of the 80 min ISP, final T_c was significantly higher after active WUP (hot conditions) compared to active WUP (thermoneutral conditions, $P < 0.05$: Figure 5.2).

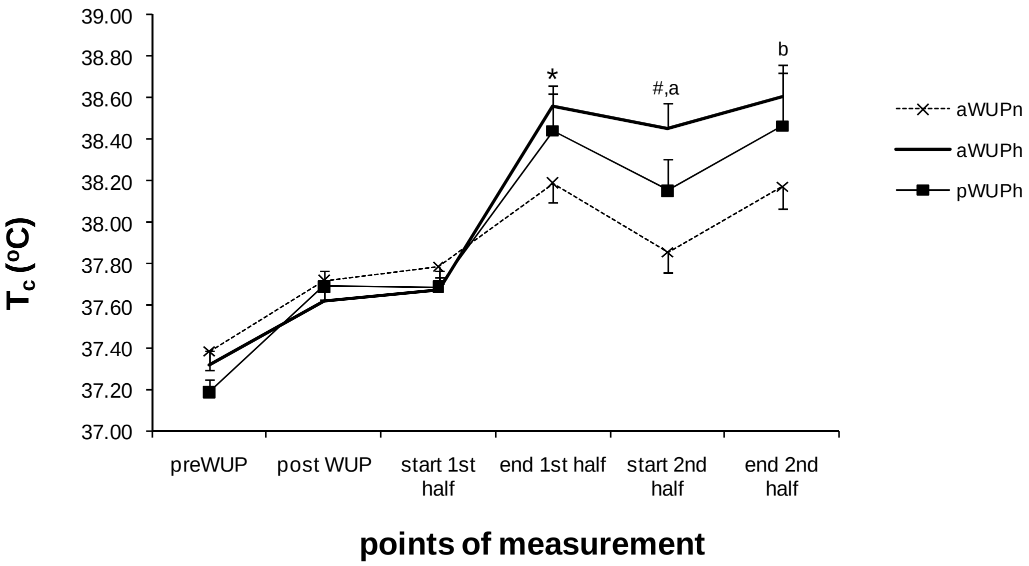

Figure. 5.2 – Core temperature (T_c) for each WUP trial at rest (pre WUP), immediately after WUP (post WUP), immediately prior to 2 x 40 min bouts (halves) of an intermittent sprint protocol (before 1st half and before 2nd half) and at the end of both halves of the intermittent sprint protocol (end 1st half and end 2nd half) following active WUP in thermoneutral environmental conditions (aWUPn), active WUP in hot and humid conditions (aWUPh) and passive WUP in hot and humid conditions (pWUPh). Values are mean ± SEM, N= 11. * = significantly different to start of 1st half for all WUP trials ($P < 0.05$). # = significantly different to end of 1st half for all WUP trials ($P < 0.05$). ^{a} = aWUPh significantly higher than aWUPn and pWUPh. ^{b} = aWUPh significantly higher than aWUPn ($P < 0.05$).

5.5.3 Blood Lactate Concentration

The only significant differences found in blood lactate concentrations over time were post-WUP, where blood lactate concentrations were significantly higher ($P < 0.05$) after active WUP in both hot and thermoneutral environmental conditions compared to the passive WUP trial in hot conditions. Further, blood lactate concentrations were significantly higher post-WUP ($P < 0.05$) compared to pre-WUP for both active WUP trials, but not for the passive WUP trial in hot conditions. Following the first 40 min half of ISP, blood lactate increased significantly in both the active and passive WUP trials that were performed in hot environmental conditions (1.8 $mmol \cdot L^{-1}$ and 3.1 $mmol \cdot L^{-1}$ increase, respectively; $P < 0.05$) compared to post-WUP values, however there were no significant differences between these values for any of the WUP trials at this time point. Blood lactate concentrations then decreased in all WUP trials after the passive rest period, with this decrease being significantly lower ($P < 0.05$) in the active WUP (thermoneutral) trial, compared to values recorded at the end of the 20th sprint in this trial. Finally, blood lactate concentrations increased in all trials during the second half of the ISP with these changes not reaching significance ($P > 0.05$). Values for blood lactate concentration can be found in Table 5.3.

5.5.4 Heart Rate

Heart rate increased significantly post-WUP compared to pre-WUP in every WUP trial (Table 5.3). However, HR was significantly higher post-WUP ($P < 0.05$) following both active WUP trials (hot and thermoneutral) compared to passive WUP (hot conditions). At the end of the first half (sprint 20) of the ISP, HR values for both the active and passive WUP trials (hot conditions) were significantly higher ($P < 0.05$) compared to the start of the ISP, with these values being significantly higher than those for the active WUP trial performed in thermoneutral conditions ($P < 0.05$). After a 10 min passive rest period, HR in all three WUP trials significantly decreased compared to values recorded at the end of sprint 20, with HR remaining significantly higher for both active and passive WUP (hot) trials compared to the active WUP (thermoneutral) trial. Final HR values in all WUP trials were significantly higher at the end of sprint 40, compared to values recorded at the end of the rest period ($P < 0.05$), with final HR values for both the active and passive WUP (hot) trials being significantly higher than the active WUP (thermoneutral) trial. Heart rate values are shown in Table 5.3.

5.5.5 Ratings of Perceived Exertion

There were no significant differences in RPE between the three WUP trials ($P > 0.05$) prior to WUP. However, RPE increased significantly from pre-WUP to post-WUP ($P < 0.05$) for both active WUP (hot and thermoneutral) trials, and then from post-WUP to the end of the first half of ISP (sprint 20; $P < 0.05$) in all three WUP trials. After 10 min of passive rest, and then at the end of the second half of the ISP (sprint 40), RPE for all three WUP trials changed in a similar pattern. Specifically, there was a significant decrease in RPE for all three WUP trials during the passive rest period ($P < 0.05$), followed by a significant increase ($P < 0.05$) in RPE in all three trials by the end of the second half (sprint 40) of the ISP (Table 5.3). Further, RPE values for active WUP in hot conditions were significantly higher than active WUP in thermoneutral conditions for every time point measured apart from pre and post-WUP ($P < 0.05$), while RPE for passive WUP (hot) was significantly lower ($P < 0.05$) than both active WUP trials immediately post-WUP.

