AUTHOR: SYMON, K.G.

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INVESTIGATION IN TO THE LIFE SPAN OF THE PHYSIOLOGICAL AND PERFORMANCE BENEFITS OF A SOCCER WARM-UP

Kevin Symon

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Investigation in to the life span of the physiological and performance benefits of a soccer warm-up.

Submitted in partial fulfilment of the requirements of Robert Gordon University for the Degree of Master of Research.

Submission Date: October 2016

Researcher: Kevin Gordon Symon

Principal Supervisor: Paul Swinton

Declaration

I hereby declare that this thesis has been composed by myself and has not been presented or accepted in any previous application for a degree, and is a record of work carried out by myself unless otherwise stated; all quotations have been distinguished by quotation marks and all sources of information acknowledged.

Kevin Symon Date: 25/10/2016

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List of Abbreviations

ANOVA – Analysis of variance

Avrg – Average

BPM – beats per minute

Countermovement vertical jump – CMVJ

EPPP – Elite player performance plan

FIFA - Fédération Internationale de Football

GXT – Graded exercise test

HR – Heart Rate

ICC – Intraclass correlation

LIST – Loughborough intermittent shuttle test

LSPT – Loughborough Soccer Passing Test

Max – Maximum

Min – Minimum

PAP – Post activation potentiation

PAR-Q – Physical Activity Readiness Questionnaire

RM – Repetition Max

RSI - Reactive strength index

SSG's – Small Sided Games

TE – Typical Error

VO_2 – Oxygen consumption

WUp – Warm-up

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Abstract

Researcher: Kevin Symon

Submitted in partial fulfilment of the requirements of Robert Gordon University for the Degree of Master of Research**.**

Title: Investigation in to the life span of the physiological and performance benefits of a soccer warm-up.

Aim: The purpose of this study was to determine the time course of the performance and physiological changes that occur in response to a pre-match soccer warm-up. **Methods:** Data was collected on 12 academy soccer players (16 ± 2 years) over 5 consecutive days. Measures of temperature, power, reactive strength, speed, agility and soccer skill were tested at 10 minute intervals over 50 minutes of inactivity following the pre-match soccer warm-up. After all experimental sessions were completed, each participant had performance measures equally spaced over 50 minutes of inactivity for each performance variable, allowing for a performance time curve to be plotted. From this performance time curve, specific times following a warm-up were identified where performance detriments occurred, allowing recommendations to be made regarding the timing of re-warm-ups. **Results:** Triangle Heart rate (-45.99% ± 4.51), triangle CMVJ (-4.33% ± 4.06) and triangle LSPT (+6.07% ± 11.52) were the most acutely affected by inactivity with the variables significantly declining from post warm-up levels after 10 minutes, or time to complete the test increasing in the case of LSPT. Contrastingly, reactive strength determined from a 30cm drop jump height was significantly reduced following 40 minutes of inactivity (-16.22% ± 9.91), and when performed off a 45cm box it took 50 minutes to significantly decline (15.55% ± 12.88). Significant reductions in performance compared to post warm-up measures occurred after 40 minutes of inactivity in both the 10m split (2.45% ± 1.73) and 20m sprint times (1.94% ± 1.36). Finally, performance of the arrowhead agility was not significantly affected throughout the extending periods of inactivity and tympanic temperature measures followed an unexpected trend following completion of the warm-up and durations of inactivity. **Conclusion:** Performance variables declined at different rates throughout the periods of inactivity. Significant decrements in performance were observed in CMVJ performance and BPM following 10 minutes of inactivity. For a substitute to be ready to join play with performance elevated at peak levels, a re-warm-up with an emphasis on improving power and increasing HR is required following this length of time. This will ensure that substitutes are at their optimal condition throughout the match and can be included in play whenever required by the team.

Key Words: soccer warm-up, substitutes, soccer performance, inactivity in soccer, warm-up benefits

1.0 Introduction

When preparing for athletic performance, taking part in a warm-up has become second nature to athletes and is common practice in the preparation for competing in most sports (Bishop 2003a). The term ‘warm-up’ stems from the temperature related physiological responses that occur due to the onset of activity, which are thought to lead to enhanced performance. However, non-temperature related responses also occur including increased blood-flow (Barcroft and Dornhorst 1949) and increased oxygen consumption (Andzel 1982) which results in enhanced muscle performance (Bishop 2003a) and a reduction in the risk of injury (Fradkin, Gabbe and Cameron 2006). In addition to this, a warm-up has also been suggested to help the athlete mentally prepare for the technical rigours of performance (Bishop 2003a). Multiple systematic reviews and meta-analyses have been published, summarising the findings of research on warm-up content and their use on enhancing performance (McGowan et al. 2015; Kilduff et al. 2013; Behm and Chaouachi 2012; Bishop 2003a; Bishop 2003b) and injury prevention (Herman et al. 2012; Simic, Sarabon and Markovic 2012; Fradkin, Zaryn and Smoliga 2010; Woods, Bishop and Jones 2007; Fradkin, Gabbe and Cameron 2006). These review papers clearly highlight the beneficial effect of warm-ups in enhancing performance. However, research investigating the positive effects of warming up on injury prevention is less conclusive.

For some sports and athletes, the start of competition may be substantially delayed following completion of the warm-up. In soccer, this is certainly the case for those who are substitutes, with these players generally experiencing a long period of inactivity post warm-up until they are included in the game. This period of inactivity occurs as substitutes typically take part in the pre-match warm-up, followed by next to no physical activity during the pre-match team talk and time on the bench observing the initial stages of the match.

Evidence of this reduction in performance between periods of activity such as the warm-up and start of the match/event, or during half-time has been reported in soccer (Edholm, Krustrup and Randers 2014; Zois et al. 2013; Lovell et al. 2013a; Lovell et al. 2013b; Lovell et al. 2007; Mohr et al. 2004), swimming (Mcgowan et al. 2015; West et al. 2013; West et al. 2013; Zochowski, Johnson and Sleivert 2007), rugby (Russel et al. 2015; West et al. 2015, Kilduff et al. 2013) and cycling performance (Faulkner et al. 2013, Faulkner et al. 2012). Different methods of preventing this inactivity related decline have been investigated including the use of heated garments, blizzard survival jackets, hot showers and active re-warms-ups (McGowan et al. 2015).

In soccer, there has been particular interest in the use of re-warm-ups to combat these performance decrements following periods of inactivity. A re-warm-up, much like a normal warm-up, is used to increase core and/or muscle temperature using passive or active methods (Zois et al. 2011). They are performed after a period of inactivity or recovery following exercise, which may have led to reduced temperature, such as the period between the end of the half-time interval and the start of the second half in soccer (Russell et al. 2015; Edholm, Krustrup and Randers 2014; Zois et al. 2013; Lovell et al. 2013a; Lovell et al. 2013b; Lovell et al. 2007; Mohr et al. 2004). From this research, the evidence suggests that during periods of passive recovery such as the half-time interval subsequent athletic performance can decrease, but by completing a re-warm-up, these performance decrements can be attenuated (Edholm, Krustrup and Randers 2014; Zois et al. 2013; Lovell et al. 2013; Lovell et al. 2007; Mohr et al. 2004).

Limited information is available, however, related to the time-course of inactivity related performance decrements rendering it difficult to make evidence-based recommendations on the most effective times at which re-warms should be undertaken. Information to inform the timings of re-warm-ups will have particular relevance to players who are substitutes and have taken part in some or all of the pre-match warm-up as they must be prepared to enter the field of play at any time when required by the team.

2.0 Literature Review

2.1 Introduction to Soccer

Soccer is considered the most popular sport in the world and is played by men, women and children of different ages and skill level (Stolen et al. 2005). It is a team sport with technical, biomechanical, tactical, mental and physiological factors effecting overall performance (Stolen et al. 2005). Two teams compete to score as many goals as possible in their opposing teams net positioned at opposite ends of the playing field. Each consists of a squad of players made up of 11 actively competing on field players and a select number of substitutes, which depends on the rules of the specific competition. The total duration of a match is 90 minutes which is separated into two 45 minute half's with a 15 minute half-time break in between.

2.2 The Physiological Demands of Soccer

Although some variation exists between league, level of competition (Rienzi et al. 2000) and playing position (Bradley et al. 2011; Di Salvo et al. 2007), soccer is a sport made up of intermittent activity, with players performing short bursts of high intensity exercise reliant on the anaerobic energy system interspersed with long spells of low intensity exercise taxing the aerobic energy system (Rampinini et al. 2007; Reilly, Bangsbo and Franks 2000). During English Premier League matches, Bradley and colleagues (2009) reported that players typically spend 6% of total playing time standing still, and 85% performing low intensity exercise. Finally, high intensity activity represents 9% of total playing time, which can be broken down into 6% running, 2% high speed running and 1% sprinting. Over the course of a 90 minute match, elite soccer players have been reported to cover 9-14km, with 1-3km of this being made up of high intensity actions (Bradley et al. 2009; Di Salvo et al. 2009; Mohr, Krustrup and Bangsbo 2003; Bangsbo et al. 1991). Through these high intensity actions, elite soccer players will typically work at an average intensity close to 70% of maximal oxygen uptake. This average intensity equates to blood lactate concentrations of approximately 4-6mmol/L, suggestive of high demands being placed on the anaerobic energy system (Mohr, Krustrup and Bangsbo 2005). It must be noted though that although players have been found to work at an average intensity of 70% of maximal oxygen uptake, it is likely that there will be periods of the game where they will experience even greater demands than 70% of maximal oxygen uptake during bursts of high intensity activity. Another important factor to consider in the physical demands of the game are acceleration and deceleration movements. These movements are significant as they are proposed to create a greater energy demand on players than that of constant velocity running (Rampinini et al. 2007; Di Prampero et al. 2005), whilst accelerations and are said to occur 3-8 times more often than sprints (Varley and Aughey 2013; Bradley et al. 2010).

Other physical demands of soccer include jumping, tackling, changes of direction, passing, dribbling and shooting. These can also be categorised as high intensity activities and are all very important in contributing to a team's success on the pitch (Stolen et al. 2005), with high intensity activities suggested to play a key role in factors such as winning possession and scoring goals (Reilly, Bangsbo and Franks 2000). In order for soccer players to efficiently perform these physical high intensity activities, it is important they possess substantial power capabilities (Stolen et al. 2005).

Having considered the physiological demands of soccer, it is important that players have the ability to perform high-intensity activities close to their maximum capabilities throughout the whole duration of their playing time. This includes being prepared from the very beginning of the match and also during the latter stages when fatigue begins to reduce technical capabilities that play an important role in determining the outcome of the match (Rampinini et al. 2009). Although it is advantageous to have players who can sustain high levels of performance throughout the match, substitutions can also be made during the latter stages of the match to replace players whose performance decline is considered too large as a result of fatigue. This is an important aspect of the game to consider as substitutes will be able to perform at a higher work rate and better meet the physiological demands discussed (Carling et al. 2010). As well as maximising the performance of the starting players then, it is also important to consider the needs and demands that are placed on players who are substitutes.

2.3 Overview of the Warm-up

A warm-up is commonly defined as a bout of exercise performed prior to competition or training designed to increase subsequent performance (Fradkin, Zaryn and Smoliga 2010). A warm-up generally starts with a period of light aerobic exercise, followed by stretching and finally a drill or exercise specific to the sport the athlete is about to take part in (Kilduff et al. 2013). Warm-ups can be separated into two temperature related categories: passive or active (Bishop 2003a). Passive warm-up methods such as hot baths, showers and heated garments aim to increase muscle or core temperature by external means without the need for potentially energy depleting exercise. In contrast, active warm-ups aim to increase muscle or core temperature through activity such as low intensity aerobic exercise (Bishop 2003b). With regard to preparing for physical activity such as soccer, active warm-ups are more commonly used and preferred, as they allow players to perform movements and skill patterns similar to those they will be required to execute in the match, and result in greater physiological performance benefits (Bishop 2003b).

2.4 Responses to Warming up

One of the primary responses that occurs through warming up is an increase in body temperature, and more specifically muscle temperature. A rapid increase in resting muscle temperature (35^{o}C) is said to occur at the start of moderate intensity exercise, and following 10-20 minutes temperature begins to plateau (Saltin, Gagge and Stolwijk 1968). In addition, a significant decline in muscle temperature has also been found to occur after a duration of 15-20 minutes following the cessation of exercise, dependent on the duration and intensity of the physical activity (Saltin, Gagge and Stolwijk 1968). With an increase in muscle temperature, further physiological responses that are beneficial to performance are said to occur (McGowan et al. 2015). These include increased muscle metabolism (Gray et al. 2011), muscle fibre conduction velocity (Pearce, Rowe and Whyte 2012) as well as also playing a role in increased oxygen delivery to the working muscles (McCutcheon, Geor and Hinchliff 1999).In addition to temperature related changes by warming up, further non temperature related changes also occur including elevated VO_2 kinetics (Burnley and Jones 2007), increased muscle contractile performance (Sale 2002) and psychological preparedness (Shellock and Prentice 1985).

