Optimisation of Warm-Up Protocols in Soccer

by

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DOCTOR OF PHILOSOPHY

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ABSTRACT

An active warm-up period prior to competitive soccer matches is habitual practice for most athletes. Typically these routines far exceed the duration recommended by the literature and may negatively affect subsequent soccer-related performance. High-intensity, short-duration warm-ups can improve subsequent power measures, however their application to soccer-specific tasks has not yet been investigated. Additionally, relatively little is known regarding the effects of high-intensity, short-duration warm-ups when implemented during half-time intermissions.

Therefore, the acute (study 1) and prolonged (study 2) performance and physiological effects of a currently implemented warm-up routine were compared with two high-intensity, short-duration warm-up protocols; the latter were also investigated as re-warm-up interventions (study 3). In randomised, cross-over study designs, participants performed a team-sport, a 5 repetition maximum leg-press, or a small-sided game warm-up followed by performance and physiological tests. The acute and extended effects of these warm-ups were investigated, with the second study incorporating two 15 min periods of field based intermittent activity. The third investigation included two 26 min periods of intermittent activity completed on a non-motorised treadmill, which was interspersed by the re-warm-up interventions. Data for all investigations were analysed using the effect size statistic with 90% confidence intervals, and percentage change, to determine magnitude of effects.

It was concluded that the leg-press warm-up induced less physiological strain and minimised acute decrements in short-sprint and reactive agility tasks, when compared to the currently implemented warm-up routine. Similar observations were reported during, and following two bouts of extended intermittent activity. Following a standardised bout of intermittent activity a leg-press re-warm-up enhanced subsequent power, short-sprint and repeated-sprint ability, while a small-sided game re-warm-up improved subsequent soccer-specific skill. These findings demonstrate that warm-up protocols implementing high-intensity activity, over short periods, can enhance subsequent soccer related physical performance. These benefits would be of direct significance to soccer and other team-sport athletes/coaches interested in enhancing players' acute or prolonged performance during competition, and can also aid the physical and skilled performance of players when implemented during half-time periods.

STUDENT DECLARATION

"I, James Zois, declare that the PhD thesis entitled "Optimisation of Warm-Up Protocols in Soccer" is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work". I would like to also acknowledge the additional work completed by Mr. Ian Fairweather, who has assisted in the development of our data acquisition software.

Signature Date

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ABBREVIATIONS

		Units
ATP	Adenosine tri-phosphate	
$Ca2^+$	Calcium ion	$mmol.l^{-1}$
CV	Coefficient of variation	
ES	Effect size	
HR	Heart rate	$beats.min^{-1}$
HR_{max}	Maximal heart rate	$beats.min^{-1}$
iMVC	Isometric maximal voluntary contraction	$N^{\cdot}m$
iRFD	Isometric rate of force development	$rads.s^{-1}$
$[Lac^-]_b$	Blood lactate concentration	$mmol.l^{-1}$
$M^{\cdot}s^{-1}$	Meters per second	
$M^{\cdot}s^{-2}$	Meters per second per second	
MVC	Maximal voluntary contraction	$N^{\cdot}m$
$N^{\cdot}m$	Newton meters	
O_2	Oxygen uptake	$l.min^{-1}$
PCr	Phosphocreatine	
RLC	Regulatory light chain	
SD	Standard deviation	
T_c	Core temperature	°C
T_m	Muscle temperature	°C
T_r	Rectal temperature	°C
$\dot{V}O_{2max}$	Maximal oxygen uptake	$l.min^{-1}$
$\dot{V}O_{2peak}$	Peak oxygen uptake	$l.min^{-1}$
°C	Degrees Celsius	

PUBLICATIONS

The following publications and conference abstracts are in support of this thesis:

Peer review publications arising directly from this thesis

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2. Zois J, Bishop D, Aughey R. (2011). High-intensity warm-ups minimise performance decrements during intermittent exercise. *Med Sci Sports Exerc, currently under review.* (Chapter 4)

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Peer reviewed abstracts

1. High-Intensity Re-Warm-ups Improve Secondary Periods of Physical and Skilled Soccer

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3. Comparing High-Intensity Short-Duration Warm-up Protocols to Current Practice.

   The

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CHAPTER 1. INTRODUCTION

In elite team-sports such as soccer (football), it is important for athletes to be physically prepared for high-power and skill activities at the commencement of a match. Equally, this performance must be maintained throughout a match, via minimising the effects of fatigue. A rest period during the half-time interval provides team-sport athletes with an opportunity to recover and prepare for the second half of competition. However, prolonged passive recovery can also hinder subsequent physical performance in soccer players (Lovell *et al.*, 2007). Therefore, this thesis aims to identify pre-match and half-time active warm-up (WU) routines that can enhance performance whilst minimising athlete fatigue.

Typically, soccer WU routines are devised by coaching staff relying on previous trial and error experiences (Bishop, 2003b), and usually include 30-40 min of moderate- to high-intensity activities (Mohr *et al.*, 2004). In contrast, research suggests five to ten minutes at 40-70% of maximal oxygen consumption ($\dot{V}O_{2max}$) is sufficient to improve short, intermediate and long-term performance (Bishop, 2003b). Longer WU routines could therefore impair subsequent performance via increasing pre-competition fatigue, depleting muscle glycogen stores, and prematurely elevating core temperature (compromising the body's ability to store and dissipate subsequently generated heat) (Gregson *et al.*, 2005). Therefore, further research is required to investigate the acute effects of current WU practices, and compare their efficacy to that of shorter WU protocols.

While acute performance is obviously important, soccer matches can last in excess of 90 min and include repeated bursts of high-intensity exercise. Therefore, it is imperative that the WU routine implemented not only enhances acute performance, but also does not contribute to performance decrements in the latter stages of a match.

One WU alternative may be the implementation of high-intensity, short-duration tasks aimed at increasing neuromuscular efficiency via a post activation potentiation (PAP) phenomenon (Hodgson *et al.*, 2005), as well as minimising physical expenditure prior to competition. Further research is warranted to investigate WU protocols which may be able to facilitate acute performance enhancement in soccer-specific tasks, as well as to minimise fatigue during extended periods of intermittent exercise.

During a soccer match, half-time rest intervals present athletes with an opportunity to recover and to replenish fuel stores in preparation for the subsequent half of competition (Lovell *et al.*, 2007). Despite the potential importance of this rest interval, limited research has investigated the effects of active re-WUs on subsequent second-half team-sport performance. Additionally, no study to date has investigated the potential skill-related benefits via WUs which include ball control and/or passing. Investigating the possible improvements in technical proficiency would provide practitioners with valuable information never before investigated This thesis will therefore investigate methods to optimise acute and extended team-sport-related physical performance through various WU protocols in soccer players, as well as investigating methods which may enhance second-half physical and skill performance via the implementation of selected active re-WU routines.

CHAPTER 2. REVIEW OF LITERATURE

2.1 Soccer

2.1.1 *Introduction to soccer*

Soccer is a team sport played predominantly on a natural grass surface area measuring 105 x 68 m (length x width). Two teams consisting of 11 players (on field) per team aim to score as many goals as possible (placed at either ends) during the allocated 90 min; 2 x 45-min period interspersed with a 15-min recovery at half time. The physical demands of soccer include periods of high-intensity sprinting, jumping, tackling, changing direction, passing, dribbling and shooting, as well as applying defensive/attacking pressure on opponents (Stolen *et al.*, 2005). Although high-intensity activities occur less often than low-intensity activities (i.e., jogging, walking and standing), high-intensity activity is of paramount importance to the team's overall success. Commonly, high-intensity activity coincides with crucial moments of the game i.e., winning possession and/or the scoring of goals (Reilly *et al.*, 2000). Players able to sustain higher work-rates during competition can therefore gain a distinct advantage over equally-skilled opponents, especially towards the completion of a match where fatigue may be prevalent (Rampinini *et al.*, 2007b). Ensuring that athletes are primed for the rigors of subsequent competition is extremely important and may enhance a team's overall success.

2.1.2 *The activity profile of competitive soccer*

The activity profile of participants in soccer varies between competitions (Rienzi *et al.*, 2000), positional roles (Di Salvo *et al.*, 2007; Bradley *et al.*, 2011) and periods of play (Reilly *et al.*, 2000; Stolen *et al.*, 2005; Krustrup *et al.*, 2006; Di Salvo *et al.*, 2009). Soccer is an intermittent sport which predominately taxes the aerobic energy system during off-ball activity, interspersed with high-intensity on-ball activities reliant on anaerobic turnover (Reilly *et al.*, 2000; Mohr *et al.*, 2003). An elite level outfield soccer player (excluding goalkeeper) will cover approximately 8000-12000 m during a 90-min competitive match (Shephard, 1999; Stolen *et al.*, 2005). During matches athletes will, on average, complete all-out sprint bouts of ~2-3s once every 90-s, one high-intensity effort every 70s, run with the ball once every 30s, and rest no more than 2-3s at any one-given time (Reilly *et al.*, 2000; Stolen *et al.*, 2005). In comparison, lower-intensity activities constitute almost 90% of all distances covered and include; walking (25%), jogging (37%), sub-maximal cruising (20%) and moving backwards (7%) (add in Stolen 2005).

The average maximum oxygen uptake ($\dot{V}O_{2max}$) for an elite soccer player is between 50 and 75 $mL \cdot kg^{-1} \cdot min^{-1}$ with some differences being accounted for by positional and tactical roles; i.e., full back and midfield players have higher values as compared to goal keepers and central defenders (Stolen *et al.*, 2005). In addition, during a 90-min soccer match, the average work intensity, as measured via the percentage of maximal HR (HR_{max}), is close to the anaerobic threshold (the highest exercise intensity where production and removal of lactate is equal; ((normally 80-90% of HR_{max} in soccer players) (Ali & Farrally, 1991; Stolen *et al.*, 2005)). While these physiological profiles may provide important information to coaches and players, interpretation of results can be difficult. For example, the elevated $[Lac^-]_b$ often observed in soccer players may not be as a result of single activities, but instead an accumulated/balanced response to a number of high-intensity activities (Bangsbo *et al.*, 2006). These brief periods of activity usually coincide with important passages of play in soccer (Reilly *et al.*, 2000) and require high levels of strength and power for optimal execution (Bangsbo, 1994).

2.1.2.1 Power-reliant tasks

Power is the product of strength and speed, and refers to the neuromuscular system's ability to produce the greatest possible impulse (force) over a given time period (Stolen *et al.*, 2005). Short bouts of high-intensity activity, such as sprinting, jumping, changing direction, tackling and kicking, are important physical tasks that can be influenced by an athlete's power capabilities (Shephard, 1999; Stolen *et al.*, 2005). Through increasing the available force within a muscle/muscle group, acceleration and speed can also be enhanced, as well as activities critical to soccer such as turning, jumping and changing direction (Bangsbo, 1994; Reilly *et al.*, 2000).

Increasing muscular power can be accomplished acutely, via active WU periods (Behm, 1995), or incur prolonged adaptations via strength training programs aimed at developing muscular hypertrophy and/or neural mechanisms (Hoff & Helgerud, 2004). The development of strength is important in the execution of powerful tasks, with jump height and 30-m sprinting performance positively correlated with strength in soccer players (r= 0.78 and 0.94, respectively) (Wisloff *et al.*, 2004). Furthermore, the strength level of players can differentiate between professional and amateur participants, with faster sprint times (Cometti *et al.*, 2001) and increased jumping abilities (Wisloff *et al.*, 2004) in some professional soccer players. Priming athletes via active WU periods can improve subsequent acute explosive ability via similar neural mechanism to those reported following training regimes (Wong *et al.*, 2009; Buchheit *et al.*, 2010). These include an increase in the firing rate of nerve impulses, increased reflex potential and increased recruitment of higher order motor units (Behm, 1995). Therefore, the enhancement of acute and prolonged power production in soccer players is important and may provide teams with additional performance benefits during competitive tasks.

2.1.2.2 Reactive agility

Reactive agility (RA) is an essential component in most team-sports, and can be defined as “a rapid whole body movement with change of velocity or direction in response to a stimulus” (Sheppard & Young, 2006). This highly complex skill set (Figure 2-1) effectively discriminates between higher- and lesser-skilled team-sport athletes (Farrow *et al.*, 2005; Gabbett & Benton, 2009; Serpell *et al.*, 2009). Elite team-sport athletes (rugby players) have faster decision making (89.5±5.8 ms vs. 111±6.4 ms), and total movement time (2.35±0.03 s vs. 2.56±0.03 s) and better response accuracy (93.2±1.9% vs. 85.5±2.5%), compared to their sub-elite counterparts (Gabbett & Benton, 2009). In soccer, RA is an important quality required when evading opponents when attacking, or placing physical pressure on opponents when defending (Young & Willey, 2009).

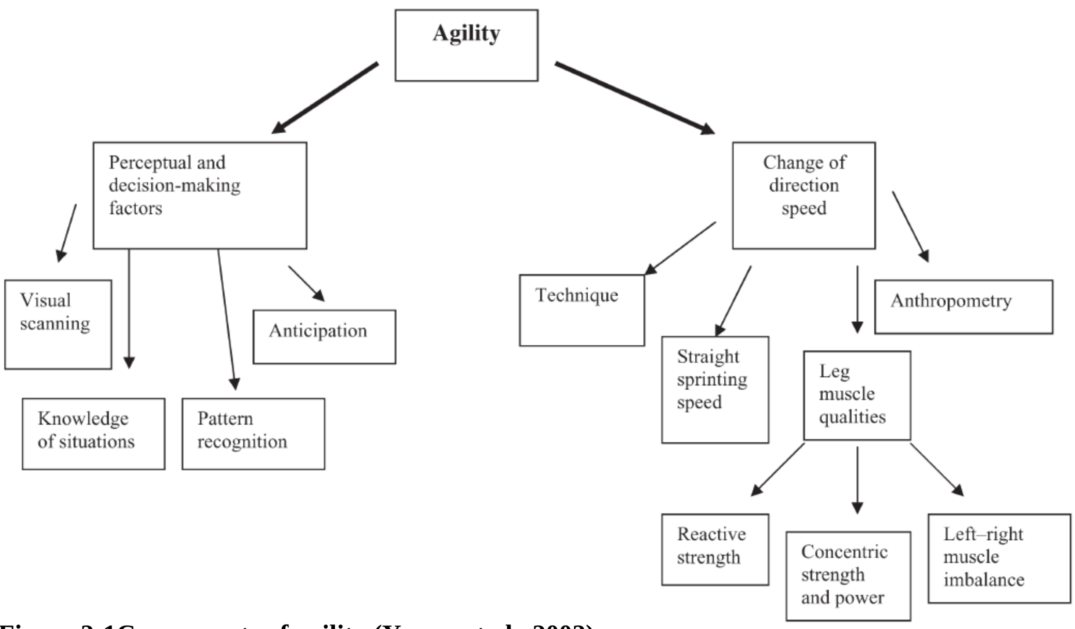


Figure 2-1Components of agility (Young et al., 2002)

Only one study has investigated the possible acute performance effects of active WUs on subsequent RA tasks, showing no improvement in performance (Gabbett *et al.*, 2008). However, the inclusion of static stretching during the WU period is likely to be responsible for the lack of effect observed by decreasing pertinent metabolic and temperature related mechanisms (Fowles *et al.*, 2000; Behm *et al.*, 2001; Church *et al.*, 2001; Cornwell *et al.*, 2001; Behm *et al.*, 2004a; Power *et al.*, 2004; Bradley *et al.*, 2007; Brandenburg *et al.*, 2007). Furthermore, the implemented WU duration (22 min) was far greater than recommended (Bishop, 2003b), and may have masked performance benefits via an accumulation of fatigue. Therefore, it is possible that active WU aimed at improving power production in subsequent tasks could be of benefit to subsequent RA tasks. This would have important implications for soccer players especially during the execution of offensive/defensive maneuvers, but is yet to be investigated.

2.1.2.3 High-intensity efforts

Another important physical attribute in soccer is the ability to perform high-intensity running. High-intensity running (≥ 4.17 $m \cdot s^{-1}$) during a soccer match only constitutes ~8% of total match time (Rampinini *et al.*, 2007a; Rampinini *et al.*, 2007b), but can include important passages of play (Mohr *et al.*, 2003). For example, dribbling past or chasing down an opponent, contesting for possession or creating space to perform a strike on goals. High-intensity running also discriminates between elite and sub-elite soccer players and teams (Rampinini *et al.*, 2007b). For example, top-class players perform 28% more high-intensity running as compared to moderate players, and cover ~500 m more distance during a soccer match (Bradley *et al.*, 2009). In addition, teams of a higher-standard perform more high-intensity running while in possession of the ball (16%), when compared to less successful teams (Rampinini *et al.*, 2007b).

Therefore, a soccer player's ability to maintain high-intensity work periods during a match, while in possession of the ball, is of critical importance to the team's overall success.

A player's ability to perform high-intensity running during competition can be improved via a period of prior active WU. Mean repeated-sprint ability time was enhanced by 2.4% (Mohr *et al.*, 2004) when it followed seven minutes of active WU (at 70% of peak HR), compared to no-WU (control). In support of this, another study investigating changes following a 10-min active WU (at 70% $\dot{V}O_{2max}$), increased mean sprint speed by 4.7%, and enhanced peak sprint speed by 9.7% (Brown *et al.*, 2008). Reported changes in subsequent high-intensity running following active WU are similar to that following eight weeks of high-intensity repeated-sprint training (i.e., 10% improvement in running economy, and 2.1% improvement in repeated sprint times) (Chamari *et al.*, 2005; Ferrari Bravo *et al.*, 2008). Therefore, in order to optimally prepare soccer players for subsequent high-intensity exercise demands, ~10 min of active WU could be included prior to competition. Further research is required to elucidate the specific tasks within this WU period which can offer the greatest performance benefits for soccer players pertaining to high-intensity efforts.

2.1.2.4 Skill performance in soccer

The skill requirements of soccer can be physically taxing and require high levels of co-ordination, strength and power for elite competition (Bangsbo *et al.*, 2006). During a soccer match, players will perform approximately 1000-1400 skilled activities, some of which include 15 tackles, 10 headers, 50 involvements with the ball and 30 passes (Bangsbo *et al.*, 1991; Rienzi *et al.*, 2000; Mohr *et al.*, 2003). Lower-ranked soccer players have less involvement with the ball (10.2%; CI: 13.3-7), complete less short passes (8.6%; CI: 11.3 to 5.9) and less successful short passes (7.9%; CI: 10.5 to 5.4) in competitive matches compared to top-level players (Rampinini *et al.*, 2007a). In addition, less successful teams perform fewer strikes, and strikes on target which challenged the goal keeper to perform a save (0.6%; CI: 0.9 to 0.2 and 0.4%; CI: 1.1 to 0.2 respectively) (Rampinini *et al.*, 2007b). Similar to power-reliant activities (i.e. sprinting and jumping), increased strength is suggested to improve an athlete's ability to perform skills critical to soccer (Bangsbo, 1994). Methods of inducing acute improvement in force output via previous exercise may assist athletes in the performance of skill-related tasks, although research is required to confirm this hypothesis.

2.1.3 *Effects of match-related fatigue on skill and physical performance*

The effects of fatigue on subsequent skill and physical performance have been documented in soccer (Bangsbo *et al.*, 2006; Rampinini *et al.*, 2007b; Reilly *et al.*, 2008). A progressive decline in the force generation required for subsequent tasks occurs between the first and second halves in competitive matches (Mohr *et al.*, 2003; Krustrup *et al.*, 2006; Rampinini *et al.*, 2007a), as well as during specific high-intensity periods (Mohr *et al.*, 2003). Furthermore, fatigue can negatively affect subsequent skill-related tasks, and differentiate successful and less successful teams (Rampinini *et al.*, 2008).

Match-related fatigue is related to reductions in short passing ability in junior soccer players (Rampinini *et al.*, 2008). The precision of passes can decrease by 43% following one half of match play, and deteriorate to 62% following a second half. Other tasks affected by previous fatiguing bouts of exercise include shooting at goals (accuracy decreased by >25%) and slalom dribbling (mean time increased by 4.5%), following a 45-min intermittent exercise protocol (Stone & Oliver, 2009). Enhanced skill execution can provide performance advantages with more successful teams (1-5 in final rankings) having greater involvement with the ball (10.2%) and more effective short passes (7.9%), than less successful teams (15 – 20 in final rankings) (Rampinini *et al.*, 2007b).

Time-motion analysis of professional male soccer players suggests that fatigue can also be experienced during transient periods of a match (Mohr *et al.*, 2003). In particular, high-intensity running performed in the last 15 min of a match was 14-45% less compared to the first four, 15-min periods (Mohr *et al.*, 2003). Additionally, five minutes following the most intense exercise periods of play, distance covered decreased substantially from 219±8 m to 106±6 m, or 12% less than the average distance covered during all 5-min intervals. In another study, mean sprint time during a repeated-sprint protocol (5 x 30-m sprints) decreased by 1.6% after intense periods of exercise in the first half of a match, and similarly was reduced by 3.6% following the second half (Krustrup *et al.*, 2006). Other research corroborates these findings (Rienzi *et al.*, 2000), and suggests decrements in physical performance may also be position specific (i.e., greater decrease in high-intensity activity linked to wide midfielders and attackers) (Di Salvo *et al.*, 2009). Thus, acute periods of high-intensity exercise during a match can be detrimental to subsequent physical performance.

Unique to team-sports, a 15-min recovery period between the first and second halves (Bangsbo *et al.*, 1991) gives players the opportunity to replenish fuel stores and to recover from repeated bouts of high-intensity activity (Lovell *et al.*, 2007). To date however, only two studies have investigated the effects of performing an active re-WU during the half-time rest interval, aimed at improving subsequent physical performance (Mohr *et al.*, 2004; Lovell *et al.*, 2007). While both studies reported improved physical performances in the subsequent half of exercise, further controlled investigations are required to identify the most appropriate methods in maintaining second half skill and physical performance.

2.1.4 *Summary of the activity profile in soccer*

High-intensity activities characterise important passages of play during a soccer match. Power and speed are critical to a player's overall ability, and can discriminate between elite and sub-elite athletes, and teams. While improvements in power and strength can occur via extensive strength training programs, similar acute improvements can also be made via optimal WU practices prior to competition. Further controlled research is required to investigate the effects of WU protocols on team-sport-related performance and skill-related tasks in soccer, as well as their extended effect during repeated tasks. Repeated periods of high-intensity efforts during a soccer match can induce temporary fatigue, which can play a pivotal role in match outcomes. A re-WU period during half-time intermissions may be just as important as a pre-game WU routine, with emerging research suggesting that an active re-WU can minimise performance decrements observed in the second half of competition.

2.2 Warming-up for soccer

2.2.1 *Definition of a warm-up*

Warm-up (WU) routines include activities aimed at preparing the body for subsequent physical activity, and have been broadly classified into two major categories i.e., (i) passive and (ii) active WU (Bishop, 2003b). Passive WUs involve raising muscle temperature (T_m) via external means (i.e., hot showers, saunas and massage), while active WU encompass a wide range of exercise routines with an emphasis placed on slowly increasing intensity of movements (Kulund & Tottossy, 1983; Safran *et al.*, 1989; Bishop, 2003a; Bishop, 2003b). Active WU can include a plethora of activities ranging from generic (jogging, sprinting, skipping and jumping) to sport-specific (kicking, throwing, tackling and changing direction) (Bishop, 2003b), and resistance type activities, performed with additional loads (Rahimi, 2007; Mitchell & Sale, 2011). Active WUs are considered more appropriate when subsequent physical performance enhancement is the primary objective, as they have a greater influence on metabolic and cardiovascular process than passive methods (Kulund & Tottossy, 1983; Bishop, 2003b), provide an opportunity for skill rehearsal, and can induce a post-activation potentiaiton (PAP) effect (Sale, 2002). Therefore, the following sections of this review will focus primarily on the physiological and performance effects of active WUs, with specific mention of aspects which may be pertinent to soccer.

2.2.2 *Physiological benefits via active warm-ups*

The physiological benefits related to active WU include temperature and non-temperature-dependent mechanisms. Temperature-related mechanisms include an increase in muscle and core temperature, increases in nerve conduction velocity to motor units, the speeding of metabolic reactions, and a reduction of muscle and joint stiffness (Saltin *et al.*, 1968; Robergs *et al.*, 1992; Bishop, 2003a). Non-temperature-related mechanisms include an increase in blood flow to working muscles, an elevation of baseline oxygen consumption, increased psychological awareness/arousal, and the induction of post-activation potentiation effect (described in detail later) (Barcroft & Edholm, 1943; Malareki, 1954; Gullich & Schmidtbleicher, 1996; Jones *et al.*, 2003). The optimal soccer WU routine may assist players' subsequent performance via one, or many of these mechanisms. For the purpose of this review, the following section outlines mechanisms which may be pertinent to the performance of soccer-related tasks.

2.2.2.1 Temperature-related changes via active warm-ups

Temperature is recognised as an important factor in muscle functioning (Bennett, 1984; Rall & Woledge, 1990; Ranatunga, 1998). An increase in muscle temperature (T_m) via an active WU can improve dynamic performance by enhancing neuromuscular functioning, balance and co-ordination (Dolan *et al.*, 1985; Shellock & Prentice, 1985; O'Brien *et al.*, 1997), all important attributes of soccer (Bangsbo *et al.*, 2006). During exercise muscle and core temperature can rise rapidly (Figure 2-2). The T_m of the quadriceps at low (25-30% $\dot{V}O_{2max}$), intermediate (42-53% $\dot{V}O_{2max}$) and high-intensity (62-78% $\dot{V}O_{2max}$) exercise can surpass, or equal elevated core temperature (T_c) within five minutes of exercise (Saltin *et al.*, 1968) and reach a plateau after 10–20 min (Saltin *et al.*, 1968; Stewart *et al.*, 2003). Therefore, the combined benefits associated with increasing T_m may be achieved within ~5 min of an active WU.

An increase in T_m (to ~39ºC) can improve subsequent activities which are reliant on power production (Bergh & Ekblom, 1979). Changes in maximal dynamic strength, power output, jumping and sprinting performance, have all been positively correlated to T_m (Bergh & Ekblom, 1979), with changes in the same order of magnitude for all measures (4-6% per 1ºC rise). This is in agreement with other investigations reporting a 7% increase in instantaneous power output during squat jumps (Stewart *et al.*, 2003), a 5.3% per 1ºC rise improvement in sprinting, and a 4.4% per 1ºC improvement in vertical jump performance (Asmussen *et al.*, 1976). Increasing T_m can improve subsequent explosive performance by increasing the rate of ATPase activity of myosin (Barany, 1967; Stein *et al.*, 1982) which, in turn, increases the rate of cross-bridge cycling (Bergh & Ekblom, 1979) and results in improved maximal shortening velocity. This would lead to concomitant changes in the force-velocity relationship of subsequent tasks, and a favourable effect on maximal dynamic contractions (Bennett, 1984). Tasks requiring explosive force in soccer include sprinting, jumping and change of direction activities. All of which are extremely important as they commonly occur whilst contesting possession, performing a save (goal keeper) or producing an attempt to score (Bangsbo, 1994; Reilly *et al.*, 2000).

Comparing investigations which have measured temperature-related changes via active WU can be difficult. Variations in the measurement of internal temperature i.e., rectal temperature (T_r), muscle temperature (T_m) or core temperature (T_c) (Bishop, 2003a), and differences in probe depths during T_m studies, can result in inconsistent findings. At rest T_m has been reported to be 3% lower (36.14ºC – 35.01ºC) when measured ~10 mm as compared to 40 mm from the femur (Figure 2-2), and up to 60% higher at 40 mm following exercise (Kenny *et al.*, 2003). Although T_m measures during WU studies may be useful, practical and consistent testing methodologies should be implemented to enable effective comparisons and evaluations of interventions during periods of exercise.

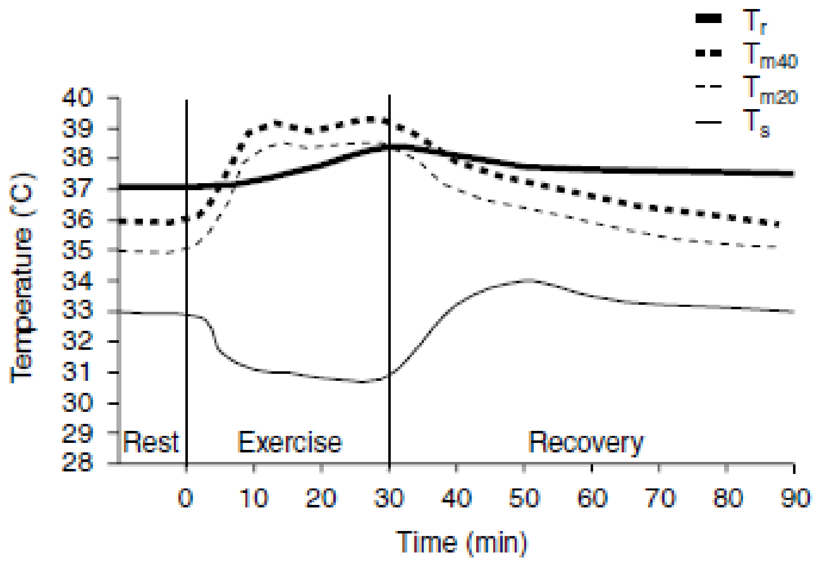


Figure 2-2 Temperature measured at rest, during moderate exercise and during recovery for the rectal (Tr), skin (Ts) and muscle at probe depths of approximately 20 mm (Tm20) and 40 mm (Tm40) in ambient conditions (10-30 ºC) (Saltin, Gagge et al. 1968; Sargeant 1987)

Measuring T_c may be an alternative method to T_m analysis in studies which prioritise performance measures, as it imposes minimal discomfort to participants and can provide an indication of thermoregulatory strain (Drust *et al.*, 2005). Furthermore, elevated T_c measures have been associated with reduced physical performance (torque decreased from 178±39 N·m to 160±44 N·m) during prolonged exposure to elevated temperatures (Thomas *et al.*, 2006). In this study (Thomas *et al.*, 2006), the prolonged elevation in T_c was responsible for decrements in voluntary muscle activation and torque, and not local T_m. The criterion tasks later returned to baseline values when T_c was reduced to pre-heating levels. Core temperature in a professional soccer match can rise during the first half of competition and remain ~5% higher than baseline values at the completion of a match (Edwards & Clark, 2006). Inadvertently elevating T_c prior to competition via extended active WU protocols may reduce players' ability to store and dissipate heat during subsequent competition, and hence reduce physical performance. Further investigations are therefore required to measure T_c and provide insight pertaining to thermoregulatory changes via currently implemented active WU protocols in soccer.