Table 5.3. Blood lactate concentration ($[La^-]$; $mmol·L^{-1}$), heart rate (HR; $beats·min^{-1}$) and rating of perceived exertion (RPE) for each warm-up (WUP) trial pre WUP, immediately post WUP, at the end of 10 min passive rest, and immediately after the 20th and the 40th sprint of 80 min of intermittent sprints, following active WUP in a thermoneutral condition (active WUP neutral), active WUP in hot and humid conditions (active WUP hot) and passive WUP in hot and humid conditions (passive WUP hot). Values are mean ± SEM, N= 11.

		pre WUP	post WUP	Sprint 20	end passive rest	Sprint 40
HR ($beat·min^{-1}$)	Active WUP neutral	79 ± 3	$137 \pm 4^{b\dagger}$	132 ± 4	$97 \pm 4^{\#}$	$132 \pm 5^{@}$
	Active WUP hot	84 ± 2	$141 \pm 3^{b\dagger}$	$150 \pm 3^{a*}$	$119 \pm 4^{a\#}$	$153 \pm 4^{a@}$
	Passive WUP hot	83 ± 2	$104 \pm 5^{\dagger}$	$145 \pm 5^{a*}$	$110 \pm 5^{a\#}$	$149 \pm 5^{a@}$
RPE	Active WUP neutral	6 ± 0.2	$10 \pm 0.6^{b\dagger}$	13 ± 0.6*	$8 \pm 0.7^{\#}$	$14 \pm 0.6^{@}$
	Active WUP hot	6 ± 0.1	$11 \pm 0.5^{b\dagger}$	$15 \pm 0.6^{a*}$	$11 \pm 0.6^{a\#}$	$16 \pm 0.8^{a@}$
	Passive WUP hot	6 ± 0.0	6 ± 0.7	14 ± 0.6*	$9 \pm 0.7^{\#}$	$15 \pm 0.9^{@}$
La ($mmol·L^{-1}$)	Active WUP neutral	1.1± 0.1	$3.5 \pm 0.4^{b,\dagger}$	4.4 ± 0.5	$2.8 \pm 0.3^{\#}$	3.8 ± 0.4
	Active WUP hot	1.0 ± 0.1	$3.1 \pm 0.3^{b,\dagger}$	4.9 ± 0.7*	3.5 ± 0.5	4.1 ± 0.6
	Passive WUP hot	1.0 ± 0.1	1.1 ± 0.1	4.2 ± 0.6*	2.9 ± 0.4	4.2 ± 0.6

. ^{a}, ^{b}, = significantly different from active WUP neutral and passive WUP hot, respectively ($P < 0.05$). † = significantly different from pre WUP, * = significantly different from post WUP, # =

significantly different from sprint 20 ($P < 0.05$), @ = significantly different to end of passive rest values ($P < 0.05$).

5.5.6 Sweat Loss

Taking into account pre and post-exercise nude body mass, as well as water ingestion during the ISP (described in methods), the amount of sweat loss during the entire exercise protocol (including active WUP), was significantly higher in hot and humid conditions than in the thermoneutral environmental condition ($P < 0.001$ for both active and passive WUP in hot conditions). Results are as follows: active WUP in thermoneutral conditions = 0.98 ± 0.08 L, active WUP in hot conditions = 1.48 ± 0.14 L, passive WUP in hot conditions = 1.40 ± 0.13 L, respectively.

5.6 DISCUSSION

5.6.1 Overview

This study is the first to assess the effects of a passive and an active WUP (where exercise intensity was midway between LI and LT), on prolonged (80 min) ISP that simulated sprint and recovery durations found in a typical team-sport game, performed in hot and humid environmental conditions. Of relevance, final values for T_c (~ 38.6°C), blood lactate concentrations (4 – 5 $mmol \cdot L^{-1}$) and HR (~ 150 $b \cdot min^{-1}$) recorded in this study were similar to those previously reported following football (soccer) matches (Krustrup et al. 2006; Mohr, Krustrup, Nybo, Nielsen & Bangsbo, 2004) and suggests that the intermittent sprint protocol used was able to replicate, in part, some of the physical demands of a typical team-sport game. The major finding of this study was that environmental conditions did not alter the effects of an active

WUP on prolonged ISP, or the first sprint of the intermittent sprint protocol. Further, results for the passive WUP trial demonstrated that raising core temperature alone (by ~ 0.5^{o}C) had no effect on prolonged ISP, but improved first sprint power output compared to active WUP performed in either thermoneutral or hot environmental conditions.

5.6.2 First Sprint Performance

Consistent with previous research, we found no effects of environmental temperature on the first sprint of ISP that was preceded by an active WUP. Similar results were also reported by Drust, Rasmussen, Mohr, Nielsen and Nybo (2005), who observed no significant difference in the performance of the first sprint of a 5 x 15 s repeated sprint test performed in normal (~20^{o}C) and hot (~40^{o}C, hyperthermia) environments. In addition, Backx, McNaughton, Crickmore, Palmer and Carlisle (2000), also reported no significant difference in performance of a 30 s Wingate test after an active WUP performed in a hot and humid environment (40ºC, 40% RH), compared to thermoneutral conditions (22ºC, 30% RH). These researchers concluded that short-term anaerobic exercise was not unduly affected by hot or humid conditions. Our findings add to the literature by demonstrating that short (4 s) sprint performance is also unaffected by environmental conditions (i.e., 22.9^{o}C, 42.7% RH vs 35.8^{o}C, 47.8% RH) when preceded by an active WUP.

An interesting observation from this current study was that the work done during the first sprint (first half of the protocol) was 14.2 % and 9.2% greater (ns) following passive WUP compared to active WUP (in thermoneutral and hot conditions, respectively), while peak power was significantly higher. This result is surprising as many previous studies have reported no significant difference between an active and passive WUP for short-term exercise performance, with this outcome proposed to reflect the importance of temperature related effects associated with both modes of WUP on subsequent short-term maximal exercise performance (Asmussen & Boje, 1945, Dolan, Greig & Sargeant, 1985; Muildo, 1946). While our results for first sprint performance following a passive WUP support the importance of temperature related effects on initial exercise, they also highlight the lack of major effect of non-temperature related benefits associated with active WUP on initial sprint performance. It would also appear that other accompanying physiological changes that occur as a result of active WUP may have attenuated temperature related benefits associated with active WUP on first sprint performance. In support of this, HR, RPE and blood lactate concentration were all significantly higher following active WUP (thermoneutral and hot conditions) compared to passive WUP, while post-WUP T_c values were similar (by design). A potential mechanism which may have dampened the ergogenic effects of the active WUP in the present study is an increase in muscle lactate (and the accompanying acidosis), which has been hypothesised to impair muscle contraction and the supply of anaerobic energy (Fabiato & Fabiato 1978). While blood lactate concentrations following active WUP (thermoneutral and hot conditions) were only 3.5 and 3.1 $mmol \cdot L^{-1}$ respectively, the significant differences between these values and those following the passive WUP (i.e., 1.1 $mmol \cdot L^{-1}$), may have been high enough to negatively impact upon subsequent first sprint performance. Further, it is unlikely that depleted phosphocreatine stores, as a result of active WUP, would have impaired subsequent first sprint performance due to the low intensity nature of the WUP, combined with the 2 min recovery period undertaken prior to exercise performance, which should have been sufficient for the near-complete resynthesis of muscle phosphocreatine stores (Nevill, Jones, McIntyre, Bogdanis, & Nevill, 1997).

Differences in results between the current study and those that reported no significant difference in short-term exercise performance between an active and passive WUP trial (Asmussen & Boje, 1945, Dolan et al., 1985; Muildo, 1946) may be related to the low cohorts used in these other studies (3-4 subjects), the different subsequent exercise protocols used, as well as the fact that statistical analyses were not performed by Asmussen and Boje (1945), or Muildo (1946). While further research is required, these results have interesting implications for the design of WUP routines aimed to improve the first sprint of ISP, with this initial action being important during the opening seconds of a team-sport game, where a quick successful sporting maneuver may be considered important to subsequent play.