2.4.1 Temperature Related Physiological Responses

With regard to muscle metabolism, increased muscle temperature is thought to increase muscle glycogenolysis, glycolysis and high energy phosphate (ATP and Phosphocreatine) degradation during exercise (Bishop 2003a). Previous research has found that through passive heating of muscle temperature, anaerobic ATP turnover was increased after 2 minutes of high intensity exercise. Beyond this 2 minute duration, the demand on anaerobic turnover is reduced and is placed more on the aerobic energy system (Gray et al. 2011). As a result of increased metabolic reactions such as ATP turnover, enhanced performance in high intensity activity is believed to be the most significant response (Bailey et al. 2012; Gray et al. 2006). Having considered the importance of power on performing high intensity activities that are linked to winning possession and scoring goals (Reilly, Bangsbo and Franks 2000), this is an important benefit soccer players can utilise through warming up and the resultant increase in muscle temperature.

In addition to increasing power through muscle metabolism, McGowan et al. (2015) suggests that there is debate regarding the type of muscle fibres that are also positively affected by increases in muscle temperature. Previous research suggests that following a passive heating method, increased phosphocreatine content is hydrolysed by type I muscle fibres when performing low cadence cycle exercise (60 Revolutions per minute (rpm)), but not in type II muscle fibres (Gray Soderlund and Ferguson, 2008). A possible explanation for this is the low cadence exercise used. During this intensity of exercise, type II fibres operate at the lower part of the power-velocity curve, meaning an increase in phosphocreatine utilisation would result in minimal additional power output. In support of this, increased muscle temperature prior to high cadence cycle exercise (160-180rpm) alongside greater phosphocreatine and ATP utilisation resulted in maximal power output exhibited in type II fibres, but not type I (Gray et al. 2011). These results suggest that increased temperature does have a beneficial role in increasing power output in type I and type II fibres, but contraction frequency of the fibres, dependent on the cycle cadence in this case, also plays a role in this increased performance. Once again, this increased power output would be beneficial to soccer performance when the demands to complete high intensity activities are placed on the players.

Muscle fibre conduction velocity is also said to be positively affected by increased muscle temperature, enhancing the force-velocity relationship as well as the power-velocity relationship, once again resulting in increased power outputs during exercise (Ferguson, Ball and Sargeant 2002; De Ruiter and Haan 2000; De Ruiter et al. 1999). Previous research on eight male subjects performing 6 second maximal sprints on a cycle ergometer found that a 3°C increase in muscle temperature via a passive heating method resulted in greater muscle fibre conduction velocity and as a result significantly greater power output (Gray et al. 2006). In addition to these findings, increased muscle fibre conduction velocity has also been found through use of an active warm-up, and more specifically, a running based warm-up performed at an intensity of 65% of heart rate max (Pearce, Grant and Whyte 2012). Although power wasn't measured, M wave peak twitch time was reduced by 5% in the hand and 8.5% in the leg (Pearce, Grant and Whyte 2012). These neuromuscular enhancements will be beneficial to soccer, with soccer related activities such as sprinting and jumping requiring a fast rate of force development in order to reach peak power output in as minimal time as possible (Bobbert et al. 1996).

The final major physiological response said to occur in response to a warm-up is increased VO_2 kinetics, more specifically increased oxygen delivery to the working muscles and an increase in baseline VO_2. Although elements of increased VO_2 kinetics can result from increased temperature, there are also non-temperature related mechanisms that also have a role in its onset, and will be discussed in the following section. In a commonly referred to study by Barcroft and King (1909), it was found that at an oxygen tension of 30mm HG, haemoglobin gave up twice the amount of oxygen at 41°C as done at 36°C. In addition to this, the oxygen dissociates from the haemoglobin twice as quickly. This will provide an important benefit, particularly when other factors such as vasodilation of blood vessels also occur through increased temperature, resulting in increased blood flow and oxygen delivery to the working muscles (Poole and Jones 2012; Burnley and Jones 2007). Although this is a clear advantage of warming up, careful consideration must be placed on the period of recovery following the warm-up and the beginning of the sport/activity. Previous research suggests that following a moderate to intense warm-up, VO_2 returns to near resting values within 5 minutes (Ozyener et al. 2001). It is possible that this is an explanation for the absence of anaerobic capacity sparing on maximal effort kayak performance following a 5 minute interval after warming up (Bishop, Bonetti and Dawson 2001). For soccer players to benefit from this increased baseline VO_2, time between the warm-up and start of the matched should be reduced as much as possible.

2.4.2 Non Temperature Related Physiological Responses

Increased baseline VO_2 is an example of a non-temperature related physiological response that occurs in response to warm-up. Following completion of a moderate/heavy intensity of warm-up for a duration of between 5-10 minutes, VO_2 reaches a steady state at which no further performance benefits will be achieved through the process. An increased baseline VO_2 and the resulting aerobic metabolism from warming up means anaerobic stores can be saved for use in subsequent performance (Jones et al. 2008). However, it must be noted that this elevated baseline VO_2 has been found to last approximately 10 minutes and will then return to baseline levels (Burnley et al. 2001) Both these oxygen related physiological responses will be beneficial to soccer performance during periods of high intensity activity that are primarily dependant on anaerobic capacity (Reilly, Bangsbo and Franks 2000).

Another non-temperature related benefit achieved through active warm-up is the onset of post activation potentiation (PAP). Evidence suggests that muscle performance can be acutely enhanced by its contractile history and more specifically, through use of a preloading stimulus resulting in the occurrence of PAP. This response is proposed to increase muscular performance using heavy resistance exercise at an intensity of approximately 75-95% of 1RM (Tillin and Bishop 2009) with a recovery period of around 8-12 minutes following this exercise (Kilduff et al. 2008). Although this is the most commonly used method, exercises such as maximal isometric contractions (Gullich and Schmidtbleicher 1996) and the use of ballistic movements have also been used to induce PAP (West et al. 2013). The mechanisms proposed to be accountable for the onset of PAP includes phosphorylation of myosin regulatory light chains, increased recruitment of higher order motor units, and a possible change in pennation angle (Tillin and Bishop 2009). Previous studies have highlighted the beneficial effects of PAP inducing exercises such as back squats (McBride, Nimphius and Erickson. 2005) and Olympic lifting (Chiu and Salem 2012) on tasks including jumping (Kilduff et al. 2008; Gourgoulis et al. 2003; Young, Jenner and Griffiths 1998) and sprinting (Smith et al. 2014; McBride et al. 2005). Although the enhanced subsequent performance would provide a benefit to the athlete, it may not always be practical to complete these types of exercises immediately prior to competition. Having said this, Zois et al. (2011b) states that some team sports are beginning to experiment using ballistic style movements such as explosive jumping and sprinting to try and replicate the onset of PAP. Some studies that have investigated using ballistic movements such as drop jumps (Byrne, Kenny and O'Rourke 2014; Hilfiker et al. 2007), and weighted jumps (Tahayori 2009; Thompsen et al. 2007; Faigenbaum et al. 2006), have reported favourable results with power output increases of between 2-5%.

Another important consideration when trying to enhance performance through a PAP effect is the transition duration, or the time following exercise taken for the PAP effect to occur. Enhanced power performance has been said to occur following 5 minute durations (Smith and Fry 2007), 8-12 minutes (Kilduff et al. 2008) and 18.5 minutes (Chiu et al. 2003). Given the large range of transition durations proposed to be optimal in these studies, it is hard to make a single recommendation as to the most effective transition duration when trying to fully utilise PAP in performance. This is likely to depend on factors such as the strength of the individual athletes, training experience and the activity used to induce PAP. Despite this, a meta-analysis by Wilson et al. (2013) suggests a duration of 7-10 minutes seems to be optimal, but this recommendation should interpreted with caution. Towlson, Midgley and Lovell (2013) stated there is a duration of 12.4 minutes between the end of the warm-up and start of kick off. Taking this in to account, if soccer players were to try and enhance performance through use of PAP, this 12.4 minute duration should be considered when trying optimise the PAP benefits. The potential benefits of a PAP effect on jump and sprint performance would certainly provide soccer players with an advantage given the already discussed demands of activities that require power in soccer. However, careful consideration will need to be placed on the practicality of trying to induce such PAP effects, including the type of exercise chosen and the transition duration following this exercise.

Finally, a benefit also said to occur through warming up is an increase in psychological arousal. Psychological arousal refers to the intensity dimensions of motivation at a particular moment (Weinberg and Gould 2014). As arousal increases, so too does performance up until an optimal point where further increases will cause a detrimental effect on performance (Landers and Arent 2001 in Williams 1993). Zois (2011) makes the point that although research is limited in this area, previous reports suggest that athletes who 'imagined' completing a warm-up actually improved physiological performance (Malareki 1954). In addition to this, warming up also gives the opportunity for athletes and team sport players to mentally prepare and take part in practising skills relevant to the activity they are about to take part in (Bishop 2003a). Practising these skills within the warm-up is also believed to give players an opportunity increase their concentration and also improve skill performance (Shellock and Prentice 1985).

Table 1

Study	References	Subjects	Activity	Physiological Response Investigated	Time Course of Response
Muscle temperature during submaximal exercise in man.	Saltin, Gagge and Stolwijk (1968)	4 healthy male subjects.	Bicycle ergometer performed at 50 rpm at 27, 46 and72% of maximal O_2 uptake.	Muscle Temperature	• Rapid increase at onset of exercise. • Plateau following 10-20 minutes of exercise. • Significant decline following 15-20 mins of inactivity.
Skeletal muscle ATP turnover and single fibre ATP and PCr content during intense exercise at different muscle temperatures in humans.	Gray et al. (2011)	6 male subjects (age, 25±3 years; height, 1.85±0.06m; mass, 87±16 kg; means±SD)	Bicycle Ergometer. 6 minutes of intense (Δ50%LT-VO_2peak) cycling, at 60 rpm.	Muscle Metabolism	• At the onset of exercise (0-2 minutes) a 28% increase in anaerobic ATP turnover occurred. • From 2-6 minutes of exercise, anaerobic ATP turnover reduced and an increased demand is placed on aerobic sources.
Skeletal muscle ATP turnover and muscle fiber conduction velocity are elevated at higher muscle temperatures during maximal power output development in humans	Gray et al. (2006)	8 male subjects (age, 25±6 years; height, 1.82±0.07m; mass,87kg ±11kg, means±SD)	Bicycle Ergometer. 6 second maximal sprint with load set at 7.5% body mass.	Muscle Metabolism and Muscle Fibre Conduction Velocity	• A 3°C increase in muscle temperature alongside a 6 second maximal sprint resulted in quicker MFCV (3.79m/s±0.47) compared to control condition (5.55 m/s±0.72).
Neural conduction and excitability following a simple warm up.	Pearce, Rowe and Whyte (2012)	12 males, 6 females (25.9±5.8 years)	General Running based warm-up for 5 minutes at an intensity of 65% of HR max.	Muscle Fibre Conduction Velocity	• M wave peak twitch time was reduced by 5% in the hand and 8.5% in the leg
The effect of temperature on the dissociation curve of blood.	Barcroft and King (1909)	-	-	VO_2 Kinetics	• At oxygen tensions of 30mm HG, haemoglobin was found to give up twice the amount of oxygen at 41°C as done at 36°C.
Effects of prior exercise and recovery duration on oxygen uptake kinetics during heavy exercise in humans	Burnley et al. (2001)	7 male subjects and 2 female subjects (age, 27±4 years; height, 1.75±0.06m; mass,71.1kg ±5.5kg, means±SD)	Bicycle Ergometer. 2 X 6 minutes bouts separated by 12 minutes recovery (6 minutes rest and 6 minutes baseline pedalling)	VO_2 Kinetics	• Elevated baseline VO_2 returns to baseline levels following transitions duration above 10 min.
Influence of recovery time on post-activation potentiation in professional rugby players	Kilduff et al. (2008)	20 professional rugby players (age, 25.4±4.8 years; height, 1.87±0.08m; mass,102.5kg ±11.5kg, means±SD)	3RM Squat and Countermovement Jump.	Post-activation potentiation	• 8-12 minute recovery duration following PAP inducing activity found to be optimal in enhancing power performance.