Another temperature-related mechanism which may be important for enhanced performance amongst soccer players is increased oxygen delivery to working muscles. A rightward shift in the oxyhaemoglobin curve can increase oxygen delivery to working muscles and improve subsequent physical performance (McCutcheon *et al.*, 1999). At 30 mm Hg of oxygen tension, haemoglobin gives up twice as much oxygen at 41°C as at 36°C, and oxygen dissociates from haemoglobin approximately twice as rapidly (Barcroft & King, 1909) (Figure 2-3). Improved oxygen delivery to working muscles could enhance physical performance in soccer when $\dot{V}O_2$ kinetics are limited by oxygen delivery (Bishop, 2003a). Therefore, high-intensity periods of activity in soccer, which typically rely on anaerobic turnover (Bangsbo *et al.*, 2001), would be the main beneficiary.

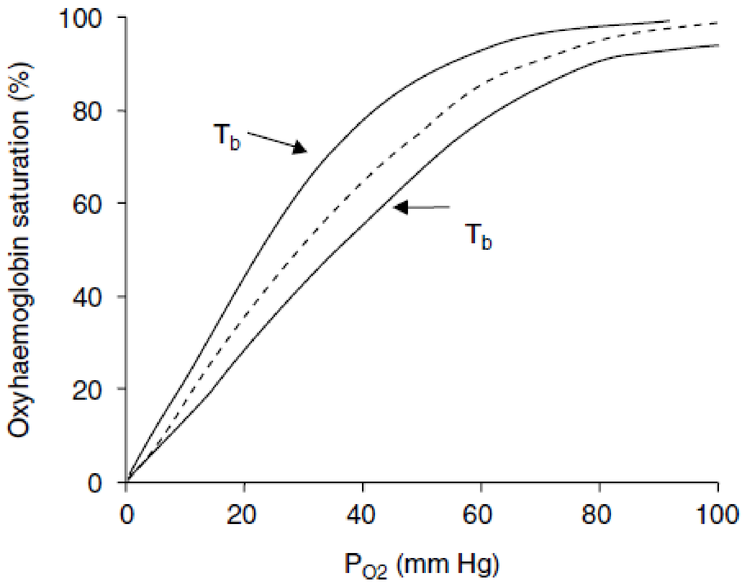


Figure 2-3 The effect of changing blood temperature (Tb) on the shape of the oxyhaemoglobin dissociation curve. PO_2= oxygen partial pressure.

2.2.2.2 Non-temperature-related changes via active warm-ups

An active WU can also augment physical performance via mechanisms not related to temperature, such as an increase in baseline $\dot{V}O_2$. For example, high-intensity activity in soccer is primarily dependant on anaerobic (phospho-creatine (PCr) and glycolytic) processes (Reilly *et al.*, 2000). However, a lag (delay) time between an immediate increase in energy demand and ATP supply exists, and can influence the level of oxygen deficit and subsequently exercise tolerance (Jones *et al.*, 2003). A previous bout of high-intensity WU is suggested to facilitate $\dot{V}O_2$ in subsequent bouts of heavy exercise (Gerbino *et al.*, 1996; Burnley *et al.*, 2000) by increasing baseline oxygen uptake, decreasing oxygen deficit at the onset of subsequent activity, and preserving anaerobic capacity via a reduction in the slow component of $\dot{V}O_2$ (Gutin *et al.*, 1976; Gerbino *et al.*, 1996) (Figure 2-4).

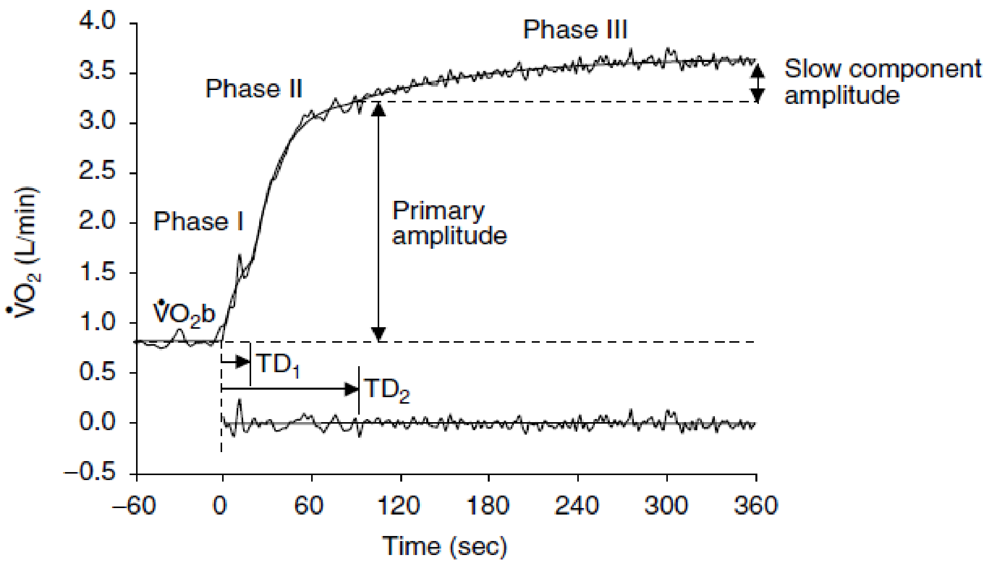


Figure 2-4 Typical pulmonary oxygen uptake ($\dot{V}O_2$) response to a single 6-min bout of high-intensity exercise. Phase I, the cardiodynamic phase, followed by the primary component (phase II) and the slow component phase (III). TD= time delay (Jones *et al.*, 2003).

Therefore, it could be theorised that less of the initial work would be completed anaerobically, thus sparing the anaerobic capacity for later in the task. Indeed, non soccer-related research has reported that a high-intensity cycling WU protocol (six-min bout of cycling at a power output of 70% of the difference between gas exchange ratio and $\dot{V}O_{2peak}$) improved mean cycling power output by 3% during a seven-minute high-intensity ergometer task (Burnley *et al.*, 2005).

However, in practice, the benefits of an elevated $\dot{V}O_2$ may not be achievable during extended periods of team-sport activity such as soccer. This is due to the intermittent nature of team sports, involving rapid changes in energy demand during various periods of play i.e., repeated sprinting bouts, chasing or evading opponents, jogging/walking into position (Bangsbo *et al.*, 2007). However, one study has investigated the relationship between prior constant exercise during the WU (10 min at 60% of $\dot{V}O_{2max}$ speed) and a subsequent acute bout of repeated sprint exercise (15x40-m sprint interspersed with 25-s of active recovery [50% of $\dot{V}O_{2max}$ speed]) (Dupont *et al.*, 2005), reporting a significant correlation between primary O_2 uptake and relative decrease in speed during the 15 sprints (r= 0.80). Furthermore, the accumulated time taken to complete the 15 sprints was also correlated with a faster O_2 uptake at the onset of exercise (r= 0.80). Therefore, it may be suggested that a faster $\dot{V}O_2$ adjustment, via a prior WU, may lead to a greater contribution of oxidative phosphorylation and a smaller O_2 deficit during subsequent short bouts of repeated sprint exercise. However, the practical relevance of these findings during extended periods of team-sport activity such as that observed in soccer may be limited.

Another non-temperature-related mechanism which may assist in subsequent soccer performance is an increase in psychological arousal. Although sparse research has been conducted in this domain, it has been reported that athletes who 'imagined' a WU, encountered subsequent enhanced physiological performance (Malareki, 1954). Likewise, active periods of WU may also provide athletes with valuable time to mentally prepare and rehearse important skilled tasks (Bishop, 2003a). A period of pre-game active WU, with an emphasis on skill execution, may act to heighten player concentration levels (Shellock & Prentice, 1985), and possibly improve subsequent skilled performance. Further research is required to confirm this hypothesis and quantify performance changes in skilled tasks via active WU.

2.2.3 *Performance benefits via active warm-ups*

Currently, limited research has investigated the effects of soccer-specific WU activities on subsequent specific performance. The implementation of various activities, sequence of activities, durations, recovery periods, performance measures, and participants, makes comparisons between studies difficult. The following section attempts to summarise research which may be related to the activity profile of soccer, and includes participants of elite or sub-elite classification from various team sports (Table 2.1).

To date, most research has investigated the acute (Pacheco, 1957; Grodjinovsky & Magel, 1970; Dolan *et al.*, 1985; Sargeant, 1987; Goodwin, 2002) and prolonged (Andzel, 1978; Burnley *et al.*, 2005; Gregson *et al.*, 2005; Hajoglou *et al.*, 2005) effects of WU activities at various intensities on performance measures related to power and speed tasks. Performance enhancement has been reported in activities such as vertical jump (Pacheco, 1957; Pyke, 1968; Goodwin, 2002), single-effort sprinting (Grodjinovsky & Magel, 1970; Stewart *et al.*, 2007) and repeated-sprint ability (Mohr *et al.*, 2004; Brown *et al.*, 2008); all important attributes in competitive soccer (Stolen *et al.*, 2005).

In one study, vertical jump improved by ~8% following five min of moderate-intensity jogging (60-70% of HR_{max}) (Goodwin, 2002), while another investigation reported a 10% improvement following five min of submaximal running combined with specific dynamic exercises (Saez Saez de Villarreal *et al.*, 2007). Similar periods of WU (~10 min) at an intensity of 70% $\dot{V}O_{2max}$ were sufficient to also improve mean repeated-sprint ability times by 2.4 - 4.7% (Mohr *et al.*, 2004; Brown *et al.*, 2008), and increase peak sprint speed by 9.7% (Brown *et al.*, 2008), when compared to the no warm conditions. However, it is difficult to rationalise the practical relevance of findings from one-off tasks in competitive soccer matches where the performances are repeated over ~90-min periods, and are interspersed with intermittent activity.

The optimal WU for team-sports and in particular soccer will depend on many factors such as training status, environmental conditions and the physical attributes of individual athletes. However, from the current research, it seems reasonable to suggest that an active WU incorporating ~10 min of moderate exercise at an intensity of 60-70% of $\dot{V}O_{2max}$, can improve performance measures which may be considered pertinent to team sports such as soccer.

Table 2.1 Summary of current team-sport warm-up research (elite and sub-elite participants)

Study	Subjects	Warm-up interventions mode	duration (min)	intensity	Measures	Outcome
Gelen 2010	26 Soccer (prof)	J	5	L-M	2 x 15-m sprint	J > J+SS, > J+D
		J+SS	15	L	Slalom dribbling	J > J+SS, > J+D
		J+D	15	L-M	Penalty kick	J >J+SS, > J+D
		J+SS+D	25	L-M		
Needham 2009	20 Soccer (youth-elite)	J+SS	15	L	CMJ	J+DSR > J+DS, > J+SS
		J+DS	15	L-M-H	10 & 20-m sprint	J+DSR > J+DS, > J+SS
		J+DSR	15	L-M-H		
Till 2009	12 Soccer (prof)	J+D	~5	L-M	10 & 20-m sprint	No Δ
		J+D+DL	~5	M-H	CMJ	No Δ
		J+D+TJ	~5	M-H		
		J+D+iMVC	~5	M-H		
Brown 2008	10 Soccer (semi-prof)	J	10	M	RSA (10 x 6 s)	J & P WU > No WU
		P WU				
		No WU				
Gabbett 2008	14 Basketball (junior elite)	GM+DS+SS+SSG	22	M-H	CMJ	No Δ
		GM+DS+SS+D	22	M-H	5-, 10- & 20-m sprint	No Δ
					COD speed	No Δ
					RA	No Δ

Table 2.1 continued

Study	Subjects	Warm-up interventions			Measures	Outcome
		mode	**duration (min)**	**intensity**		
McBride, 2005	15 Football (NCAA)	C+W C+W+HS C+W+LCMJ	9 ~10 ~10	L L-H L-H	40-m sprint	C+W+HS > C+W
Rahimi, 2007	20 Soccer (prof)	C+W R HS R MS R LS	9 ~12 ~12 ~12	L L-H L-M L	40-m sprint	R HS, R MS & R LS> C+W R HS >R LS
Burkett, 2005	29 Football (NCAA)	Sub max CMJ RD SS No WU	<5 <5 5	L M L	CMJ	RD > SS, sub max CMJ & No WU
Stewart, 2007	14 Rugby league (semi-prof)	No WU SS J J+SS	 12 12 12	 L L-M-H L-M-H	40-m sprint	J > No WU & SS
Fletcher, 2010	27 Soccer (semi-prof)	J J+SS J+DS	5 11 11	L	CMJ 20-m sprint Agility	J+DS> J >J+SS J+DS> J >J+SS J+DS> J >J+SS

J= Jog, L= low, M= moderate, H= high, SS= static stretching, D= dynamic exercise, DS= dynamic stretching, DSR= dynamic stretching + resistance, R= resistance, DL= Dead lift, TJ= Tuck jumps, iMVC= isometric maximal voluntary contraction, WU= Warm-up, P= passive, GM= general movements, COD= change of direction, RA= reactive agility, C= cycling, W= walking, L= loaded, HS= Heavy squat load, MS= moderate squat load, LS= light squat load.

2.2.3.1 Effects of short-duration warm-ups on physical performance

Low-to-moderate-intensity, generic movement WU routines, lasting between ~5-12 min, can enhance team-sport-specific tasks. Four studies have reported improved performance in single-effort sprinting tasks (McBride *et al.*, 2005; Rahimi, 2007; Stewart *et al.*, 2007; Gelen, 2010), while others have reported improvements in repeated-sprint ability (Brown *et al.*, 2008), and skilled tasks such as slalom soccer dribbling and penalty kick speed (Gelen, 2010). Improvements may be caused via T_m-related mechanisms such as, enhanced neuromuscular efficiency (Hamada *et al.*, 2000; Sale, 2002), augmentation in the force-velocity relationship (Binkhorst *et al.*, 1977; Ranatunga *et al.*, 1987), and an increase in high-energy phosphate degradation (Hirvonen *et al.*, 1987; Febbraio *et al.*, 1996).

Similar improvements in vertical jump (~7-8%) are attained when 3-5 min of moderate-intensity activity (jogging) is performed (Pacheco, 1957; Goodwin, 2002). Although T_m was not measured in these studies, 3-5 min of moderate-intensity exercise can increase T_m by ~2°C (Saltin *et al.*, 1968), similar to what is recommended for improved short-term performance (Bishop, 2003b). It may therefore be suggested that a brief (~5-12 min) period of low-to-moderate-intensity WU activity can sufficiently raise T_m and improve short-explosive tasks such as vertical jump and short-sprint ability, in an elite team-sport population.

2.2.3.2 Effects of long-duration warm-ups on physical performance

A prolonged increase in the above mentioned mechanisms with inadequate recovery periods between the warm-up and performance task could have an opposing effect (Gregson *et al.*, 2005; Bishop & Maxwell, 2009). Short, explosive activities, such as vertical jump height, short-sprint ability and repeated-sprint ability, rely on the breakdown of high energy phosphate stores for the physical task to be executed with maximal force (Hirvonen *et al.*, 1987). A prolonged WU (>15 min), or a WU which is too intense (> approximately 70% $\dot{V}O_{2max}$) (Karlsson *et al.*, 1970) has the potential to decrease the availability of high-energy phosphates, and subsequently impair the execution of athletic tasks (Bishop, 2003b). In fact, a 5-min jog WU was better at improving soccer-specific performance than a WU lasting 15- 25 min (Gelen, 2010).

Although no study has yet investigated the specific performance effects of prolonged WU routines in team-sports, other related research has reported the detrimental effects of prolonged WUs (Table 2.2). For example, a 15-min jog WU performed at 80% $\dot{V}O_{2max}$ reduced subsequent running time-to-exhaustion by 10% in rugby league players (Stewart & Sleivert, 1998). Similarly, an intermittent time-to-exhaustion task on a motorised treadmill was decreased by 28% with the same WU duration (15-min), implemented at an intensity range of 70% $\dot{V}O_{2max}$ (Gregson *et al.*, 2005). Intermittent exercise is a common physical demand in team sports such as soccer (Bangsbo *et al.*, 2006), and one which can discriminate between elite and sub-elite soccer players (Rampinini *et al.*, 2007b). It is likely that further skill and cardiovascular performance decrements following prolonged WU periods in soccer could also hinder a team's overall success.

Although the current literature is limited, it seems important that the optimal WU for team-sport athletes incorporates a sufficient active period to increase T_m and facilitate an neuromuscular activation. However, the WU duration and intensity should be closely monitored and should not interfere with the availability of high-energy phosphates, which has the potential to impair subsequent physical performance (Bishop, 2003b; Fradkin *et al.*, 2009). This may be accomplished by incorporating a recovery period following high-intensity WUs (~70-90% $\dot{V}O_{2max}$) or altering the intensity and/or duration of the active WU performed prior to competition.

Table 2.2 Effects of prolonged warm-up routines

Study	Subjects	Warm-up mode	duration (min)	intensity	Performance task mode	performance change
Bishop, 2001	4 T females 4 T males	Kayak	15	75% $\dot{V}O_{2max}$	2 min Kayak T.T	5.4% ↓ mean power
Bishop, 2009*	8 T males	Cycle	20	35-100% $\dot{V}O_{2peak}$	36 min IST	8% ↓ mean work
Stewart, 1998	9 T males	T. Run	15	80% $\dot{V}O_{2max}$	Running TTE	10% ↓ TTE
Gregson, 2005	6 U males	T. Run	15	70% $\dot{V}O_{2max}$	Intermittent TTE	28% ↓ TTE
Gregson, 2002	6 U males	T. Run	18	70% $\dot{V}O_{2max}$	Steady state TTE	23% ↓ TTE
Uckert, 2007*	20 R males	T. Run	20	70% HR_{max}	Running TTE	11.2% ↓ TTE

U= untrained, **T**= trained, **T.T**= time trial, **TTE**= time to exhaustion, ***** completed in hot conditions, **IST**= intermittent sprint test,

R=recreationally trained, **T. Run**= treadmill running

2.2.3.3 Effects of high-intensity, short-duration warm-ups on physical performance

High-intensity, short bouts of exercise within soccer WU protocols can provide ergogenic assistance possibly via a post-activation potentiation (PAP) effect (Rahimi, 2007). Post-activation potentiation refers to a muscle's previous contractile history and suggests that short periods of high-intensity resistance exercise can facilitate the volitional production of subsequent force (Hodgson *et al.*, 2005; Tillin & Bishop, 2009). The performance-enhancing effects of high-intensity, short-duration WU have been reported with various populations (Chiu *et al.*, 2003); however, only three studies have investigated this phenomenon within elite team-sport athletes (Rahimi, 2007; Needham *et al.*, 2009; Till & Cooke, 2009).

In two of these studies enhanced vertical jump and short-sprint ability (up to 40 m) of ~2-3% occurred following WU protocols which included various weighted-squat exercises (Rahimi, 2007; Needham *et al.*, 2009), while the other investigation found no change in performance (Till & Cooke, 2009). Methodological differences, such as the use of a dead-lift instead of a squat exercise intervention, may partly explain some of the disparities found between these investigations, while large individual variations in the responses to the treatment (-7.1% to + 8.2%) were related to participants' strength training background in the study reporting no effect (Till & Cooke, 2009). Indeed, a 2.6% improvement in vertical jump performance amongst the stronger group was reported, compared to no change in the weaker group. These findings are not surprising since other investigations have suggested that the benefits of high-intensity, short-duration WUs are more likely to be observed amongst a population which has a history of resistance training (Gourgoulis *et al.*, 2003; Kilduff *et al.*, 2007).

Previously, the induction of a PAP effect via high-intensity, short-duration WU, could only be implied. However, one recent study has reported that a squat exercise consisting of 5 repetitions, with a resistance that will elicit a 5 repetition maximum (RM) effort, can induce an increase in peak twitch torque (measured via M-waves) in the quadriceps (10.7%), as well as improving vertical jump height by 2.9% (Mitchell & Sale, 2011). In addition, a PAP effect was also reported following a 10-s maximal isometric contraction of the knee extensor muscles (Requena *et al.*, 2010), with an increase in twitch peak torque of 45.6%, that was later positively correlated with improvements in vertical jump height (r= 0.61). This study also reported a correlation with improved 15-m sprint time (r= -0.59) following the WU interventions (Requena *et al.*, 2010). Further investigations are required to elucidate if short-bouts of high-intensity activity (i.e., 5RM or maximal isometric contractions) can also improve other team-sport-specific tasks such as reactive agility and skill tasks i.e., passing. This research would have important implications for team-sport coaches and athletes interested in utilising the WU period to improve subsequent performance tasks specific to team sports such as soccer.

2.2.4 *Summary of team-sport warm-up research*

In summary, it seems possible that more than one type of activity or combination of various activities can have a positive effect on subsequent team-sport performance. An active period of ~5-12 min of low-to-moderate-intensity activity is sufficient to improve subsequent physical performance and alter important underlying mechanisms (see section 2.2.2). High-intensity, short-duration activities (i.e., a 5RM squat) can provide additional ergogenic benefit in subsequent explosive physical tasks regularly performed by team-sport athletes, and may be an important inclusion in soccer WU routines. On the contrary, prolonged periods (≥ 15-min) of moderate-high intensity active during the WU prior to competition, can decrease players' subsequent physical performance.

2.2.5 *The influence of stretching during the warm-up*

The inclusion of stretching routines during the WU is suggested to assist in physically preparing the body by increasing range of motion, decreasing muscle stiffness and reducing the risk of subsequent injury (Safran *et al.*, 1989; McHugh & Cosgrave, 2009). However, a seminal investigation (Pope *et al.*, 2000) demonstrated that prior stretching routines do not appear to protect participants from subsequent injury, and that the occurrence of training-induced-injuries, is more likely related to an individual's fitness levels. Following this, many investigations have subsequently reported the negative effects associated with stretching routines prior to performing explosive tasks (Fowles *et al.*, 2000; Behm *et al.*, 2001; Church *et al.*, 2001; Cornwell *et al.*, 2002; Power *et al.*, 2004; Faigenbaum *et al.*, 2005; Nelson *et al.*, 2005; Bradley *et al.*, 2007; Brandenburg *et al.*, 2007). In addition, research has typically reported no beneficial effect of stretching on injury prevention and that instead, pre-activity stretching may actually increase the likelihood of musculoskeletal injuries (Shellock & Prentice, 1985; Safran *et al.*, 1988; Shrier, 1999, 2008; McHugh & Cosgrave, 2009). These findings have important implications for soccer players who continue to participate in stretching routines during their pre-game WU.

2.2.5.1 Defining stretching

Stretching can be divided into four categories that include: ballistic, dynamic, proprioceptive neuromuscular facilitation (PNF), and static stretching, all of which have previously been described (Hoffman, 2002a; Powers & Howley, 2004). Static stretching is the most common form of stretching and involves voluntarily lengthening of a muscle to the point of resistance, followed by a pre-determined static hold phase (Bloomfield *et al.*, 1994). Suggested durations in this static position vary amongst authors, with recommendations ranging from 10 to 60 s (Anderson & Burke, 1991; Pope *et al.*, 2000; Chan *et al.*, 2001; Knudson *et al.*, 2001; Hoffman, 2002b; Power *et al.*, 2004) per repetition, while entire stretching routines can last between ~4 (Behm *et al.*, 2004a; Duncan & Woodfield, 2006) to 30 min (Bazett-Jones *et al.*, 2005; Yamaguchi *et al.*, 2006).

2.2.5.2 Performance decrements following stretching

The negative effects of stretching on subsequent performance have been reported in CMJ (Cornwell *et al.*, 2002; Wallmann *et al.*, 2005; Behm & Kibele, 2007), sprinting (Fletcher & Jones, 2004; Stewart *et al.*, 2007; Chaouachi *et al.*, 2009; Needham *et al.*, 2009; Gelen, 2010) and repeated-sprint ability (Beckett *et al.*, 2009; Sim *et al.*, 2009). In one study, five static stretches of the lower limbs (2 x 20-s holds) decreased 30-m sprint times by 8.5% compared to participants who completed a 5-min jogging WU at low-moderate intensity (HR~ 140 bpm) (Gelen, 2010). Decreased performance in single-effort sprints (between 2-3%) have been reported for 10- (Needham *et al.*, 2009), 20- (Fletcher & Jones, 2004), 30- (Chaouachi *et al.*, 2009) and 40-m sprints (Winchester *et al.*, 2008) following various stretching routines. In addition, static stretching reduced performance in a slalom dribbling test (4.1%), which incorporates speed and skill characteristics important to soccer performance (Bangsbo *et al.*, 2006). Prolonged performance decrements via stretching have also been reported (~4%), when implementing vertical jump as the criterion measure (Cornwell *et al.*, 2001; Bradley *et al.*, 2007; Brandenburg *et al.*, 2007); decrements lasting up to 60 min post have been reported following static stretching (Fowles *et al.*, 2000; Power *et al.*, 2004).

The mechanisms underlying reduced explosive performance following stretching may be neural and/or temperature related (Dolan *et al.*, 1985; Rosenbaum & Hennig, 1995). A decreased excitability of α-motor neurons has been suggested by some authors (Fowles *et al.*, 2000; Behm *et al.*, 2001), while others suggest altering the absolute length of muscles may negatively influence muscle spindle discharge (Fletcher & Anness, 2007), as well as altering muscle proprioceptor sensitivity (Kokkonen *et al.*, 1998). Alternatively, the passive nature of static stretching may negatively affect T_m-related mechanisms important for optimal performance, and therefore would be in direct opposition to the fundamental principles of an active WU period (Safran *et al.*, 1989). Investigations reporting the HR response during stretching conditions have reported a reduced HR of between 27-29% (~100 beats per min) following static stretching (Faigenbaum *et al.*, 2005; Fletcher & Monte-Colombo, 2010). This may be one of the precursors responsible for decreased performance following static stretching, especially if the stretching is performed close to the commencement of competition (Fowles *et al.*, 2000; Power *et al.*, 2004).

It should be noted that many WU routines which include static stretching also consist of secondary sport-specific WU periods (Taylor *et al.*, 2008). Although an active secondary WU period can reverse the negative effects of static stretching to ~100% of baseline values (e.g., vertical jump and 20-m sprint) (Taylor *et al.*, 2008; Pearce *et al.*, 2009), no performance enhancement is achieved when combining static stretching and secondary active WUs (Taylor *et al.*, 2008). Therefore, it would be advisable that athletes endeavouring to enhance performance via pre-competition WU routines should avoid the inclusion of static stretching, at least 60-min prior to competition (Fowles *et al.*, 2000; Power *et al.*, 2004). Furthermore, although a secondary active

WU may minimise performance decrements, static stretching is likely to compromise subsequent explosive performance relevant to team sports such as soccer.

2.3 Post-activation potentiation (PAP)

2.3.1 *A definition of post-activation potentiation (PAP)*

Post-activation potentiation (PAP) refers to the phenomenon by which muscular performance is enhanced as a result of its contractile history (Sale, 2002; Hodgson *et al.*, 2005). Whether induced via electrical stimulation or maximal voluntary contractions (MVC), a brief period of high-intensity, short-duration muscular contraction can increase the subsequent rate of force development (Vandenboom *et al.*, 1993; Abbate *et al.*, 2000; Gossen & Sale, 2000), enhance speed/power-reliant tasks (Sale, 2002; Chatzopoulos *et al.*, 2007), and offset low frequency fatigue (Rijkelijkhuizen *et al.*, 2005). The existence of a “window of opportunity” has been theorised in some studies, suggesting that an optimal time frame exists, whereby potentiation takes precedence over fatigue and improved muscular performance is achieved (Figure 2-5) (Young *et al.*, 1998; Hamada *et al.*, 2000; Kilduff *et al.*, 2008). However, identifying improved performance via PAP can be difficult due to the various methodologies used to induce PAP; isometric contractions (Gossen & Sale, 2000; French *et al.*, 2003; Behm *et al.*, 2004b), electrical stimulation (Abbate *et al.*, 2000; Baudry & Duchateau, 2007) and weighted resistance protocols consisting of various loads and repetitions (Gourgoulis *et al.*, 2003; McBride *et al.*, 2005; Chatzopoulos *et al.*, 2007; Rahimi, 2007). Protocols that can induce PAP via loaded exercise would be of distinct interest to soccer players and coaches interested in utilising this technique to improve subsequent performance.

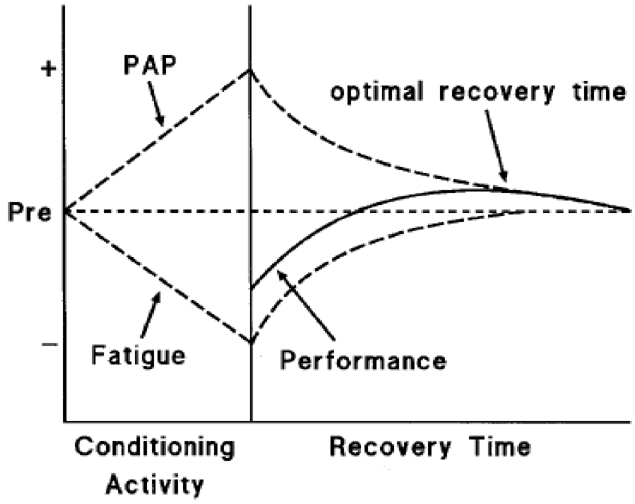


Figure 2-5 Theoretical strategy for exploiting PAP. If fatigue dissipated faster than PAP decays, as illustrated, subsequent performance will transiently exceed the best performance before the conditioning activity (Sale, 2002).

2.3.2 *Physiological benefits of PAP*

The two underlying mechanisms pertaining to PAP and improved performance include; the phosphorylation of myosin regulatory light chains (RLC) (Hamada *et al.*, 2000; Hodgson *et al.*, 2005; Baudry & Duchateau, 2007) rendering actin-myosin interaction more sensitive to calcium released from the sarcoplasmic reticulum (Sweeney *et al.*, 1993; Rassier & Macintosh, 2000), and an increase in the recruitment of higher order motor units (Gullich & Schmidtbleicher, 1996; Chiu *et al.*, 2003).