5.6.3 Prolonged Intermittent Sprint Performance

In contrast to our hypothesis, ISP following an active WUP, was not impaired when performed in hot and humid conditions compared to thermoneutral conditions. These results are different to those of two previous studies which reported significant impairment in prolonged, ISP in hot (~ 30ºC) compared to moderate (~ 17ºC) environmental conditions (Morris et al. 1998; Morris et al. 2000). However, impaired ISP reported in these two studies was linked to elevated T_c (39.1-39.4ºC), which was greater than that reported in the current study (38.5 – 38.7ºC). The impact of high body temperature on exercise performance is also noted by Drust et al. (2005), who reported reduced power output during a cycle test performed in hot (~40ºC) compared to cooler (~20ºC) environmental conditions and suggested that these results were due to an elevated T_c (39.5ºC) that may have affected the function of the central nervous system, and hence exercise performance. Furthermore, Gregson et al. (2002) proposed that reduced exercise time to exhaustion, following both an active and passive WUP (compared to a no WUP condition), was most likely due to the significantly higher T_{re} that occurred in both WUP conditions (with final T_{re} values ranging between 39.3 – 39.4ºC), which most likely resulted in changes to heat storage capacity. Consequently, the increase in T_c during the hot and humid exercise trials in the present study may not have been sufficient to impair ISP. This is consistent with the results of Bishop and Maxwell (2009), who also reported no significant differences in prolonged ISP (36 min) when final rectal temperatures reached 'only' 38.6 ºC. While the existence of a critical T_c and its effects on fatigue and hence exercise performance has recently been challenged (Ely et al., 2009), these researchers still concluded that heat stress and fatigue were dependent upon a complex interplay of multiple physiological systems, which included T_c. Of importance, there have been many previous studies that have described a critical T_c associated with impaired exercise performance.

Similar ISP reported in the current study between environmental conditions may also be partially attributed to the recruitment of team-sports athletes, as opposed to non-athletes (Drust et al. 2005; Morris et al. 1998), who were accustomed to performing intermittent sprint exercise, as well as to exercising in hot environmental conditions. In support of this, it has previously been reported that the performance of intermittent sprints (repeated 15 m sprints) took longer in the heat for female endurance athletes, but not female team-sport athletes (Morris et al. 2000). Furthermore, the current study was performed during October and November, when average local temperatures ranged from 21 – 27ºC, suggesting that subjects were likely to have been partially heat acclimatized. Importantly, heat acclimatisation has been reported to reduce the impact of hot environmental conditions on exercise performance (Nadel & Horwath 1977).

There were also no significant differences in prolonged ISP between the passive and active WUP trials (hot conditions) in this study. Most likely, this can be attributed to the similar increase in T_c following both WUP protocols (by design). In addition, it is possible that the first few sprints of the ISP, following the passive WUP, may have provided non-temperature-related benefits associated with an active WUP on subsequent exercise (described earlier), resulting in comparable overall ISP. Alternatively, there may come a time point during prolonged intermittent exercise where benefits associated with both active and passive WUP reach their maximum potential, with no further advantage imparted on subsequent exercise performance. A similar explanation was provided by Gray and Nimmo (2001) to explain comparable subsequent performance results (30 s of intense cycling followed one min later by a cycle test to exhaustion) between an active and a no WUP trial. This would suggest that WUP has greater ergogenic effects during the early stages of exercise. Linked to this proposition is the possibility that any benefit related to the performance of an active or passive WUP on subsequent ISP may be overridden in time by the associated metabolic costs of prolonged ISP (i.e., decreased phosphocreatine and glycogen stores and increased blood lactate concentration and other metabolic wastes). The increasing metabolic strain of prolonged ISP is demonstrated, to some extent, in this study by the significant increases in T_c, HR, RPE and blood lactate concentrations over the course of prolonged ISP in all three trials.

Alternatively, similar prolonged ISP between all trials may reflect the use of a pacing strategy by subjects (despite subjects being told to sprint as fast as they could) (Abbiss & Laursen, 2008). It has previously been proposed that a subconscious “controller” determines the overall pacing strategy used during exercise by matching the rate of energy expenditure and the current energy reserves with the predicted energy cost of the exercise (Ulmer, 1996). Furthermore, this "controller" considers the duration of the planned effort and calculates the pacing strategy on the basis of previous experience (Ulmer, 1996). It has been further been suggested that pacing may be employed by athletes in order to avoid the attainment of a critical Tc, beyond which thermal injury becomes imminent (Marino, 2004). However, similar results for prolonged ISP between environmental conditions found in our study challenges this concept. The use of a pacing strategy may not have allowed the ergogenic effects of the different WUP conditions to be fully realised.

5.7 CONCLUSION

Our results are consistent with the notion that the main benefits of WUP, for single sprint performance, are derived from temperature related effects. However, it appears that other physiological changes associated with the active WUP protocol used in this study may have attenuated these benefits. In contrast to our hypothesis, active WUP did not impair prolonged ISP in the heat. This can most likely be attributed to the moderate increase in temperature achieved by our intermittent sprint protocol. However, it is worth noting that the changes in T_c following our ISP were similar to those previously observed during competitive football (soccer) matches. Further studies that include a no WUP trial and a passive WUP performed in a thermoneutral environment would provide more information on the effects of WUP on subsequent prolonged, ISP.

5.8 KEY POINTS

- First sprint of a prolonged intermittent sprint protocol is improved when preceded by a passive WUP compared to an active WUP performed in thermoneutral and hot and humid condotions.
- A 10-min active WUP, performed at an intensity midway between lactate inflection and lactate threshold, does not impair prolonged (80 min) intermittent sprint performance in the heat compared to thermoneutral conditions.
- There is no difference in prolonged (80 min) intermittent sprint performance, performed in hot environmental conditions, when preceded by an active or a passive WUP.

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CHAPTER 6

6.0 DISCUSSION

6.1 OVERVIEW

This current research consisted of a series of three studies that focused on the effects of WUP on ISP that simulated movement patterns found in a team-sport game. The important and novel aspect of these studies was that the WUP intensities used were based around each subject's lactate thresholds in an effort to standardise the metabolic strain experienced by all subjects during these different WUP protocols. This method was selected as it has previously been shown that HR and blood lactate differed between subjects of varying fitness levels when exercise was performed at a % of $\dot{V}O_{2max}$, but were similar during exercise performed at a given percent of their anaerobic threshold (also known as lactate threshold: LT) (Baldwin, et al., 2000). To the author's knowledge, only one other published study to date has employed WUP intensities based on lactate accumulation, as opposed to % $\dot{V}O_{2max}$, in order to assess the impact of these intensities on subsequent exercise performance, with this particular study assessing the impact of WUP on a 2 min kayak sprint (Bishop et al., 2001). In addition, there has been minimal research to date that has assessed the effect of WUP on exercise that simulates sprints found in a team-sport game, with the only two studies known by the author to have assessed this aspect having used % $\dot{V}O_{2max}$ as a guide for WUP intensity (Bishop & Claudius, 2004; Bishop & Maxwell, 2009). Finally, there have been no studies known to the author that have assessed the effect of a passive WUP and an active WUP (where intensity was based on lactate thresholds) on sprints that simulated a team-sport game performed in hot and humid environmental conditions.

6.2 SUMMARY OF THE AIMS OF THE STUDIES

In an effort to explore the use of lactate thresholds as a guide for WUP intensity, the first study aimed to assess the effects of five WUP intensities based on varying lactate thresholds on 6 x 4 s intermittent sprints, performed on a cycle ergometer, with 21 s of recovery between sprints. This analysis also involved the assessment of first sprint performance. In accordance with the summations made in the literature review, the duration of the active WUP was 10 min, while a 2 min passive recovery period was included prior to subsequent exercise performance.