Table 1: *Summary of literature on physiological responses and time course of warm-ups.*

2.5 Stretching

A specific component of warming up often included in team sports is stretching, and this is no different to soccer. The common use of stretching, particularly static stretching, prior to performance results from the alleged belief that it will increase performance whilst also reducing the risk of injury (Little and Williams

2005). Despite this belief, evidence seems to suggest that stretching can actually be detrimental to performance and there is conflicting views on the efficacy of stretching on injury prevention (McHugh and Cosgrave 2010; Woods, Bishop and Jones 2007). In fact, Zois et al. (2011) states that the detrimental effects of stretching, and more specifically static stretching, have been found in multiple activities such as those performed in soccer, including countermovement jumping (Behm and Kibele 2007; Wallman et al. 2005), sprinting (Alikhajeh et al. 2012; Gelen 2010; Chaouachi et al. 2010; Needham et al. 2009) and also repeated sprint ability (Beckett et al. 2009; Sim et al. 2009). The results of these studies highlights the need for careful consideration to be made on the specific stretch protocol and type of stretching used in preparation for soccer.

Static stretching is said to be the most readily used method and involves moving a limb to the end of its range of motion, followed by holding this stretched position for 15-60 seconds (Young and Behm 2002). Another method used is dynamic stretching, which is beginning to be favoured over the static stretching method. It is described simply, as a controlled movement through the active range of motion of a joint (Fletcher 2010). The proposed reasons behind static stretching reducing performance is thought to be linked to the musculotendinous unit becoming more compliant, limiting the force development by decreasing musculotendinous unit stiffness (Fowles, Sale and MacDougal 2000). The reduced stiffness is then said to result in acute neural inhibition and a decrease in neural drive to the muscles, ultimately causing a reduction in power output (Fowles, Sale and MacDougal 2000). Although this is thought to occur through static stretching, dynamic stretching is believed to limit this negative effect on the mechanical and neural activation associated with static stretching.
In a study by Alikhajeh et al. (2012) on elite level soccer players, the effects of static stretching, dynamic stretching and a no stretch warm-up was investigated. Performance was measured using 10m acceleration, 20m sprint and a zig zag agility test. The results showed that following the warm-up consisting of dynamic stretching, 20m sprint performance (3.61s) and agility (6.14s) was significantly quicker in comparison to warm-ups including static stretching (3.74s, 6.22s) and a no stretch warm-up (3.76s, 6.20s). These results suggest that dynamic stretching is the more favourable method with regard to soccer related performance. An interesting finding however, was that the no stretch protocol

resulted in quicker agility times than the static stretch protocol and also resulted in quicker 10m acceleration times (1.85s) than both the static (1.86s) and dynamic (1.87s) stretch based warm-ups. These findings further highlight the possible performance decrements associated with static stretching on soccer related performance measures, but also highlight the need for further research investigating the proposed beneficial effects of a dynamic stretch warm-up over a no stretch protocol.

Taken collectively, it appears that performing a warm-up prior to exercise results in a number of physiological changes that may positively impact performance, including increased muscle metabolism (Gray et al. 2011), increased muscle fibre conduction velocity (Pearce, Rowe and Whyte 2012), increased oxygen delivery to the working muscles (McCutcheon, Geor and Hinchliff 1999), elevated VO_2 kinetics (Burnley and Jones 2007) and increased muscle contractile performance (Sale 2002). Given that some of the beneficial effects of warming up can decrease within a relatively short period of time, such as increased baseline VO_2 (Ozyener et al. 2001), and some effects such as the onset of PAP require a transition duration to occur (Kilduff et al. 2008), careful consideration should be placed on the duration between completing the pre-match warm-up and start of the match to take advantage of these beneficial responses. Although this is relevant to the selected starting 11 players, it is something that will be harder to control with players who are starting the match as substitutes. It is unlikely that substitutes will have any knowledge of when they are going to be included in the match as their main roles are to replace fatigued or injured players, as well as also being brought in to play as a tactical decision. Further information with regard to the lifespan of the specific performance attributes required in soccer that are elevated following a warm-up would allow practitioners to determine at what point substitutes will need to re-elevate these levels by completing a re-warm-up. Furthermore, this may also prevent unnecessary depletion of energy substrates performing re-warm-ups whilst on the bench that aren’t necessary given that performance may still be elevated.

2.6 Pre-Match Soccer Warm-ups

A typical soccer warm-up will last between 25-40 minutes and will include exercises of both low and high intensity (Towlson, Midgley and Lovell 2013; Zois et al. 2011; Mohr et al. 2004). At the professional level, soccer teams are provided an allotted time slot to complete a warm-up prior to performance (The Football Association Premier League 2015). Previous research has investigated the different activities that comprise a warm-up and their subsequent effects on various performance attributes required in team sports and soccer (Anderson, Landers and Wallman 2014; Alikhajeh et al. 2012a; Alikhajeh et al. 2012b; Yaicharoen et al. 2012; Alikhajeh, Ramenzanpour and Moghaddam 2011; Zois et al. 2011; Little and Williams 2005). Although these studies have researched the effects of different variations of warm-ups on performance measures that can be related to soccer performance, there are few studies that have specifically investigated soccer specific warm-ups (Zois, Bishop and Aughey 2014; Zois et al. 2013; Zois et al. 2011) or the effects warm-ups have on soccer performance (Edholm, Krustrup and Randers 2014).

Despite soccer warm-ups having a tendency to last between 25-40 minutes, research suggests that a warm-up over this extended period of time may not be effective at increasing performance (Zois et al. 2011) and may in fact diminish muscle glycogen levels thus fatiguing players prior to starting the match (Gregson et al. 2005). A study by Towlson, Midgley and Lovell (2013) surveyed coaches and sport scientists working for English soccer teams in the Premier League and Championship. The respondents of the survey stated the primary physiological response they were trying to achieve through warm-ups over this period of time was increased intra-muscular temperature and blood-flow. This finding is surprising, given that both of these responses have been found to begin after as little as 6-10 minutes of moderate intensity exercise (Bishop 2003b). However, of the clubs invited to take part in the survey, only 43% responded. Even though this response provides an indication of the practice of English professional soccer teams, it may not be truly representative of the entire population. Having considered this, it is important to further understand what a pre-match soccer warm-up consists of, and the proposed benefits of this activity.

Anecdotal evidences suggests that rather than using the traditional based team sport warm-up, some teams are beginning to place more emphasis on using small sided games (SSG’s) within their warm-up to allow them to practice sport-specific activity prior to beginning the match (Zois et al. 2011b). SSG's comprise a competitive, within team activity that allows players to practice the skills required in their sport such as passing, shooting and dribbling. Another alternative to the traditional team sport warm-up are warm-ups comprised of PAP inducing activities. Zois et al. (2011b) suggests that team sports are beginning to include activities such as jumping and sprinting within their pre-match activity in attempts to increase subsequent performance through a PAP effect.

In a study investigating the acute effects of SSG, PAP and a traditional warm-up protocol, Zois, Bishop and Aughey (2014) found that following at least one 15 minute intermittent bout of exercise, CMVJ height and reactive agility were improved by following completion of the PAP based warm-up compared to the other two interventions. Furthermore, mean 20m sprint performance was quicker after the first intermittent bout of exercise following the PAP warm-up in addition to improved average 30m repeated sprint ability times following the second bout of intermittent activity when compared to the other warm-up methods.
This suggests that a warm-up designed to induce PAP may be a better method of enhancing and maintaining performance in team sports that involve intermittent activity such as soccer, in comparison to a traditional and SSG warm-up. Although this seems promising, it is also important to consider the practicalities of performing such exercise prior to performance.

An important consideration when trying to utilise the performance benefits of a PAP inducing warm-up is the time frame used between the exercise and start of the intermittent activity. Zois, Bishop and Aughey (2014) used a 4 minute time frame between the end of the PAP based warm-up and start of intermittent activity. This duration was chosen as a 4 minute period of passive recovery is thought to be the preferred method when investigating the effects of PAP (Zois et al. 2013; Zois et al. 2011). However, this is not representative of the previously found 12.4 minutes duration said to occur between finishing the warm-up and kick off in previous research (Towlson, Midgley and Lovell 2013). Having used a 12.4 minute would have meant the results from the study could have been more useful in the applied setting.

2.7 Re-Warm-Ups

2.7.1 Definition of a Re-Warm-Up

As well as the continued research on warm-ups, another area of related research that is becoming increasingly prevalent is that of re-warm-ups. In sports, particularly team sports, periods of play are often separated by a rest interval. This interval, often referred to as half-time, is given as an opportunity for players to physically and mentally recover from the demands of the first half. During this time, players will typically rehydrate, refuel, receive treatment for minor injuries and receive feedback from coaching staff on the period of play they have just completed (Towlson, Midgley and Lovell 2013). In addition to the half-time interval, further periods of inactivity can also occur. These periods happen between the completion of the pre-competition warm-up and start of the event or match in both the selected starting players, but also in substitutes that have taken part in the pre-match warm-up and may be substituted in to play at an even later stage in the match.

2.7.2 Effects of Active Re-Warm-Ups on Performance

Although the need for this period of rest is important, there is a growing amount of research that suggests extended durations of recovery following activity may result in decreased performance (McGowan et al. 2015; West et al. 2015; Russell et al. 2015; Zois et al. 2013; Faulkner et al. 2013; Faulkner et al. 2012; Kilduff et al. 2013; West et al. 2013; Zochowski, Johnson and Sleivert 2007; Lovell et al. 2007; Mohr et al. 2004). Furthermore, decreased work rate (Lovell et al. 2013b; Lovell et al. 2013) and soccer specific performance (Edholm, Krustrup and Randers 2014) has also been found to occur in the opening stages of the second half following the period of recovery at half-time. It has been suggested however, that by administering a short duration active (Russell et al. 2015; Edholm, Krustrup and Randers 2014; Lovell et al. 2013b; Zois et al. 2013; Lovell et al. 2007; Mohr et al. 2004) or passive warm-up (Russell et al. 2015; West et al. 2015; McGowan et al. 2015; Faulkner et al. 2013; Kilduff et al. 2013) or re-warm-up following this recovery period, performance decrements can be attenuated.

In the study by Edholm, Krustrup and Randers (2014), the effects of a half-time re-warm-up on performance and movement patterns in soccer match play was investigated. In a crossover design over two matches, 22 male professional soccer players either performed what would be considered the typical half-time protocol of passive recovery, or performed a low intensity re-warm-up during the half-time period. Sprint and jump performance in the passive recovery control group reduced by 2.6% and 7.6% respectively during half-time. This is in comparison to the low intensity re-warm-up group where sprint performance was maintained and the reduction in jump performance lowered (3.1%). Furthermore, the re-warm-up group was found to have increased possession of the ball in the beginning of the second half alongside decreased high intensity defensive running, suggestive of a greater game advantage. Although a major strength of this study is the applied nature and inclusion of measurements of actual soccer performance alongside soccer related performance measures, there are some limitations. Having discussed the effect of muscle temperature on performance, it would have been an advantageous measure to include. However, Edholm, Krustrup and Randers (2014) state this would have required changes to the methodology used with regard to the length of the half-time period or the need for players to be temporarily removed from the game for testing, thus sacrificing the beneficial applied nature of the study. In addition, although increased ball possession presents a game advantage, reduced high intensity defensive running also proposed as a game advantage could be the result of a variety of different factors. Previous research has determined large variation exists between soccer matches with regard to high intensity running and sprinting (Gregson et al. 2010). Research investigating a greater number of matches with regard to movement patterns in soccer match play may strengthen the supporting evidence for use of a re-warm-up.

2.7.3 The Role of temperature on performance

Although temperature wasn't measured in the study by Edholm, Krustrup and Randers (2014), previous research investigating the effect of a passive half-time suggests a possible reason behind reduced performance and activity is linked to a reduction in both core (Kilduff et al. 2013; Lovell et al. 2007) and muscle temperature (Lovell et al. 2013; Mohr et al. 2004). Studies have found that muscle temperature can drop by as much as 2.0°C (Mohr et al. 2004) in soccer players and 1.2°C in referees during half-time (Krustrup and Bangsbo 2001). In addition, the findings from these studies have also demonstrated that this reduction in temperature can be lessened through use of an active re-warm-up and can attenuate the performance decrements that occur through a passive half-time. (Lovell et al. 2013b; Mohr et al. 2004). From these results, it would seem that muscle temperature loss is a contributing factor to the reduced performance following the half-time interval. The importance of temperature on muscle performance was previously investigated by Sargeant (1987), finding that each 1°C increase in muscle temperature was associated with a 4% increase in leg muscle power output. In contrast to this, each 1°C decrease in muscle temperature resulted in a 3% decrease in leg muscle power (Sargeant 1987). Taking the research by Sargeant (1987) in to consideration, it seems likely that reduced temperature during half-time is a contributing factor in the reduced performance following the half-time interval.