Post-activation potentiation induced via exercise can produce methodological challenges. Variables such as intensity, duration, recovery period following contraction, and type of contraction, are all factors which can shift the net impact towards either potentiation or fatigue (Tillin & Bishop, 2009). In addition, the impact of PAP may vary for the different physical tasks which are subsequently performed (Sweeney *et al.*, 1993; Hamada *et al.*, 2000; Sale, 2002), and these are discussed later (see section 2.1.14).

2.3.2.1 Phosphorylation of regulatory light chains

At the peripheral level, the principal mechanism associated with muscular potentiation stem from the phosphorylation of myosin regulatory light chains (RLC) via myosin light chain kinase, which theoretically increases the sensitivity of the actin-myosin interaction to calcium released from the sarcoplasmic reticulum (Sweeney *et al.*, 1993; Hamada *et al.*, 2000; Rassier & Macintosh, 2000). As represented below, (Figure 2-6) calcium/calmodulin binds to myosin light chain kinase, and the enzyme is then converted from inactive to active. The activated kinase subsequently phosphorylates RLC, leading to an increase in the rate by which myosin cross bridges move into their force-producing state (Sweeney *et al.*, 1993).

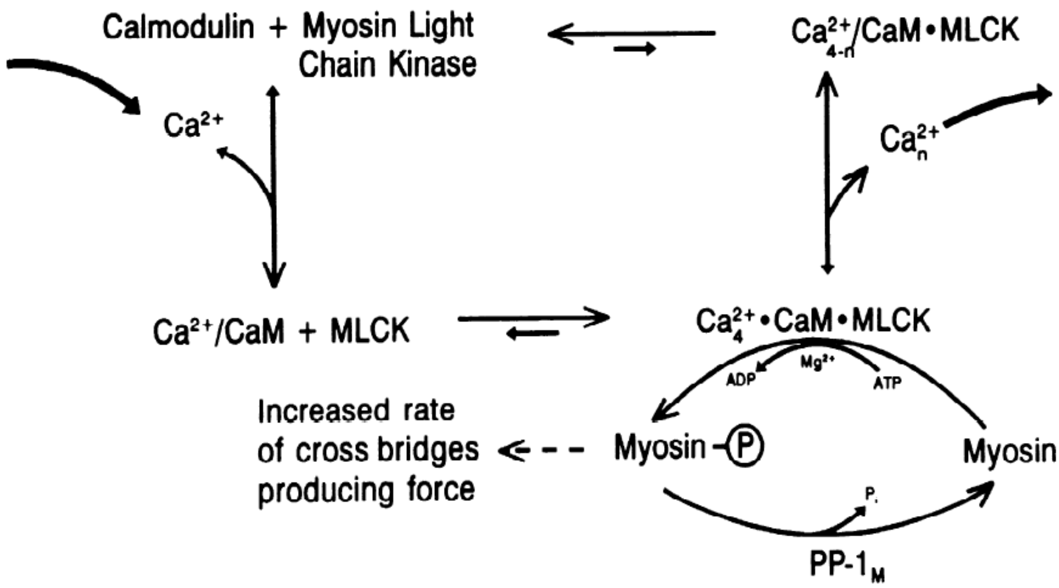


Figure 2-6 Schematic representation of regulation of myosin light chain phosphorylation in striated muscle. $Ca2^+$= calcium, CaM= calmodulin, MLCK= myosin light chain kinase, PP-1_m= myofibrillar protein phosphate type 1 (Sweeney et al., 1993).

With a brief period of near-maximal (unfused tetanic) contraction, RLC phosphorylation may enhance motor performance in soccer-related tasks by increasing the rate and extent of force development (Sweeney *et al.*, 1993). An increase from 69 to 84% of initial steady state force was observed when non-phosphorylated RLC-reconstituted fibres were subsequently phosphorylated with exogenous myosin light chain kinase (Szczesna *et al.*, 2002). In another investigation, a 10-s MVC increased the phosphate content of the knee extensor muscles from approx. 0.25 to approx. 0.50 mol phosphate per mol RLC (Houston *et al.*, 1987), subsequently increasing twitch amplitude by up to 25%. Many studies have reported an acute increase in RLC phosphorylation and a parallel increase in twitch tension following stimulation in mammalian skeletal muscle (Manning & Stull, 1982; Moore & Stull, 1984; Vandenboom *et al.*, 1993; Szczesna *et al.*, 2002), but few have investigated changes in human skeletal muscle with similar outcomes (Stuart *et al.*, 1988; Smith & Fry, 2007). Therefore, although RLC phosphorylation can be elevated via previous exercise bouts and in some instances increase the rate of force development, further investigation is required to elucidate its effect on subsequent team-sport and soccer-related performance.

2.3.2.2 Increased recruitment of higher order motor units following PAP

The second mechanism which may assist subsequent performance via a WU aimed at inducing PAP is the recruitment of higher order motor units. Post-activation potentiation can increase force output, while reducing motor unit discharge rates during sustained, submaximal muscle contractions (Inglis *et al.*, 2011). This is accomplished by decreasing the threshold required to re-activate motor units (e.g., decreasing transmitter failure and/or increasing the after-hyperpolarisation phase of motor neurons) (Gossen *et al.*, 2003; Tillin & Bishop, 2009). Indeed, a 10-s MVC of the tibialis anterior muscles increased force output by 2.6-fold compared to the un-potentiated condition, while motor unit discharge rates were decreased by 10.0±0.2%

following the MVC (Inglis *et al.*, 2011) (Figure 2-7). A reduced motor unit discharge rate was also reported in the triceps brachii muscle following a brief 5-s contraction at 75% of MVC (Klein *et al.*, 2001). Similarly, the latter investigation reported increased twitch force following the conditioning contraction (~2 fold), while motor unit discharge rates declined in the potentiated muscle by 1-6 Hz. A strong correlation was reported between twitch potentiation and declining motor unit discharge rates (*r*= 0.74). Therefore, a bout of PAP can trigger the recruitment of higher order motor units (commonly fast-twitch fibres) while reducing motor unit discharge rates. This could aid the integrity of excitation-contraction coupling (Sale, 2004), and enhance subsequent explosive activity (Gullich & Schmidtbleicher, 1996) which may be related to enhanced soccer-specific physical performance.

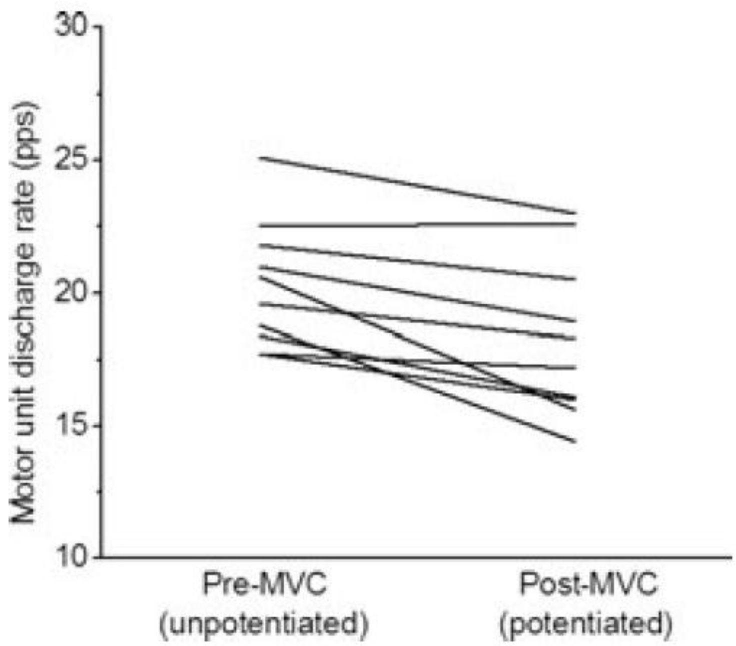


Figure 2-7 Motor unit discharge rate in the tibialis anterior, before and after a 10-s maximum voluntary contraction (MVC). Motor unit discharge rate decreased in 9 out of 10 subjects tested (Inglis et al., 2011).

It is also possible that an increased efficiency in motor unit firing rate during subsequent activity could mitigate the onset of fatigue (Green & Jones, 1989). Commonly known as low-frequency fatigue, repeated concentric and eccentric exercise can decrease subsequent force output at low frequencies (Edwards *et al.*, 1977), and has been observed in team sports via CMJ measures (Cormack *et al.*, 2008). Post-activation potentiation may play a special role in reversing, or at least attenuating, subsequent decrements in force output by recruiting higher order motor units at lower frequencies, and thus preserving central drive (Taylor & Gandevia, 2008). For example, a 10-s MVC induced following a fatiguing task (3 x 60 s of knee extension exercise), increased twitch tension from 40.9±4.0 to 54.8±3.7 Nm, while torque, assessed at 10 Hz, increased at 60, 120 and 240 min post-MVC (36.3±4.1 vs. 50.7±6.2 Nm, 40.8±6.3 vs. 56.5±8.9 Nm and 42.0±4.7 vs. 57.5±8.3 Nm, respectively) (Green & Jones, 1989). The practical relevance of these findings may be theorised, however further investigations are still required to elucidate the interplay of both central (i.e., motor unit recruitment) and peripheral mechanism (i.e., phosphorylation of regulatory light chains) following a PAP conditioning activity.

2.3.3 *Performance benefits via PAP*

Many studies have investigated the application of PAP interventions on subsequent physical performance. For reviews see (Sale, 2002; Docherty & Hodgson, 2007; Tillin & Bishop, 2009). Performance enhancement via PAP has been reported in vertical jump (Young *et al.*, 1998) and short-sprint ability (Chatzopoulos *et al.*, 2007) tasks; however, a more detailed approach may be required in soccer to investigate the effects of equally important physical tasks such as intermittent exercise performance, repeated-sprint ability, and reactive agility. Of the studies reporting a beneficial effect via PAP (Table 2.3), methodological continuity is lacking, and therefore an optimal method for application in soccer is difficult to conclude.

Table 2.3 Summary of studies reporting positive effects via high-intensity conditioning exercises during the warm-up

Author	Participants	Conditioning contractions	Measure	Results
McBride 2005	15 AT M	1x3 squat at 90%; 1RM 1x3 loaded CMJ at 30%; 1RM	10-, 30- & 40-m sprint	Sprint time ↓ 1.39% (10 m) & 0.87% (40 m) ⇔
Saez Saez 2007	12 AT M	a)3x5 loaded CMJ b)2x4 squats at 80%, 2x2 at 85%; 1RM c) 2x4 squats at 80%, 2x2 at 90%, 2x1 at 95%; 1RM d) 3x5 DJ e) Specific WU for volleyball match f) 3x5 squats at 30%; 1RM	CMJ CMJ with extra load DJ	CMJ ↑ by 4.1% (a), 5.01% (b), 4.59% (c) & 6.96% (e) DJ ↑ in (a) 4.18%, (b) 2.98%, (c) 5.47% & (e) 4.49% DJ ↑ or ⇔ 6 hrs post in a, b & c P_{max} ↑ 2.5% (a), 11.4% (b), 9% (c), 10.9% (e)
Kilduff 2008	20 AT M	3x3 squat (87%; 1RM)	CMJ	CMJ ↓ 5.5 % (15 s post) CMJ ↑ 4.9% (8 min post) PRFD ↑ 24% (8 min post)
Kilduff 2007	23 AT M	3RM squats (↑ load until fatigue) 3RM bench press	CMJ BPT	CMJ: 2.9% ↓ (15 sec), ⇔ (4 min), ↑ 6.8% (8 min), ↑ 8.0% (12 min), ⇔ (16 & 20 min) BPT: 4.7% ↓ (15 sec), ⇔ (4 min), 2.8% ↑ (8min) 5.3% ↑ (12 min) & 0.8% ↑ (16 min)
Rahimi 2007	12 AT M	2x4 squats at 60%; 1RM 2x4 squats at 70%; 1RM 2x4 squats at 85%; 1RM	40-m sprint	Sprint times ↓ 1.09% Sprint times ↓ 1.77% Sprint times ↓ 2.98%
Chatzopoulos 2007	15 UT M	1x10 squat at 90%; 1RM	30-m sprint	Sprint times ↓ 3% (10 m) & ↓ 2% (30 m)

Author	Participants	Conditioning contractions	Measure	Results
Baker 2003	16 AT M	1x6 bench press at 65%; 1RM	1x5 reps BPT (with 50 kg)	Power ↑ 4.5%
French 2003	14 AT (10 M, 4 F)	iMVC KE 3x3 s iMVC KE 3x5 s	DJ CMJ 5-s cycle sprint 1RM isokinetic KE	DJ ↑ 5.03%, GRF ↑ 4.94% ⇔ ⇔ P_t ↓ 3%
Young, 1998	10 UT M	1x5 squats at 5RM	CMJ 5 reps (with 19 kg load)	CMJ ↑ 2.8%
Gourgoulis 2003	20 M (11 RT, 9 UT)	1x2 half squats at 20, 40, 60, 80 & 90%; 1RM	CMJ	CMJ ↑ 4% in RT CMJ ↑ 2.4 % in RT + UT CMJ ⇔ UT
Burkett 2005	29 AT M	CMJ with 10% BW load 1x5 CMJ at 75% VJ_{max} load	CMJ	CMJ ↑ 3.1% ⇔
Smith 2001	9 UT M	1x10 squats at 90%; 1RM	10-s sprint cycle	AP ↑ 5.1% (5 min post) AP ↓ 6.3% (20 min post) AP/Kg ↑ 4.8% (5 min post) AP/Kg ↓ 6.3% (20 min post)
Gullich 1996 (study 1)	34 AT (22 M, 12 F)	3x5 iMVC (leg press)	CMJ & DJ	CMJ & DJ ↑ 3.3%

Author	Participants	Conditioning contractions	Measure	Results
Gullich 1996 (part 2)	8 AT	5x5 iMVC (plantar flexion)	iMVC plantar flexion	iRFD ↓ 13% (1 min post) iRFD ↑ 19% (5-13 min post)
Smilios 2005	10 RT M	3x5 half squats at 30% & 60%; 1 RM 3x5 jump squats at 30% & 60%; 1 RM	CJ CMJ	CJ: ↑ 5% with half squats at 60%; 1 RM CMJ: ↑ 4% with jump squat at 60%; 1RM CMJ: ↑ 4% with jump squat at 30%; 1RM CMJ: ↑ 3% with half squat at 60%; 1RM
Batista 2007	10 UT M	1x10 maximal KEs ($60^{o}.s^{-1}$)	KE (T_p)	T_p ↑ 1.3 N.m (± 0.79) & remained ↑ 12 min post

AP=average power; **AT=**athletes; **BP=**Bench press; **BPT=**Bench press throws; **BW=**body weight; **CJ=**concentric jump; **CMJ=**counter movement jump; **DJ=**drop jump; **ES=**effect size; **F=**females; **KG=**Kilograms; **iMVC=**maximum isometric voluntary contraction; **iRFD=**isometric rate of force development; **KE**=knee extension; **M=**males; **MVC=**maximum voluntary contraction; **PPO=** peak power output; $\mathbf{P_{max}}$ =maximum power; $\mathbf{P_p}$=peak power; **PRFD=** Peak rate of force development; **Reps=**repetitions; **RI=**rest interval; **RT=**resistance trained; **RM=**repetitions maximum; $\mathbf{T_p}$=peak torque; **UT=**untrained; **VGR=**vertical ground reaction; **VJ=**vertical jumps; **WU=**warm up; ↑=indicates increase; ↓=indicates decrease; ⇔=no change.

The majority of PAP research has implemented exercises that include the lower limbs such as the loaded squat (McBride *et al.*, 2005; Kilduff *et al.*, 2007; Rahimi, 2007; Kilduff *et al.*, 2008) and the half-squat exercise (Gourgoulis *et al.*, 2003; Smilios *et al.*, 2005), while others have reported positive effects on knee-extension tasks (French *et al.*, 2003; Batista *et al.*, 2007) and upper-body power tasks (Baker, 2003; Kilduff *et al.*, 2007). The volume and intensity implemented during these studies can vary remarkably, with some using a set/repetition range of 1x3 (McBride *et al.*, 2005; Kilduff *et al.*, 2007), while others have used 2x4 (Rahimi, 2007; Saez Saez de Villarreal *et al.*, 2007), 3x3 (Kilduff *et al.*, 2008), 3x5 (Smilios *et al.*, 2005; Saez Saez de Villarreal *et al.*, 2007). Even 1x10 repetitions have been reported to have performance benefits (Chatzopoulos *et al.*, 2007). With such discrepancies, it is difficult to compare, or recommend, an optimal PAP protocol for implementation in soccer.

To date, only three studies have investigated the subsequent performance effects of PAP within soccer players. Amongst 12 elite adult soccer players, 40-m sprint performance improved by 1-3% when proceeded by 2x4 repetitions of squats performed at various loads (i.e., 60% of 1RM, 70% of 1RM and 85% of 1RM) (Rahimi, 2007). Similar findings for sprint and vertical jump performance have also been observed within elite youth soccer players utilising a WU protocol which included 1x8 repetitions of front squats (20% load), when compared to a WU including static stretching (Needham *et al.*, 2009). On the contrary, sprint performance (10-20 m) and vertical jump improved, but not significantly, when performed following a 5RM dead-lift exercise (Till & Cooke, 2009). Large variations in performance measures following the PAP protocol in this latter study (-7.1% to +8.2%) suggest other factors may have negatively influenced performance in some participants (Till & Cooke, 2009). For example, the modality of the intervention, load, intensity, recovery time, type of contraction, as well as inter-individual variability including training age and strength-power ratio can all play a role in either potentiating subsequent performance, or inducing fatigue (Tillin & Bishop, 2009) (Figure 2-8).

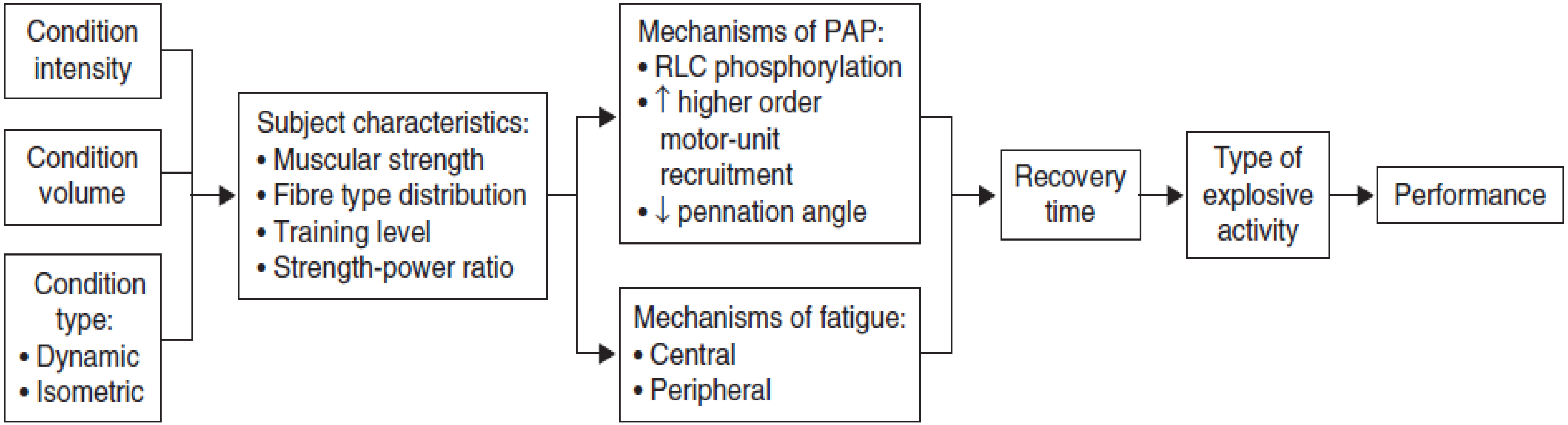


Figure 2-8 Factors influencing the performance of voluntary explosive activity following a post-activation conditioning contraction (Tillin & Bishop, 2009).

Nevertheless, PAP induced via loaded exercises during the WU period may be an effective ergogenic aid for subsequent power-related performance in soccer players. Reported performance enhancement may be attributed to increased rate of force production via the recruitment of higher order motor units (Gullich & Schmidtbleicher, 1996; Inglis *et al.*, 2011), or an elevation in the phosphorylation of RLC (Sweeney *et al.*, 1993; Szczesna *et al.*, 2002). Although further research is required to confirm an optimal methodology to induce PAP in soccer players, and, in particular, identify relevant performance changes via PAP, there is substantial evidence to support its use for improved power performance in tasks that are related to team sports (Table 2.3). This has important implications for soccer players and coaches interested in acutely enhancing the power performance of players during matches.

2.4 Skill-based warm-ups

2.4.1 *Small-sided games background*

Small sided games (SSG) consist of open-play, sport-specific, activities, usually set in a competitive environment. Small-sided games are aimed at replicating a particular sport, or skills within a sport, and are played on a smaller than usual scale i.e., smaller playing field, less participants, or both (Lawson, 2001). Traditionally, SSG have been used to improve players' tactical awareness, and assist with the development of specific team-plays and strategies (Gabbett, 2006). However, the high-intensity nature of SSG ($Peak_{HR}$ >70%) (Castagna *et al.*, 2007), can also improve an athlete's cardiovascular capacity following prolonged SSG exposure (Nurmekivi *et al.*, 2002; Gamble, 2004; Gabbett, 2006; Impellizzeri *et al.*, 2006). The acute effects of SSG activities regularly completed during WU periods remain unknown. Small-sided games completed during the WU period may provide additional performance enhancement in subsequent tasks via priming of neuromuscular mechanisms, and the rehearsal of pertinent skilled tasks (Allison & Thorpe, 1997).

2.4.2 *Skill improvements via small-sided games*

Anecdotally it has been suggested that the most effective mode of training for preparing athletes for competition is that which most closely replicates the competitive performance itself (Gamble, 2004), and is the central tenet of "The Specificity of Training Principle" (Daniels, 2001). To date, only one study has attempted to investigate the acute effects of SSGs and their efficacy within the WU (Gabbett *et al.*, 2008). In this investigation, 15 min of non-skill-related WU activities (closed skills) was compared to a WU which consisted of 15 min of SSG tasks (open skills). No differences were reported between the two interventions for measures of vertical jump, short sprint-speed, reactive agility, or change of direction tasks. However, limitations of this study include the use of static stretching prior to the intervention, the use of prolonged, high-intensity SSG activity, and not measuring the enhancement of game-specific technical skills following the SSG WU. Static stretching inhibits muscular force and power performance (Behm *et al.*, 2001; Cornwell *et al.*, 2001; Fletcher & Anness, 2007), with changes lasting up to 60 to (Fowles *et al.*, 2000) 120 min (Power *et al.*, 2004). In addition, prolonged periods of high-intensity SSG activity with no recovery may not have been an appropriate methodology for the junior (16 year old) participants, and therefore, inadvertently induced temporary fatigue. With inadequate recovery, temporary fatigue can occur following as little as five min of high-intensity activity, and can subsequent reduce sprint ability (Krustrup *et al.*, 2006). Therefore, further research which avoids the use of prior static stretching, and fatigue-inducing protocols, is required to elucidate if SSG completed during the WU phase can improve subsequent performance. Research should also investigate the performance changes pertaining to game-specific technical skills, as improvements following SSG are possibly more closely related to complex skill activities, instead of closed or non-skilled tasks (Gabbett *et al.*, 2008).

2.4.3 *Application of small-sided games within the warm-up*

Training regimes which include SSG as a conditioning tool are an effective, and time efficient method for developing both fitness and skill components in team-sport athletes. However, little is known regarding the short-term effects of SSG which are commonly implemented (unpublished observation) within team-sport WU routines. Understanding the acute performance effects of high-intensity, short-duration periods of SSG activities may assist in the development of optimal team-sport WU strategies.

2.5 Re-warm-up strategies for soccer

2.5.1 *Definition and background*

Re-warm-ups can consist of active or passive warming of the body during enforced match intervals, such as the half-time intermissions. Active re-WUs are more effective than passive methods at attenuating the decline in T_m (Mohr *et al.*, 2004) and physical performance during subsequent bouts of activity (Mohr *et al.*, 2004; Lovell *et al.*, 2007). However, only two studies (Mohr *et al.*, 2004; Lovell *et al.*, 2007) have investigated the effects of re-WU strategies in team sport athletes, and, as a consequence, re-WU routines are largely based on the trial and error experience of the athlete and coaching staff.

2.5.2 *Current re-warm-up literature*

Traditionally, pre-determined rest periods during competition allows coaches to relay tactical information and motivational encouragement to players, in preparation for the second half of competition (Lovell *et al.*, 2007). However, extended passive recovery periods can also have a detrimental effect on subsequent physical performance (Sargeant, 1987). For example, a passive rest period of 15 min can decrease sprint performance in the second half of a soccer match by 2.4% (Mohr *et al.*, 2004). In contrast, five to seven min of moderate-intensity activity can maintain subsequent sprint performance to levels reported in the first half of competition (Mohr *et al.*, 2004; Lovell *et al.*, 2011). Mechanisms responsible for improved performance following active re-WU periods may be related to re-elevating T_m following recovery periods.

2.5.2.1 Re-warm-up: Muscle temperature and performance

Following a rest interval, it seems important that athletes complete some form of brief low-to-moderate-intensity activity in order to re-elevate T_m. In a friendly soccer match, performing no re-WU decreased both T_m and sprint performance (r= 0.60) (Mohr *et al.*, 2004). However, seven min of moderate-intensity, soccer-specific activities increased T_m by 1.5°C, when compared to the no re-WU condition (Figure 2-9), while sprint performance following the re-WU was unchanged (4.47±0.04 s), when compared to before the match (4.45±0.04) (Figure 2-10). In contrast, the 15-min period of passive rest decreased T_m by 1.4°C, when compared to before the match, and subsequently a reduction in sprint performance of 2.4% was reported in the no re-WU condition (Mohr *et al.*, 2004).

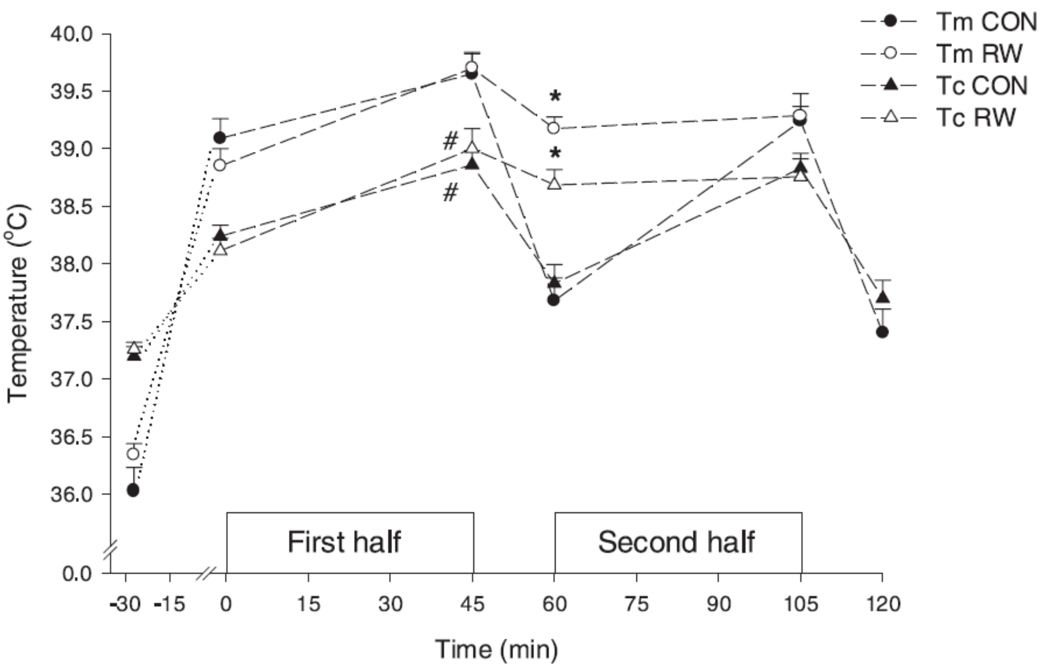


Figure 2-9 Muscle and rectal temperatures during a soccer match with or without re-warm-up at half time. Means ± SEM, *: significant difference between CON and RW, #: significant difference before the first half (p<0.05) (Mohr *et al.*, 2004).

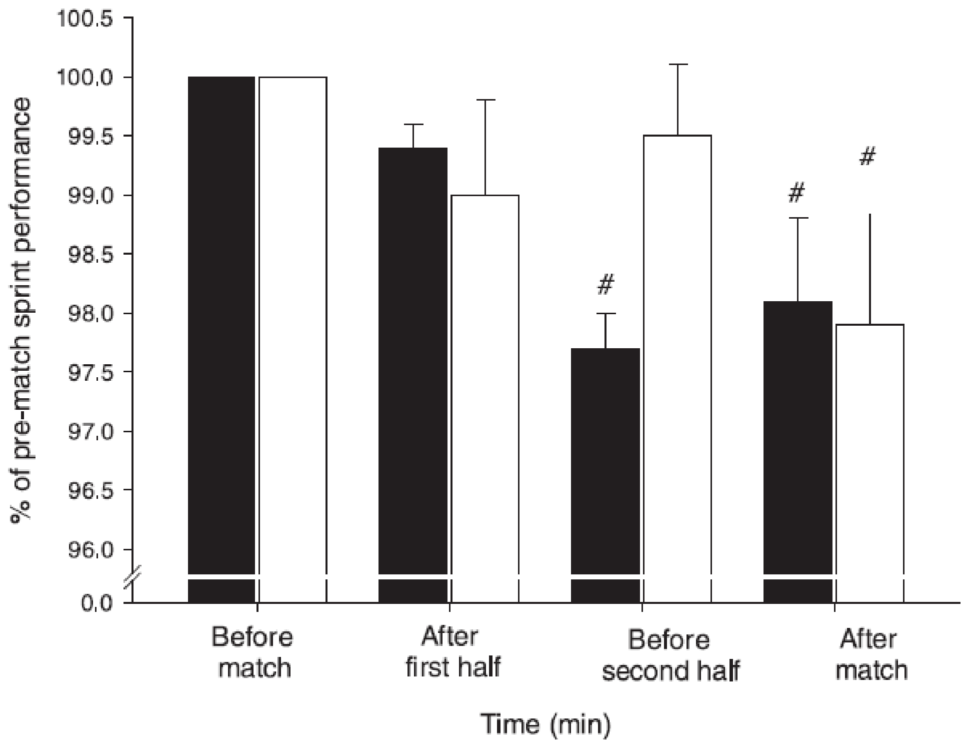


Figure 2-10 Sprint performance (average of three 30-m sprints) during a soccer match with (re-warm-up, open bars) and without (control, closed bars). Means ± SEM, #: significant difference between pre-match values (p<0.05) (Mohr et al., 2004).