Based on the results of study 1, the second study aimed to assess the effects of a no WUP condition and an active WUP (performed midway between LI and LT) on single sprint performance and prolonged ISP. The effects of WUP on the first sprint of the ISP were also assessed. The ISP used in this study simulated sprints performed in a typical team-sport game (Spencer et al., 2004), while the duration equated to that of a full team-sport game (80 min consisting of 2 x 40 min 'halves' separated by 10 min rest).

Finally, the third study aimed to assess the effects of passive and active WUP (performed midway between LI and LT) on prolonged ISP (80 min) that was performed in hot and humid environmental conditions (35^{o}C, 50% RH), where the sprints and the duration of exercise simulated those found in a team-sport game. A third trial involved the assessment of active WUP on ISP in cooler environmental conditions (20-25^{o}C, 20-40% RH). In addition, the initial sprint of the ISP was assessed in all three WUP trials.

6.3 SUMMARY OF STUDY FINDINGS

Results from the first study demonstrated that none of the WUP protocols used resulted in significant changes in subsequent ISP (including first sprint performance). These results were contrary to our hypothesis that improved ISP would be achieved following a moderate WUP intensity, which was not too high so to impair exercise performance, or too low as to not achieve temperature related benefits associated with WUP. Furthermore, this study found no significant correlations between T_{mu}, T_{re} or T_b and any of the performance variables assessed. An interesting observation of this study was the minimal (non significant) or no change in T_{mu}, T_{re} and T_b during the recovery period immediately following WUP and prior to subsequent exercise, which suggested that this period was not too long as to negate any possible benefits associated with temperature related mechanisms of WUP on ISP.

While results from study one showed no significant impact of varying WUP intensities (based on lactate thresholds) on subsequent exercise performance, total work values were highest after WUP 3 (midway between LI and LT), whilst percent work decrement values were the lowest. In addition, these results, as well as work and power output for the first sprint, were supported by moderate to large effect sizes associated with WUP 3, suggesting that this intensity may be the most appropriate for eliciting improvement in ISP. Of relevance, WUP 3 was of similar intensity (~55% $\dot{V}O_{2max}$) to the WUP protocols used in other studies that reported improved single sprint performance (Sargeant & Dolan, 1987; Stewart &, Sleivert, 1988).

Results from study two demonstrated that active WUP, compared to a no WUP trial, improved single sprint ability (peak power) and the first sprint of ISP ($J \cdot kg^{-1}$), as hypothesised, but had no significant effect on prolonged ISP. In addition, as hypothesised, power output for single sprint performance following active WUP was significantly higher when compared to the first sprint of ISP in both the WUP and no WUP trials.

In the third study, results for the initial sprint of ISP following active WUP in both hot and thermoneutral environmental conditions were consistent with previous studies by Drust et al. (2005) and Backx et al. (2000), who reported no effect of environmental temperature on 15 s and 30 s single sprint performance, respectively. Similar results for initial sprint performance following active WUP in both environmental conditions were also reflected by comparable results for T_c, RPE and blood lactate concentrations recorded post-WUP for these two trials. Interestingly, work done during the first sprint of ISP was 14.2 % and 9.2% greater (ns) following passive WUP, compared to active WUP (in thermoneutral and hot conditions, respectively), while peak power was significantly higher. While results for work done during the first sprint of ISP were not statistically significant, their practical significance in a team-game situation is important. Results from study three also demonstrated that there was no effect of environmental temperature on 80 min of ISP that simulated sprints performed in a team-sport game.

6.4 SUMMARY OF OVERALL FINDINGS – DID WARM-UP BENEFIT EXERCISE PERFORMANCE?

Lack of a control group in study one precluded the determination of whether WUP had a beneficial, deleterious or no effect on subsequent exercise performance. Of interest, however, insignificant results between the various WUP intensities for ISP and first sprint performance demonstrated in this study suggested that the significantly higher blood lactate concentrations reported pre-bout after WUP's 4 and 5 compared to WUP's 1, 2 and 3 did not have a detrimental effect on subsequent exercise performance that consisted of intermittent sprinting. Furthermore, significant differences in T_{mu}, T_{re} and T_b recorded prior to ISP between some but not all WUP trials demonstrated that temperature also did not play a major role in performance outcomes. This would suggest that the intensity of the WUP was inconsequential in respect to subsequent intermittent sprint performance. This result was surprising, particularly as Bishop et al. (2000) had earlier reported impaired 2 min 'all-out' kayak ergometer performance following a WUP that resulted in an average blood lactate concentration of 5.1 ± 1.4 $mmol \cdot L^{-1}$ immediately post-WUP. Perhaps the differences between results for study one and those by Bishop et al. (2000) relates to the subsequent exercise protocols used. For example, it would be expected that a 2 min all out kayak rowing task would result in greater reliance on anaerobic glycolysis than a 6 x 4 s intermittent sprint protocol separated by 21 s, where energy would have predominantly come from high energy phosphate stores. A greater reliance on anaerobic glycolysis would have resulted in increasing blood lactate accumulation over the course of the exercise, thus augmenting the original post-WUP values. It is therefore possible that final post-exercise blood lactate values in the study by Bishop et al. (2000) (not reported) may have been significantly higher than the 13.2 ± 1.9 $mmol \cdot L^{-1}$ reported post-exercise for WUP 5, thus resulting in a greater overall negative impact on exercise performance. Therefore, while it was concluded by Bishop et al. (2000) that a high level of metabolic acidemia associated with WUP was responsible for the impaired exercise performance, the effect of the subsequent exercise task on overall blood lactate levels, and hence performance, also needs to be considered. Nonetheless, it was still surprising that the significantly higher post-WUP blood lactate concentrations associated with WUP's 4 and 5 in study one, compared to the other WUP trials, did not impair subsequent ISP.

An explanation for the similar performance results between the various WUP intensities, that takes into consideration the significant differences in blood lactate concentrations and temperature (T_{re} and T_{mu}) recorded post-WUP between WUP trials, may be that the subjects adopted a pacing strategy (as described in the literature review) in order to maximise over-all exercise performance, consequently minimising potential beneficial effects of WUP on subsequent exercise performance. This assumption suggests that subjects did not cycle at maximal pace throughout the exercise protocol, even though they were instructed to sprint as fast as they could. Employment of a pacing strategy during ISP was proposed by Bishop and Claudius (2004) to explain similar results for sprint performance between an active and a no WUP condition.

Results for study one also suggest that a shorter recovery period following the lower intensity WUP protocols (WUP's 1 - 3) may have resulted in greater non-temperature related benefits associated with active WUP on subsequent exercise performance (see earlier review for a summary of these benefits). While this premise ignores the impact of pacing, it is based on the low blood lactate concentrations recorded post-WUP for these three protocols and the likelihood that phosphocreatine stores would have been minimally affected by these lower WUP intensities. Further studies are needed to assess this premise. Finally, insignificant results between WUP protocols in study one may relate to the small cohort used. Of importance, however, the tendency for improvement in exercise performance following WUP 3 is important when considering the translation of these results to a sporting field, where a fraction of a second can be the difference between a successful or unsuccessful sporting manoeuvre.