2.7.4 Passive Re-Warm-Ups

In addition to the use of active re-warm-ups following periods of inactivity, passive re-warm-ups using heat maintenance strategies have also been investigated in their use of reducing the decline of temperature typically experienced through periods of inactivity between bouts of exercise (McGowan et al. 2015; Russell et al. 2015; West et al. 2015; Cook et al. 2013; Faulkner et al. 2013; Kilduff et al. 2013). Passive heat maintenance strategies include the use of heated clothing, outdoor survival jackets or heated pads (Russell et al. 2015) that can be applied to specific muscle groups to maintain muscle temperature and thus the temperature related performance benefits it (Kilduff et al. 2013).

In the study by Kilduff et al. (2013), a blizzard survival garment lined with a reflective surface designed to retain body heat was worn by professional rugby league players following the warm-up and the start of the match. By wearing the heat maintenance garment, core temperature loss was offset by 50% whilst also improving lower body peak power output and repeated sprint ability in comparison to a no heat maintenance control condition. Although the results of this study support the role of temperature on performance and the beneficial effects of passive heat maintenance strategies in attenuating the loss of temperature between bouts of exercise, the study was not without limitations. Core temperature rather than muscle temperature was used as muscle temperature was deemed not feasible, presumably because of the nature of the methodology. Despite this being deemed a possible limitation, previous research has supported the use of both temperature measures as having an influence of performance (Mohr et al. 2004; Bishop 2003b). In addition, the researcher makes the point that based on previous studies, it is likely muscle temperature would have followed changes over time similar to that of core temperature (Mohr et al. 2004). Another possible limitation Kilduff et al. (2013) raises is the addition of the heat maintenance garment following the warm-up could have resulted in a placebo effect. Although this is a possibility, the results of the study alongside the growing amount of literature showing favourable results in using passive heat maintenance as an effective method for enhancing performance supports the role of temperature related physiological reasons behind the results over a placebo effect (McGowan et al. 2015; Russell et al. 2015; West et al. 2015; Cook et al. 2013; Faulkner et al. 2013; Kilduff et al. 2013).

2.7.5 Effects of Re-Warm-Ups on Injury Risk

In addition to reduced performance following the half-time interval (Russell et al. 2015; McGowan et al. 2015; Edholm, Krustrup and Randers 2014; Lovell et al. 2013b; Zois et al. 2013; Lovell et al. 2007; Mohr et al. 2004), studies have also highlighted a substantially greater risk of injury in the first 20 minutes of the match following this break in play (Hawkins and Fuller 1996). Although there are multiple reasons as to why players seem to be at greater risk during this period, previous research has related an increased risk of injury alongside a reduction of muscle temperature (Safran et al. 1989), similar to that experienced during a passive half-time interval. In support of these findings, Rahnama, Reilly and Lees (2002) analysed 10 premier league soccer matches assessing the exposure of players to injury risk in relation to playing actions, also finding the greatest number of injuries occur in the first period of each half. Although reduced temperature through passive recovery could be contributing to this heightened risk, Greig (2008) suggests other reasons as to why this may occur. During 90 minutes of treadmill running replicating the intermittent conditions of soccer, concentric strength of knee extensors and flexors was maintained, but eccentric peak torque measurements taken after the half-time break were reduced in comparison to the start of half-time. This decline in eccentric hamstring strength could be a result of the greater demands placed on the hamstring in controlling the running mechanics during the intermittent nature of the treadmill run (Greig et al. 2006). As a result, Greig (2008) suggests increased susceptibility to muscle strain injury could be caused by performing explosive actions such as accelerations and decelerations in the opening stages of the second half. Further research in this area would be valuable in determining the role of muscle temperature on injury occurrence. In addition, having a greater understanding of where re-warm-ups are required could help reduce the risk of injury as well as increase performance.

2.8 Extended Periods of Inactivity

Having considered the temperature related detrimental effects on performance caused by periods of inactivity during half-time intervals and the period between pre-match warm-up and start of the match, further knowledge must be gained on periods of inactivity that extend over longer durations. Although the currently available research can be applied to players competing in the starting 11 players in soccer, another important consideration is a team's substitutes. Substitutes will usually take part in the full or at least some elements of the pre-match warm-up, followed by a period of passive recovery during the pre-match team talk and initial stages of the match. Following this extended period of inactivity, substitutes will perform multiple short duration re-warm-ups in an attempt to maintain preparedness for involvement in the match, with the first re-warm-up usually starting around 15 minutes in to the first half. This means that substitute players, dependent on club protocol, could have a period of recovery following the pre-match warm-up much greater than the 15 minutes used in previous studies to represent the period during half-time and between the pre-match warm-up and kick off.

Research in soccer on extended periods of inactivity over 15 minutes is limited, however, one study that has investigated this was that by O'Donnell (2013). In the study, the effects of inactivity duration between warm-up and competition was assessed using physiological, perceptual and performance measures on a sample of 13 male soccer players. The participants were assessed over 2 sessions to determine maximal functional capacity through a graded exercise test (GXT) and baseline athletic performance for sprint, agility and jump ability. A further 3 experimental trials were used to assess performance following inactivity periods of 5, 10 and 20 after completion of a standardised warm-up protocol. In addition to these measures of performance, perceptual measures of feeling, arousal and perceived exertion, as well as physiological measures of HR and blood lactate were assessed during completion of the Loughborough Intermittent Shuttle Test (LIST) that also followed after the different durations of inactivity.

After 5 minutes and 10 minutes of inactivity, sprint performance was found to be 3.45% slower than the baseline levels and following 20 minutes was 3.62% slower. With regard to agility performance, O'Donnell (2013) found little difference between the baseline measure and all 3 durations of inactivity ($p=0.17$), however a trend towards a decline in agility performance was observed following 20 minutes of inactivity ($p>0.17$). Finally, CMVJ performance was typically found to enhance following 10 minutes of inactivity ($p=0.026$). With regard to the physiological measures, no differences were observed between blood lactate responses following the durations of inactivity ($p>0.05$). However, significant differences in HR following 20 minutes of inactivity when compared to 5 minutes of inactivity was found ($p=0.02$). Having highlighted some of these results, it must also be noted that within the study, some of the data for the performance variables following the periods of inactivity were missing meaning exact values could not be extracted.

Specifically focusing on the performance measures, reduced performance following inactivity would have been expected considering the results of similar studies showing a decline in performance of similar durations (Russell et al. 2015; Edholm, Krustrup and Randers 2014; Lovell et al. 2013b; Zois et al. 2013; Lovell et al. 2007; Mohr et al. 2004). However, the decreased sprint performance following as little as 5 minutes passive recovery may have been considered surprising considering its proximity to the warm-up. However, this decline in performance could be a result of fatigue following completion of the warm-up, rather than reduced muscle temperature that has occurred over the 5 minute duration. O'Donnell (2013) suggests 5 minutes may not have been a long enough duration for substrates to be replenished following the warm-up activity, and while it occurs rapidly, it can take as long as 6 minutes for substrates to return to 85% of pre-exercise levels (Dawson et al. 1997; Bogdanis et al. 1995).

An interesting area of the study investigated by O'Donnell (2013) is the use of perceptual measures to assess participants following periods of inactivity. As previously stated, the primary response practitioners are aiming for through warming up is increased intra-muscular temperature and blood-flow (Towlson, Midgely and Lovell 2013). Although the physiological aspects of warming up are unquestionably important, an area that should not be overlooked is the psychological preparation of a player prior to performance. From the results, a warm-up finishing 5 minutes or 10 minutes before competition resulted in players indicating greater feelings of positivity in the feeling scale when compared to a 20 minute duration ($p<0.01$). Players also indicated greater levels of arousal following the 5 minute duration in comparison to the 20 minutes of inactivity ($p=0.015$). This suggests that players favoured completing a warm-up closer to the start of the match. This is a unique finding and is something that should also be considered with regard to the structuring of warming up prior to performance.

Although studies investigating the effects of inactivity following warm-ups in soccer are limited, some studies have been conducted on extended post warm-up recovery times in swimming and subsequent performance (Mcgowan et al. 2015; West et al. 2013; Zochowski, Johnson and Sleivert 2007). In a randomised, counterbalanced study on 8 international level swimmers, West et al. (2013) compared the effects of a 20 minute period of inactivity following a warm-up against a 45 minute duration. This was done to determine the effects on performance caused by the requirement of entering a marshalling call room prior to the start of competition. This requirement in swimming often results in swimmers having to complete their warm-up 45 minutes prior to the start of the race. The study found that 200m freestyle performance following the 20 minute post warm-up recovery period improved by 1.5% as a result of increased core temperature maintenance when compared to a 45 minute recovery period. This increased performance is substantial with regard to swimming performance, with improvements of just 0.4% being found to substantially increase a swimmers chances of finishing in a medal position (Pyne, Trewin and Hopkins 2004). Similar improvements in swimming performance were also found in a comparable study by Zochowski, Johnson and Sleivert (2007), also investigating the effects of different durations of inactivity following a warm-up. On this occasion, the study investigated 10 national level swimmers also performing 200m freestyle performance. Zochowski, Johnson and Sleivert (2007) found a marginally lower improvement of 1.4% when compared to West et al. (2013) but this was following a shorter post warm-up duration of 10 minutes whilst also being compared to a 45 minute duration. A key finding in the study by West et al. (2013) is that core temperature returned to baseline levels following the 45 minute post warm-up recovery period, whereas core temperature remained significantly elevated throughout the 20 minute duration of recovery in comparison to baseline measures. These findings suggest that periods of inactivity in excess of 20 minutes are required for core temperatures to return to baseline. Taking these results in to consideration, the elevated core temperature over the duration of the 20 minute recovery period is the likely reason behind the 1.5% improved 200m time trial performance compared to the 45 minute recovery duration.

Despite the findings of both these studies highlighting the beneficial effects on performance of reducing the duration between warm-up and the start of competition, the practical application of these results is questioned by West et al. (2013). In international competition, swimmers are required to enter the marshalling call room 20 minutes prior to the start of the race. This means both the shorter durations of 20 minutes and 10 minutes investigated between warming up and the start of the race would be unable to be put in to practice.

Finally, using a slightly different study design but similar sample of 16 junior competitive swimmers, McGowan et al. (2015) examined the effect of a passive, active and combination re-warm-up strategy on sprint swimming performance in comparison to a no intervention control trial. These interventions were compared following a 30 minute period of inactivity after completion of a standardised pool warm-up. Following the pool warm-up, core temperature had increased by 0.7^{o}C, and reduced in all conditions during the 30 minute recovery period, with a significant reduction in temperature found in the control condition of 0.6^{o}C. Improvements of 100m freestyle time trial performance was found in the active and combined re-warm-up strategies of 0.7% and 1.1% respectively in comparison to the no intervention group. These results further strengthen the association of core and muscle temperature maintenance on improved performance and also highlight the detrimental effects of extended periods of inactivity between bouts of exercise. Although these studies allow for a greater insight in to the detrimental effects of extended periods of inactivity on performance, further investigation is necessary. It would have been beneficial to have performance measured over more regular time intervals in comparison to the two different durations used in previous research (McGowan et al. 2015; West et al. 2013; Zochowski, Johnson and Sleivert 2007). Repeatedly testing performance at regular time intervals would allow more specific insight in to how performance changes throughout extended durations of inactivity and may inform us of specific times during inactivity where performance has significantly reduced, highlighting the need for a re-warm-up.