These results are supported by the relationship between sprint performance and T_m (De Bruyn-Prevost, 1980; Sargeant, 1987; Sargeant & Dolan, 1987). An elevated T_m can increase muscle glycogenolysis, glycolysis and high-energy phosphate (ATP and phosphocreatine) degradation during exercise (Febbraio *et al.*, 1996) (Figure 2-11). This may enhance the performance of high-intensity tasks other than sprinting i.e., change-of-direction and skill execution tasks, both pertinent to a team's overall success in soccer (Reilly *et al.*, 2000). Further team-sport research should investigate the effect of rest intervals and re-WUs, aiming to re-elevate T_m and enhance subsequent physical performance during the second half of competition.

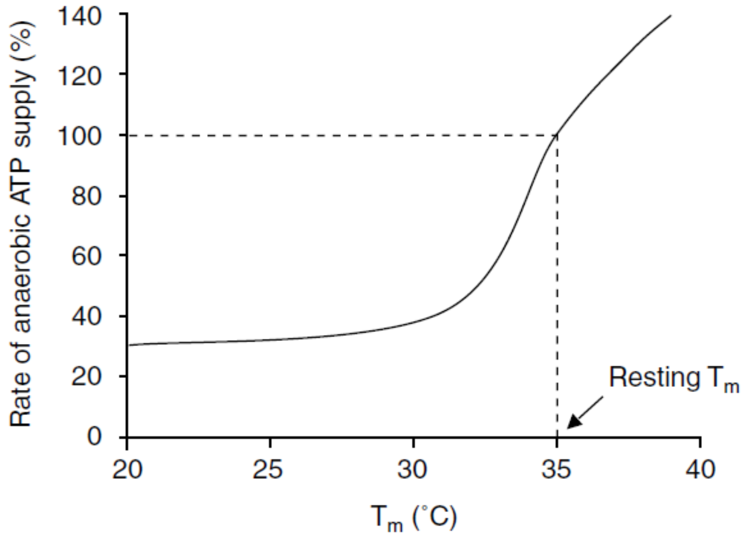


Figure 2-11 Anaerobic adenosine triphosphate (ATP) supply during exercise at different muscle temperatures (Tm). Rates are expressed as a percentage of normal (100%) (Edwards et al., 1972; Febbraio et al., 1996).

2.5.2.2 Re-warm-up: Soccer-specific endurance performance

Active bouts of re-WU can also improve physical tasks which are aimed at replicating the demands of soccer. Distance covered during two bouts of soccer-specific endurance (Bangsbo & Lindquist, 1992) was measured following four different re-WU protocols (seven min of cycling at 70% $HR_{max,}$ seven min of soccer-specific running exercises at 70% HR_{max}, no re-WU, or passive heating of the lower limbs until 40°C was reached) (Lovell *et al.*, 2007). Both active re-WUs attenuated performance decrements in soccer-specific endurance (cycling -0.5%, soccer specific re-WU; -0.4%), compared to passive heating, which reported a 3.1% decrease in second-half distance covered, when compared to the first half (Figure 2-12).

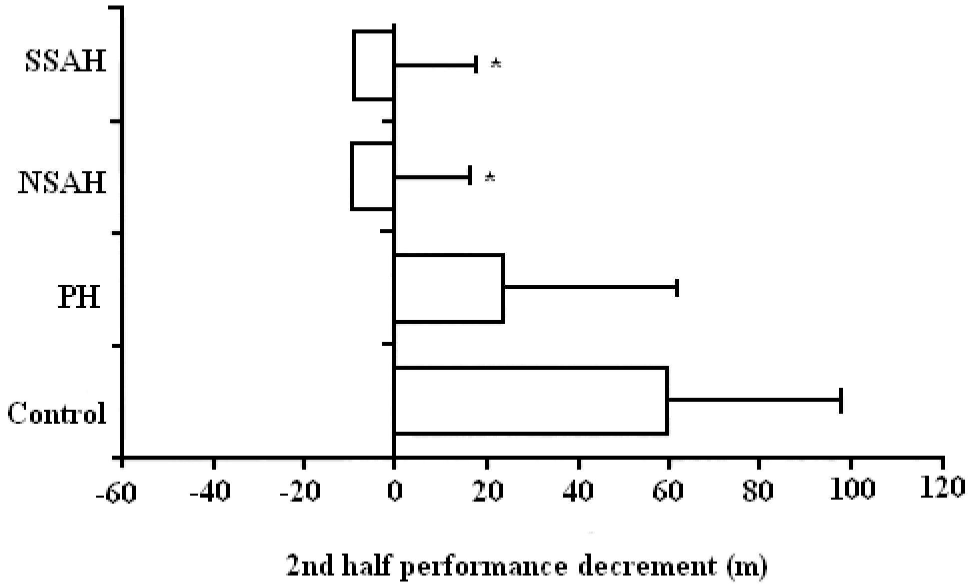


Figure 2-12 Soccer-specific endurance performance decrement. SSAH: soccer-specific active heating; NSAH: non-specific active heating; PH: passive heating; CON: control. * denotes significantly lower than CON (P<0.013) (Lovell et al., 2007).

It is possible that active re-WU could produce additional ergogenic benefits to passive methods. The current investigation (Lovell *et al.*, 2007) speculated that active re-WU bouts may increase T_m and blood flow to working muscles, as well as increasing baseline $\dot{V}O_2$ in comparison to passive heating methods (Lovell *et al.*, 2007). Although further research is required to confirm these hypotheses, an increase in baseline $\dot{V}O_2$ would decrease accumulated O_2 deficit during subsequent constant load exercise, and possibly during short, repeated-sprint bouts as well (Dupont *et al.*, 2005). Theoretically, less of the initial work would then be fuelled anaerobically, thus sparing this fuel source for later activity (Bishop, 2003a). This could lead to improved anaerobic capacity later in the exercise bout and thus enhance the performance of high-intensity activity. This may, in part, explain differences reported between the active and passive re-WU methods, however further investigations are required to elucidate if specific activity task can further enhance subsequent performance.

2.5.3 *Summary of re-warm-up literature*

Although a scarcity of re-WU research currently exists (Mohr *et al.*, 2004; Lovell *et al.*, 2007), a brief period (~seven min) of active re-WU (~70% HR_{max}) during half time intervals is currently a better alternative to a passive re-WU, or no re-WU at all. Improved short-sprint ability following active re-WUs may be related to an increase in T_m and blood flow to working muscles, or an increase in baseline $\dot{V}O_2$; however further research is required to confirm the role of these mechanisms during the re-WU. Further research is also required to identifying whether specific re-WU activities can provide an additional ergogenic aid in subsequent skill and physical performance tasks related to soccer.

2.6 Aims and hypothesis

To date, limited research has investigated the subsequent performance effects of current WU routines in soccer, as well as the performance effects of re-WU protocols conducted during half-time recovery periods. Recent research has imitated investigations into the effects of PAP, the application of WUs aimed at inducing potentiation and their subsequent effect, require further research. Taking this into consideration, the following outlines the aims of this thesis:

2.6.1 *Aims*

The purpose of this thesis was to investigate the optimisation of pre-competition WU protocols in soccer. Furthermore, this thesis investigated the effects of high-intensity, short-duration WU protocols in comparison to current practice, and the implementation of such during a re-WU period.

2.6.2 *Study 1 (Chapter 3)*

This study examined the acute (short-term) effects of one WU which aimed to producing a PAP effect (5 RM leg-press), another which replicated SSG activities, and a currently-implemented soccer WU routine.

The hypotheses for this study were that:

1. A 5RM leg press and/or a SSG WU would improve soccer-related performance compared to a currently-implemented WU routine.
2. The currently-implemented WU would reduce intermittent exercise performance.

2.6.3 *Study 2 (Chapter 4)*

The aim of the second study was to compare the prolonged performance effects of a 5RM leg-press, a SSG and team-sport WU, both during, and following periods of intermittent exercise.

Specific hypotheses tested were that:

1. Repeated intermittent exercise performance would be depressed following a currently-implemented WU routine.
2. Post-activation potentiation induced via a 5RM leg-press WU would mitigate performance decrements concomitant to fatigue.

2.6.4 *Study 3 (Chapter 5)*

Further aims of this research were to investigate the effects of a 5RM leg-press and SSG re-WU following standardised periods of intermittent, non-motorised-treadmill activity, on soccer-related physical performance and skills.

Specific hypotheses tested were that:

1. Second half physical performance would be enhanced when incorporating a 5RM re-WU.
2. Second half skilled performance would be greater following a SSG re-WU.

CHAPTER 3. STUDY 1: HIGH-INTENSITY WARM-UPS ELICIT SUPERIOR PERFORMANCE TO A CURRENT SOCCER WARM-UP ROUTINE

Accepted for publication:

Zois J, Bishop D, Ball K & Aughey J, R. (2011). High-intensity warm-ups ilicit superior performance to a current soccer warm-up routine. *J Sci Med Sport (Accepted for publication 03/12/2011) doi 101016/jjsams201103012.*

3.1 Introduction

The benefits of an active warm-up (WU) have been attributed to increases in muscle temperature, nerve conductivity, and the speeding of metabolic reactions (Bishop, 2003a). Non-temperature-related benefits include an increased blood-flow to working muscles, elevated baseline oxygen consumption, and the induction of a post activation potentiation (PAP) effect (Hodgson *et al.*, 2005). While typical WU routines involve constant-intensity exercise, team-sport athletes are increasingly utilising WUs which simulate the movement and metabolic demands of team sports. However, no research has investigated the acute effects of currently-implemented WU protocols on team-sport-related performance.

Typical team-sport WU routines include 30-40 min of moderate- to high-intensity activities (Mohr *et al.*, 2004), whereas research suggests that five to ten minutes at 40-70% of maximal oxygen consumption ($\dot{V}O_{2max}$) is sufficient to improve short, intermediate and long-term performance (Bishop, 2003b). Longer WU routines could impair subsequent performance by increasing pre-competition fatigue, depleting muscle glycogen stores, and prematurely elevating core temperature (potentially compromising the body's ability to store and dissipate subsequently generated heat) (Gregson *et al.*, 2005). Further research is therefore required to compare the efficacy of current team-sport WUs with that of shorter WU protocols.

Anecdotal evidence indicates that some team sports are experimenting with the inclusion of explosive jumping and sprinting activities aimed at inducing a PAP effect, during pre-game WU routines. Post-activation potentiation is a phenomenon by which muscular performance is acutely enhanced when preceded by maximal or near maximal neuromuscular activation (Tillin & Bishop, 2009). Two proposed mechanisms responsible for PAP are an increase in the phosphorylation of myosin regulatory light chains (Hodgson *et al.*, 2005) and increased recruitment of higher order motor units (Gullich & Schmidtbleicher, 1996). Voluntary resistance methods of inducing PAP (e.g., loaded squat exercises) can improve CMJ (counter-movement jump) height (Saez Saez de Villarreal *et al.*, 2007) and short-sprint performance (Chatzopoulos *et al.*, 2007). A sport-specific WU aimed at inducing PAP in volley ball has also been reported to improve CMJ height by ~2% more than traditional resistance methods (Saez Saez de Villarreal *et al.*, 2007). However, the specific effects of PAP may have been masked by the inclusion of multiple exercise tasks during the WU bout, therefore further research is required to de-lineate the proposed mechanism. In addition, the effects of a WU aimed at inducing PAP on subsequent team-sport-specific tasks, such as reactive agility (RA) and intermittent exercise performance, have not been investigated.

There are also reports of some team sports utilising small-sided games (SSG), including passing, shooting and ball-control activities, within WU routines (unpublished observation). Small-sided games incorporate activities and movement patterns specific to competitive team-sport tasks and are aimed at simulating the skill/metabolic demands of a sport (Gamble, 2004). The specificity of SSGs has been suggested to provide additional ergogenic benefits over generic conditioning methods by increasing neuromuscular activation (Gabbett, 2008). Only one study to date has investigated the application of SSG as a WU protocol, finding no beneficial effect compared with closed-skill activities (i.e., forward skipping, lateral skipping and 20-m maximal effort sprints) (Gabbett *et al.*, 2008). Limitations of that study include the use of a 22-min WU, far greater than previously recommended (Bishop, 2003b), unspecified recovery periods prior to testing, and the inclusion of static stretching during the WU protocol, despite previous research reporting performance decrements following static stretching (Behm *et al.*, 2001). Therefore, a high-intensity, short-duration, SSG WU may enhance subsequent performance if intensity and duration conform to previous research, and static stretching bouts are avoided. Accordingly, this study examined the acute (short-term) effects of one WU which aimed to produce a PAP effect (5 RM leg-press), another which replicated a SSG activity, and a currently implemented WU routine.

3.2 Methods

Ten male, amateur football (soccer) players competing in the Italian Serie D competition gave written informed consent to participate. The mean age, height, body mass and maximum heart rate (HR_{max}) of participants was 23.3 ± 2.5 y, 1.78 ± 0.04 m, 69.1 ± 4.1 kg, and 191 ± 8 bpm respectively. Physical screenings were conducted by medical staff to establish each candidate's previous injury history, general health, and suitability for participation.

Participants attended one familiarisation, one baseline and three experimental sessions. Sessions were separated by ≥ 72 h. Familiarisation included a five-minute baseline jog WU maintaining HR at 60% of the predicted HR_{max} (220 – chronological age), followed by all physiological (blood lactate, rating of perceived exertion, HR, core temperature) and performance (CMJ, RA, 20-m sprint time) tests. The YO-YO Intermittent Recovery test (level 1) (Bangsbo *et al.*, 2008a) was then administered to determine each individual's intermittent exercise performance and HR_{max}. During the baseline session, participants repeated all physiological and performance tests (excluding the YO-YO Intermittent Recovery test). Participants then completed a seated 5RM leg-press test. Following this, participants rehearsed the SSG and team-sport WU protocols with additional player assistance, and standardised verbal instructions.

The three experimental sessions were completed on a natural-grass soccer field, in a randomised, crossover and counterbalanced order. Participants wore specific soccer boots and clothing, and were instructed to avoid strenuous exercise prior to or during the testing period, to avoid caffeine and alcohol ingestion, and to maintain their usual nutritional intake. Sessions were completed at similar times for each participant (within 1 h) to minimise circadian influences (Racinais *et al.*, 2005). Environmental conditions (degrees Celsius, humidity and wind speed) were assessed and recorded via a local meteorology station (Golosine, Verona). Mean temperature, humidity and wind speed were 26.4 ± 3.3°C, 46.9 ± 18.9% and 2.2 ± 1.3 $m.s^{-1}$ respectively. For each experimental session participants completed a five-minute baseline jog WU at 60% of their individualsied HR max followed immediately by one of the three WU interventions.

One of the WU interventions included 3 repetitions of a 3 vs. 3 SSG WU with two minutes of play, interspersed with two minutes of passive rest (approximately 12 minutes total time). Pitch-size increased from 20 m (length) x 12 m (width) in the first repetition to 25 m x 15 m in the second repetition and to 30 m x 18 m in the third repetition, to progressively increase the WU intensity. This protocol was chosen due to its high reproducibility (CV for HR= 2.2-2.4%) and promotes high-intensity efforts from participants (~89% of HR_{max}) (add in Rampinini 2007 ref). Teams aimed to continuously perform five successful passes/possessions, and were required to maintain high-intensity throughout the duration of the SSG (~70-80% HR_{max}). Unlimited ball control touches were allowed.

The effect of a 5-min jog WU followed by a 5 RM seated leg press (Techno gym, Italy) lasting approximately 15 s, was investigated on a separate day. Standardised foot settings and 90° knee-flexion was maintained prior to the commencement of each pressing phase.

Finally, a currently-used premier league football (soccer) club WU routine, which lasted approximately 23 min, was modified and administered (see supplementary 1). The strength and conditioning staff assisted with modifications to this protocol to account for differences in fitness levels. The WU included general activities (high-knees, butt-kicks and body-weight squats; performed at medium intensity [submaximal velocity] for 6 mins), specific movements (back and forth sprinting, lateral skipping and change of direction movements; performed at high intensity [maximal velocity] for 9 min) and ball-control activities (dribbling, passing and run-throughs; performed at high intensity for 6 min). One 60-s and two 30-s passive recovery periods were interspersed within the routine. Four minutes post each intervention, physiological and performance measures described below were recorded.

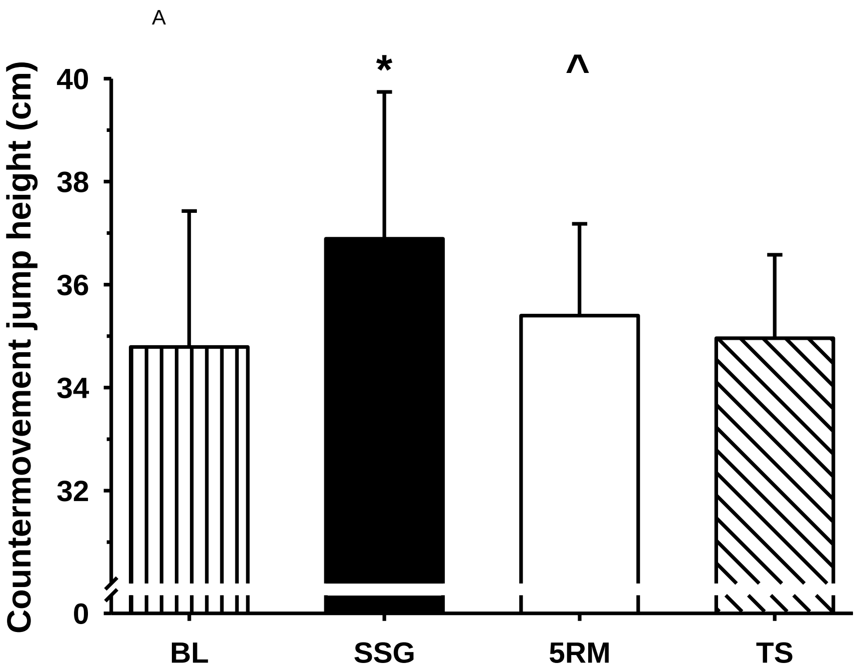
Performance measures such as CMJ height was calculated via Opto Jump (Lynx System Developers, USA); a day-to-day CV of 2.7% was established during preliminary testing. Participants performed maximal-effort CMJs, with the average of two jumps recorded. A self-selected knee depth in the CMJ was instructed, while hands were placed on hips at all times during the jump trials. Trunk flexion was avoided, as was knee flexion prior to final decent. Reactive agility, as described elsewhere (Sheppard *et al.*, 2006), was also measured post interventions, and included participants responding to the tester pre-planned physical cues; moving forwards and then veering towards either the right or left direction. Total time taken to change direction and sprint through finishing gates was measured using Photocells (Lynx Systems Developers, USA); a CV of 2.8% was established during preliminary testing. Thereafter, participants completed an intermittent exercise task including physical activities specific to team sports (Bishop *et al.*, 2001b). Briefly, participants completed 15, 60-s circuits that included activities such as sprinting, slalom, walking, jogging, decelerations, changes of direction, backwards running and striding (see supplementary 2). The protocol replicates soccer specific utility tasks undertaken during competition and was assessed for its suitability by specific fitness staff of respective soccer teams involved in this study. During each circuit, twenty-meter sprint times were recorded at the beginning of each repetition using Photocells (Lynx Systems Developers, USA); a CV of 0.8% from all 15 sprint times was established.

Physiological measures following each intervention included the CR 0-10 rating of perceived exertion scale which was implemented using 1 unit integers (Foster *et al.*, 2001). This scale uses descriptors linked to a numbered scale ranging from 0 (rest) to 10 (maximal effort). Rating of perceived exertion was then multiplied by duration (min) of activity to analyse data as load units (Foster *et al.*, 2001). Blood lactate concentration was determined from ear lobe blood samples (30 μL) immediately post WU interventions and analysed via an automated analyser with an enzymatic approach (Biosen C Line; EKF Diagnostics, Germany). Calibration was completed as per manufacture instructions with the use of samples of known lactate concentration. Heart rate was continuously recorded every 5 s using a short-range telemetry HR monitoring systems (VantageNV, S710, and Xtrainer models, Polar Electro, Kempele, Finland). Finally, core temperature was measured using an ingestible telemetric sensor (CORETEMP™ COR-100 Wireless Ingestible Temperature Sensor, HQ Inc, Palmetto, FL, USA) (Byrne & Lim, 2007). As per manufacturers instructions, sensors were ingested 3 h prior to testing. Temperature signals were transmitted via radio waves to an external temperature-recording device (CORETEMP™ CT2000 Miniaturised Ambulatory Recorder, HQ Inc, Palmetto, FL, USA).

Variables measured were log transformed, to reduce bias due to non-uniformity of error, and analysed using effect size (ES) statistics with 90% confidence intervals (CI), and percentage change to determine the magnitude of effects, using a customised spreadsheet (Hopkins *et al.*, 2009). Magnitudes of change were classified as a substantial increase or decrease when there was a ≥ 75% likelihood of the effect being equal to or greater-than the smallest worthwhile change (estimated as 0.2 x between subject standard deviation), and classified as small (ES: 0.2–0.6) moderate (ES: 0.6-1.2) large (ES: 1.2-2.0) and very large (ES: 2.0-4.0). Effects with less certainty were classified as trivial and where the ± 90% CI of the ES crossed the boundaries of ES -0.2 and 0.2, the effect was reported as unclear.

3.3 Results

The mean YO-YO Intermittent Recovery score, 5 RM leg-press strength and 5RM strength/body mass ratio of the participants was 1640.0 ± 208.4 m, 88.4 ± 8.4 kg and 1.3 ± 0.1 respectively. Compared to baseline measures, CMJ height was greater following the SSG (6%, ES: 0.8±0.8) and 5RM (2%, ES: 0.3±0.5) WU than the team-sport WU (<1%, ES: 0.1±0.7; unclear) (Figure 3-1). When compared to baseline, reactive agility was 4.7% (ES: 1.1±0.7) faster following the 5RM WU, 3.8% (ES: 0.8±0.7) faster after the SSG WU and 'unclear' following the team-sport WU (0.9%, ES: 0.2±0.7) (Figure 3-1).



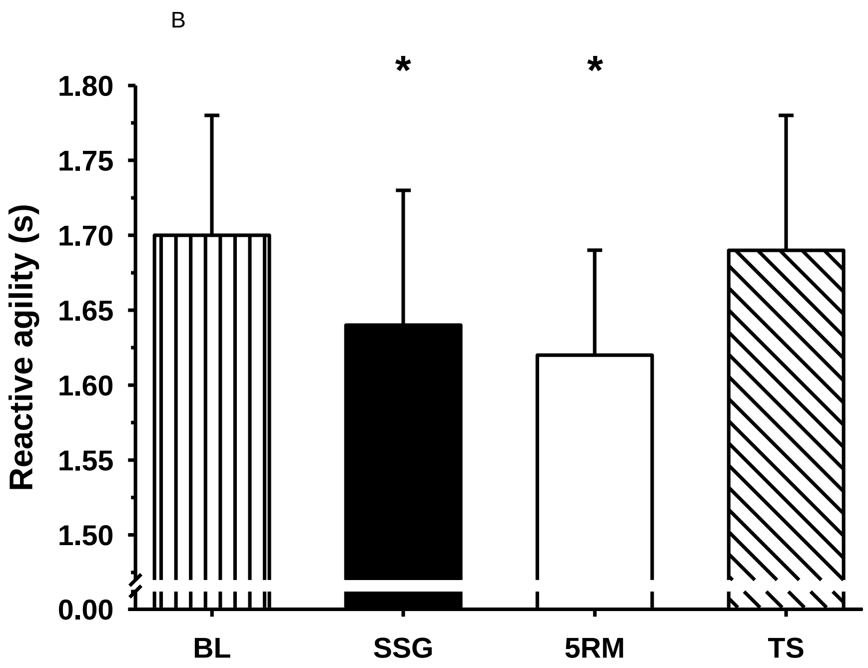


Figure 3-1 Effect of interventions on (A) countermovement jump height expressed in cm and (B) reactive agility expressed in seconds (s). Vertically-filled columns= baseline measures (BL), solid columns= SSG WU, open columns= 5RM WU, and diagonally-filled columns= the team-sport (TS) WU. Data are Mean ± SD, ^ denotes a small improvement (ES: 0.2-0.6) from baseline measures; * denotes a moderate improvement (ES: 0.6-1.2) from baseline measures, n=10.

Twenty-meter sprint times were faster following the 5RM WU, compared to following the SSG WU, from sprint six (5.7%, ES:0.7±0.4) to sprint 15 (4.9%, ES: 0.5±0.4), with a peak difference of 8.9% (ES: 0.9±0.3) during sprint 13. Compared to the team-sport WU, 20-m sprint times were also faster following the 5RM WU from sprint two (2.9%, ES: 0.4±0.4) to sprint 14 (5.8%, ES: 0.5±0.4), with a peak difference of 7% (ES: 0.6±0.5) during sprint 13 (Figure 3-2). When comparing 20-m sprint times between the team-sport WU and SSG WU, sprint performance was faster following the SSG WU in sprint one (2.8%, ES: 0.6±0.5) to sprint five (3.1%, ES: 0.4±0.4), with an absence of a meaningful effect during sprint three (“unclear”). There was no difference between WU protocols for mean time taken to complete each circuit of the intermittent exercise task.

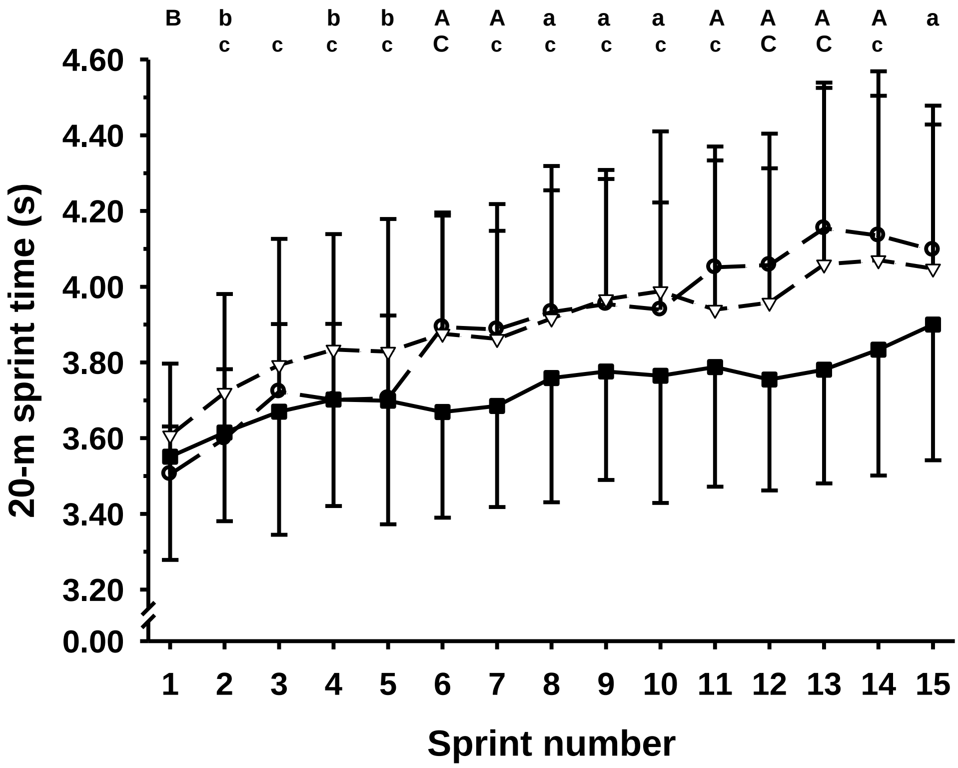
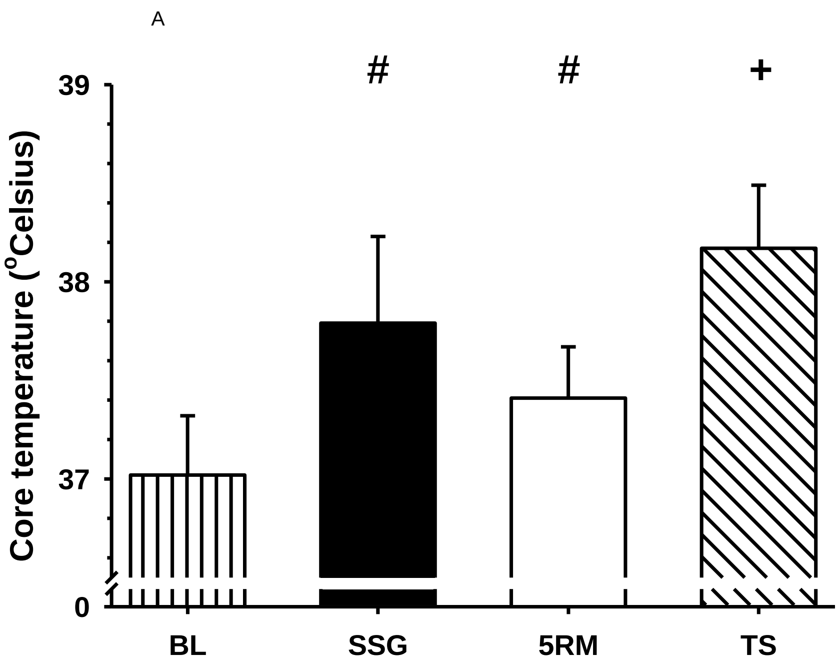


Figure 3-2 20-m sprint times expressed in seconds during the intermittent exercise task. Open circles= SSG WU, solid squares= 5RM WU, and open triangles= the team-sport (TS) WU. Data are Mean ± SD, 'a' denotes a small performance difference (ES: 0.2-0.6) between the 5RM and SSG WUs; 'A' denotes a moderate (ES: 0.6-1.2) difference between the 5RM and SSG WUs; 'b' denotes a small difference between SSG and TS WUs; 'B' denotes a moderate difference between SSG and TS WUs; 'c' denotes a small difference between the 5RM and TS WUs; 'C' denotes a moderate difference between the 5RM and TS WUs, n=10.