Results from study two demonstrated the benefits associated with performing an active WUP compared to no WUP. Improved single sprint performance following a moderate intensity WUP (compared to no WUP) reported in this study are supported by numerous studies (Dolan et al., 1985; Grodjinovsky & Magel, 1970; McKenna et al., 1987; Pacheco, 1957; Sargeant & Dolan, 1987; Thompson, 1958) and most likely reflect temperature and non-temperature related benefits associated with WUP. However, the significant detriment in first sprint results of prolonged ISP (active WUP and no WUP trials) compared to the single sprint performance following active WUP, could be due to use of a pacing strategy by subjects designed to maximise overall prolonged exercise performance. This summation is supported by EMG data that demonstrated significantly higher muscle activation in gluteus maximus for single sprint performance that was preceded by a WUP, when compared to the first sprint of prolonged ISP that was also preceded by a WUP. Further EMG data for a selected group of muscles were all higher (ns) for single sprint performance (WUP and no WUP trials), when compared to the first sprint of ISP (WUP and no WUP trials).

Improved first sprint results of ISP that was preceded by an active WUP, compared to a no WUP trial, suggests that temperature and non-temperature benefits associated with active WUP were of benefit to initial exercise performance, even though these benefits may have been moderated by the possible employment of a pacing strategy. These results differ to those reported by Bishop and Maxwell (2009) and Bishop and Claudius (2004), who reported no significant difference in first sprint results of a prolonged intermittent protocol (that mimicked that used in the current study), following either an active or no WUP trial. Similar results for ISP between the active and no WUP trials in these two studies may relate to the WUP intensities used by these investigators that included high intensity bouts of exercise and a sprint. The subsequent significant increase in blood lactate concentrations, as a result of these WUP intensities, may have consequently negated the temperature and non-temperature related benefits associated with active WUP. However, similar post-WUP blood lactate levels recorded after 10 min of active WUP in the current study to those by Bishop and Claudius (2004) and Bishop and Maxwell (2009) suggests that this factor was unlikely to be the reason for the difference in exercise performance results between studies. Another possible explanation is that the recovery period used by both Bishop and Maxwell (2009) and Bishop and Claudius (2004), (2 min of passive rest) was not long enough to allow phosphocreatine stores that would have been diminished during the high intensity and sprint components of the active WUP to completely replenish prior to subsequent exercise performance. This in turn would prevent optimal subsequent sprint performance. Furthermore, an effect of T_{mu} and T_c on subsequent sprint performance, as a result of active WUP, cannot be determined as these measures were not assessed in the second study or by Bishop and Claudius (2004).

Similar results for prolonged ISP after an active WUP and a no WUP trial demonstrated in study two were also reported by Bishop and Maxwell (2009) and Bishop and Claudius (2004), albeit the protocol used by Bishop and Maxwell (2009) was shorter in duration (36 min) and was performed in hot environmental conditions. Of relevance, these investigators suggested that any benefits associated with active WUP on prolonged ISP may have been masked by the initial sprints performed in the no WUP trial providing a WUP effect on latter sprint performance, culminating in similar work performed between the two trials, as well as similar final physiological values for blood lactate concentration, HR and RPE. Another explanation for similar ISP results between the active WUP and no WUP trials may be that there comes a time point during prolonged ISP where temperature and non-temperature benefits related to active WUP reach their maximum potential, with no further advantage imparted on subsequent exercise performance. This would suggest that active WUP may be only beneficial during the early stages of ISP. This conjecture is supported by the improved first sprint results of ISP that followed an active WUP, compared to a no WUP trial, in the current study. Linked to this proposal, is the possibility that benefits associated with WUP on subsequent ISP are negated over time due to the increasing metabolic costs associated with prolonged exercise performance (i.e., increasing body temperature; reduced energy substrate availability, in particular phosphocreatine stores; increased hydrogen ions and metabolic wastes). Finally, similar prolonged ISP results between the WUP and no WUP trials may be due to subjects adopting a pacing strategy (as described earlier).

Our results for prolonged ISP are different to other studies that reported improved continuous, long-term exercise following an active WUP (Atkinson et al., 2005; Grodjinovsky & Magel, 1970; Thompson, 1958). However, the reasons previously proposed to explain the similar ISP between the active and no WUP trials in the current study may not be applicable to these other studies due to the considerably shorter exercise durations used in these studies (~25 min vs 36 - 80 min), as well as to the exercise protocols employed (continuous exercise vs ISP), where the percentage of energy contribution from the three energy systems would be different.

Of interest, results from study three demonstrated that environmental conditions did not have an effect on initial 4 s sprint performance that formed part of a prolonged ISP, when preceded by an active WUP. Furthermore, improved work and power results following passive WUP, compared to active WUP (in thermoneutral and hot conditions, respectively) suggests that temperature related benefits of WUP are more important than non-temperature related effects. Secondly, these results also suggest that negative effects associated with active WUP, such as increased blood lactate concentration and metabolic wastes and depleted energy stores, negate (to some extent) these temperature related benefits. This premise is supported, in part, by the significantly higher HR, RPE and blood lactate values recorded following both active WUP trials post-WUP, compared to the passive WUP trial. Therefore, while blood lactate concentrations following active WUP (thermoneutral and hot conditions) were only 3.5 and 3.1 $mmol \cdot L^{-1}$ respectively, the significant differences between these values and that for passive WUP (i.e., 1.1 $mmol \cdot L^{-1}$), may have been high enough to negatively impact upon subsequent first sprint performance. In addition, it is unlikely that depleted phosphocreatine stores, as a result of active WUP, would have impaired subsequent first sprint performance due to the low intensity nature of the WUP, combined with the 2 min recovery period undertaken prior to exercise performance.

Furthermore, as results from study two demonstrated improved first sprint and single sprint performance following an active WUP (compared to no WUP), it can be assumed that the combined (positive and negative) effects of active WUP on first sprint performance are preferable to no WUP, but inferior to just the temperature related effects imparted by the performance of a passive WUP. This result is surprising as no previous studies are known to the author that have reported benefits associated with passive WUP on subsequent short-term exercise performance, compared to an active WUP (refer to literature review). However, our study is different to these previous studies in that the first sprint formed part of prolonged (80 min) ISP, with the possibility of pacing being proposed to modulate first sprint performance (as demonstrated in study two where first sprint performance was impaired compared to single sprint performance). If first sprint performance was not maximal, as would occur if pacing was used, then non-temperature related benefits associated with active WUP may not have been completely realised.

Results from study three are contrary to those of two previous studies which reported significant impairment in prolonged, ISP in hot (~ 30ºC) compared to moderate (~ 17ºC) conditions (Morris et al. 1998; Morris et al. 2000). However, T_{re} recorded during exercise in the heat in both these studies ranged from 39.1 – 39.4ºC, with this factor considered by the investigators to be the prime reason for detriment in exercise performance. Of relevance, final T_c in the hot and neutral environmental conditions in study three did not exceed 38.6ºC, with this value being well below a critical T_c proposed to impair prolonged intermittent sprint exercise (39.4 – 40.0 ^{o}C, Drust et al., 2005; Morris et al. 1998). Consequently, lack of attainment of a critical T_c during the hot and humid trial in this study may explain the similar performance results between environmental conditions. While the existence of a critical T_c and its effects on fatigue and hence exercise performance has recently been challenged (Ely et al., 2009), the researchers still concluded that heat stress and fatigue were dependent upon a complex interplay of multiple physiological systems, which included T_c. Furthermore, results for similar prolonged ISP between trials may also be partially attributed to the recruitment of team-sports athletes, as opposed to non-athletes (Morris et al. 1998), who were accustomed to performing intermittent sprint exercise, as well as to exercising in hot environmental conditions. As the present study was performed during October and November, when average local temperatures ranged from 21 – 27ºC, it was likely that subjects were, at least, partially heat acclimatised. Heat acclimatisation and endurance training have both been reported to reduce the impact of hot environmental conditions on exercise performance (Nadel & Horwath 1977).