Table 2

Study	References	Subjects	Activity	Performance Measures	Time Course of Performance
The effect of the recovery duration between warm-up and competition on physiological and psychological markers in well-trained football players	O'Donnell (2013)	13 Physically Active males (age, 24.1±3.9 years, height, 1.80±0.06m, mass, 76.2±7.9kg)	20 minute Standard football warm-up comprised of passing activities, jogging, stride outs, dynamic stretching and leg swings.	• 15m Max Sprint • Agility – 3 cone shuttle drill • Vertical Jump – Vertec • Graded Exercise Test – Maximal functional capacity	• Following 5 and 10 minutes of inactivity sprint performance was 3.45% slower than baseline levels. • Following 20 minutes, sprint performance was 3.62% slower. • Significant reduction in heart rate BPM following 20 minutes of inactivity.
Influence of post-warm-up recovery time on swim performance in international swimmers	West et al. (2013)	8 International Level swimmers n=4 males, n=4 females, (age, 18.8±1.3 years, height, 1.74±0.07m, mass, 64.7±7.4kg)	Standardised Coach Led pool warm-up	2x200m freestyle time trial performance.	• Performance following a 20 minute post warmup recovery period resulted in a 1.5% improvement in comparison to a 45 minute recovery period.
Effects of varying post-warm-up recovery time on 200-m time-trial swim performance	Zochowski, Johnson and Sleivert (2007)	10 National Level swimmers n=5 males, (age, 17.0±1.2 years, height, 1.84±0.07m, mass, 73.2.2±6kg; n=5 females, age, 16±1 years, height, 1.69±0.03m, mass, 63.4.6±2.1kg)	Standardised Coach Led pool warm-up	2x200m freestyle time trial performance.	• Performance following a 10 minute post warmup recovery period resulted in a 1.4% improvement in comparison to a 45 minute recovery period.
Heated jackets and dryland-based activation exercises used as additional warm-ups during transition enhance sprint swimming performance.	McGowan et al. (2016)	16 National Junior swimmers (age, 16±1 years, n=11 males, height, 1.79±0.08m, mass, 72.2±9.8kg; n=5 females, height, 1.67±0.06m, mass, 61.6±1.5kg)	Four different warm-up strategies during 30 min transition duration following warm-up: • Seated control wearing a conventional tracksuit top and pants • Passive method using insulated top with integrated heating elements • Active methods using 5 min dryland-based exercise circuit • Combination method using Passive and active strategies	4x100m freestyle time trial performance.	• Performance following active method resulted in a 0.7% improvement in comparison to passive (control) method. • Performance following combination method resulted in a 1.1% improvement in comparison to a 45 minute recovery period.

Table 2: *Summary of literature on performance changes over extended durations of inactivity.*

2.9 Rationale for Present Study

Given the evidence regarding warm-ups prior to performance and re-warm-ups following periods of passive recovery, it is surprising there is currently no research available with regard to warm-ups in substitutes. Substitutes will usually take part in the full or at least some elements of the pre-match warm-up, followed by a period of passive recovery during the pre-match team talk and initial stages of the match. Following this extended period of inactivity, substitutes perform multiple short duration re-warm-ups separated by further periods of recovery, in an attempt to maintain preparedness for involvement in the match.

Understanding how long the physiological and performance benefits of a pre-match warm-up lasts will allow recommendations to be made on how long after the pre-match warm-up substitutes should perform a re-warm-up. In addition, it will also allow us to determine whether the repeated warm-ups substitutes perform are really needed, preventing the onset of fatigue caused by performing unnecessary re-warm-ups. In addition, the research will allow for identification of the specific performance variables that have dropped, which could potentially inform practice of the specific content to be included in the re-warm-up.

3.0 Research Aim and Objectives

3.1 Aims

To quantify the duration of physiological and performance benefits derived from a soccer warm-up.

3.2 Objectives

1. To record temperature, power, reactive strength and soccer skill at a baseline, post warm-up and at evenly spaced time intervals of inactivity.
2. To assess the impact of inactivity on temperature, as measured through tympanic temperatures tests at 10 minute intervals throughout a 50 minute period of inactivity
3. To assess the impact of inactivity on power, as measured through performance of the CMVJ tests at 10 minute intervals throughout a 50 minute period of inactivity
4. To assess the impact of inactivity on reactive strength, as measured through performance of drop jump tests at 10 minute intervals throughout a 50 minute period of inactivity
5. To assess the impact of inactivity on sprint speed, as measured through performance of 20m sprint tests at 10 minute intervals throughout a 50 minute period of inactivity
6. To assess the impact of inactivity on agility, as measured through performance of arrowhead agility tests at 10 minute intervals throughout a 50 minute period of inactivity
7. To assess the impact of inactivity on skill, as measured through performance of LSPT tests at 10 minute intervals throughout a 50 minute period of inactivity

4.0 Methods

4.1 Study Design

A cross-sectional repeated measures design was used in the study. The design consisted of each participant performing 5 separate experimental sessions. During the experimental sessions, each participant completed a test battery 3 times, including one prior to the soccer warm-up, one immediately after the warm-up and one at one other time point depending on the experimental session. The test battery consisted of a measure of tympanic temperature, countermovement vertical jump (CMVJ) to calculate power, drop jump to measure reactive strength (Reactive Strength Index (RSI)), 20m sprint speed with 5m and 10m splits measuring acceleration, arrowhead agility as a measure of agility and finally the Loughborough Soccer Passing Test to evaluate skill. The tests used within the battery were selected as they measured the main physical attributes associated with performance in soccer including power, strength (Stolen et al. 2005), speed and agility (Little and Williams 2005).

4.2 Population and Sample

The sample was comprised of 12 male professional male soccer players (age 16±2 year, mass 62±5kg) attached to Leicester City FC's Thai International Academy soccer team. The participants played a range of positions and were involved in regular training and competitive matches. As a result of the large number of variables being tested in the study, power calulcations to determine the sample size to be used would not have been practical. It is likely that the outcome wpould have depended on the variable tested potentially creating ambiguous results. As a result, the sample size was chosen as it was similar to that used in previous studies investigating warm-ups in soccer and the effects on subsequent performance allowing for comparison to be drawn (O'Donnell 2013; Zois et al. 2013; Zois 2011; Mohr et al. 2004).

All participants were provided with a participant information sheet and had the opportunity to ask questions prior to providing informed written consent to take part in the project. Ethical approval for this study was provided by the School of Health Sciences Research Review Group (SRRG reference number: SHS/14/31)

4.3 Protocol

The test protocol for sprint speed, CMVJ and agility was the same protocol used in the English Premier League benchmark fitness testing (The Football Association Premier League 2011). This benchmark testing was introduced as part of the Elite Player Performance Plan (EPPP) published by the English Premier League. The EPPP proposed that a national database of Academy level soccer players physical ability was created in order to compare them to "benchmark profiles" (The Premier League 2011). Experimental sessions took place at 14:30 on 5 consecutive days during a mid-season break from the competitive period. Scheduling the sessions at the same time of day, on 5 consecutive days during a non-competitive period minimised confounding factors such as the possible influence of training adaptations, fatigue or the effect of circadian rhythm on the results of this study. In addition to this, the tests completed in the test battery were arranged in an order that would limit the influence they have on each other. Short duration explosive tests where the primary energy stores are quickly replenished such as the CMVJ and Drop Jumps were performed at the start of the test battery, with the more fatiguing tests placed towards the end.

Prior to testing, participants attended a familiarisation session where they were asked to complete the full test battery. This allowed the participants to become accustomed to the full test battery order, ensuring the efficient running of each testing session as well as helping to reduce variation in time between completing each test. Further familiarisation was achieved through incorporating the performance based outcome measures within training in the weeks prior to testing. This meant each participant had practised each test within the test battery at least 5 times prior to up to the experimental sessions where data was collected.

4.3.1 Experimental Sessions

Prior to starting each experimental session, participants were provided with a heart rate monitor and belt (Polar Team 2) to be worn around the chest. Using this device provided the researchers with data related to the intensity of the warm-up and test battery. This data included the heart rate response to the different components of the warm-up and test battery, as well as the subsequent periods of inactivity. All testing was performed on an indoor artificial 4G (FIFA

Approved) pitch enabling greater control over environmental conditions between testing sessions that could influence results. Water was freely accessible to particpants for the full duration of testing and players were also instructed to wear the same clothing for each experimental sessions. The testing ran in the order of Tympanic temperature, Drop Jump reactive strength, CMVJ, 20m Sprint, Arrowhead Agility, and LSPT.

4.3.2 Participant Groups

Participants were randomly assigned to one of 5 separate groups, with 2 or 3 participants per group. In each group, the initial test batteries and warm-up were staggered so one group began as the previous group finished (Figure 1). As the investigation aimed to determine the time course of the initial pre-match warm-up effects, it was necessary to perform the testing over five experimental sessions. Had each participant been tested for multiple durations of inactivity during the same session, the warm-up and test batteries would have had to have been repeatedly performed. This would have resulted in the players becoming fatigued, effecting the validity of the study. To limit the effect of this, the test battery was performed 3 times over 5 experimental sessions to reduce the activation effect being caused by the tests and allow for evenly distributed testing points – allowing for a performance time curve to be plotted.

4.3.3 Reduced Test Battery

Each experimental session started with the participants in a group completing the pre warm-up reduced test battery comprised of a Tympanic temperature measurement, CMVJ, reactive strength, and LSPT in this order. Tests involving maximal exertion (i.e. sprint and agility) were removed from the pre warm-up battery in order to reduce the risk of injury. Having measures of sprint speed and agility at a baseline level would have meant comparison could have been drawn to these variables performed following the warm-up and inactivity. However, the decision was made to exclude these tests to minimise the risk of injury through lack of warm-up (Fradkin, Gabbe and Cameron 2006).

4.3.4 Warm-Up

Immediately following the reduced test battery, participants were then lead through a standardised pre-match soccer warm-up. This was based on the recommendations of Cervantes and Snyder (2011) who reviewed dynamic warm-ups concluding that beneficial dynamic warm-ups typically include a progressive general cardiovascular warm-up, periods of dynamic style exercise and sport-specific activities.

Taking this in to consideration, the warm up was split in to 3 different elements – a progressive cardiovascular element with dynamic movements/stretching, a skill based element and a final stretching element. The warm-up started at a low intensity with the participants jogging up the inside of a 15m channel and returning to the start performing a movement/dynamic exercise on the outside of the channel. Following the initial 6 runs, the warm-up progressively became more dynamic in nature by performing dynamic exercises and stretching up the inside of the 15m channel and also on the return. Dynamic exercises performed were included to help facilitate movements in the major body joints such as the shoulders, trunk, hips, knees and ankles (Bishop 2003a; Herman and Smith 2008). As the warm-up progressed, the intensity gradually increased. Players were instructed to complete exercises and movements at a percentage relevant to their max speed, (e.g. 'Stride out at 85% of your max'). This ensured players were progressively increasing the intensity they were working at. Following the initial channel element of the warm-up, participants then worked in pairs passing the ball to each other over a distance of 15m. This then progressed to passing to each other with a lateral 5m side step in between each pass. Finally, participants finished with a further dynamic stretch and two static stretches, each being performed for 30 seconds (15 seconds per leg). The total duration of the warm-up was 12.5 minutes.

The content of the warm-up was as follows:

<u>Progressive Cardiovascular Element</u>
Jog – Shake the arms and legs
Jog – Skip with arms across body
Jog – Skip with arms in circles
Jog – Skip with knee drive
Jog – Kareoke (right shoulder lead)
Jog – Kareoke (left shoulder lead)

Knees up heels up knees up heels up – jog

High knee (Right) to 1/2 way – jog

High Knee (Left) to 1/2 way – jog

High Knees (both) to 1/2 way - jog

Side Steps (right shoulder lead) - Jog

Side Steps (left shoulder lead) - Jog

Close groins - open groins

Forward jockey – Squat

Forward jockey – Stretch groins

75% stride – Hamstring sweep

80% stride – Knee up and down the shin

Acceleration to 1/2 way – backwards pedal one side

Acceleration to 1/2 way – backwards pedal other side

85-90% stride – Hamstring swing through

Slalom run – Lunge

85% stride – Quads

95% stride – END

Skill Element

Passing in pairs (stationary)

Passing in pairs with 5m lateral side step movement

Stretch Element

Hamstring swing through in pairs

Quad Stretch in pairs

Calf stretch in pairs

4.3.5 Post warm-up Test Batteries and Inactivity

After completing the warm-up, participants immediately completed the full test battery. On completion, participants were instructed to sit 'on the bench' and watch a soccer match on a projected screen to simulate the inactivity of a soccer substitute during a competitive match. They were instructed to keep activity to a minimum and remain in their seats for the duration of inactivity they were completing. The bench was situated at the side of the testing area with the seats pointed in the opposite direction of the tests, facing the screen. This was done to prevent participants observing other participants during testing and keep their attention on the projected projected match. Participants then completed one other full test battery according to the experimental session that they had been allocated (10-50 minutes after their post warm-up test). All five groups were tested over five experimental sessions with each group performing the initial test batteries and warm-ups at different times (Figure 1).