Core temperature was lower following the 5RM WU compared with both the SSG (1%, ES: 0.9±0.8) and team-sport WU (2%, ES: 1.6±0.5) (Figure 3-3). $[Lac^-]_b$ post-WU was higher following the SSG (67.2%, ES: 2.7±0.8) and team-sport WUs (65.5%, ES: 2.9±0.9) compared to baseline, while $[Lac^-]_b$ following the 5RM WU was unchanged (classified as ‘unclear’) (Figure 3-3). Mean HR following the 5RM intervention (128±14 bpm) was lower than following both the SSG (37%, ES: 3.4±0.8) (175±10 bpm) and the team-sport WU (35%, ES: 3.2±0.8) (172.9±10.2 bpm), while load units were lower following the 5RM intervention (1.1±0.2) compared to the SSG (78.0±11.6) and team-sport WU (147.2±32.9).



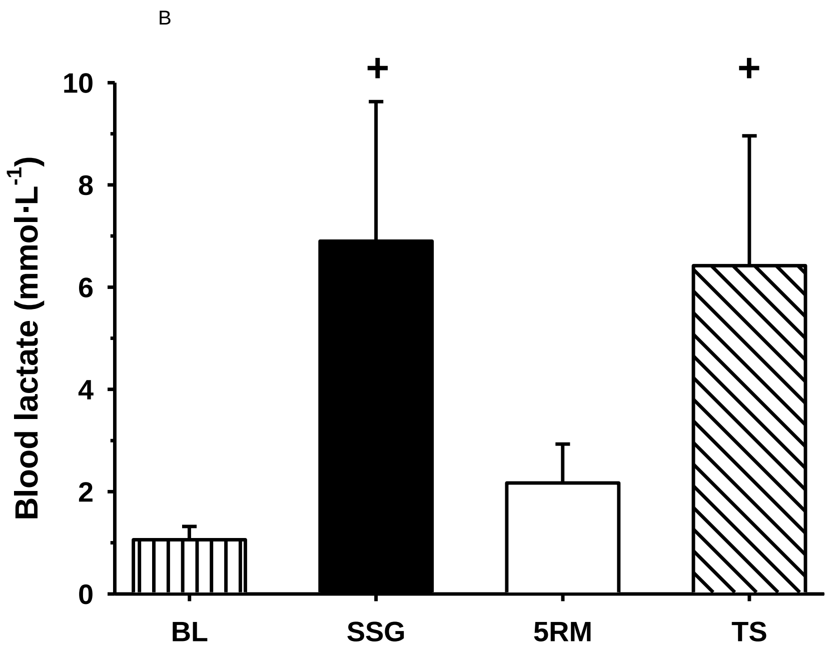


Figure 3-3 Core temperature (°Celsius) (A) and blood lactate concentration ($[Lac^-]_b$) (B) measured at the completion of WUs. Vertically-filled columns= baseline measures (BL), solid columns= SSG WU, open columns= 5RM WU, and diagonally-filled columns= team-sport (TS) WU. Data are Mean ± SD, # denotes a large change (ES: 1.2-2.0) from baseline measures; + denotes a very large change (ES: 2.0-4.0) from baseline measures, n=10.

3.4 Discussion

Compared to baseline measures, we observed a 6% and a 2% enhancement of CMJ performance following the SSG and the 5RM WU respectively, and ~4% improvement in RA following both. The 5RM WU was associated with small-large improvements in 20-m sprint times during the intermittent exercise task, minimised metabolic strain/internal load as indicated by core temperature (T_c), $[Lac^-]_b$ and load units, and provided greater performance benefits than a currently-implemented, team-sport WU. Compared to baseline, the team-sport WU had no effect on CMJ or RA, while a 5% slower performance was evident during the 20-m sprints (sprints six to 15), when compared to the 5RM WU.

The absence of a positive effect via the team-sport WU on subsequent performance is surprising as the WU routine mimicked that currently implemented by a premier-league soccer club. However, previous WUs, using a similar intensity (60-80% $\dot{V}O_{2max}$) and duration (15-30 min), have also reported no improvement in various performance measures (Stewart & Sleivert, 1998; Bishop *et al.*, 2001a; Gregson *et al.*, 2005). A 15-min kayak WU performed at 75% of $\dot{V}O_{2max}$ impaired subsequent two-min kayak performance (Bishop *et al.*, 2001a), and similar decrements in treadmill running to exhaustion were observed following a 15-min WU at 80% of $\dot{V}O_{2max}$ (Stewart & Sleivert, 1998). The fixed WU intensities in these previous studies make results difficult to compare, but it can be suggested that participants in the present study also experienced fatigue via repeated-bouts of maximal sprinting, changing of direction, bounding, jumping and dribbling during the team-sport WU. This is supported by a work load that was 0.86 and 131-fold greater than the SSG and 5 RM WU.

Peripheral and/or central fatigue of locomotor muscles may have resulted from the prolonged high-intensity exercise incorporated in the team-sport WU. High-intensity exercise lasting 13.2 min can reduce force output of the quadriceps by ~30%, with the force output only recovering following 70 min of rest (Romer *et al.*, 2006). An increasing demand for respiratory muscle blood flow during high-intensity exercise can compromises blood flow to working limbs due to sympathetically-mediated vasoconstriction (Harms *et al.*, 1997). In turn, a locomotor vasoconstriction can decrease oxygen transport to working muscles and increase fatigue, as well as the level of perceived effort (Dempsey *et al.*, 2006). In the current study, the team-sport WU took longer to complete than the SSG WU, and was associated with greater load units, core temperature and $[Lac^-]_b$, compared to the alternative WU methods. This may be an indication of greater residual fatigue and inhibition of central and/or peripheral mechanisms responsible for muscular contraction. However, these mechanisms are beyond the scope of this study, and warrant further investigation.

It is also possible that the deleterious effects experienced following the team-sport WU may have been exacerbated by the lower fitness level of our participants. However, modifications to the WU protocol were accounted for, and the WU was judged as being similar to the participants' usual WU routine. Further research is required to investigate if current team-sport WUs are of any benefits at all, and alternatively, if more efficient methods of preparing athletes prior to team-sport competition exist. In the current study, a SSG WU bout increased CMJ height more than both the 5 RM and the team-sport WU. This may be attributed to an intensity-dependent relationship (Saez Saez de Villarreal *et al.*, 2007) following repeated high-intensity sprinting efforts performed during the SSG WU. Dynamic bouts of activity, interspersed with movement-pattern-specific exercises, have shown similar improvements in CMJ height (~7%) (Saez Saez de Villarreal *et al.*, 2007). Although the mechanisms were not measured, performance enhancement was suggested via increases in muscle temperature, increased neural activation, and the movement specificity of the WU (Saez Saez de Villarreal *et al.*, 2007). In the current study, the SSG WU also included bouts of moderate-to-high intensity activity, as well as sport-specific tasks. The augmentation of mechanisms pertaining to muscle temperature (i.e., increased muscle blood flow, improved force-velocity relationship) (Binkhorst *et al.*, 1977; Febbraio *et al.*, 1996; Saez Saez de Villarreal *et al.*, 2007) via SSG tasks may be responsible for the reported enhanced performance. In addition, the present study demonstrated that a SSG WU can also enhance reactive agility (4%), as well as

CMJ performance (6%), suggesting that benefits may be transferable to tasks which closer replicate team-sport demands. Further research is required to elucidate the mechanisms responsible for the observed changes in acute performance following a SSG WU.

In contrast, the SSG WU did not improve 20-m sprint performance during the intermittent exercise task, when compared to the 5RM WU. Mean 20-m sprint times were, on average, 6% slower (during the last 10 sprint bouts) compared to the 5RM WU. Increased physiological strain compared to the 5RM WU may account for the slower sprint times reported during the intermittent exercise task. Although the SSG WU did enhance acute performance (i.e., CMJ and RA), it is likely that the high-intensity efforts during the SSG WU negatively affected prolonged high-intensity intermittent exercise specific to team sports.

This study demonstrated that a 5RM WU aimed at inducing PAP can improve CMJ performance, and team-sport related tasks, when compared to a team-sport WU. Improved reactive agility times suggest that the mechanisms involved in potentiation may also be transferrable to explosive change-of-direction tasks. Only one other study has investigated reactive agility performance following various WUs (Gabbett *et al.*, 2008), finding no improvement. Differences in sample population and methodologies may account for the variation in results, e.g., the current study recruited 10 young adult males compared to male and female youths (Gabbett *et al.*, 2008) and excluded static stretching to avoid performance decrements previously reported (Behm *et al.*, 2001).

Following the 5 RM WU, 93% of all sprint bouts were ≥ 3% faster than following the team-sport WU, and 67% of all sprint were ≥ 4.4% faster than following the SSG WU. Although PAP cannot improve maximal sprint speed/velocity, it can enhance the rate of force development (Sale, 2002). Therefore, the positive influence of potentiation during the 20-m sprints may be due to an increased rate of acceleration and decreased time to attain maximal velocity. This study is unable to confirm whether potentiation per se is responsible for improved performances, or if the increased physiological demands associated with the opposing interventions caused the changes in performance. Nonetheless, these results have important implications for team-sport athletes relying on repeated, high-intensity, sprint efforts, with minimal recovery during competition, and raise issues pertaining to the appropriateness of current team-sport WU routines. Further research is required to identify the mechanisms responsible for improved repeated-sprint performance following a 5RM WU, and its potential performance application during half-time periods and/or following player substitution.

3.5 Conclusions

In this study, a 5RM leg press WU induced less physiological strain and minimised decrements in 20-m sprint times during a 15-min intermittent exercise task. Future research should investigate if similar effects are evident following team-sport specific intermittent exercise tasks longer than 15 min in duration, and the effects of team-sport WUs on the execution of skills. A 5RM or SSG WU may increase specific performance of team-sport athletes, however further research is necessary to confirm these findings with an elite population, and to investigate its practical application in professional team-sport competition.

CHAPTER 4. STUDY 2: HIGH-INTENSITY, WARM-UPS MINIMISE PERFORMANCE DECREMENTS DURING INTERMITTENT EXERCISE

Submitted for publication:

Zois J, Bishop D, Aughey R. (2011). High-intensity warm-ups minimise performance decrements during intermittent exercise. *Med Sci Sports Exerc, currently under review*.

4.1 Introduction

In professional team sports, such as football (soccer), it is imperative that the warm-up (WU) not only enhances acute performance, but also does not contribute to performance decrements in the latter stages of a match. I have established that WU routines including a 5 repetition maximum (5RM) leg-press or a small-sided game (SSG), are superior to currently-implemented team-sport WU routines for improving the performance of acute, team-sport, specific-tasks (Chapter 3, study 1). However, while acute performance is obviously important, soccer matches can last in excess of 90 min; it is therefore important to understand the effects of different WU routines on team-sport-related performance following prolonged periods of intermittent exercise.

Extended periods of intermittent exercise can reduce the physical performance of elite soccer players (Mohr *et al.*, 2003). At the conclusion of a soccer match, 30-m sprint performance decreases by 2%, compared to pre-match (Mohr *et al.*, 2004), while high-speed running (>15 $km{\cdot}h^{-1}$) is reduced by ~40% in the last 15 min of a match (Mohr *et al.*, 2003). These decreases have been linked to high intra-muscular temperature (Drust *et al.*, 2005) and decreases in muscle glycogen stores (Krustrup *et al.*, 2006), but may also be due to low-frequency fatigue experienced in team sports (Fowles, 2006) and the accompanying reduction in calcium sensitivity via the sarcoplasmic reticulum in skeletal muscles (Hill *et al.*, 2001). Therefore, WU routines which exacerbate these physiological changes may provoke greater decreases in subsequent performance. In support of this, WU routines lasting between 10-16 min (at ~60-70% of $\dot{V}O_{2max}$) can decrease time- to exhaustion in subsequent intermittent exercise tasks, when compared to a prior rest condition (Gregson *et al.*, 2005).

Despite the above, and recommendations in the literature (Bishop, 2003b), professional team-sport WU routines typically include moderate- to high-intensity activities lasting ~30-40 min (Mohr *et al.*, 2004). These WU practices are likely to negatively affect team-sport performance by exacerbating fatigue-inducing mechanisms. This has important implications for team-sport athletes who rely on their ability to maintain high-intensity exercise performance throughout a competitive match (60-90 min) (Bangsbo *et al.*, 2006).

An alternative to current team-sport WU routines may be a high-intensity, short-duration WU, aimed at inducing a post-activation potentiation (PAP) effect (e.g., loaded-squat exercises). A growing body of evidence supports the use of such WUs for the acute enhancement of counter-movement jumps (CMJ) (Kilduff *et al.*, 2007), sprint time (Chatzopoulos *et al.*, 2007) and team-sport-specific performance tasks (Chapter 3, study 1). However, their effect on prolonged team-sport-specific performance has not yet been investigated. Given that such WU routines would not provoke major perturbations in fatigue-inducing mechanisms, it may be hypothesised that they will be superior to typical, prolonged WU routines, for maintaining team-sport-related performance.

Small-sided-game WUs are also high in intensity, and short in duration, and can acutely improve CMJ and reactive agility (RA) tasks, while replicating the specific skills of a sport (Chapter 3, study 1). However, the effects of a SSG WU on prolonged intermittent-sprint performance, and repeated-sprint ability (RSA) tasks typical of team-sport athletes, have not been investigated. Therefore, the purpose of this study was to compare the effects of a SSG, 5RM leg-press and team-sport WU, on team-sport-related performance both during and following extended periods of intermittent exercise.

4.2 Methods

Ten healthy amateur, male, football (soccer) players gave written informed consent to participate in this study, which was granted ethics approval by Victoria University Human Research Ethics Committee. The mean age, height, body mass and maximum HR (HR_{max}) of the participants was 23.3 ± 2.5 y, 1.78 ± 0.04 m, 69.1 ± 4.1 kg, 191 ± 8 bpm, respectively. Participants competed in various divisions of the Italian Serie D during the time of this investigation. Participants attended one familiarisation session, one baseline session, and three experimental sessions, each separated by ≥72 h. The familiarisation session included a five-minute baseline jog WU maintaining HR at 60% of the predicted HR_{max}, followed by all physiological (blood lactate, HR, core temperature) and performance (CMJ, RA, RSA) measures. Following five minutes of rest, participants completed the YO-YO Intermittent Recovery test (level 1) (Bangsbo *et al.*, 2008b) to characterise their intermittent exercise capacity and HR_{max}. During the subsequent baseline session, participants repeated all physiological and performance tests, and following another five-minute rest, participants completed a seated 5RM leg-press test. At the completion of the 5RM, participants individually rehearsed the SSG and team-sport WU protocols. Lastly, following a five-minute rest, participants completed the 1 x 15-min intermittent activity protocol (IAP), described below.

Each experimental session (three) was completed in a random, counterbalanced order, at similar times (within 1 hour) to minimise circadian influences (Racinais *et al.*, 2005). During experimental sessions participants completed a five-minute baseline jog WU at 60% HR_{max}, followed immediately by one of the three WU interventions; a SSG, a 5RM leg-press, or a professional team-sport WU routine. The SSG WU has been previously described (Chapter 3, study 1) and included a 3 vs. 3 soccer game with two min of play interspersed with two min of passive rest (x 3) (~10 min duration). On a separate day, a previously described (Chapter 3, study 1) 5RM leg-press (Techno gym, Italy) WU lasting 15 s was investigated. Lastly, a premier league football (soccer) club WU lasting ~23 min, and previously described in detail (Chapter 3, study 1), was implemented.

Four minutes post each WU intervention, participants completed a 15-min IAP (see: Chapter 3, study 1), consisting of 15 repetitions of a 60-s circuit that included sprinting, slalom, walking, jogging, decelerations, changes of direction, backwards running and striding activities. The protocol which was modified from previous team sport research (Bishop *et al.*, 2001b) replicates soccer specific utility tasks undertaken during competition and was assessed for its suitability by specific fitness staff of respective soccer teams involved in this study. The IAP was performed twice, with performance and physiological measures taken immediately following each 15-min period, which was then proceeded by a five-min passive recovery period. At the beginning of each 60-s circuit of the IAP, twenty-meter sprint times were recorded as measures of specific sprint ability using Photocells (Lynx Systems Developers, USA);

a coefficient of variation (CV) for the mean time of all 15 sprints was established (0.8%).

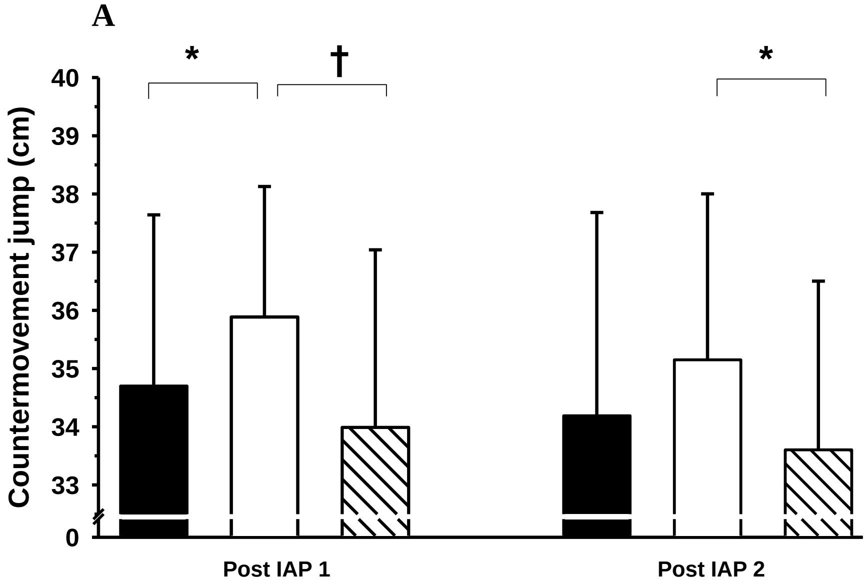
Performance measures recorded following both 15-min IAP included CMJ height, RA and RSA (measured in this order) with ~60 s recovery between each measure. Counter-movement jump height was calculated via Opto Jump (Lynx System Developers, USA) with a previously established day-to-day CV of 2.7% (Chapter 3, study 1). The RA test has a CV of 2.8% and is described in detail elsewhere (Sheppard *et al.*, 2006). We used Photocells (Lynx Systems Developers, USA) to measure time taken to complete the RA test. A previously-used RSA test (Impellizzeri *et al.*, 2008; Pyne *et al.*, 2008), incorporating 6 x 30-m sprints starting on 20 s, was also implemented, with mean sprint times measured via Photocells (Lynx Systems Developers, USA) and with a day-to-day CV of 0.8%.

Physiological measures were taken following both 15-min IAP, including blood lactate concentration ($[Lac^-]_b$), HR and core temperature (T_c). Approximately 30 μL of blood was sampled from the ear lobe and analysed for $[Lac^-]_b$ using Biosen C Line (EKF Diagnostics, Germany). Heart rate was continuously recorded every 5 s during testing using short-range telemetry HR monitoring systems (VantageNV, S710, and Xtrainer models, Polar Electro, Kempele, Finland). Lastly, T_c was measured using an ingestible telemetric sensor (CORETEMP™ COR-100 Wireless Ingestible Temperature Sensor, HQ Inc, Palmetto, FL) (Byrne & Lim, 2007). Temperature signals were transmitted via radio waves to an external temperature-recording device (CORETEMP™ CT2000 Miniaturised Ambulatory Recorder, HQ Inc, Palmetto, FL).

Measured variables were log transformed, to reduce bias due to non-uniformity of error, and analysed using effect size (ES) statistics with 90% confidence intervals (CI) and percentage change to determine the magnitude of effects using a customised spreadsheet (Hopkins *et al.*, 2009). Magnitudes of change were classified as small (ES: 0.2–0.6), moderate (ES: 0.6-1.2), large (ES: 1.2-2.0) and very large (ES: 2.0-4.0). Effects with less certainty were classified as trivial, and where the ± 90% CI for the ES crossed the boundaries of ES -0.2 and 0.2, the effect was described as “unclear”.

4.3 Results

The mean YO-YO score and 5RM leg-press strength of the participants was 1640 m and 88 ± 8 kg respectively. Counter-movement jump height was greater in the 5RM WU compared to the team-sport WU following both IAP, (6%, ES: 0.7±0.4, 4.6%, 0.5±0.4 respectively), and greater in the 5RM WU than the SSG WU following the first IAP (3.5%, ES: 0.4±0.5) (Figure 4-1), with an “unclear” difference following the second IAP (3%, ES: 0.3±0.6).



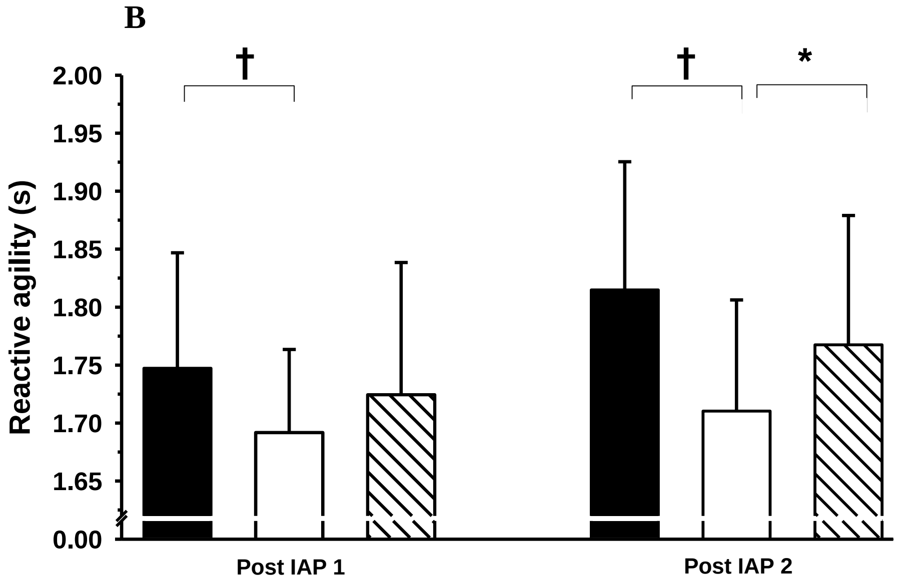


Figure 4-1 Countermovement jump height expressed in centimeters (cm) (A) and reactive agility expressed in seconds (s) (B) measured after each of the two 15-min intermittent activity protocols (IAP). Solid columns indicate the SSG WU, open columns indicate the 5RM WU, and diagonally-filled columns indicate the team-sport WU. Data are Mean ± SD, * denotes a small (ES: 0.2-0.6) difference in performance; † denotes a moderate (ES: 0.6-1.2) difference in performance, n=10.

Reactive agility was faster in the 5RM WU following the first (3.1%, ES: 0.6±0.5) and second IAP (5.7%, ES: 0.9±0.4), when compared to the SSG WU, as well as faster than the team-sport WU following the second IAP only (3.3%, ES: 0.5±0.4, Figure 4-1). Similarly, mean RSA times following the first and second IAP were faster following the 5RM WU, when compared to the team-sport WU (3.4%, ES: 0.5±0.6) (4.4%, ES: 0.6±0.3), and faster than the SSG WU following the first IAP (3%, ES: 0.6±0.5). Mean RSA times in the SSG WU were faster than the team-sport WU following the second IAP only (2.6%, ES: 0.3±0.4). Mean 20-m sprint times during both IAP were consistently faster following the 5RM WU when compared to both the SSG (4.2%, ES: 0.5±0.7 and 4.3%, ES: 0.5±0.7 respectively) and the team-sport WUs (4.2%, ES: 0.5±0.7 and 5.1%, ES: 0.5±0.7 respectively)

Figure 4-2).

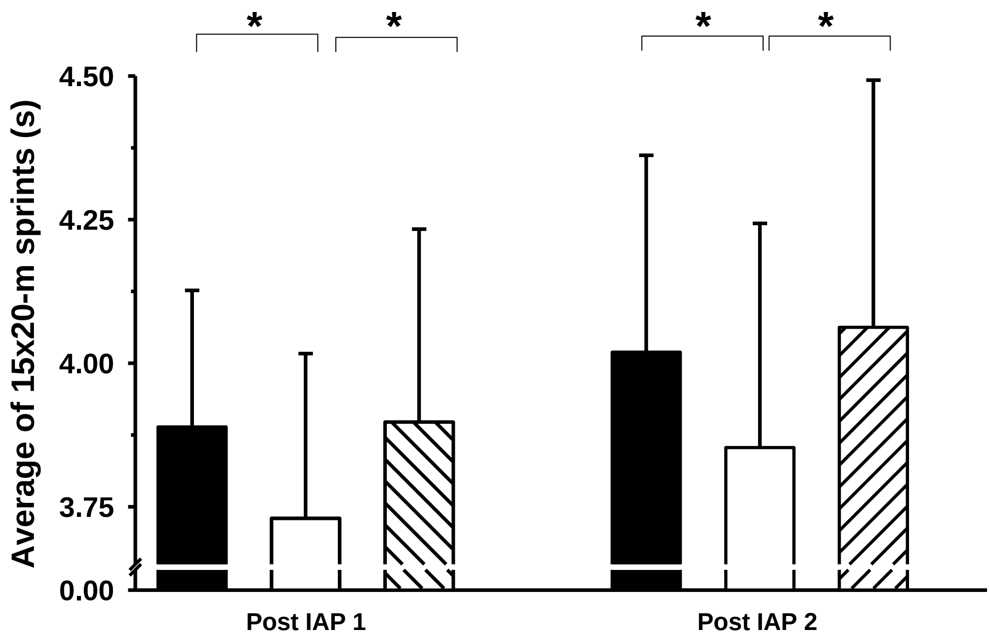


Figure 4-2 The average of 15x20-m sprints imbedded in each of the intermittent activity protocols (IAP), expressed in seconds. Solid columns indicate the SSG WU, open columns indicate the 5RM WU, and diagonally-filled columns indicate the team-sport WU. Data are Mean ± SD, * denotes a small (ES: 0.2-0.6) difference in performance, n=10.

Following both IAP, $[Lac^-]_b$ was higher following the 5RM WU when compared to the SSG WU (27.5%, ES: 0.7±0.8 and 46.7%, ES: 0.5±0.8 respectively). Statistically there were no differences between the 5RM and the team-sport WU, but $[Lac^-]_b$ was elevated in the 5RM condition following both IAP (18.6%, ES: 0.4±0.8 and 14.9%, ES: 0.3±0.8 respectively) (Figure 4-3).

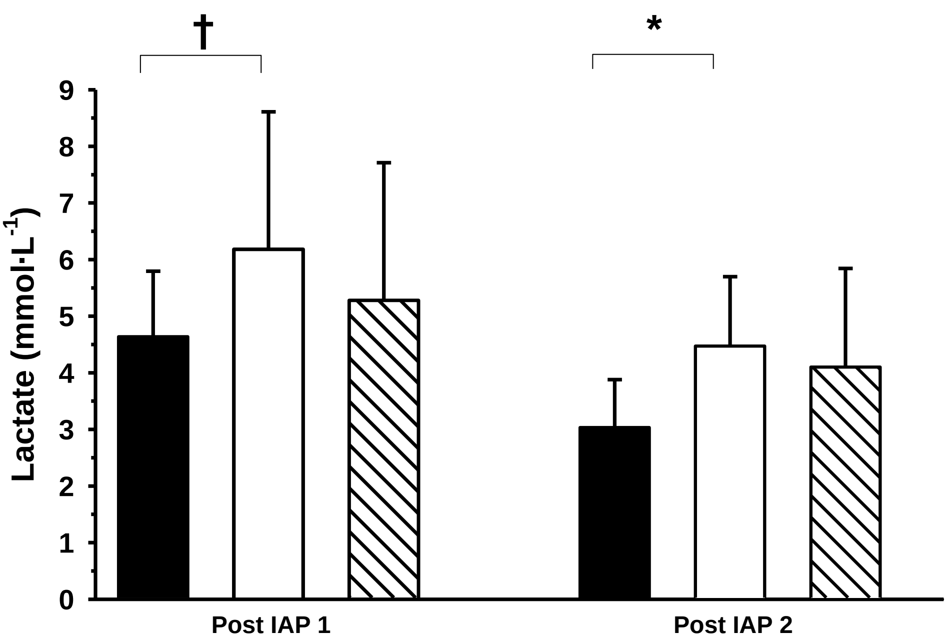


Figure 4-3 Blood lactate concentration ($[Lac^-]_b$) measured post each 15-min intermittent activity protocol (IAP), expressed in $mmol \cdot L^{-1}$. Solid columns indicate the SSG WU, open columns indicate the 5RM WU, and diagonally-filled columns indicate the team-sport WU. Data are Mean ± SD, * denotes a small (ES: 0.2-0.6) difference; † denotes a moderate (ES: 0.6-1.2) difference, n=10.

Core temperature following the first IAP increased similarly in the SSG (1.6±0.7°C, ES: 2.5±0.8), 5RM (1.5±0.5°C, ES: 3.2±0.8) and the team-sport WU (1.2±0.5°C, ES: 3.9±0.8), when compared to baseline measures (37±0.3°C). There were no differences in T_c (5RM= 38.8±0.7°C, SSG= 38.7±1.0°C, team-sport= 38.8±0.6°C) following the second period of intermittent activity, nor were there any differences in HR following the first (5RM= 172±9, SSG= 172±8, team-sport= 172±8 beats per min) and second periods of intermittent activity (5RM= 173±10, SSG= 172±10, team-sport= 173±10 beats per min).