Similar prolonged ISP was also demonstrated in study two following an active WUP and a no WUP trial, with explanations proposed for this outcome being applicable (with some modifications) to the comparable results for prolonged ISP demonstrated in study three. Briefly, these explanations are as follows: (1) the initial sprints of ISP may have imparted non-temperature benefits associated with active WUP on subsequent sprint performance in the passive WUP trial; (2) benefits associated with WUP (passive and active) are likely to be achieved in the early stages of prolonged ISP, with these effects diminishing over the course of prolonged exercise; (3) benefits associated with WUP are overridden over time by the metabolic consequences of prolonged ISP; and (4) subjects may have employed a pacing strategy designed to maximise overall ISP.

6.5 LIMITATIONS TO THE STUDIES

There were a number of limitations to these studies. Firstly, use of a control group in study one would have provided more information regarding the performance effects of WUP. A control group was not used in this study due to the high number of visits subjects needed to make to the laboratory, with the belief that the inclusion of an extra visit may have made it difficult for recruitment. Secondly, a power analyses was not performed for these studies, with this possibly being the reason behind the insignificant results found for most variables. These studies did however, recruit subjects based on numbers typically reported in similar published studies. Recruitment was also limited by time and financial restraints. Furthermore, an improvement to study two would have been the assessment and reporting of T_{mu} and T_c. Again this was not done due to financial restraints. A further limitation to study three relates to the lack of a protocol that involved passive WUP in thermoneutral conditions. Inclusion of this trial would have supplied valuable data on the effects of this form of WUP in normal ambient conditions. Again, this trial was not performed due to the extra onus it would have placed on subjects attending the laboratory. A final limitation relates to the use of a cycle protocol rather than a running protocol that would have better reflected sprints performed in team-sport games. Cycling was used as a protocol in these studies due to the ease in assessing work and power. Further, as noted in the studies, a good correlation has been previously reported between cycle sprints and running performance.

6.6 FUTURE STUDIES

Further studies are required in order to determine whether different recovery periods between WUP and subsequent exercise would result in different performance results. This enquiry should also involve the use of different WUP intensities (based on lactate thresholds) to those used in the current series of studies. Additionally, the inclusion of a no-WUP condition would allow for the better comparison of results on subsequent exercise performance. Furthermore, future studies should aim to determine whether there is a time limitation to benefits associated with active WUP on subsequent prolonged ISP, as this would provide relevant information to team-game sports that involve the use of an interchange bench, such as basketball and Australian Rules football.

6.7 CONCLUSION

A WUP intensity based on lactate thresholds can assist in standardising the metabolic strain placed on subjects prior to the performance of subsequent exercise. However, it would appear that the significant differences in blood lactate levels, T_{mu}, T_{re} and T_b found in study one, as a result of five different WUP intensities, had no significant effect on subsequent ISP or the first sprint of ISP. These results may have been due to subjects adopting a pacing strategy designed to maximise overall performance. Nonetheless, a WUP intensity performed midway between LI and LT resulted in a tendency for better initial sprint and ISP (ES > 0.5), although results were not significant.

Active WUP, as opposed to no WUP, resulted in improved single sprint and first sprint performance of prolonged ISP in a thermoneutral environment. In addition, passive WUP, when compared to active WUP, resulted in improved first sprint performance of prolonged ISP. This would suggest that temperature related benefits associated with passive WUP are superior to the combined positive (temperature and non-temperature related) and negative effects associated with active WUP. However, these results may have been confounded by use of a pacing strategy as demonstrated by impaired first sprint performance compared to single sprint performance in study two, which suggests that benefits associated with active WUP may not have been fully realised.

Similar prolonged ISP following an active WUP (hot and thermoneutral conditions), no WUP (thermoneutral conditions) and a passive WUP (hot conditions) trial demonstrated no effect of environmental conditions, or benefits associated with performing a WUP (passive or active), on prolonged ISP. Reasons proposed to explain similar ISP between trials include: the use of pacing; diminishing effects of WUP over the course of prolonged ISP; that the effects of WUP (passive and active) are overridden over time by the metabolic consequences of prolonged ISP; as well the possibility that the initial sprints of prolonged exercise provide a WUP effect (temperature and non-temperature) on subsequent ISP.

Finally, it would appear that neither the intensity of the WUP, nor the environmental conditions, compromised the performance of prolonged ISP, despite significant changes in RPE, HR, body temperature and blood lactate concentrations. Further, while graded WUP intensities did not negatively affect sprint performance it may have provided protection against soft tissue injury during subsequent ISP.

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APPENDIX A

The Effects of Warm-Up Intensity on Selected Physiological Parameters and Repeated-Sprint Performance

— Subject Information Sheet —

PURPOSE

The purpose of this proposed research is:

- to add to the current body of literature concerning the differences in team-sport performance following different types of warm-up.
- to investigate the physiological responses of the body following warm-up protocols that differ in intensity.

This information is essential to provide a scientific rationale to underpin recommended warm-up strategies to improve the performance of team-sport athletes.

PROCEDURES

You will be required to complete three preliminary sessions and five experimental trials over a seven-week period.

Preliminary Session

During the first preliminary visit, you will perform a familiarisation session of the graded exercise test and the repeated-sprint test. During this visit, we will measure your height, body mass and skin folds.

On the second visit you will perform the graded exercise test. During this test you will breathe through a mouth piece and your expired air will be collected to determine your $\dot{V}O_{2max}$. The test will commence at a low workload and there after, the workload will be increased every 3 minutes until volitional exhaustion. Blood will be sampled from the earlobe at rest and during the 1-min rest period following each 3-min stage. Blood samples will be used to determine your lactate threshold.

On the third visit, you will perform a second familiarisation of the repeated-sprint test.

On subsequent days, in a random order, you will perform one of the five experimental trials.

Experimental trials

Each experimental trial will require you to perform the repeated-sprint test which consists of ~6-second sprint (x 5 times) with 24 s of active recovery between each sprint in the laboratory following one of five warm-up conditions. The five experimental trials will be conducted once a week over a five-week period.

Warm up

In a random, counterbalanced order, you will perform one of five different intensities warm-up conditions in the laboratory. The warm-up intensities will be either: 1) lower than lactate inflection (LI) level, 2) at LI level, 3) midway between LI and lactate threshold (LT) level, 4) LT level and 5) above LT level.

Temperature

Rectal temperature will be measured using a thermistor from a site 10 cm beyond the anal sphincter.

Skin thermistors will be attached to four sites, the upper chest, lower forearm, upper thigh and medial side of the calf.

Muscle temperature will be monitored via a needle thermistor probe inserted 4 cm into an anaesthetized area of the Vastus Lateralis muscle.

All subject preparation and testing will be performed by a medically-trained researcher.