Figure 1

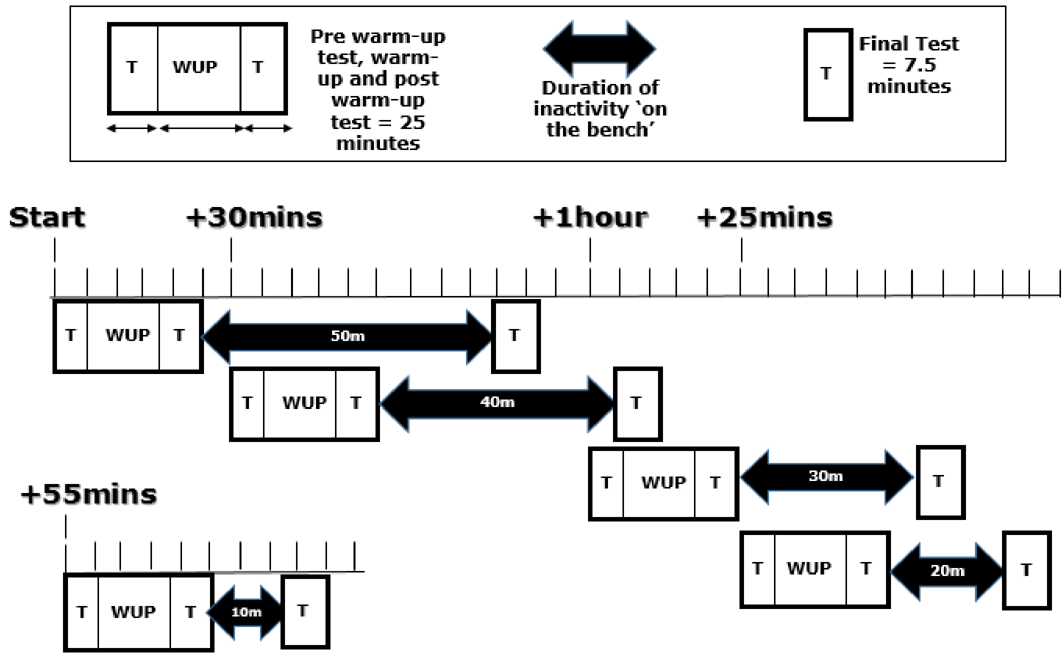

Figure 1: *Example Experimental Session highlighting timings of test batteries, warm-ups and inactivity durations.*

The following sections provide justification for the selection of the specific tests and protocols used.

4.3.6 Tympanic Temperature

Temperature has a significant influence on muscle function, with temperature increases during a warm-up resulting in increased ability to perform dynamic exercise movements as well as improve neuromuscular functions, balance and co-ordination (O'Brien et al. 1997; Shellock and Prentice, 1985). The method of measuring temperature used in the study was through use of a Tympanic thermometer. This measure was selected as it is typically regarded as the 'best' field measure of core temperature for its speed and acceptance of subjects (Lim, Byrne and Lee 2008). Temperature is measured by inserting the device in to the ear canal of the participant to record tympanic temperature. Two measures were taken from the right ear to calculate reliability of the measure.

4.3.7 Reactive Strength

Reactive strength was measured through use of the Reactive Strength Index (RSI). The measurement is considered to provide an accurate/valid assessment of an athlete's efficiency and speed changing from an eccentric contraction to a concentric contraction (Young 1995) that occurs in important team sports actions including jumping, change of direction and sprinting (Werstein and Lund 2012). A common method used to measure reactive strength is through use of a drop jump where an athlete steps off a box, minimises ground contact time upon landing, and immediately performs a maximal vertical jump. A value for the RSI is then calculated by dividing the jump height achieved (m) by ground contact time (s) of the initial landing. In this study, RSI was calculated with participants performing one jump from a box 0.3m high and one jump off a box 0.45m high. The RSI for each jump was calculated using the Microgate Optojump measuring device. The Optojump device is made up of 2 interacting receiver bars that can sense motion, allowing for device software to calculate RSI.

4.3.8 Countermovement Vertical Jump

The ability to jump in soccer is considered highly important for an effective performance (Winckel et al. 2014). Additionally, a jump test that can be used to determine the explosive power of an athlete is the jump height achieved during a vertical jump (Tanner and Gore 2000; Young 1995; Tidow 1990). Vertical jump height was measured using the Microgate Opto jump measuring device.

4.3.9 20m Sprint

During a competitive match, players will typically perform a maximal sprint once every 90 seconds, with the sprint lasting an average of 2-4 seconds (Stolen et al. 2005; Reilly, Bangsbo and Franks 2000). Furthermore, elite players sprint distances typically land between 10 and 20m and in some cases longer than 20m (Andrzejewski et al. 2013; Barros et al. 2007; Spencer et al. 2005; Bangsbo, Norregaard and Thorso 1991). Taking this in to consideration, a 20m sprint test was used to gain a measure of running velocity, similar to that performed in a competitive match. In addition, it is another test used in the premier league benchmark fitness testing battery.

4.3.10 Arrowhead Agility

Agility is the ability of an athlete to react to a stimulus, make a quick and efficient start, move in an accurate direction and be ready to make a change of direction or stop quickly to make a play in a fast, smooth, efficient and repeatable manner (Verstegen and Marcello 2001). In a study by Mirkov et al. (2008) investigating the reliability of soccer-specific field tests, it was proposed that agility tests could be the best indicator of all round soccer performance.
The agility test currently used by the Premier League Benchmark Fitness Testing is the Arrowhead Agility Test (Figure 2) and it was used within this test battery.
The test is made up of an initial 10m acceleration to cone c, followed by a cut to the right or left dependent on what run is being completed. Participants must then accelerate and manoeuvre around an outward cone D or F, and finish the run by running around top cone E before sprinting back through the start line.
Each participant performed the test twice, once leading from the right and once from the left. Participants were allowed to begin the test after they had been instructed by a coach that the timing system was ready.

Figure 2

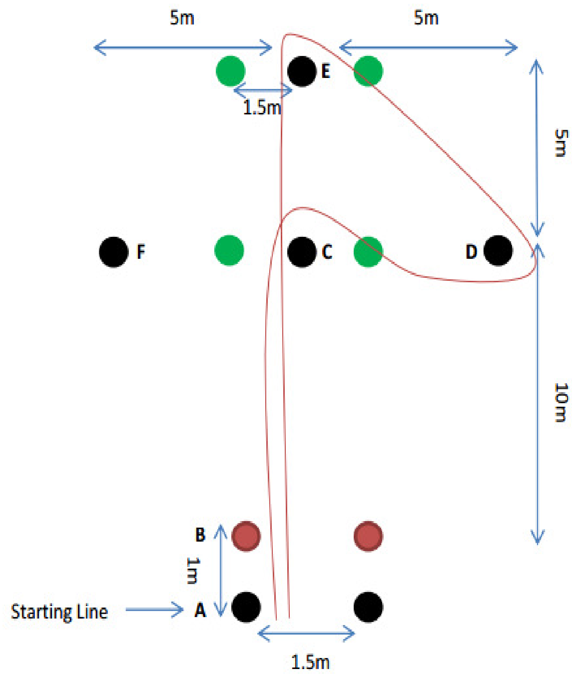

Figure 2: *Arrowhead agility layout (Premier League 2015)*

4.3.11 Loughborough soccer passing test

The Loughborough Soccer Passing Test (LSPT) is both a reliable and valid test that measures multiple aspects of skill performance in soccer. These include passing, dribbling, control and decision making (Le Moal et al. 2014; Ali 2011; Ali et al. 2007).

The LSPT requires four soccer passing rebound boards to be placed, as shown in figure 3, on each of the four lines marking the 12 X 9.5m grid – on the inside of the bench. On each of the boards, a differently coloured card is taped to the middle. To allow the participants to identify the passing zone, tape marks the inner (1 X 2.5m) and outer (2.5 X 4m) lines of the rectangles with the passing zone being the area in between. As well as this, coloured cones are used to help the participants distinguish the different zones within the test with one more cone placed in the middle of the marked inner rectangle.

On the call of the examiner, the ball is played from the middle of the inner rectangle in to the passing zone to start the test. A specific colour on each board is called out for the participant to pass to with another called just prior to the participant completing the current pass. The ball must be dribbled through the inner most rectangle and back in to the passing zone from where passes must be made. The test should be performed as quickly and efficiently as possible with mistakes recorded and time penalties given for each. Timing of the test is stopped once 16 passes are completed. Time penalties for mistakes include:

- 5 seconds for completely missing the board or passing to the wrong board
- 3 seconds for missing the target area
- 3 seconds for handling the ball
- 2 seconds for passing the ball out-with the designated zone
- 2 seconds for the ball touching any cone
- 1 second for every second over the allocated 43 seconds to complete the test

Figure 3

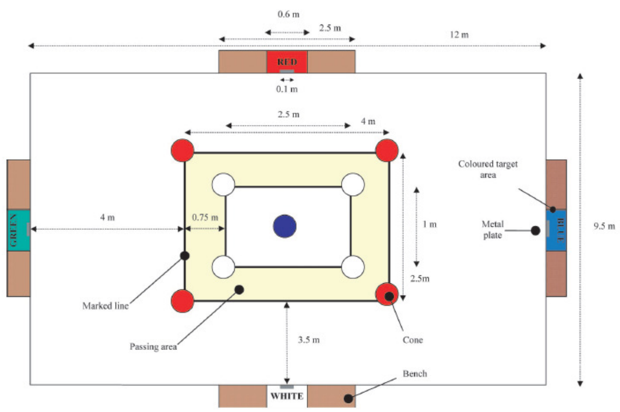

Figure 3: *LSPT layout (Ali et al., 2007)*

5.0 Data Analysis

With specific reference to heart rate analysis multiple variations were used to interpret the data collected. The first method measured the minimum BPM of the participants prior to the Pre-WUp test battery, the maximum of the Post-WUp test and the minimum BPM of the different durations of inactivity. The second also measured the minimum BPM of the participants prior to the Pre-WUp test battery and the maximum of the Post-WUp test battery but took the average BPM of the periods of inactivity. The final method measured the average BPM of the participants prior to the Pre-WUp, the average Post-WUp and the average for the different durations of inactivity.

For the pre warm-up and post warm-up measures, each participant had CMVJ and temperature measures repeated twice on each of the 5 experimental sessions. The average of all these measures were calculated for each participant and then a further average and standard deviation calculated to give one value for pre warm-up and one value for post warm-up performance representative of the whole participant group. Reliability of these measures was also calculated using Hopkins spreadsheet to determine typical error and intraclass correlation coefficient (Hopkins 2009). As the CMVJ and temperature measures were repeated twice following the periods of inactivity as well, the average for both of these measures for each participant was calculated. From all the individual averages calculated, the average and standard deviation was then calculated to give one value to represent all participants following the periods of inactivity. For the remaining tests, mean and standard deviation was calculated for each duration of inactivity. Prior to data analysis, data was organised in to mean scores for each participant at the 7 different test times - Pre-WUp, Post-WUp and the 5 durations of inactivity.

For each of the performance and physiological variables assessed, data were analysed using a one way Repeated Measures ANOVA. This analysis determined whether a significant difference ($\alpha=0.05$) exists for the tested performance variables across time points. Where a significant main effect of time was obtained, post hoc analyses using Bonferroni corrections were applied to identify the location of any pairwise difference. Data were presented using mean and standard deviations. Shaprio-wilks test was run for all variables with $p>0.05$ in all cases other than tympanic temperature following 40 minutes of inactivity.

6.0 Overview of Ethical Issues

There were a number of ethical issues to be considered within this study and control measures had to be put in place so to minimise the potential of adverse effects occurring. As with any maximal testing there was an element of risk with regard to the physiological stress being placed upon the participants. However, the physical exertion placed on the participants in the study was below that of what they would typically encounter in their daily training sessions. Testing took place on an indoor soccer pitch with a 4G artificial surface – an area and surface that participants were familiar with having previously performed fitness testing there. During testing, participants were supervised by qualified physiotherapists and sport scientists to ensure the smooth running of the testing and safety of the participants. Participation in this study was on a voluntary basis and it was stressed to players that their choice to participate or not would not incur any disadvantages to them. Participants were provided with the opportunity to read the study information and to discuss it with the researchers and/or others of their choosing prior to volunteering to take part in the study. They had at least 48 hours to consider participating and also had the opportunity to withdraw from the study at any time. Participants were screened through completion of a PAR-Q form and provided informed consent prior to initiation testing. Data protection was an issue, as with all studies. All data were coded to allow for anonymised data analysis meaning identification of individual participants was restricted. Data was stored on password-protected RGU computer and all raw data and consent forms were stored in a lockable filing cabinet. Data collected from this study was only used for research purposes and all hard copies of the data sheets were destroyed once all reporting had been completed.