4.4 Discussion

The major finding from this study is that performance during, and following, two 15-min periods of high-intensity intermittent activity, was greater post a 5RM WU when compared to both a SSG and a team-sport WU. Following both 15-min periods of intermittent activity, CMJ height and RA were greater in the 5RM WU, when compared to both the team-sport and SSG WUs. Additionally, mean 20-m sprint performance, imbedded within each IAP, and average 30-m RSA times following both periods of the intermittent activity were faster in the 5RM WU when compared to the alternative interventions. Apart from an elevated $[Lac^-]_b$ in the 5RM WU, following both IAP, participants experienced similar physiological perturbations following all three WUs.

In the current study, a 5RM WU, which has previously been shown to produce a PAP effect (Mitchell & Sale, 2011), was associated with greater 20-m sprint and RSA performance during and following intermittent bouts of exercise. Although no previous studies have investigated the prolonged effects of PAP during team-sport-related intermittent activity, one study has reported an increase in peak power and average power in rebound jump performance (~3%), 18.5 min post a WU aimed at inducing PAP (5x1RM back squat) (Chiu *et al.*, 2003). Improved performance may be attributed to mechanisms pertaining to PAP such as, increases in neuromuscular efficiency, decrease in the required motor unit firing rate for subsequent tasks, and the offsetting of low frequency fatigue (Green & Jones, 1989). These findings suggest WU protocols invoking a PAP effect may be more appropriate for the maintenance of sprint performance during subsequent intermittent activity tasks, which is of high relevance in soccer and similar team sports.

It is possible that the various mechanisms which have been proposed to underlie PAP could enhance different aspects of subsequent physical performance. For example, a reduction in performance via low-frequency fatigue can result from the impairment of excitation-contraction coupling (Edwards *et al.*, 1977), which may include a reduced Ca^{2+} release from the sarcoplasmic reticulum per action potential (Hill *et al.*, 2001). However, in some circumstances this may be minimised, or even reversed via PAP (Bigland-Ritchie *et al.*, 1983; Green & Jones, 1989). It is therefore possible that the enhanced performance reported in the current investigation (RSA and 20-m sprint time) via the 5RM WU, may be attributed to an increase in phosphorylation of myosin light chains, leading to an increase in protein sensitivity to Ca^{2+} (Moore & Stull, 1984), which in turn would counteract the negative effects experienced via low-frequency fatigue. However, due to the performance nature of this study, further mechanistic research is required to confirm if, in fact, this mechanism was responsible for enhanced 20-m sprint and RSA performance during and following the intermittent exercise bouts.

Another mechanism of PAP (i.e., an enhanced neuromuscular efficiency) may have also benefited subsequent explosive tasks such as RA. Following periods of intermittent activity, RA was improved by ~3-6%, when compared to the alternative interventions. An increase in higher order motor-neuron recruitment following the 5RM WU can lead to a decrease in the motor unit firing rate in subsequent submaximal contractions (Sale, 2002). During constant force activity, 80% of all contractions can be successfully maintained with decreased firing rates in the tibialis anterior and the first dorsal interosseus (de Luca *et al.*, 1996). This particular mechanism may provide economies pertaining to membrane excitability and excitation-contraction coupling efficiency following the 5RM WU, both possible factors involved in delaying the onset of fatigue during intermittent exercise (Edwards *et al.*, 1977) and enhancing the performance of subsequent explosive tasks (Gullich & Schmidtbleicher, 1996). Although further research is required to confirm the time course effects of PAP during intermittent exercise, it seems plausible that PAP, induced via a 5RM, could minimise performance decrements in subsequent high-intensity explosive activity (e.g., RA) during intermittent activity.

An alternative hypothesis for the reported performance changes is that prolonged WU routines can negatively affect subsequent intermittent sprint performance. Warm-up protocols employing similar intensities (60-80% $\dot{V}O_{2max}$) and durations (15-30 min) to that of both the team-sport and the SSG WUs used in the present study, have previously been associated with decrements in subsequent performance (Gregson *et al.*, 2002; Gregson *et al.*, 2005). Similarly, we observed slower mean 20-m sprint times and mean RSA times following both the team-sport and the SSG WUs, when compared to the 5RM WU. Potential mechanisms responsible for these observed changes may include the inhibition of anaerobic glycolysis and/or an increase in thermal strain via prolonged periods of active WU (Hermansen, 1981). I have previously reported greater increases in both $[Lac^-]_b$ and T_c following team-sport and SSG WUs compared to a 5RM WU (Chapter 3, study 1). Other team-sport research has suggested that a decrease in muscle glycogen stores may also be responsible for the onset of fatigue during intermittent team-sport activity (e.g., soccer) (Krustrup *et al.*, 2006). The results from the current investigation support the hypothesis that prolonged WU routines can negatively impact subsequent team-sport-related performance. These findings have important implications for team-sport coaches interested in designing efficient WU methods to prepare athletes for subsequent competition.

In contrast to my previous findings (Chapter 3, study 1), this study reported enhanced CMJ performance in the 5RM WU following both 15-min periods of intermittent activity, when compared to the SSG WU. These disparities suggest that acute WU research may not be applicable to team-sport performance which is characterised by prolonged periods of intermittent activity. It is possible that ~10 min of SSG activity may be beneficial for acute power performance, but too long when combined with 2x15-min of intermittent exercise. In support of this, I have previously reported that 20-m specific-sprint-ability decreased by ~5% (during sprints 7-15) following a SSG WU, when compared to a 5RM WU (Chapter 3, study 1). Small-to-moderate decreases in the latter stages of intermittent-sprint performance may be associated with the onset of fatigue following the SSG WU. Similar sprint ability decrements (4%) have been reported following high-intensity, 5-min periods during a soccer match and may also be related to the temporary onset of fatigue (Krustrup *et al.*, 2006). In the current investigation, CMJ was enhanced in the 5RM WU by 3.5% following intermittent activity, when compared to the SSG WU. Therefore, acute power performance may be improved via ~10 min of a SSG WU (Chapter 3, study 1), however coaches/athletes should consider reducing WU duration when subsequent intermittent activity takes place in order to minimise the possible onset of subsequent fatigue.

The physiological responses to the three WU interventions in this investigation were similar across both periods of the IAP, with the exception of $[Lac^-]_b$. In the 5RM WU condition, $[Lac^-]_b$ was greater following both 15-min periods (28% and 47% respectively) when compared to the SSG WU. Although results were "unclear", $[Lac^-]_b$ in the 5RM WU condition was also 19% and 15% higher than the team-sport WU. These findings may be attributed to faster 20-m sprint times during the intermittent activity tasks following the 5RM WU, compared to both the SSG (4.2% and 4.3% faster) and the team-sport WU (4.2% and 5.1% faster). Finally, an absence of differences in the physiological responses in the two 15-min exercise periods suggests that the 5RM WU was able to improve physical performance, without altering the physiological strain compared to the other conditions.

Despite the findings of the current study, feedback provided by participants showed a distinct preference for WUs which included some skill component (e.g., ball-control tasks). Participants suggested that the inclusion of SSG activities during a WU phase may be more pertinent to skill-related tasks within a soccer match. Future research is therefore warranted to investigate if a SSG WU can indeed provide additional skilled performance enhancement in subsequent tasks, compared to a 5RM WU.

4.5 Conclusions

In the present study, the 5RM WU was associated with greater CMJ height, 20-m specific-sprint-ability, RA, and RSA performance, during and following two, 15-min periods of intermittent activity. This may be attributed to smaller physiological perturbations provoked by the 5RM WU, compared to the SSG and team-sport WUs, and/or the induction of a PAP effect which persisted during subsequent intermittent activities. Coaches and athletes interested in optimising performance following WU routines should explore the use of shorter, high-intensity tasks aimed at inducing a PAP effect, while reducing the total duration of time spent physically preparing athletes, therefore minimising the possible fatiguing effects of such WU practices. Future research should investigate if a 5RM WU can further enhance performance when implemented as a re-WU strategy during half-time intervals, as well as investigating if a SSG WU can improve subsequent team-sport-specific skilled tasks. The results from this study have important implications for athletes, coaches and physical training staff interested in designing WU protocols that can provide a competitive edge during competition.

CHAPTER 5. STUDY 3: HIGH-INTENSITY RE-WARM-UPS CAN IMPROVE SECONDARY PERIODS OF TEAM-SPORT-RELATED PHYSICAL AND SKILL PERFORMANCE

Submitted for publication:

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5.1 Introduction

In team sports, an athlete's ability to execute skilled tasks, while maintaining repeated high-intensity endurance efforts, is important to a team's overall success (Mohr *et al.*, 2003). Pre-game warm-up (WU) routines that include high-intensity, short-duration activities, can improve acute (Chapter 3, study 1) and extended (Chapter 4, study 2) performance of high-intensity tasks relevant to team sports (e.g., countermovement jumps [CMJ], reactive agility and sprint performance) (Reilly *et al.*, 2000). Improvements may be related to a post-activation potentiation (PAP) effect, which is thought to increase neuromuscular efficiency, the rate of force development (Sale, 2002), and to minimise subsequent low-frequency fatigue (Morana & Perrey, 2009). However, the effects of high-intensity, short-duration WUs implemented following periods of recovery (e.g., during half-time) are poorly understood. Few studies have investigated the effects of active re-WUs and subsequent physical performance, and no study has investigated the benefits of performing specific re-WU activities on subsequent skilled performance.

Traditionally, half-time rest intervals are utilised by teams to relay strategic information, replenish fuel stores and recover for subsequent performance (Lovell *et al.*, 2007). Despite their potential importance, only three studies have investigated the effects of performing an active re-WU during half-time rest intervals on subsequent physical performance of team-sport athletes (Mohr *et al.*, 2004; Lovell *et al.*, 2007; Lovell *et al.*, 2011). The inclusion of a repeated-agility re-WU, performed at 70% HR_{max} for seven minutes, maintained subsequent field-based, soccer-specific physical performance, with the no re-WU group covering 3.1% less distance (~70 m) in the second half (Lovell *et al.*, 2007). A re-WU consisting of utility type movement exercises completed during the half-time rest interval of a soccer friendly match, maintained second-half 30-m repeated-sprint performance, compared to a 2.4% decrease following no re-WU (Mohr *et al.*, 2004). Similarly, no re-WU increased sprint times from the end of the first half compared to the start of the second (P=0.028), while a bout of intermittent agility exercise tasks performed during a half-time recovery attenuated decrements with no such changes observed (p=0.82) (Lovell *et al.*, 2011). However, these investigations did not control, or measure, the relative work completed by athletes during the first half of match-play or the soccer-specific endurance tasks. Therefore, participants may have experienced dissimilar levels of fatigue prior to re-WU interventions, making it difficult to draw valid conclusions from subsequent performance measures. Thus, the first aim of this study was to control/measure work performed during activity/simulation tasks, ensuring participants experience similar work demands during intermittent periods of prior activity.

Given the limited number of studies investigating re-WU protocols (Mohr *et al.*, 2004; Lovell *et al.*, 2007; Lovell *et al.*, 2011), further research is required to explore the influence of different re-WU strategies on subsequent physical and skilled performance. I have previously reported that a 5RM WU, aimed at inducing a PAP effect, enhanced reactive agility by 3.3% and repeated 20-m sprint performance by ~5% during a prolonged intermittent activity protocol (IAP), when compared to a professional team-sport WU (Chapter 4, study 2). The effect of a 5RM leg-press during half-time rest periods may provide athletes with similar performance enhancements during subsequent periods of activity, but to date has not been examined.

The inclusion of small sided-game (SSG) activities may also be an effective re-WU strategy aiding the performance of skilled tasks pertinent to team-sports (Ali, 2011). I have shown that SSG WUs can improve acute (Chapter 3, study 1), but not prolonged physical performance in soccer players (Chapter 4, study 2). However, given the well-known training principle of specificity, it is likely that improvements following a SSG WU would be more closely related to tasks requiring high levels of skill execution (e.g., ball control/passing) instead of explosive physical ability (e.g., CMJ and repeated-sprint ability). Therefore, the second aim of the current study was to investigate the effects of two re-WU interventions (e.g., 5RM leg-press and a SSG), following standardised periods of intermittent, non-motorised treadmill activity, on team-sport-relevant physical performance and skills.

5.2 Methods

Eight male, amateur soccer players (age 23.6 ± 4.1 y, height 1.73 ± 0.52 m, mass 75.5 ± 7 kg, and maximum HR 187 ± 4 bpm) competing in division one of the Victorian Football Federation gave written informed consent to participate. All participants had a minimum of five years of physical training experience in strength and conditioning programs relevant to soccer. All testing procedures were completed at least four weeks post completion of the competition season. Participants first completed a YO-YO Intermittent Recovery test (level 1) (Bangsbo *et al.*, 2008b) to determine intermittent exercise performance and HR_{max}. Participants then attended two familiarisation, one baseline, and two experimental sessions, each separated by ≥ 72 h. Familiarisation one included a 5-min baseline jog WU at 60% of the predicted HR_{max}, followed by familiarisation with physiological (blood lactate and HR), perceptual (rating of perceived exertion, visual analogue scales), and performance measures (CMJ) and the Loughborough Soccer Passing Test (LSPT). The LSPT is a reliable and valid method for assessing skill among soccer players and can be implemented in a controlled environment (Ali *et al.*, 2007). Following this the 5RM leg-press test was completed. After a 5-min rest period, participants performed three maximal four-second sprints (repeated-sprint ability measures) on a non-motorised treadmill (NMT), each separated by 14 s of passive recovery. The maximal velocity attained was used to determine individual velocity ranges during the IAP which was also performed on the NMT. Finally, participants completed a 13-min IAP. During a second familiarisation session participants completed all physiological, perceptual and performance measures, and completed 26 min of the IAP.

In a randomised, counterbalanced order, participants then completed one baseline/control session and two re-WU intervention sessions. Testing was completed at similar times of the day for each participant (within one hour) to minimise circadian influences (Racinais *et al.*, 2005). For each session, participants completed a 5-min jog WU at 60% HR_{max}, followed immediately by the first bout of the IAP (26 min). A 15-min rest and re-WU interval was then implemented, with re-WU interventions commencing either 10 min (5RM leg-press), or 8 min (SSG) into this period. A second IAP was then administered. All performance and physiological tests were completed following the first and second IAP, and 4 min following the re-WU interventions.

The 5RM re-WU intervention was implemented on a 45° seated leg-press (Calgym, Australia), and was completed within ~15 s, as previously described in detail (Chapter 3, study 1). A second re-WU intervention included the modification of a previously-implemented SSG WU (Chapter 3, study 1). Briefly, a 3-min, 2 v. 2, ball-possession game was implemented on a 20-m x 12-m field. During control trials, participants were instructed to passively rest for 15 min.

The IAP was performed on a NMT (Woodway Force, Waukesha, WI, USA) and was modified from previous research (Sirotic & Coutts, 2007) in order to better represent exercise tasks required in competitive soccer matches and induce fatigue; it required participants to interchange between six individually-established speed zones (i.e., 100%= maximal sprint, 65%= fast run, 45%= run, 35%= jog, 20%= walk, 0%= standing; see supplementary material 3). The duration of one IAP was 26.4 min, and included three sets of repeated-sprint ability (RSA) tasks (i.e., set one and three = 4 x 4-s sprints with 14 s of passive recovery between repetitions, set two = 2 x 4-s sprints with 14 s of recovery between repetitions). During the RSA tasks acceleration, peak velocity and mean velocity were measured. Acceleration was calculated as the rate of change in velocity in the 0.5 s immediately after reaching a velocity of 1 $m \cdot s^{-1}$ (Serpeillo *et al.*, 2010). The coefficients of variation (CV) for peak velocity, mean velocity, and acceleration were 3.5%, 4.0% and 12.3%, respectively. The total work during both of the IAPs was controlled (excluding the bouts of RSA) to ensure that the relative work completed by participants was the same for each trial. Data acquisition on the NMT was set at 25 Hz and subsequently exported to customised software to analyse mean and peak velocity. As previously recommended (Serpeillo *et* *al.*, 2010), the start point for the analysis of each sprint was standardised to 1 $m \cdot s^{-1}$; from this point, a 4-s period was calculated.

To assess changes in explosive ability, participants performed a maximal CMJ, with measures recorded via a force plate (400 Series Force Plate-Fitness Technology, Adelaide, Australia). A day-to-day CV for flight-time to contraction-time ratio, peak velocity and relative maximum rate of force development (RFD_{max}) was established (3.6%, 1.2% and 14.8%, respectively). The LSPT was implemented to assess individual's soccer-specific skill (described elsewhere) (Ali *et al.*, 2007). A CV of 2.8% was reported prior to testing for this group of participants.

Physiological measures included blood lactate concentration ($[Lac^-]_b$) and HR measures. Finger-tip blood samples were analysed using a Lactate pro analyser (Arkray Inc, Kyoto, Japan). Heart rate was continuously recorded every 5 s using short-range telemetry HR monitoring systems (VantageNV, S710, and Xtrainer models, Polar Electro, Kempele, Finland). Lastly, perceptual measures included the CR 0-10 (Foster *et al.*, 2001) and two visual analogue scales (VAS) (Gould *et al.*, 2001), which were used to measure perceived effort, feelings of soreness, and fatigue.

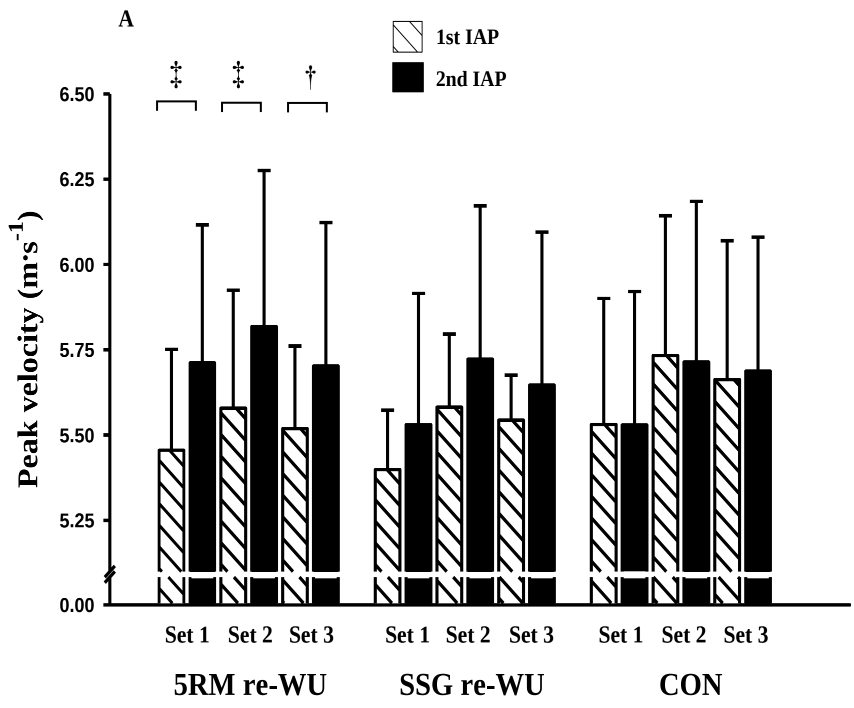
Variables were log-transformed, to reduce bias due to non-uniformity of error, and analysed using effect size (ES) statistics with 90% confidence intervals (CI) and percentage change to determine the magnitude of effects using a customised spreadsheet (Hopkins *et al.*, 2009). Magnitudes of change were classified as small (ES: 0.2–0.6) moderate (ES: 0.6-1.2) large (ES: 1.2-2.0) and very large (ES: 2.0-4.0). Effects with less certainty were classified as trivial and where the ± 90% CI of the ES crossed the boundaries of ES -0.2 and 0.2, the effect was reported as unclear.

5.3 Results

The mean YO-YO score, 5 RM leg-press strength and maximal sprint velocity of participants was 1485 ± 235 m, 233 ± 31 kg and 5 ± 0.5 m.s^{-1}.

There was no difference between groups for total work performed during the first IAP (Control 1= 191.2±32.2 kJ, SSG 1= 196.9±28.8 kJ and 5RM 1= 195.6±34.6 kJ) and the second IAP (Control 2= 184±21.9 kJ; SSG 2= 190±27.7 kJ; and 5RM 2= 191.9±34 kJ). There were no clear differences in work between groups despite the CON condition completing 3.2% less total work during the second IAP.

During individual sets of RSA, peak and mean velocity in the 5RM re-WU were greater when results for the second IAP were compared to the first IAP (within group analysis); improvement in peak velocity for set 1= 4.6%, (ES: 0.6±0.5), set 2= 4.2%, (ES: 0.5±0.4), and set 3= 3.2%, (ES: 0.4±0.5) (Figure 5-1); improvement in mean velocity for set 1= 3.5%, (ES: 0.4±0.3), set 2= 3.2%, (ES: 0.4±0.3), set 3= 2.3%, (ES: 0.4±0.2) (Figure 5-1). Acceleration also improved following the 5RM re-WU; set 1= 12.5%, (ES: 0.9±0.3), set 2= 21.6%, (ES: 1.0±0.4), set 3= 19.3%, (ES: 1.3±0.4) (Figure 5-1). Acceleration decreased following the SSG in set 3 by 4.6%, (ES: 0.3±0.2) and following the CON condition in set 2 by 10.4%, (ES: 0.7±0.4) and set 3 by 4%, (ES: 0.4±0.4).



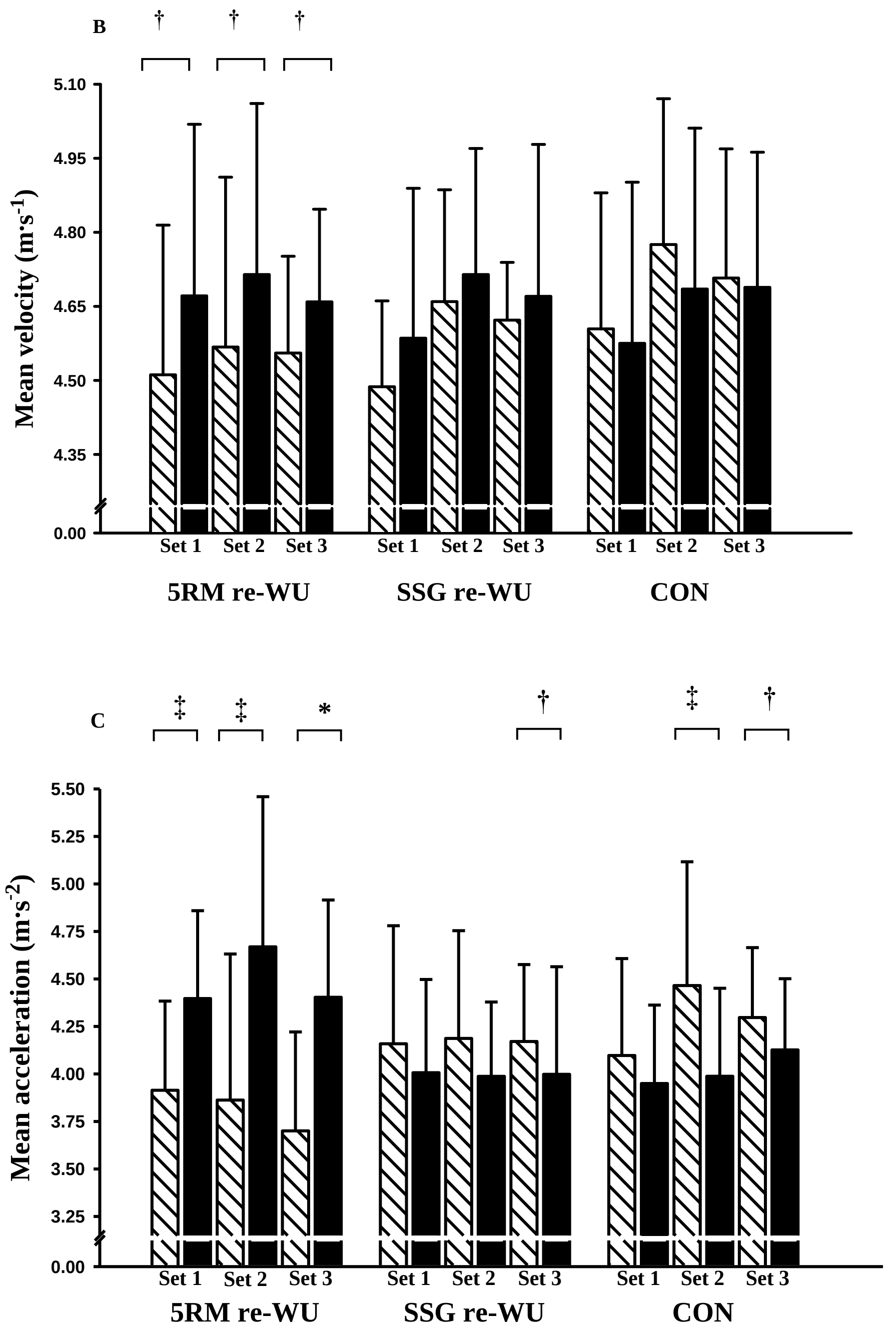


Figure 5-1 Peak velocity (A), mean velocity (B) and mean acceleration (C) during RSA sets from the first and second intermittent activity protocols (IAP) and expressed in meters per second ($m.s^{-1}$) or meters per second^2 ($m.s^{-2}$). Data are mean ± SD, † denotes a small (ES: 0.2-0.6) change in performance, ‡ denotes a moderate (ES: 0.6-1.2) change in performance, and * denotes a large (ES: 1.2-2.0) change in performance from first to second IAP, n=8.

The post-intervention flight-time to contraction-time ratio was 9.8% (ES: 0.5±0.3) and 9.4% (ES: 0.7±0.5) greater following the 5RM re-WU, when compared to the SSG and CON re-WUs (

Figure 5-2); it remained higher following the second IAP (8.8%, ES: 0.5±0.3 and 10.2%, ES: 0.6±0.6, respectively). Peak velocity during the CMJ was higher following the 5RM (3%, ES: 0.4±0.3) and SSG re-WUs (2.4%, ES: 0.3±0.2) when compared to CON (

Figure 5-2). Relative RFD_{max} during the CMJ was greater in the 5RM condition following the second IAP, when compared to the SSG (29.3%, ES: 0.7±0.5) and CON conditions (16.2%, ES: 0.6±0.6).

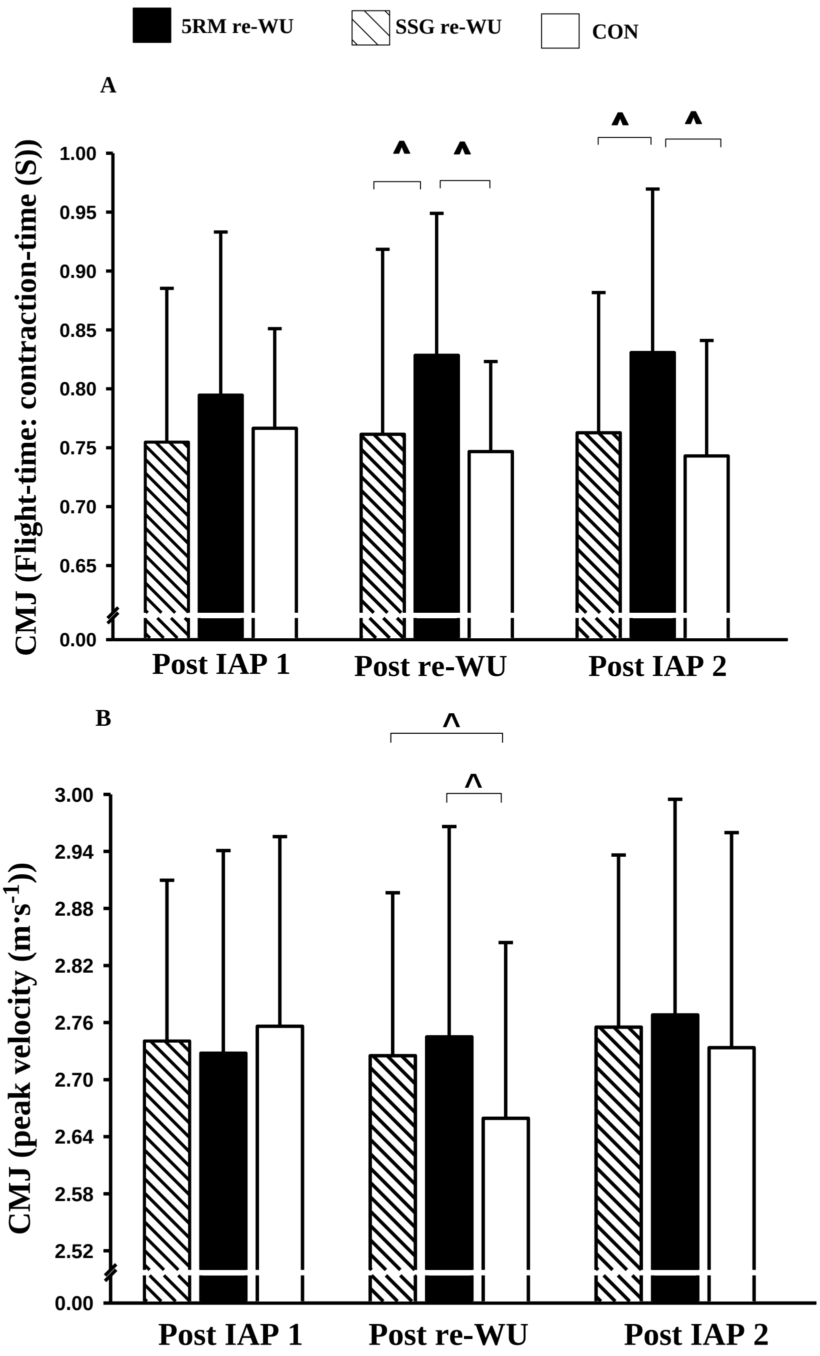


Figure 5-2 Flight-time to contraction-time (A) expressed in seconds (s), and peak velocity (B) expressed in meters per second ($m \cdot s^{-1}$). Data are mean ± SD, ^ denotes a small difference between conditions (ES: 0.2-0.6), n= 8.