RISKS

This study will require you to perform intermittent-sprint testing, that is a high-intensity exercise. This task is generally well tolerated by active young individuals and you perform a similar task in each of your weekly rugby games. It is important to note that you will be free to stop the exercise task at any stage during testing if you wish to do so or if you experience any form of discomfort.

Muscle temperature measuring and blood sampling are essential to this study. You may experience some discomfort or pain at the sites of blood sampling and during insertion of muscle temperature measuring needle electrode. The risks associated with this procedure are minimal, but may include soreness at the insertion site for the next 1-2 days. Although there is a slight risk of infection at the sites we mentioned above, this will be minimised by the adoption of sterilised equipment and procedures.

BENEFITS

1. You will be informed about your $\dot{V}O_{2\,max}$, the best cardiorespiratory fitness test to evaluate your own fitness.
2. After analysing the data, you will be informed of the best warm-up protocol to improve your performance in a team-sport.

TIME COMMITMENT AND SUBJECT RIGHTS

First preliminary session may be approximately 1-2 hours.
Second session may take approximately 1hour.
Third session may take approximately half an hour.
Each experimental trial takes approximately one and a half hour.
Participation in this research is voluntary and you are free to withdraw from the study at any time without prejudice. You can withdraw for any reason and you do not need to justify your decision. If you withdraw from the study and you are an employee or student at the University of Western Australia (UWA) this will not prejudice your status and rights as employee or student of UWA.
If you do withdraw we may wish to retain the data that we have recorded from you, but only if you agree, otherwise your records will be destroyed.
Your participation in this study does not prejudice any right to compensation that you may have under statute of common law.

If you have any questions concerning the research at any time please feel free to ask the researcher who has contacted you about your concerns. Further information regarding this study may be obtained from Pongson Yaicharoen (04 3210 4717) or Dr. David Bishop (6488 7282)

Any publication resulting from this research will not indicate the name of any subject. If any individual data is reported, it will be by subject number only.

APPENDIX B

The Effects of Warm-Up Intensity on Selected Physiological Parameters and Repeated–Sprint Performance.

— Consent Form —

I ___________________________ have read the information provided and any questions I have asked have been answered to my satisfaction. I agree to participate in this activity, realising that I may withdraw at any time without reason and without prejudice.

I understand that all information provided is treated as strictly confidential and will not be released by the investigator unless required to by law. I have been advised as to what data is being collected, what the purpose is, and what will be done with the data upon completion of the research.

I agree that research data gathered for the study may be published provided my name or other identifying information is not used.

______________________ ____________________

Participant Date

The Human Research Ethics Committee at the University of Western Australia requires that all participants are informed that, if they have any complaint regarding the manner, in which a research project is conducted, it may be given to the researcher or, alternatively to the Secretary, Human Research Ethics Committee, Registrar's Office, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009 (telephone number 6488-3703). All study participants will be provided with a copy of the Information Sheet and Consent Form for their personal records.

APPENDIX C

The Effects of Warm-Up on Single and Repeated-Sprint Performance

— Subject Information Sheet —

PURPOSE

The purpose of this proposed research is:

- to investigate the effect of warm-up on single sprint performance and prolonged intermittent-sprint performance.

This information is essential to provide a scientific rationale to underpin recommended warm-up strategies to improve the performance of team-sport athletes.

PROCEDURES

You will be required to complete two preliminary sessions and four experimental trials over a four-week period.

Preliminary Session

During the first preliminary visit, you will perform a familiarisation session of the graded exercise test (GXT) and the intermittent-sprint test (IST). During this visit, anthropometric data (height, body mass and percent fat) will also be determined. The GXT will then be performed on the second preliminary visit to determine both the lactate threshold (LT) and $\dot{V}O_{2\,max}$. On subsequent days, in a random order, you will perform one of the four experimental trials.

Graded exercise test (GXT)

The GXT, a multi-stage discontinuous test, consist of graded exercise steps (3-min stages), using an intermittent protocol (1-min break between stages). The test will commence at 70 W and there after, intensity will be increased by 30 W every 3 minutes until volitional exhaustion. Capillary blood samples will be taken at rest and immediately following each 3-min stage to measure plasma lactate concentration. Both LT and $\dot{V}O_{2\,max}$ will be determined from the GXT.

Experimental trials

Each experimental trial will require you to perform the single-sprint test or IST in the laboratory either with or without prior warm-up. Exercise will be performed on a calibrated, front-access cycle ergometer.

These four experimental trials are:

1. WUP + 1 all-out sprint
2. No WUP + 1 all-out sprint
3. WUP + Intermittent sprint test (IST)
4. No WUP + IST

The four experimental trials will be conducted once a week over a four-week period. All trials, for a given subject, will be conducted at the same time of day, to control for diurnal effects. You will be asked to maintain your normal diet and training throughout the study, and will be required to consume no food or beverages (other than water) during the two-hour period prior to testing and will be asked not to consume alcohol or perform vigorous exercise in the 24 h prior to testing. In all trials (including no WUP), you will perform a standard stretching protocol 10 min prior to the start of the trial.

Warm up

You will perform each warm-up at just below the lactate threshold level intensity (approximately 60-70% of the maximum power output determined from the GXT).

All out sprint test

You will sprint 4 s only 1 time as hard as possible.

Intermittent-sprint protocol

The novel intermittent-sprint test (IST) is designed to mimic the sprint and recovery durations of one half of a typical team-spot game and consists of 40 min of intermittent sprint exercise (Fig. 1). The protocol is divided into ~2-min blocks of sprinting, active recovery and passive rest. On two occasions during the 40-min protocol, there is a repeated-sprint bout (RSB) comprising five, 2-s sprints, where the active recovery between successive sprints is ~20 s. The protocol will be completed twice so as to simulate a full game.

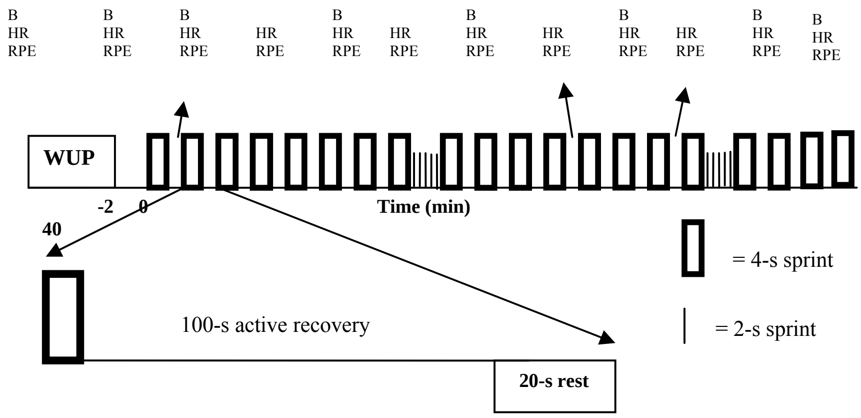

Fig.1. Schematic of the first half of the intermittent-sprint test (IST). Each ~2-min block comprises a 4-s maximal sprint, 100-s active recovery at a low intensity and 20-s passive rest.

B = Blood sample WUP = Warm-up

RPE = Rating of Perceived Exertion HR = Heart rate

Muscle EMG

The electrical activity (EMG) from the vastus lateralis (VL), gluteal and hamstring muscles of the right leg will be recorded via bipolar surface electrodes placed on the skin. Before placing the electrodes, the overlying skin will be carefully prepared. The hair will be shaved, the skin lightly abraded to remove the outer layer of epidermal cells and thoroughly cleansed with alcohol.