7.0 Results

Table 3

Countermovement Vertical Jump	TE	ICC
Pre warm-up	1.14	0.94
Post warm-up	1.08	0.96
10 minutes inactivity	0.82	0.98
20 minutes inactivity	0.82	0.98
30 minutes inactivity	0.64	0.99
40 minutes inactivity	0.93	0.97
50 minutes inactivity	1.09	0.96

Table 3: *Typical error and intraclass correlation reliability data for countermovemnt vertical jump (Hopkins 2009).*

Table 4

Tympanic Temperature	TE	ICC
Pre warm-up	0.13	0.78
Post warm-up	0.13	0.76
10 minutes inactivity	0.13	0.87
20 minutes inactivity	0.06	0.91
30 minutes inactivity	0.08	0.91
40 minutes inactivity	0.21	0.96
50 minutes inactivity	0.09	0.95

Table 4: *Typical error and intraclass correlation reliability data for tympanic temperature.*

7.1 Heart Rate

Heart rate data are reported in Figure 4. Multiple methods of expressing and analysing HR data exists dependent on whether HR was selected to represent the overall phase or a particular segment of a phase such as the pre warm-up lowest HR to represent close to resting values. Significant main effects were found for heart rate BPM for minimum resting, maximum WUp and minimum inactivity [$f(6,66)=343.386$, $p<0.05$], minimum resting, maximum WUp and average inactivity [$f(6,66)=353.579$, $p<0.05$, and heart rate BPM for average resting, average WUp and average inactivity [$f(6,66)=169.288$, $p<0.05$]. Compared to the minimum BPM found in the Pre-WUp resting measures, a significant pairwise comparison was found in comparison to the maximum BPM reached in the Post WUp test battery (figure 4 left and figure 4 middle) (106.2±11.71). In addition, a significant pairwise comparison was also obtained with an increase between the average Pre-WUp resting BPM and average BPM reached in the post WUp test battery (figure 4 right) (71.0±12.32). Significant pairwise comparisons were also found with reductions in BPM when comparison was drawn between the maximum BPM of the WUp to the minimum BPM following 10 minutes of inactivity (81.0±10.1) and the average BPM after 10 minutes inactivity (63.1±7.7). Finally, a significant reduction was also found comparing the average BPM of the Post WUp to the average BPM of 10 minutes inactivity (44.73±8.36). Minimum and average BPM all remained significantly lower throughout the 10-50 minute durations of inactivity.

Figure 4

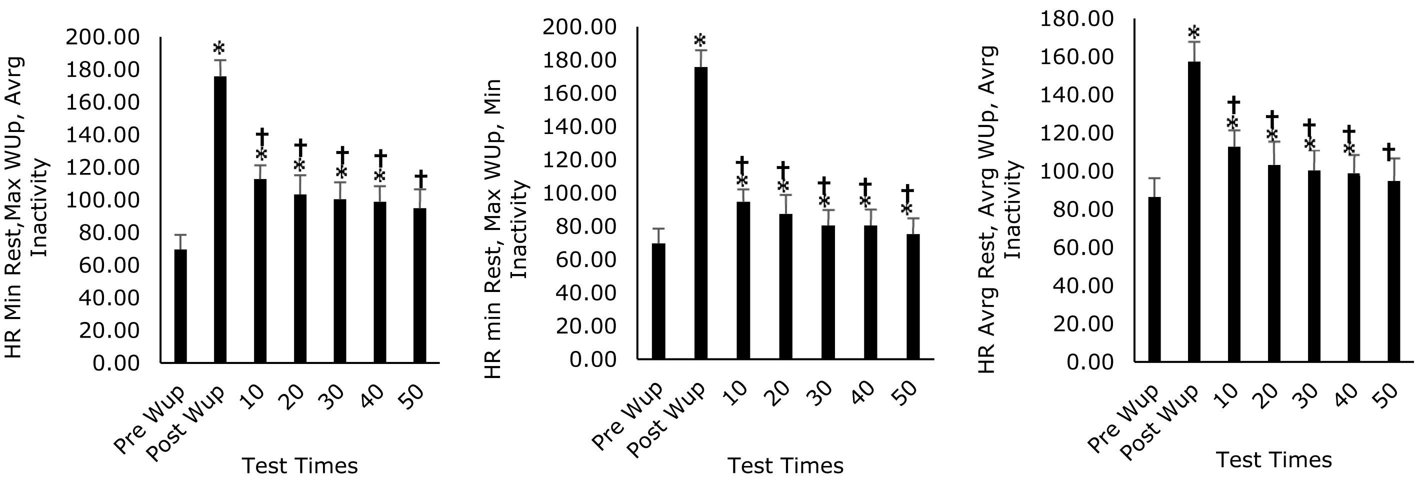

***Figure 4 (Left):** Comparison of heart rate BPM for minimum resting, maximum WUp and minimum inactivity response across all trials.* ***Figure 4 (Middle):** Comparison of heart rate BPM for minimum resting, maximum WUp and average inactivity response across all trials.* ***Figure 4 (Right):** Comparison of heart rate BPM for average resting, average WUp and average inactivity response across all trials.* = Significant difference ($p < 0.05$) from Pre-WUp measures; † = Significant difference ($p < 0.05$) from Post-WUp measures.*

7.2 Countermovement Vertical Jump

A significant main effect was found for CMVJ height [f(6,66)=28.563, p<0.05]. Significant pairwise comparisons were also obtained with an increase in Post-WUp measures in comparison to Pre-WUp (5.39±1.26). CMVJ performance remained significantly greater than the Pre-WUp baseline measures for a further 20 minutes inactivity. However, a significant decrease in performance from Post-WUp was observed at 10 minutes (1.65±1.54) and remained significantly lower for all remaining test times.

Figure 5

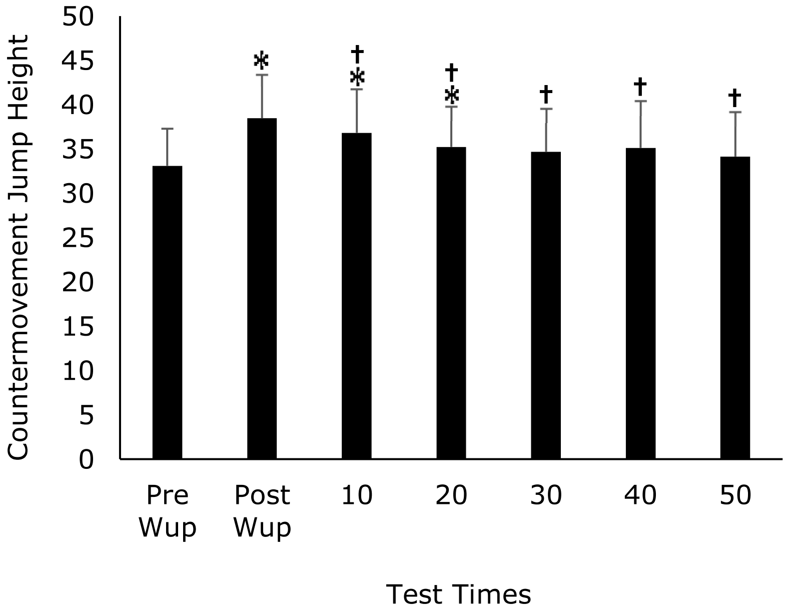

Figure 5: *Comparison of countermovement jump response across all trials. * = Significant difference (p < 0.05) from Pre WUp measures; † = Significant difference (p < 0.05) from Post WUp measures.*

Table 5

	CMVJ Relative to Baseline	
	Absolute Values (cm)	**Relative Values (%)**
Post Warm-up	+5.39 ± 3.53	+16.33 ± 1.26
10 minutes inactivity	+3.73 ± 4.26	+11.23 ± 1.54
20 minutes inactivity	+2.14 ± 5.75	+6.58 ± 1.91
30 minutes inactivity	+1.59 ± 5.23	+4.79 ± 1.76
40 minutes inactivity	+2.03 ± 6.30	+6.01 ± 2.16
50 minutes inactivity	+1.06 ± 4.97	+2.84 ± 1.71

Table 5: *Absolute (cm) and relative (%) CMVJ values compared to baseline measures.*

Table 6

	CMVJ Relative to Post Warm-up	
	Absolute Values (cm)	**Relative Values (%)**
10 minutes inactivity	-1.65 ± 1.54	-4.33 ± 4.06
20 minutes inactivity	-3.25 ± 1.93	-8.35 ± 4.76
30 minutes inactivity	-3.80 ± 1.55	-9.91 ± 3.98
40 minutes inactivity	-3.36 ± 1.84	-8.86 ± 4.88
50 minutes inactivity	-4.32 ± 2.01	-11.32 ± 5.62

Table 6: *Absolute (cm) and relative (%) CMVJ values compared to post warm-up measures.*

7.3 Reactive Strength

A significant main effect was found for both 30cm [f(3.435,37.785)=7.581, p<0.05] drop height and 45 cm drop height [f(6,66)=7.176, p<0.05]. In addition, significant pairwise comparisons were also found with significant increases Post-WUp in both 30cm (0.24±0.10) and 45cm drop height (0.32±0.08). From the 30cm drop jump height, RSI remained significantly greater than the Pre-WUp baseline measure for 30 minutes and significantly dropped below Post-WUp measures (0.21±0.13) after 40 minutes of inactivity. From the 45cm drop jump height, RSI remained significantly greater than the Pre-WUp baseline measure for 10 minutes and significantly dropped below Post-WUp measures (0.22±0.18) after 50 minutes of inactivity.

Figure 6

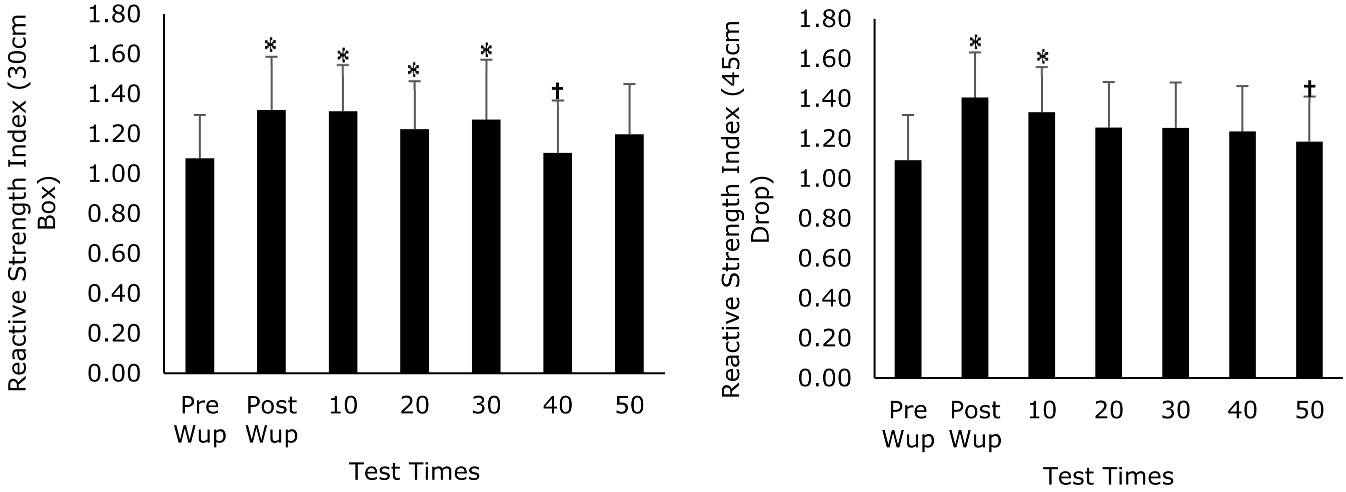

Figure 6: *Comparison of Reactive Strength Index from 30cm (Left) and 45cm (Right) Drop Jump responses across all trials. * = Significant difference (p < 0.05) from Pre WUp measure;* **†** *= Significant difference (p < 0.05) from Post WUp measure.*

Table 7

	RSI Relative to Baseline			
	Absolute Values (cm)		**Relative Values (%)**	
	30cm	**45cm**	**30cm**	**45cm**
Post Warm-up	+0.24 ± 0.1	+0.32 ± 0.08	+22.50 ±8.92	+29.68 ± 8.64
10 minutes inactivity	+0.24 ± 0.12	+0.24 ± 0.14	+22.94 ± 12.98	+22.09 ± 11.30
20 minutes inactivity	+0.15 ± 0.11	+0.16 ± 0.15	+14.29 ±11.28	+15.98 ± 14.64
30 minutes inactivity	+0.19 ± 0.17	+0.16 ± 0.18	+18.01 ± 15.21	+14.25 ± 15.42
40 minutes inactivity	+0.03 ± 0.11	+0.14 ± 0.18	+2.17 ± 10.26	+13.14 ± 16.91
50 minutes inactivity	+0.12 ± 0.16	+0.09 ± 0.13	+12.09 ± 15.46	+8.81 ± 12.67

Table 7: *Absolute (cm) and relative (%) RSI values compared to baseline measures.*

Table 8

	RSI Relative to Post warm-up			
	Absolute Values (cm)		**Relative Values (%)**	
	30cm	**45cm**	**30cm**	**45cm**
10 minutes inactivity	-0.01 ± 0.14	-0.07 ± 0.14	0.60 ± 10.13	-5.63 ± 9.14
20 minutes inactivity	-0.10 ± 0.18	-0.15 ± 0.16	-5.99 ± 13.45	-10.46 ± 10.67
30 minutes inactivity	-0.05 ± 0.13	-0.15 ± 0.16	-3.69 ± 9.93	-11.76 ± 12.08
40 minutes inactivity	-0.21 ± 0.13	-0.17 ± 0.16	-16.22 ± 9.91	-12.63 ± 12.21
50 minutes inactivity	-0.12 ± 0.18	-0.22 ± 0.18	-8.22 ± 12.70	-15.55 ± 12.88

Table 8: *Absolute (cm) and relative (%) RSI values compared to post warm-up measures.*

7.4 20m Sprint

A significant main effect was found for 5m split times [f(5,55)=3.041, p=0.017], 10m split times [f(5,55)=2.636, p=0.033] and 20m split times [f(5,55)=3.586, p=0.007]. In the 10m split times, no significant pairwise comparisons were obtained between the different periods of inactivity following the Post-WUp measures. However, following 40 minutes of inactivity a significant pairwise comparison was found in the 10m (<0.04±0.03) and 20m (<0.06±0.04)split times in comparison to Post-WUp measures.