Performance on the LSPT was greater following the 5RM (17.7%, ES: 1.2±0.8) and SSG (14.7%, ES: 1.7± 0.8) re-WUs, when compared to CON, with similar changes reported following the second IAP (5RM= 12.4%, ES: 0.7±0.7 and SSG= 17.2%, ES: 1.5±0.6). However, when compared to pre-intervention (post first IAP), within group analysis showed greater LSPT performance only in the SSG condition (6.4%, ES: 0.6±0.8, post intervention), which was maintained following the second IAP (6.2%, ES: 0.6±0.6). Across the same time points, the 5RM re-WU had no clear effect, while CON had a negative effect on LSPT performance (post intervention; 7.3%, ES: 0.6±0.5, post second IAP; 9.9%, ES: 0.7±0.5, Figure 5-3).

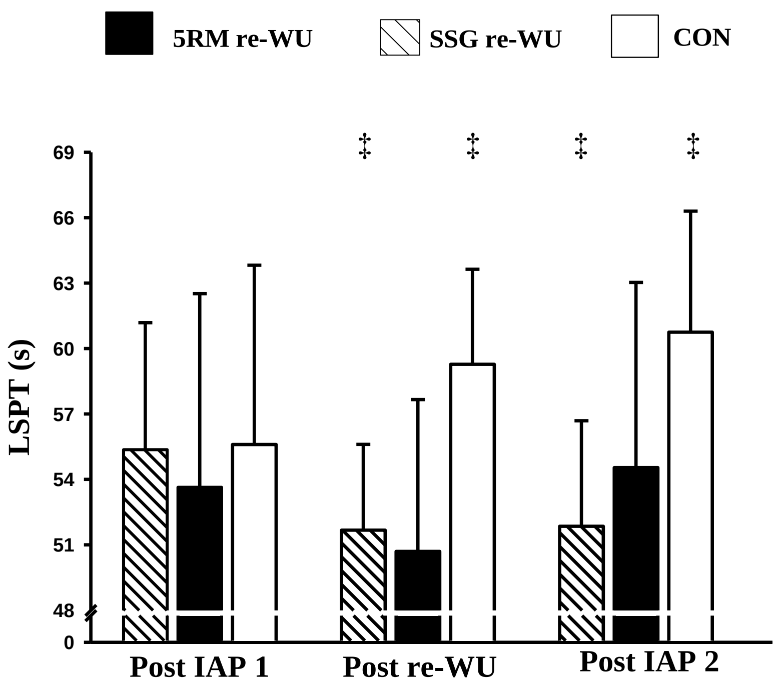


Figure 5-3 Loughborough soccer passing test measured in second (s). Data are mean ± SD, ‡ denotes a moderate (ES: 0.6-1.2) change in performance compared to the first intermittent activity protocol (IAP), n=8.

There were no differences in perceived fatigue immediately following the 5RM and SSG re-WUs; however, both reported a rise of 73% (ES: 2.7±1.0 and ES: 2.9±0.4) when compared to CON. In addition, perceived fatigue following the second IAP was higher in the 5RM (29%, ES: 0.8±0.5) and SSG re-WUs (22%, ES: 0.5±0.5), when compared to CON. There were no group differences for soreness following either IAPs, although muscle soreness was greater following 5RM re-WU intervention, when compared to SSG re-WU (39.5%, ES: 0.7±0.7) and CON (49.7%, ES: 0.7±0.7). Physiological differences between the two re-WU interventions were only observed immediately post, with ($[Lac^-]_b$) and HR lower following the 5RM condition, (3.6 vs. 7.2 $mmol \cdot L^{-1}$ in the SSG condition, ES: 1.4±0.4; and HR 28.4% lower in the 5RM condition, ES: 2.3±0.6). Post re-WUs, RPE was 31.3% (ES: 0.8±0.4) higher following 5RM compared to the SSG re-WU.

5.4 Discussion

The major findings of this study were that CMJ performance was greater immediately following a 5RM re-WU, and following a subsequent period of high-intensity intermittent exercise, when compared to a SSG re-WU or CON, while a 3-min bout of SSG re-WU activity enhanced subsequent skilled performance as measured by the LSPT. The 5RM re-WU was perceived as more intense, and produced higher muscle soreness scores; however, it also produced lower $[Lac^-]_b$ and HR values when compared to the SSG re-WU. There were no physiological differences between conditions following both IAPs, nor was there any difference in total work completed. The similarities in total work suggest we successfully replicated the IAP over the three experimental sessions, thus confirming the robustness of our findings.

Performing no re-WU was associated with decrements in maximal acceleration (4-10%), CMJ peak velocity (~3%) and flight-time to contraction-time ratio (9%) during the second period of high-intensity intermittent exercise. This is congruent with other investigations where 15 min of no activity during the re-WU decreased repeat-sprint ability by 2.4% (Mohr *et al.*, 2004), and total distance covered during a soccer-specific field test by 3.1%, compared to a general active WU lasting seven minutes (Lovell *et al.*, 2007). A decrease in muscle temperature due to prolonged periods of inactivity has been correlated with a decrease in sprint performance (r= 0.6) (Mohr *et al.*, 2004), and may be one mechanism contributing to the decrements observed in the current study. In support of this, a higher muscle temperature (~39°C) has been suggested to facilitate the performance of work through increased nerve conduction rate and increased contraction velocity (Bergh & Ekblom, 1979). It is possible that an absence of performance improvement in skilled tasks is also related to a decline in muscle temperature following the no re-WU condition. However, due to the performance nature of this investigation, changes in muscle temperature were not investigated and warrant future exploration.

A novel finding from this study was the improvement in CMJ and RSA performance following the 5RM re-WU, whereas there was no improvement in performance following the SSG and CON conditions. This supports the previously-reported finding of a maintenance effect on soccer-specific endurance performance (Lovell *et al.*, 2007; Lovell *et al.*, 2011) and 30-m sprint time (Mohr *et al.*, 2004), following active re-WUs. The improvement in RSA performance following the second IAP in the 5RM re-WU condition included an enhanced peak velocity, mean velocity, and acceleration, when compared to the first IAP. Although it’s difficult to confirm if PAP was the primary mechanism responsible for performance benefits in the CMJ and

RSA measures, similar WU activities (e.g., 5 x 1 RM back squat) have reported enhanced CMJ performance (~3%), while concurrently reporting enhanced muscle twitch responses (~11%), which characterises PAP (Mitchell & Sale, 2011). These findings are important in team-sports such as soccer, where at the conclusion of a match sprint performance decreases by 2% compared to pre-match measures (Mohr *et al.*, 2004), and high-speed running (>15 $km \cdot h^{-1}$) is reduced by ~40% in the last 15 min of a match (Mohr *et al.*, 2003).

The offsetting of fatigue via PAP has been postulated as one mechanism responsible for improved subsequent physical performance (Morana & Perrey, 2009). In a study where PAP was induced via electrical stimulation, a 28% increase in peak torque following 10 min of intermittent activity occurred, suggesting that potentiation can prevail during submaximal contractions and possibly delay the onset of low frequency fatigue (Morana & Perrey, 2009). During submaximal exercise, low frequency fatigue can result from the impairment of excitation-contraction coupling (Edwards *et al.*, 1977), leading to a reduced Ca^{2+} release from the sarcoplasmic reticulum per action potential (Hill *et al.*, 2001). Conversely, one of the mechanisms of PAP, is an increase in the phosphorylation of myosin light chains (Moore & Stull, 1984), leading to an increase in protein sensitivity to Ca^{2+}. Therefore, PAP could counter the effects of low frequency fatigue, and enhance extended periods of subsequent physical performance. Another potential mechanism contributing to enhanced performance via PAP is an increase in higher-order motoneuron recruitment, leading to a decrease in motor unit firing rate in subsequent submaximal contractions (Sale, 2002). During constant-force isometric contractions, 80% of all contractions can be successfully maintained with decreasing firing rates in the tibialis anterior and first dorsal interosseus (de Luca *et al.*, 1996). This may provide economies pertaining to membrane excitability and excitation-contraction coupling efficiency, both possible factors in delaying the onset of fatigue (Edwards *et al.*, 1977).

The second key finding in this study was that a SSG re-WU did not improve subsequent physical performance, but did improve LSPT performance. Passing ability was enhanced by ~15% immediately following the SSG intervention, and 17% following the second IAP, when compared to the CON condition. Skill improvements of this magnitude are extremely important when considering that a 15% decrement in passing performance occurs following one half of a soccer match, with a similar trend following short periods of high-intensity activity (Rampinini *et al.*, 2008). Additionally, when compared to within group results, the SSG re-WU was the only intervention to enhance LSPT performance immediately post (6.4%) and following the second IAP (6.2%). It is possible that skilled performance was enhanced via a "transfer-appropriate processing" phenomenon. This theory suggests practice sessions which promote the acquisition of specific motor skills, can facilitate the transfer of germane cognitive processing in subsequent like-tasks (Lee, 1988) In the current investigation, the SSG re-WU consisted of passing and dribbling tasks similar to the skilled tasks measured in the LSPT. These findings suggest that highly-skilled sports such as soccer should include short bouts of skilled activity during the re-WU period to optimise subsequent skill execution.

A strength of this study was the use of a tightly-controlled laboratory environment to accurately assess performance changes attributable to the re-WU interventions. However, future research should investigate methods of practically implementing similar re-WU strategies to optimise skill and physical performance of athletes during secondary periods of intermittent activity. Research is also required to confirm the mechanisms responsible for reported changes in performance, and to investigate if a combination of both interventions could be the best re-warm-up strategy for subsequent team-sport performance.

5.5 Conclusions

A 5RM leg-press re-WU, implemented prior to a second period of intermittent activity, can improve subsequent physical performance pertinent to soccer, while a SSG re-WU enhanced subsequent soccer-skill performance. The results of this study suggest that second-half performance in team-sports can be improved, or, at least second half decrements in tasks reliant on power or skill attenuated, via a 5RM or SSG re-WU. This has important implication for team-sport athletes looking to enhance physical performance in the latter stages of competition. It is possible that a combination of both a 5RM leg-press and skilled activity could provide an optimal stimulus during the re-WU period of team-sport competition.

CHAPTER 6. GENERAL DISCUSSION AND CONCLUSIONS

6.1 Introduction

This thesis investigated the performance and physiological effects of warm-up (WU) and re-WU interventions (e.g., during half-time rest periods) amongst amateur soccer players. Specifically, I compared the acute and prolonged effects of high-intensity, short-duration WU routines, aimed at inducing post-activation potentiation (PAP), to those of a currently-implemented, professional, soccer WU routine. The results of this thesis have been discussed in earlier chapters (chapters 3, 4 and 5); therefore this section will assimilate and discuss the major results from the three investigations completed as part of this thesis.

6.1.1 *Acute effects of warm-up interventions*

Study one (Chapter 3) investigated the acute effects of a 5RM, a SSG and a team-sport WU protocol. Only the shorter, higher-intensity 5RM and SSG WU protocols improved acute performance in CMJ (2-6%), RA (4-5%) and short sprint ability tasks (~10%). Acute enhancement in explosive tasks has previously been reported in WUs aimed at inducing a PAP effect (Chatzopoulos *et al.*, 2007; Kilduff *et al.*, 2007; Rahimi, 2007); however, this is the first study to report enhanced acute performance in tasks which are specific to soccer. Interestingly, the SSG WU in this first study provided a further 4% increase in CMJ performance, when compared to the 5RM. An intensity-dependant relationship has been postulated with similar acute improvements in CMJ height (~7%) amongst volleyballers when high-intensity movement-pattern activities were completed during the WU (Saez Saez de Villarreal *et al.*, 2007).

Less physiological strain reported following the 5RM WU, when compared to both the SSG and team-sport WU (i.e., lower T_c ~2%, and reduced load units 0.86-131 fold, respectively) suggests that the alternative WU protocols, especially the team-sport WU, increased players' perceived levels of fatigue prior to performance tests, and may have negatively affected acute physical performance. Indeed, the professional team-sport WU did not provide any performance enhancement to criterion measures which may be considered pertinent to soccer (i.e., CMJ, sprint ability and RA). These findings are in agreement with previous research implementing similar WU intensities of 60-80% $\dot{V}O_{2max}$ (Stewart & Sleivert, 1998; Bishop *et al.*, 2001a) and durations of between 15-30 min, which reported decreased performance in power-reliant tasks. These findings have important implication for soccer and team-sport athletes interested in the designing of efficient WU protocols prior to performance of explosive tasks.

6.1.2 *Extended effects of warm-up interventions*

Team-sport competition such as soccer engages athletes in prolonged periods of high-intensity intermittent activity. With this in mind, study two (chapter 4) aimed to further explore the extended performance and physiological effects of a 5RM, a SSG and a team-sport WU, during and following two 15-min bouts of field-based, high-intensity intermittent activity. Although all three WU protocols experienced similar physiological perturbations during both intermittent bouts of activity, the 5RM condition improved physical performance during and following both intermittent bouts, when compared to the SSG and team-sport WU. Mean 20-m sprint ability imbedded within both 15-min intermittent activity tasks, and 30-m RSA performance, remained faster by 4-5 and 3-4% in the 5RM condition, when compared to the team-sport and SSG WUs.

This is the first performance-based study to investigate the prolonged effects of a WU aimed at inducing a PAP effect in a subsequent team-sport-based intermittent activity. Therefore, it is difficult to confirm which mechanisms of PAP specifically may have been responsible for the improved performances reported. However, it is likely that the recruitment of higher-order motor units, which has been previously reported via PAP (de Luca *et al.*, 1996), could have provided economies pertaining to membrane excitability and excitation-contraction coupling efficiency following the 5RM WU; these are both possible factors offsetting fatigue during intermittent exercise (Edwards *et al.*, 1977). The results of this study demonstrate the transferable application of PAP during prolonged, intermittent exercise tasks, and suggest that acute investigations may not be germane to team sports such as soccer, were the competitive period can be in excess of 90 min, and include bouts of high-intensity intermittent activity.

6.1.3 *Optimisation of re-warm-up periods*

In study 3 (Chapter 5) I investigated the efficacy of implementing the most effective WU protocols from studies one and two, as a re-WU intervention during two intermittent, standardised, non-motorised treadmill (NMT) activities (each bout lasting 26 min). I compared the performance, physiological, and skill effects of a 5RM and SSG re-WU, as well as the effects of completing no re-WU following one bout of intermittent activity. Similar to the performance results from study two, the 5RM re-WU was associated with greater subsequent performance than the SSG re-WU, or no re-WU, during the second bout of NMT intermittent activity. Both CMJ variables and repeat-sprint ability measures (imbedded in the two 26-min activity tasks), were greater by ~10-29% (CMJ measures), and 3-18% (RSA measures).

Comparable improvements have been reported via PAP during 10 min of knee-extension intermittent activity (Morana & Perrey, 2009) and are likely related to the offsetting of low frequency fatigue via increased phosphorylation of myosin light chains and calcium sensitivity (Moore & Stull, 1984). Only two studies (Mohr *et al.*, 2003; Lovell *et al.*, 2007) have investigated the effects of other re-WU protocols (generic movement activities). However, neither study controlled the relative work completed by participants in the initial activity bouts prior to the interventions; therefore subsequent results may have been influenced by varying levels of fatigue experienced in the first half, and not as a direct result of the re-WU interventions.

Although the SSG re-WU did not enhance subsequent physical performance, it did improve skill as assessed via the Loughborough Soccer Passing Test (LSPT). The SSG re-WU increased passing performance (measures via combined time and accuracy) post-intervention by 6.4% and remained better following the second NMT protocol by 6.2%. This may be explained via a 'transfer-appropriate processing' phenomenon which suggests prior rehearsal of specific motor skills can result in the transfer of relevant cognitive processing, which is required to perform subsequent like tasks (Lee, 1988). Therefore, the combination of both a 5RM and a short bout of SSG activity may be the optimal method in preparing soccer players for competition. Further research is required to elucidate the mechanisms involved in the enhancement of skilled tasks following the SSG re-WU protocol.

6.2 Practical application

The findings from this thesis provide applied knowledge for the optimisation of WU protocols in soccer. A 5RM WU aimed at inducing a PAP effect can improve both acute and prolonged team-sport-specific performance during intermittent activity, more than a currently-implemented, team-sport WU. Importantly, these improvements have been reported in tasks which are not dissimilar to those required for team-sport performance such as RA, RSA, CMJ and specific sprint ability during intermittent exercise. In addition, in this thesis I report improved methods for re-WU of team-sport participants; the use of a 5RM leg-press re-WU and the implementation of brief (~3 min) SSG tasks, which can enhance both physical and skill tasks relevant to soccer. Therefore, team-sport coaching staff should avoid the use of prolonged WU periods (>15 min) completed at moderate-high intensity if acute or prolonged explosive performance is important to match outcomes. Furthermore, a 15-min period of inactivity during half-time rest intervals can negatively affect subsequent physical and skill-related performance. Instead, a brief, high-intensity re-WU which combines explosive tasks and skill rehearsal (~3 min) would be a recommended method in physically preparing athletes for subsequent team-sport performance.

6.3 Conclusions

The specific conclusions of this thesis are:

1. A 5RM and/or SSG WU may benefit subsequent acute power and repeat-sprint task performance in team-sport athletes.
2. A currently-implemented, team-sport WU routine did not provide a beneficial effect to subsequent team-sport-related physical tasks.
3. Current team-sport WU practices can negatively affect acute performance, most likely via an increase in pre-performance fatigue levels.
4. A 5RM WU may be an effective WU alternative for team-sport athletes who take part in subsequent prolonged intermittent activity.
5. Specific SSG tasks completed at high-intensity for $\geq$ 10 min during the WU can negatively affect subsequent repeated-sprint ability and RA tasks when combined with extended periods of intermittent activity.

6. Team-sport WUs lasting ~23 min can negatively impact subsequent explosive and intermittent physical performance.
7. Results from acute WU studies may not be applicable to prolonged team-sport performance.
8. A 5RM re-WU can improve CMJ and RSA measures during secondary periods of controlled intermittent activity.
9. A SSG re-WU can improve subsequent passing performance in amateur soccer players.
10. Performing no re-WU during rest intervals is detrimental to subsequent physical and skilled performances in soccer.

CHAPTER 7. DIRECTIONS FOR FUTURE RESEARCH

Research conducted for this thesis has investigated the optimisation of WU protocols via high-intensity, short-duration WU interventions. This thesis has reported that a 5RM leg-press aimed at inducing a PAP effect can enhance acute and prolonged physical performance, while SSG activities during the WU period can improve subsequent skill execution tasks. Findings from this thesis provide important knowledge to team-sport coaches and athletes interested in enhancing physical performance via the optimisation of WU protocols. Future avenues of investigation are discussed in the following sections.

7.1 Mechanisms related to improved performance during intermittent activity

Acute performance enhancement in CMJ tasks arising from PAP has been reported via interventions similar to those implemented in the current thesis (e.g., 5RM squat) (Mitchell & Sale, 2011). However, I was unable to perform the measures necessary to identify the mechanisms responsible for these effects. In the current thesis it was speculated that the performance enhancement following the 5RM leg-press was due to mechanisms associated with PAP i.e., increased phosphorylation of myosin regulatory light chains (Hodgson *et al.*, 2005), recruitment of higher-order motor-units (Gullich & Schmidtbleicher, 1996), or via minimising the effects of low frequency fatigue (Green & Jones, 1989). The performance nature of this thesis did not allow investigation of neuromuscular mechanisms responsible for changes reported following interventions. Therefore, further research is required to elucidate the mechanisms accountable for improved acute team-sport-specific performance, as well as improved performance following prolonged intermittent activity. In addition, a time course of reported mechanistic changes via PAP, during team-sport-specific intermittent activity, would provide important knowledge for future application of such WU routines. Lastly, the application of high-intensity WU routines during competitive match play is still to be investigated as is investigating the potential effects on injury rate via adopting different WU routines and warrants further investigation.

7.2 Skill effects of small-sided games during the warm-up

Skilled performance was improved by ~6% following a SSG re-WU in the final investigation of this thesis. While these findings have important implications for subsequent performance in soccer, and possibly team-sports in general, mechanistic investigations are required to confirm the causes of the observed changes. It has been purported that improved skilled performance following similar skill rehearsal tasks may be associated with a ‘transfer-appropriate processing’ phenomenon (Lee, 1988). However, this thesis focused on the optimisation of WU periods during team-sport performance, and hence could not explore the mechanisms involved with improved skill acquisition following the SSG WU. Therefore, future research is warranted to investigate if perceptual, psychological, or psychomotor skills are more sensitive to augmentation following a short bout of SSG activity during a pre-competition WU routine.

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APPENDIX 1: INFORMATION FOR PARTICIPANTS

7.3 Information for participants for study one and two

INFORMATION TO PARTICIPANTS FOR INVOLVEMENT IN:

“Comparing Performance and Physiological Effects of Current Warm Up Practices In Football (Soccer) To Shorter, High Intensity Warm Up Protocols”

You are invited to participate

You are invited to participate in a research project entitled:

“Comparing Performance and Physiological Effects Of Current Warm Up Practices In Football (Soccer) To Shorter, High Intensity WU Protocols”

This project is being conducted by a student researcher Mr. James Zois as part of a PhD study at Victoria University under the supervision of Dr. Rob Aughey from School of Human Movement, Recreation and Performance.

Project explanation

The project aims to compare the performance and physiological effects of three different types of warm-up (WU) protocols on football specific performance measures. Participants will be asked to complete one WU/testing session per week for a total testing duration of three weeks. The WU protocols will consist of two different high intensity-short duration protocols, with the third being a standard match day WU as prescribed by the Chievo Verona Physical Performance staff.

Study overview:

Participants will undertake a five min baseline jog WU. This will be followed by one of the three WU protocols which will include either; heavy resistance-short duration squat sets or, a modified small sided football game or, a current football WU protocol devised by Chievo Verona Physical Performance staff. Participants will complete only one WU per testing session.

Immediately post WU protocol, participants will be tested in a range of performance and physiological measures related to football:

Performance measures:

- **Vertical jump** – participants will be required to stand on a force plat form and jump as high as possible with hands placed on hips throughout jump, landing back onto force plat form.
- **20 m sprint** – participants will be required to run from start line marked out to finish line (total distance to be covered is 20 m) as fast as possible. Light gates will record elapsed time during sprint.
- **Reactive agility** – participants will be required to accelerate towards tester, then change direction quickly in reaction to given cue by the tester. Light gates will record elapsed time during task.
- **Repeat sprint ability** – participants will be required to complete 6 sprints, each covering 30 m in distance (as fast as possible). Between each sprint, participants will be given 20 seconds passive rest. Total time taken to complete task will be recorded.

Physiological measures:

- **Core temperature** – participants will swallow a regular sized pill two hours prior to commencement of testing. Measurements of core temperature will be taken throughout testing. Participant must wear a safety bracelet until pill is removed via normal bowel movement. The bracelet will inform other medical practitioners of swallowed item and to not perform any magnetic resonance imaging until pill has been discarded. Core temperature measures will be taken after initial 5 min WU, post intervention, during intermittent protocol (at 17 mins) and at the completion of the intermittent protocol.
- **Blood lactates –** participants will be required to give finger prick samples of blood from the index finger or thumb that will be used for analyses of blood lactate concentration. The re-bleeding technique (squeezing out droplets of blood from initial puncture site) will be implemented to avoid re-pricking participants. Blood lactate measures will be taken after initial 5 min WU, post intervention, during intermittent protocol (at 17 mins) and at the completion of the intermittent protocol.
- **Heart rate –** participants will be required to wear a Polar heart rate monitor during testing, with measures taken on a regular basis throughout the testing protocol.
- **Rate of perceived exertion –** participants will be required to point to scale (or yell out a rating) that will reflect their perceived rate of exertion during a soccer specific intermittent filed protocol. The scale ranges from 0 (being no effort at all) to 10 (being extremely hard). Measures will be taken at regular intervals through the intermittent field protocol.

What will I be asked to do?

- Participants will be required to attend the Chievo Verona training centre for familiarisation prior to commencement of each testing session. Familiarisation sessions will take approximately 60-mins in total.

- The study will consist of three testing session separated by one week. Testing sessions will be held at Chievo Verona training centre / Verona University (as required) and will be completed in approximately 2 hrs. Testing will consist of different WU routines, intermittent exercise as well as, physiological and performance tests (mentioned in above study overview).

What will I gain from participating?

The knowledge gained from this study will assist athletes and fitness coaching staff to implement improved WU strategies, which may positively affect match outcomes for the club. Furthermore, this study will help optimise WU protocols for athletes involved and may reduce the likelihood of fatigue related injuries in future competition as well as better understanding energy contributions of specific WU techniques in elite athletes.

How will the information I give be used?

Data resulting from testing sessions will be presented in a non-identifiable manner in the thesis write up and future publications to protect participant's confidentiality. Presentations resulting from these studies will report on group and individual data through non-identifiable methods i.e. using a numbering system. Personal information provided for studies will only be accessed by research staff (principle investigator; Dr. Rob Aughey, Co-supervisor; Dr. Kevin Ball, research student; Mr James Zois and Assoc. Prof. David Bishop).

What are the potential risks of participating in this project?

Heavy squat protocol

The weighted squat protocol is of high intensity (90% of 1 repetition maximum) consisting of 2 sets with 3 repetitions per set. Athletes may encounter muscle strains or aggravate existing injuries due to the nature of the activity. This will be managed by consulting with medical staff and fitness advisors regarding current and past injury concerns for each individual and assessing individuals capability to perform the protocol. Furthermore, participant's unable to complete the squat protocol (due to injury or technique concerns), will complete the WU protocol through the implementation of a seated leg press machine.

Small Sided Game

The Small Sided Game protocol will include a 3 vs. 3 match play simulation based activity. Although rule modifications will be put in place to reduce the risk of collision injuries, there is a chance of muscle strains or tears occurring and accidental contact injuries. The risk of these occurring will be no greater than that seen in a typical football match.

Performance and intermittent soccer specific field tests

All measures will be taken to insure participant's safety in performing maximal effort testing; however there is a risk associated with maximal testing. The risks will include muscle strains and tears as well as ankle sprains or slipping of testing surface. These will be managed by ensuring adequate warm up prior to testing and only allowing participation by athletes with correct footwear. All testing procedures and activities will be explained and participants will have ample time to familiarise themselves with the required activities.

Physiological tests

As with most physiological tests there is a risk of infection from invasive measures such as blood lactate analyses and muscle temperature measures. However all measures will be taken to maintain a safe and sterile environment, whilst qualified medical practitioners will be on hand throughout all test to assist and conduct tests as required. Discomfort, bruising, bleeding and some levels of pain may be felt by various individuals during some of the procedures such as blood lactate measures. There is a risk of the core temperature pill rupturing if a magnetic resonance imaging (MRI) scan is conducted. However this will be managed by participants wearing a safety bracelet stating that this procedure is not to be conducted until pill is removed via normal bowel movement.

Psychological risks

Psychological risks associated with this study include; a fear of sustaining an injury from the exercise protocols / interventions. However, exercise protocols and interventions in this study will not be more strenuous then what is required for competitive match play or strength training sessions completed on a weekly basis. Lancets (finger prick device) used for and blood lactate measuring may cause some concern to participants who fear these apparatuses. In this case, participants will not be required to participate if they feel uncomfortable with these devices. Participants may also fear the results of their tests being known by other participants or staff within the club. All results will be kept strictly confidential and only accessed by the research team. Lastly, participants may fear their results will influence team selection by coaches, however individual results will not be made accessible to coaching staff.

Who is conducting the study?

Victoria University, School of Human Movement, Recreation and Performance

Principal Investigator: Dr. Rob Aughey (e. robert.aughey@vu.edu.au, p. 9919 5551, m. 0448 153 597,)

Student Researcher: Mr. James Zois (e. james.zois@live.vu.edu.au, p. 9919 4207, m. 0413 497 090)

Associate Investigator: Dr. Kevin Ball (e. kevin.ball@vu.edu.au, m. 0404 876 480)

Verona University Collaborator: Assoc. Prof. David Bishop (e. david.bishop@univr.it)

Any queries about your participation in this project may be directed to the Principal Researcher listed above.

If you have any queries or complaints about the way you have been treated, you may contact the Secretary, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 phone (03) 9919 4781.

7.4 Translated information for participants for study one and two

INFORMAZIONI PER I PARTECIPANTI COINVOLTI NELLA RICERCA:

"Confronto degli effetti fisiologici e di prestazione delle attuali procedure di riscaldamento nel calcio con protocolli di riscaldamento più breve e di alta intesità"

Siete invitati a partecipare

Siete invitati a partecipare ad un progetto intitolato:

"Confronto degli effetti fisiologici e di prestazione delle attuali procedure di riscaldamento nel calcio con protocolli di riscaldamento più breve e di alta intensità"

Questo progetto è condotto dal Sig. James Zois, studente di Ricerca, e verrà incluso in un dottorato di ricerca presso la *Victoria University*, con la supervisione del Dott. Rob Aughey della "*School of Human Movement, Recreation and Performance"* .

Spiegazione del progetto

L'obiettivo di questo progetto è quello di confrontare gli effetti in termini fisiologici e di risultato di tre diversi tipi di protocolli di riscaldamento basandosi su misurazioni di prestazioni proprie del calcio. Sarà chiesto ai partecipanti di completare una sessione di riscaldamento/test alla settimana per un totale di tre settimane. I protocolli di riscaldamento consisteranno di due diversi protocolli di alta intensità-breve durata, e di un terzo protocollo rappresentato da un riscaldamento standard pre-partita come previsto dal personale tecnico del Chievo Verona.

Panoramica dello studio:

I partecipanti cominceranno con una corsa di riscaldamento di cinque minuti. Questa sarà seguita da uno dei tre protocolli di riscaldamento che potrà includere: una serie di piegamenti massimi (*squat*) di breve durata-forte resistenza o una partita di esercitazione su campo ridotto o un protocollo di riscaldamento calcistico attuale ideato dal personale tecnico del Chievo Verona. I partecipanti completeranno soltanto un tipo di riscaldamento per sessione di prova.