RISKS

This study will require you to perform intermittent-sprint testing, that is a high-intensity exercise. This task is generally well tolerated by active young individuals. It is important to note that you will be free to stop the exercise task at any stage during testing if you wish to do so or if you experience any form of discomfort.

BENEFITS

1. You will be informed about your $\dot{V}O_{2\,max}$, the best cardiorespiratory fitness test to evaluate your own fitness.
2. After analysing the data, you will be informed of the best warm-up protocol to improve your performance in a team-sport.

TIME COMMITMENT AND SUBJECT RIGHTS

First preliminary session takes about 2 hours.
Second session takes about 1.30 hours.
Experimental trials with all-out sprint may be approximately 1 hour.
Experimental trials with IST take about 2-3 hours.
Participation in this research is voluntary and you are free to withdraw from the study at any time without prejudice. You can withdraw for any reason and you do not need to justify your decision. If you withdraw from the study and you are an employee or student at the University of Western Australia (UWA) this will not prejudice your status and rights as employee or student of UWA.
If you do withdraw we may wish to retain the data that we have recorded from you, but only if you agree, otherwise your records will be destroyed.
Your participation in this study does not prejudice any right to compensation that you may have under statute of common law.
If you have any questions concerning the research at any time please feel free to ask the researcher who has contacted you about your concerns. Further information regarding this study may be obtained from Pongson Yaicharoen (04 3210 4717) or Dr. David Bishop (6488 7282)
Any publication resulting from this research will not indicate the name of any subject. If any individual data is reported, it will be by subject number only.

APPENDIX D

The Effects of Warm-Up on Single and Repeated–Sprint Performance.

— Consent Form —

I ___________________________ have read the information provided and any questions I have asked have been answered to my satisfaction. I agree to participate in this activity, realising that I may withdraw at any time without reason and without prejudice.

I understand that all information provided is treated as strictly confidential and will not be released by the investigator unless required to by law. I have been advised as to what data is being collected, what the purpose is, and what will be done with the data upon completion of the research.

I agree that research data gathered for the study may be published provided my name or other identifying information is not used.

______________________ ____________________

Participant Date

The Human Research Ethics Committee at the University of Western Australia requires that all participants are informed that, if they have any complaint regarding the manner, in which a research project is conducted, it may be given to the researcher or, alternatively to the Secretary, Human Research Ethics Committee, Registrar's Office, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009 (telephone number 6488-3703). All study participants will be provided with a copy of the Information Sheet and Consent Form for their personal records.

APPENDIX E

The Effects of Warm-Up on Repeated-Sprint Performance in Hot and Humid Conditions.

— Subject Information Sheet —

PURPOSE

The purpose of this proposed research is:

- to investigate the effects of increase body temperature by either active or passive warm-up on prolonged intermittent-sprint performance in a hot and humid environment.
- to investigate whether performance impairment is due to only body temperature increment or other factors.

This information is essential to provide a scientific rationale to underpin recommended warm-up strategies to improve the performance of team-sport athletes.

PROCEDURES

You will be required to complete two preliminary sessions and three experimental trials over a four-week period.

Preliminary Session

During the first preliminary visit, you will perform a familiarisation session of the graded exercise test and the intermittent-sprint test. During this visit we will measure your height, body mass and skin folds. On the second visit you will perform graded exercise test. During this test you will breathe through a mouth piece and your expired air will be collected to determine your $\dot{V}O_{2max}$. The test will commence at a low workload and there after, the workload will be increased every 3 minutes until volitional exhaustion. Blood will be sampled from the earlobe at rest and during the 1-min rest period following each 3-min stage. Blood samples will be used to determine your lactate threshold.

On subsequent days, in a random order, you will perform one of the experimental trials.

Experimental trials

The three experimental trials will be conducted in a climate chamber (35 ^{o}C 50% humidity) and performed once a week over a three-week period. These three experimental trials are:

1. Warm-up + intermittent-sprint test (at room temperature)
2. Warm-up + intermittent-sprint test (at high temperature condition)
3. No warm-up + intermittent-sprint test (at high temperature condition)

(In condition 3, you will sit in a warm bathtub to raise the core temperature to the same value as in condition 2.)

Warm up

You will perform warm-up for 10 min at just below the lactate threshold level intensity (approximately 60-70% of the maximum power output determined from the graded exercise test).

Intermittent-sprint protocol

The intermittent-sprint test consists of 40 min of intermittent –sprint exercise. The protocol will be completed twice so as to simulate a full game.

Temperature

Core temperature will be measured using a radiotelemetry pill that you will need to ingest approximately 6-8 hr before you come to laboratory.

All subject preparation and testing will be performed by a medically-trained researcher.

RISKS

This study will require you to perform intermittent-sprint testing, that is a high-intensity exercise. This task is generally well tolerated by active young individuals. Due to performing experimental trials in the climate chamber, you may have heat stress symptom. But during the test, you will be monitored closely and if your core temperature reaches critical level (~39.5^{o}C), you will be asked to stop immediately. It is important to note that you will be free to stop the exercise task at any stage during testing if you wish to do so or if you experience any form of discomfort.

BENEFITS

1. You will be informed about your $\dot{V}O_{2\,max}$, the best cardiorespiratory fitness test to evaluate your own fitness.
2. After analysing the data, you will be informed of the best warm-up protocol to improve your performance in a team-sport.

TIME COMMITMENT AND SUBJECT RIGHTS

First preliminary session takes about 2 hours.
Second session takes about 1.30 hours.
Each experimental trial may take 2-3 hours.
Participation in this research is voluntary and you are free to withdraw from the study at any time without prejudice. You can withdraw for any reason and you do not need to justify your decision. If you withdraw from the study and you are an employee or student at the University of Western Australia (UWA) this will not prejudice your status and rights as employee or student of UWA.
If you do withdraw we may wish to retain the data that we have recorded from you, but only if you agree, otherwise your records will be destroyed.
Your participation in this study does not prejudice any right to compensation that you may have under statute of common law.

If you have any questions concerning the research at any time please feel free to ask the researcher who has contacted you about your concerns. Further information regarding this study may be obtained from Pongson Yaicharoen (04 3210 4717).

Any publication resulting from this research will not indicate the name of any subject. If any individual data is reported, it will be by subject number only.

APPENDIX F

The Effects of Warm-Up on Single and Repeated–Sprint Performance in Hot and Humid Condition.

— Consent Form —

I ___________________________ have read the information provided and any questions I have asked have been answered to my satisfaction. I agree to participate in this activity, realising that I may withdraw at any time without reason and without prejudice.

I understand that all information provided is treated as strictly confidential and will not be released by the investigator unless required to by law. I have been advised as to what data is being collected, what the purpose is, and what will be done with the data upon completion of the research.

I agree that research data gathered for the study may be published provided my name or other identifying information is not used.

______________________ ____________________

Participant Date

The Human Research Ethics Committee at the University of Western Australia requires that all participants are informed that, if they have any complaint regarding the manner, in which a research project is conducted, it may be given to the researcher or, alternatively to the Secretary, Human Research Ethics Committee, Registrar's Office, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009 (telephone number 6488-3703). All study participants will be provided with a copy of the Information Sheet and Consent Form for their personal records.