Subito dopo il protocollo di riscaldamento, i partecipanti verranno sottoposti ad una serie di misurazioni di tipo fisiologico e di prestazione specifiche per il calcio:

Misurazioni di prestazione:

- **Salto verticale** – i partecipanti dovranno salire su una piattaforma dinamometrica, saltare il più in alto possibile tenendo le mani sui fianchi durante il salto e atterrare sulla stessa piattaforma.
- **Sprint di 20 mt** – i partecipanti dovranno correre dalla linea di partenza alla linea di arrivo (percorrendo una distanza totale di 20 mt) il più velocemente possibile. Delle fotocellule rileveranno il tempo dello sprint.
- **Cambi di direzione** – i partecipanti dovranno accelerare in direzione di colui che li sta sottoponendo al test, poi cambiare direzione rapidamente in base ad un'indicazione del preparatore. Delle fotocellule rileveranno il tempo durante la prova.
- **Tiro per distanza massima** – i partecipanti dovranno tirare un pallone da partita il più lontano possibile con la gamba che preferiscono. Il pallone dev'essere fermo sul suolo prima del tiro. Verrà misurata la distanza percorsa dalla palla dal contatto iniziale con il piede al contatto iniziale con il suolo in fase di atterraggio.
- **Abilità di ripetere sprint** – i partecipanti dovranno completare 6 sprint, di una distanza di 30 mt ciascuno, il più velocemente possibile. Tra uno sprint e l'altro i partecipanti avranno 20 secondi di recupero passivo. Verrà registrato il tempo totale impiegato per completare la prova.

Misurazioni di tipo fisiologico:

- **Temperatura corporea interna** – i partecipanti prenderanno una pillola, di normali dimensioni, due ore prima dell'inizio della prova. Le misurazioni di temperatura corporea verranno prese nel corso della prova. I partecipanti dovranno indossare un braccialetto di sicurezza fino a quando la pillola non verrà espulsa con le feci. Tramite il braccialetto, anche altri medici potranno vedere che cosa è stato ingerito e si asterranno dal sottoporre il soggetto ad ogni forma di risonanza magnetica finchè la pillola non sarà stata espulsa. Le misurazioni di temperatura corporea verranno prese dopo i primi 5 minuti di riscaldamento, dopo un intervento, durante il protocollo intermittente (a 17 minuti) e a completamento del protocollo intermittente.
- **Concentrazione di lattato nel sangue –** i partecipanti dovranno fornire un campione di sangue che verrà prelevato pungendo il polpastrello del loro dito pollice o indice. Questo campione verrà usato per le analisi della concentrazione di lattato nel sangue. Per evitare di dover "ri-pungere" i partecipanti più volte, basterà premere dove sono stati punti inizialmente per far fuoriuscire altre goccioline di sangue. Le misurazioni della concentrazione di lattato nel sangue verranno prese dopo i primi 5 minuti di riscaldamento, dopo un intervento, durante il protocollo intermittente (a 17 minuti) e a completamento del protocollo intermittente.
- **Frequenza cardiaca –** i partecipanti dovranno indossare un fascia cardiaca Polar durante il test, e verranno prese delle misurazioni in maniera costante nel corso del protocollo di prova.
- **Valore dello sforzo recepito –** su una scala da 0 a 10, i partecipanti dovranno indicare o dire qual è il valore dello sforzo da loro percepito durante un protocollo calcistico intermittente sul campo. La scala va da 0 (per nessuno sforzo) a 10 (per estremamente faticoso). Le misurazioni verrano prese ad intervalli regolari durante il protocollo intermittente sul campo.

Che cosa mi sarà chiesto di fare?

- I partecipanti dovranno presentarsi al centro di allenamento del Chievo Verona prima dell'inizio di ogni sessione di prova per familiarizzarsi. Le sessioni di familiarizzazione avranno una durata totale di circa 60 minuti.
- Lo studio consisterà di tre sessioni di prova, con una settimana di intervallo fra l'una e l'altra. Le sessioni di prova si terranno al centro di allenamento del Chievo Verona o all'Università di Verona (a seconda di come richiesto) e avranno una durata di circa due ore. Le prove consisteranno di diverse serie di riscaldamento, esercizi intermittenti e prove fisiologiche e di prestazione (accennate nella panoramica dello studio qui sopra).

Quali vantaggi trarrò dal partecipare?

Le informazioni ricavate da questo studio saranno utili agli atleti e agli allenatori per poter mettere in pratica delle strategie di riscaldamento che potrebbero influenzare positivamente i risultati delle partite per la squadra. Inoltre questo studio servirà ad ottimizzare i protocolli di riscaldamento per gli atleti coinvolti e potrebbe ridurre la probabilità di infortuni da affaticamento durante le partite future, oltre a fornire una miglior comprensione dei contributi energetici in tecniche specifiche di riscaldamento per atleti di elite.

Come verranno utilizzate le informazioni da me fornite?

Per proteggere la privacy del partecipante, i dati raccolti durante le sessioni di prova verranno presentati nella stesura della tesi e in pubblicazioni future in modo non-identificativo. Anche le presentazioni derivanti da questi studi riporteranno dati di gruppo ed individuali attraverso metodi non-identificativi, ad esempio utilizzando un sistema numerico. Le informazioni personali fornite ai fini dello studio saranno accessibili solo dal personale di ricerca (ricercatore principale; Dott. Rob Aughey, Co-supervisore; Dott. Kevin Ball, studente di Ricerca; Sig. James Zois e il Prof. Associato David Bishop).

Quali sono i potenziali rischi derivanti dalla partecipazione a questo progetto?

Protocollo di squat con sovraccarico

Il protocollo di squat con sovraccarico è un protocollo di alta intensità (max. 90% di 1 ripetizione) e consiste di 2 serie da 3 ripetizioni ciascuna. La natura di questa attività potrebbe comportare stiramenti muscolari o aggravare lesioni già presenti negli atleti. Per questo motivo, si prevede una consultazione con personale medico ed esperti di fitness in merito ad infortuni preoccupanti, attuali o passati, di ciascun individuo, e una stima della capacità dei soggetti di eseguire il protocollo. Inoltre, i partecipanti che non riusciranno a completare il protocollo di squat (a causa di infortuni o preoccupazioni tecniche), completeranno il protocollo di riscaldamento con l'aiuto di una pressa per gambe.

Partita di esercitazione su campo ridotto

Il protocollo di esercitazione su campo ridotto prevede un'attività basata sulla simulazione di una partita con 3 giocatori per squadra. Nonostante le modifiche delle regole che verranno applicate per ridurre il rischio di infortuni da scontro, rimane la possibilità di incorrere in stiramenti muscolari o strappi o infortuni da contatto accidentale. Il rischio non è comunque maggiore di quello presente in una normale partita di calcio.

Prove di prestazione e prove intermittenti sul campo specifiche per il calcio

Saranno intraprese tutte le misure necessarie per garantire la sicurezza dei partecipanti durante le prove di sforzo massimo; tuttavia ci sono dei rischi connessi con i test massimali. Questi rischi comprendono stiramenti o strappi muscolari, distorsioni di caviglie o il rischio di slittamento della superficie di prova. Questi verranno gestiti assicurando un riscaldamento adeguato prima della prova e negando la partecipazione ad atleti con calzature inadeguate. Tutte le procedure ed attività di prova verranno spiegate e i partecipanti avranno del tempo a disposizione per familiarizzarsi con le attività richieste.

Rischi a livello fisiologico

Come nella maggiorparte dei test fisiologici, c'è un rischio di infezione durante i test invasivi quali le analisi della concentrazione di lattato nel sangue e le misurazioni di temperatura muscolare. Tuttavia saranno prese tutte le misure necessarie per mantenere un ambiente sicuro e sterile, e medici qualificati saranno a portata di mano nel corso di tutti i test per offrire assistenza e condurre i test in modo adeguato. Durante alcune delle procedure come le misurazioni del lattato e della temperatura muscolare, alcuni potrebbero riscontrare fastidio, lividi, fuoriuscita di sangue o un certo grado di dolore. Inoltre, qualora venisse condotta una risonanza magnetica, c'è il rischio che la pillola per misurare la temperatura corporea si rompa. Per evitare ciò, verrà fatto indossare ai partecipanti un braccialetto di sicurezza che informi i medici di non effettuare una risonanza magnetica fin quando la pillola non sarà stata espulsa con le feci.

Rischi a livello psicologico

I rischi di questo studio a livello psicologico possono essere la paura di subire un infortunio in seguito ad interventi/protocolli di esercizio. Tuttavia, i protocolli di questo studio non saranno più faticosi di quelli previsti per le partite di campionato o per le sessioni di allenamento settimanali. Alcuni partecipanti potrebbero avere paura di arnesi come gli aghi e le lancette (usate per pungere le dita) utilizzati per misurare la temperatura muscolare o il lattato nel sangue. In questi casi, i partecipanti potranno fare a meno di partecipare se non si sentono a loro agio. I partecipanti potrebbero inoltre avere paura di far conoscere agli altri partecipanti e al personale della squadra i risultati dei loro test ma tutti i risultati verranno mantenuti strettamente riservati e saranno resi accessibili solo al personale di ricerca. Infine, i partecipanti potrebbero avere il timore che i loro risultati possano influenzare la selezione della squadra da parte degli allenatori, tuttavia i risultati individuali non saranno resi noti agli allenatori.

Da chi è condotto lo studio?

Victoria University, School of Human Movement, Recreation and Performance

Capo ricercatore: Dott. Rob Aughey (email. robert.aughey@vu.edu.au, tel. [+61 (03)]9919 5551, cell. [+61] (0)448 153 597,)

Studente di Ricerca: Sig. James Zois (email. james.zois@live.vu.edu.au, tel. [+61 (03)] 9919 4207, cell.[+61] (0)413 497 090)

Socio ricercatore: Dott. Kevin Ball (email. kevin.ball@vu.edu.au, cell. [+61] (0)404 876 480)

Collaboratore dell'Università di Verona: Prof. Associato David Bishop (email. david.bishop@univr.it)

Qualsiasi domanda riguardo la vostra partecipazione a questo progetto può essere rivolta al Capo ricercatore qui sopra elencato.

Per domande o lamentele in merito al trattamento della vostra persona, potete rivolgervi al Segretario, alla Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 *[AUSTRALIA]* Tel. [+61] (03) 9919 4781.

7.5 Information for participants for study three

INFORMATION TO PARTICIPANTS FOR INVOLVEMENT IN:

"Effects of a Re-Warm-up During Match Simulation on a Non-Motorised Treadmill"

You are invited to participate

You are invited to participate in a research project entitled:

"Effects of a Re-Warm-up During Match Simulation on a Non-Motorised Treadmill"

This project is being conducted by a student researcher Mr. James Zois as part of a PhD study at Victoria University under the supervision of Dr. Rob Aughey from School of Human Movement, Recreation and Performance.

Project explanation

The project aims to compare the performance and physiological effects of three different types of re-warm-up (re-WU) protocols on soccer-specific performance measures. Participants will be asked to complete two familiarisation sessions and three testing session with one week break between each testing session. Total sessions will be five. The re-WU protocols will consist of two different high intensity-short duration protocols, with the third being a standard match day re-WU protocol including general movements such as jogging, side skipping etc.

Study overview:

Participants will undertake a five min baseline jog WU and squat protocol. This will be followed by 30 min fatigue protocol on a non-motorised treadmill. This is then followed by testing (as described below) and then one of the three re-WU protocols which will include either; heavy resistance-short duration squat sets or, a modified small-sided football game or, a current football re-WU protocol. Participants will complete only one WU per testing session.

Immediately following the first fatigue protocol, the re-WU and second fatigue protocol, participants will be tested in a range of performance and physiological measures related to soccer:

Performance measures:

- **Vertical jump** – participants will be required to stand on a force plat form and jump as high as possible with hands placed on hips through out jump, landing back onto force plat form.
- **Repeat sprint ability** – participants will be required to complete 6 sprints, each covering 30 m in distance (as fast as possible). Between each sprint, participants will be given 20 seconds passive rest. Total time taken to complete task will be recorded.
- **Soccer specific passing test** – participants will be given four targets to pass the ball to in a random order. Your aim will be to execute passes with precision and speed in order to complete the task within the allocated 43 seconds.
- **Fatigue protocol** – participants will be required to complete two 30 min fatigue protocols on a non-motorised treadmill. This protocol has been devised through the analysis of day-to-day match demands as seen in soccer, rugby and football and will involve six movement categories i.e. standing, walking, jogging, running, fast running and sprinting.
- **YOYO Intermittent Recovery Test (level 1) –** participants will be required to undertake one maximal aerobic capacity test (approximately 15 minutes in duration). This will involve running at incremental speeds between pre-marked 20-m distances. Similar to a beep test, participants will continue until they are no longer able to maintain the pace of each audible sound. This test is specifically designed for team-sport athletes and results can be directly compared to various levels including International elite level players.

Physiological measures:

- **Core temperature** – participants will swallow a regular sized pill two hours prior to commencement of testing. Measurements of core temperature will be taken throughout testing. Participant must wear a safety bracelet until pill is removed via normal bowel movement. The bracelet will inform other medical practitioners of swallowed item and to not perform any magnetic resonance imaging until pill has been discarded. Core temperature measures will be taken after initial 5 min WU, post first fatigue protocol, post re-WU and at the completion of the second fatigue protocol.

- **Blood lactates –** participants will be required to give finger prick samples of blood from the index finger or thumb that will be used for analyses of blood lactate concentration. The re-bleeding technique (squeezing out droplets of blood from initial puncture site) will be implemented to avoid re-pricking participants. Blood lactate measures will be taken after initial 5 min WU, post first fatigue protocol, post re-WU and at the completion of the second fatigue protocol.

- **Heart rate –** participants will be required to wear a Polar heart rate monitor during testing, with measures taken on a regular basis throughout the testing protocol.
- **Rate of perceived exertion –** participants will be required to point to scale (or yell out a rating) that will reflect their perceived rate of exertion during both fatigue protocols. The scale ranges from 0 (being no effort at all) to 10 (being extremely hard). Measures will be taken at regular intervals.

What will I be asked to do?

- Participants will be required to attend the Victoria University Exercise Physiology laboratory for two familiarisation sessions prior to commencement of three testing sessions. Familiarisation sessions will take approximately 60 mins in total and will include familiarisation with al testing and intervention procedures as well as, completing a 1 repetition maximal squat and a maximal aerobic capacity (VO_{2max}) tests.

- The study will consist of three testing session separated by one week. Testing sessions will be held at Victoria University and will be completed in approximately 2 hrs. Testing will consist of different re-WU routines, intermittent exercise as well as, physiological and performance tests (mentioned in above study overview).

What will I gain from participating?

The knowledge gained from this study will assist athletes and fitness coaching staff to implement improved re-WU strategies at half time intervals, which may positively affect match outcomes for the club. Furthermore, this study will help optimise re-WU protocols for athletes involved and may reduce the likelihood of fatigue related injuries in future competition as well as better understanding energy contributions of specific WU techniques in elite athletes.

How will the information I give be used?

Data resulting from testing sessions will be presented in a non-identifiable manner in the thesis write up and future publications to protect participant's confidentiality. Presentations resulting from these studies will report on group and individual data through non-identifiable methods i.e. using a numbering system.
Personal information provided for studies will only be accessed by research staff (principle investigator; Dr. Rob Aughey, Co-supervisors; Dr. Kevin Ball and Assoc. Prof. David Bishop, and research student; Mr James Zois).

What are the potential risks of participating in this project?

Heavy squat protocol

The weighted squat protocol is of high intensity (1 x 5 repetitions maximum). Participants may encounter muscle strains or aggravate existing injuries due to the nature of the activity. This will be managed by consulting with medical staff and fitness advisors regarding current and past injury concerns for each individual and assessing individuals capability to perform the protocol. Furthermore, participant's unable to complete the squat protocol (due to injury or technique concerns), will complete the protocol through the implementation of a seated leg press machine instead.

Small Sided Game

The Small Sided Game protocol will include a 3 vs. 3 match play simulation based activity. Although rule modifications will be put in place to reduce the risk of collision injuries, there is a chance of muscle strains or tears occurring and accidental contact injuries. The risk of these occurring will be no greater than that seen in a typical football match.

Performance testing and fatigue protocols

All measures will be taken to insure participant's safety in performing maximal effort testing; however there is a risk associated with maximal testing. The risks will include muscle strains and tears as well as ankle sprains or slipping of testing surface. These will be managed by ensuring adequate warm-up prior to testing and only allowing participation by persons wearing correct attire. All testing procedures and activities will be explained and participants will have ample time to familiarise themselves with the required activities.

Physiological tests

As with most physiological tests there is a risk of infection from invasive measures such as blood lactate analyses. However all measures will be taken to maintain a safe and sterile environment, whilst qualified medical practitioners will be on hand throughout all tests to assist and conduct tests as required. Discomfort, bruising, bleeding and some levels of pain may be felt by various individuals during blood lactate testing. There is a risk of the core temperature pill rupturing if a magnetic resonance imaging (MRI) scan is conducted. However this will be managed by participants wearing a safety bracelet stating that this procedure is not to be conducted until the pill is removed via normal bowel movement.

Psychological risks

Psychological risks associated with this study include; a fear of sustaining an injury from the exercise protocols / interventions. However, exercise protocols and interventions in this study will not be more strenuous then what is required for competitive match play or strength training sessions completed on a weekly basis. Lancets (finger prick device) used for blood lactate measuring may cause some concern to participants who fear this apparatus. In this case, participants will not be required to participate if they feel distressed. Participants may also fear the results of their tests being known by other participants or staff within the club. All results will be kept strictly confidential and only accessed by the research team. Lastly, participants may fear their results will influence team selection by coaches, however individual results will not be made accessible to coaching staff.

Who is conducting the study?

Victoria University, School of Human Movement, Recreation and Performance

Principal Investigator: Dr. Rob Aughey (e. robert.aughey@vu.edu.au, p. 9919 5551, m. 0448 153 597,)

Associate Investigator: Dr. Kevin Ball (e. kevin.ball@vu.edu.au, m. 0404 876 480)

Associate Investigator: Assoc. Prof. David Bishop (e. david.bishop@univr.it)

Student Researcher: Mr. James Zois (e. james.zois@live.vu.edu.au, p. 9919 4207, m. 0413 497 090)

Any queries about your participation in this project may be directed to the Principal Researcher listed above.

If you have any queries or complaints about the way you have been treated, you may contact the Secretary, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 phone (03) 9919 4781.

APPENDIX 2: INFORMED CONSENT FORM

7.6 Informed consent for study one and two

VICTORIA UNIVERSITY | A NEW SCHOOL OF THOUGHT

CONSENT FORM

FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:

We would like to invite you to be a part of a study analysing the optimisation of warm-up procedures in elite team sports.

CERTIFICATION BY SUBJECT

I,(participants name)……………………………………………………………………………………………

of (suburb)……

certify that I am at least 18 years old* and that I am voluntarily giving my consent to participate in the study

"Comparing Performance And Physiological Effects Of Current Warm Up Practices In Football (Soccer) To Shorter, High Intensity WU Protocols"

being conducted at Verona University by:

Dr. Rob Aughey (principal investigator)

Mr. James Zois (student researcher)

Dr. Kevin Ball (associate investigator)

Assoc. Prof. David Bishop (Collaborator)

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by:

Dr. Rob Aughey (principal investigator)

Mr. James Zois (student researcher)

Dr. Kevin Ball (associate investigator)

Assoc. Prof. David Bishop (Collaborator)

and that I freely consent to participation involving the below mentioned procedures:

- Preliminary pre-participation screening.
- High intensity warm up protocols and intermittent exercise.
- Maximal effort performance testing including vertical jump, 20 metre sprint, reactive agility, and repeat sprint ability testing.
- Physiological testing including blood lactates, rate of perceived exertion (RPE), heart rate and core temperature measures.

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed: ....

Date: ....

Any queries about your participation in this project may be directed to the researcher Dr. Rob Aughey 9919 5551. If you have any queries or complaints about the way you have been treated, you may contact the Secretary, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 phone (03) 9919 4781

[*please note: Where the participant/s are aged under 18, separate parental consent is required; where the participant/s are unable to answer for themselves due to mental illness or disability, parental or guardian consent may be required.]

7.7 Translated informed consent for study one and two

MODULO DI CONSENSO

PER I PARTECIPANTI COINVOLTI NELLA RICERCA

INFORMAZIONI PER I PARTECIPANTI:

Vi invitiamo a far parte di uno studio che analizza come ottimizzare le procedure di riscaldamento in sport di squadra d'elite.

DICHIARAZIONE DEL SOGGETTO:

Il sottoscritto, (nome del partecipante)…………………………………………………………………………

Residente a (città)…………………………………………………………………………………………

dichiara di aver compiuto almeno 18 anni di età* e di consentire volontariamente a partecipare allo studio

"Confronto degli effetti fisiologici e di prestazione delle attuali procedure di riscaldamento nel calcio con protocolli di riscaldamento più breve e di alta intensità"

condotto presso l'Università di Verona da:

Dott. Rob Aughey (Capo ricercatore)

Sig. James Zois (Studente di Ricerca)

Dott. Kevin Ball (Socio ricercatore)

Prof. Associato David Bishop (Collaboratore)

Il sottoscritto dichiara che sia gli obiettivi dello studio, sia i rischi e le misure di sicurezza connessi con le procedure che verranno attuate nella ricerca e qui di seguito elencati, sono stati chiaramente spiegati al sottoscritto da:

Dott. Rob Aughey (Capo ricercatore)

Sig. James Zois (Studente di Ricerca)

Dott. Kevin Ball (Socio ricercatore)

Prof. Associato David Bishop (Collaboratore)

e di consentire spontaneamente alla partecipazione, che prevede le seguenti procedure:

- Screening preliminare pre-partecipazione.
- Protocolli di riscaldamento di alta intensità ed esercizio intermittente .
- Prove di prestazione di massimo sforzo quali salto verticale, sprint di 20 metri, cambi di direzione, tiro per distanza massima e abilità di ripetere sprint.
- Test fisiologici comprensivi di misurazioni di temperature muscolari, lattato nel sangue, valore dello sforzo percepito, consumo di ossigeno, frequenza cardiaca e misurazioni della temperatura corporea interna.

Il sottoscritto dichiara di aver avuto l'opportunità di fare domande e di ottenere chiarimenti e di aver capito che è possibile ritirarsi dallo studio in qualsiasi momento e che tale ritiro non comprometterebbe il sottoscritto in alcun modo.

Il sottoscritto è stato informato sulla riservatezza delle informazioni da lui stesso fornite.

Firma: ....

Data: ....

Per eventuali domande riguardo la vostra partecipazione a questo progetto, siete pregati di rivolgervi al ricercatore Dott. Rob Aughey al numero [+61 (03)] 9919 5551. Per domande o lamentele in merito al trattamento della vostra persona, potete contattare il segretario della "Victoria University Human Research Ethics Committee", all'indirizzo Victoria University, PO Box 14428, Melbourne, VIC, 8001[Australia] o al numero [+61] (03) 9919 4781

[*Attenzione: Laddove il/i partecipante/i sia/siano minorenni, si richiede un consenso a parte dei genitori; laddove il/i partecipante/i sia/siano incapaci di rispondere a causa di disabilità o malattie mentali, potrebbe venire richiesto il consenso dei genitori o di chi ne fa le veci.]

7.8 Informed consent for study three

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CONSENT FORM

FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:

We would like to invite you to be a part of a study analysing the optimisation of re-warm-up procedures in team sports.

CERTIFICATION BY SUBJECT

I,(participants name)……………………………………………………………………………………

of (suburb)……………………………………………………………………………………..................

certify that I am at least 18 years old* and that I am voluntarily giving my consent to participate in the study

"Effects of a re-Warm-up During Match Simulation on a Non-Motorised Treadmill" being conducted at Victoria University by:

Dr. Rob Aughey (principal investigator)

Mr. James Zois (student researcher)

Dr. Kevin Ball (associate investigator)

Assoc. Prof. David Bishop (associate investigator)

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by:

Dr. Rob Aughey (principal investigator)

Mr. James Zois (student researcher)

Dr. Kevin Ball (associate investigator)

Assoc. Prof. David Bishop (associate investigator)

and that I freely consent to participation involving the below mentioned procedures:

- Preliminary pre-participation screening and maximal aerobic capacity testing
- High intensity re-warm-up protocols and intermittent exercise on a non-motorised treadmill
- Maximal effort performance testing including $\dot{V}O_{2max}$, vertical jump, repeat sprint ability testing and weighted squat protocols
- Soccer specific skill test
- Physiological testing including blood lactates, rate of perceived exertion (RPE), heart rate and core temperature measures.

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed: ....

Date: ....

Any queries about your participation in this project may be directed to the researcher Dr. Rob Aughey 9919 5551. If you have any queries or complaints about the way you have been treated, you may contact the Secretary, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 phone (03) 9919 4781

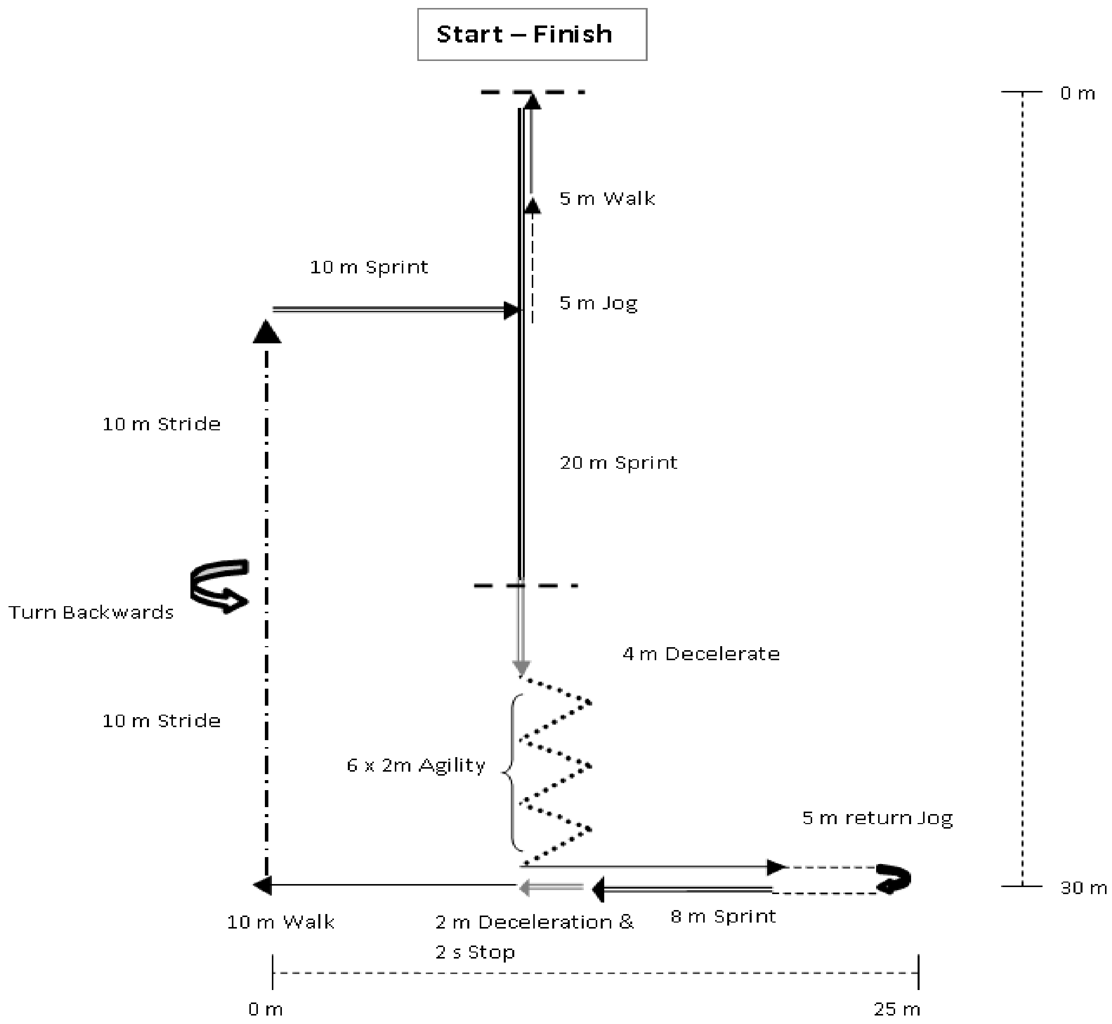
[*please note: Where the participant/s are aged under 18, separate parental consent is required; where the participant/s are unable to answer for themselves due to mental illness or disability, parental or guardian consent may be required.]

APPENDIX 3: SUPPLEMENTARY INFORMATION

7.9 Currently implemented team-sport warm-up protocol (Supplementary 1)

General Movement Patterns			
Activity	***Sets***	***Reps***	***Duration***
20-m high knees, into 10-m jog, into 30-m stride	1	3	2 min
20-m butt kicks, into 10-m jog, into 30-m stride	1	3	
30 s passive rest			
Body-weight squats	3	5	4 min
High-knees	3	10	
Body-weight squats	3	5	
High-knees	3	10	
30-s passive rest			
Specific Movement Patterns with Ball			
Activity	***Sets***	***Reps***	***Duration***
15-m dribble and pass, into 5-m sprint	1	4	9 min
30-m stride with walk return	1	1	
15-m dribble and pass, into 5-m sprint	1	4	
30-m stride with walk return	1	1	
15-m dribble and pass, into 5-m sprint	1	4	
8-m dribble out, turn and dribble return	1	4	
15-m run out, jump and header incoming ball	1	4	
60-s passive rest			
Specific Movement Patterns without Ball			
Activity	***Sets***	***Reps***	***Duration***
4-m butt kicks, into 4-m high knees, into 4-m sprint	1	3	6 min
4-m low side skip (left), into 4-m low side skip (right), into 4-m sprint	1	3	
8-m sprint, into 4-m backwards running, into 4-m sprint	1	3	
8-m sprint, into 4-m backwards side skip, (left) into 4-m sprint	1	3	
8-m sprint, into 4-m backwards side skip (right), into 4-m sprint	1	3	
4-min passive rest prior to testing			

7.10 Schematic diagram of the intermittent exercise task (Supplementary 2)



7.11 One 26.4 min period of the non-motorised treadmill intermittent exercise protocol (Supplementary 3)