Figure 7

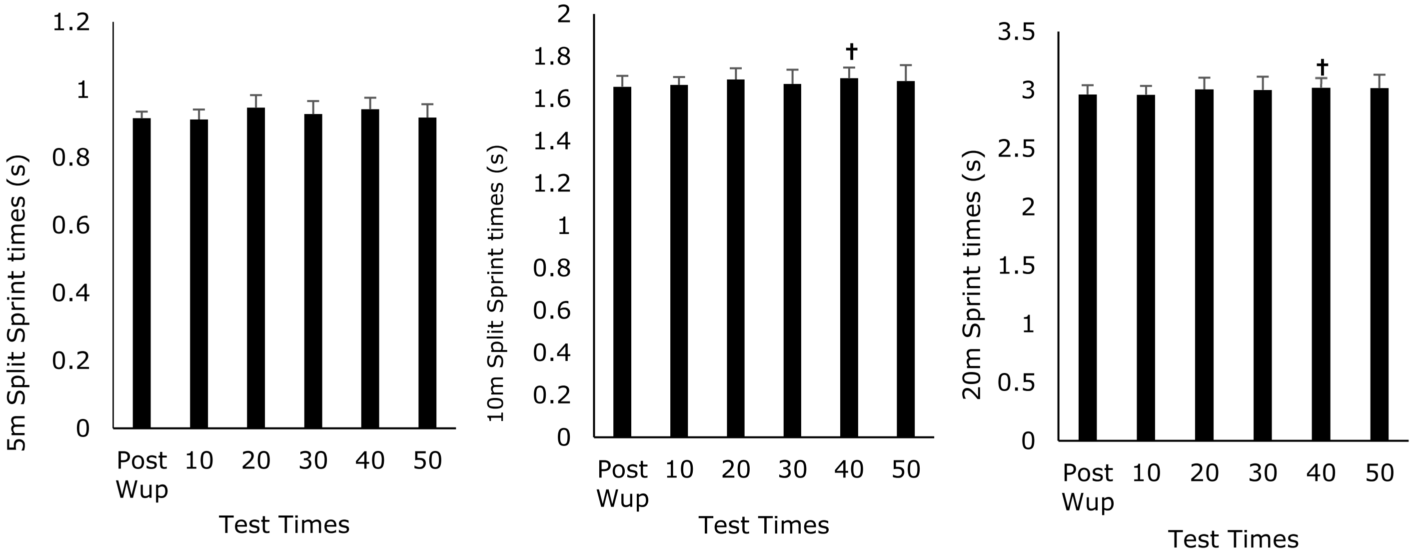

Figure 7: *Comparison of 5m, 10m and 20m Sprint times across all trials. † = Significant difference (p < 0.05) from Post WUp measures.*

Table 9

	Sprint Relative to Post warm-up					
	Absolute Values (s)			**Relative Values (%)**		
	5m	**10m**	**20m**	**5m**	**10m**	**20m**
10 minutes inactivity	-0.004 ± 0.03	+0.01 ± 0.04	-0.004 ± 0.07	-0.38 ± 3.66	0.52 ± 2.55	-0.09 ± 2.45
20 minutes inactivity	+0.03 ± 0.04	+0.03 ± 0.04	+0.05 ± 0.06	+3.42 ± 3.81	2.06 ± 2.32	+1.40 ± 1.86
30 minutes inactivity	+0.01 ± 0.03	+0.01 ± 0.04	+0.03 ± 0.05	+1.29 ± 2.98	0.76 ± 2.12	+1.27 ± 1.81
40 minutes inactivity	+0.03 ± 0.03	+0.04 ± 0.03	+0.06 ± 0.04	+2.87 ± 3.53	2.45 ± 1.73	+1.94 ± +1.36
50 minutes inactivity	+0.002 ± 0.02	+0.03 ± 0.04	+0.06 ± 0.07	+0.19 ± 2.72	1.55 ± 2.16	+1.81 ± 2.25

Table 9: *Absolute (s) and relative (%) 5m, 10m and 20m values sprint times compared to post warm-up measures.*

7.5 Arrowhead Agility

No main effect was found for both right [f(2.664,29.308)=1.072, p=0.370] and left [f(5,55)=0.952, p=0.452] turns in the arrowhead agility test. Im addition, no significant pairwise comparisons were found between the Post-WUp measures and subsequent measures of the test following periods of inactivity.

Figure 8

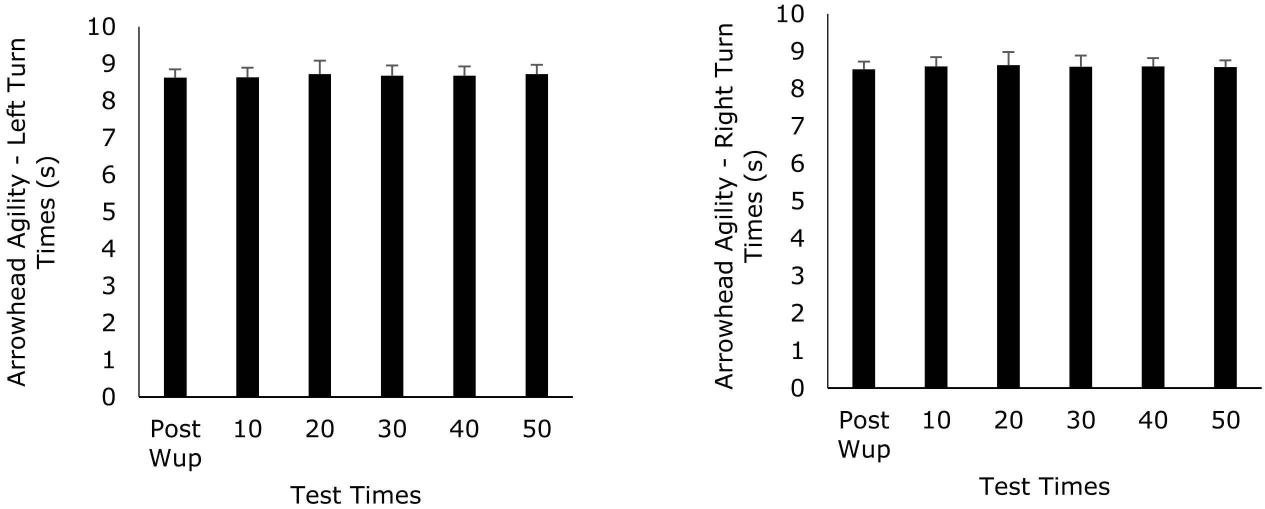

Figure 8: *Comparison of Arrowhead Agility Right and Left Turn times across all trials. † = Significant difference (p < 0.05) from Post WUp measures.*

Table 10

	Arrowhead agility Relative to Post warm-up			
	Absolute Values (s)		Relative Values (%)	
	Right	Left	Right	Left
10 minutes inactivity	+0.08 ± 0.18	+0.01 ± 0.18	+0.88 ± 0.96	+0.07 ± 2.09
20 minutes inactivity	+0.11 ± 0.22	+0.10 ± 0.22	+1.30 ± 2.29	+1.08 ± 2.54
30 minutes inactivity	+0.07 ± 0.13	+0.05 ± 0.13	+0.82 ± 1.88	+0.56 ± 1.56
40 minutes inactivity	+0.08 ± 0.13	+0.05 ± 0.13	+0.91 ± 1.59	+0.53 ± 1.45
50 minutes inactivity	+0.06 ± 0.16	+0.09 ± 0.16	+0.74 ± 1.80	+1.04 ± 1.80

Table 10: *Absolute (s) and relative (%) values for right and left arrowhead agility times compared to post warm-up measures.*

7.6 Loughborough Soccer Passing Test

No main effect was found for LSPT times [f(6,66)=1.340, p=0.252], however, a significant pairwise comparison was found with a decrease in Post-WUp measures (7.26±3.78) in comparison to Pre-WUp measures. LSPT times then returned to baseline levels throughout out all remaining test times with no significant changes found to occur throughout the extended periods of inactivity.

Figure 9

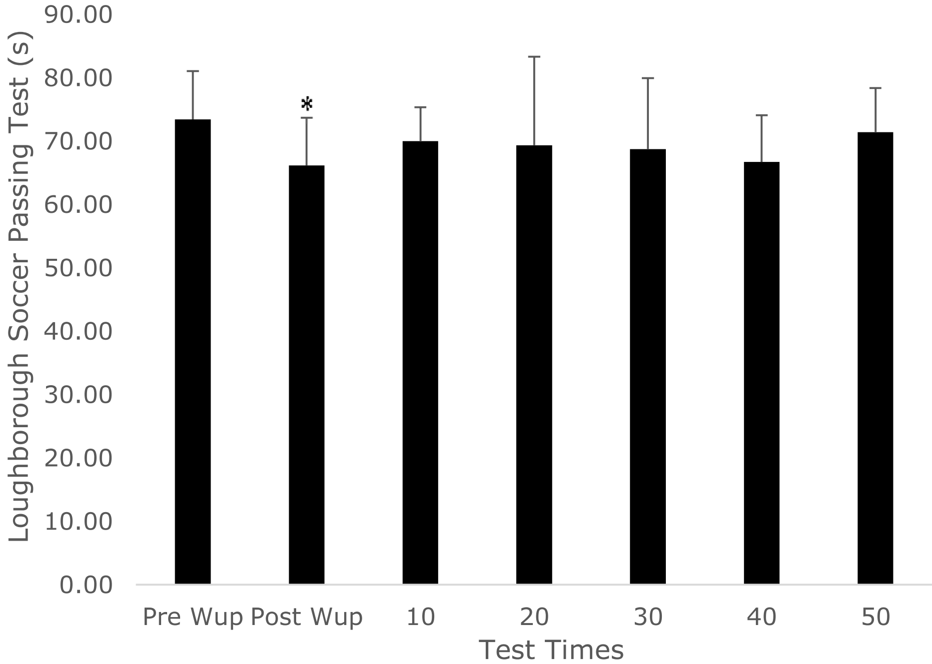

Figure 9: *Comparison of Loughborough soccer passing test responses across all trials. * = Significant difference (p < 0.05) from Pre WUp measures.*

<u>Table 11</u>

	LSPT Relative to Baseline	
	Absolute Values (s)	**Relative Values (%)**
Post Warm-up	-7.26 ± 3.78	-9.78 ±4.95
10 minutes inactivity	-3.45 ± 8.38	-4.38 ± 11.09
20 minutes inactivity	-4.12 ±6.93	-5.51 ± 9.33
30 minutes inactivity	-4.70 ± 11.32	-6.25 ± 15.90
40 minutes inactivity	-6.70 ± 13.05	9.20 ± 17.51
50 minutes inactivity	-2.03 ± 8.11	-2.29 ± 11.45

Table 11: *Absolute (s) and relative (%) LSPT times compared to baseline measures.*

<u>Table 12</u>

	LSPT Relative to Post warm-up	
	Absolute Values (s)	**Relative Values (%)**
10 minutes inactivity	+3.81 ± 7.92	+6.07 ± 11.52
20 minutes inactivity	+3.15 ± 6.32	+4.78 ± 9.13
30 minutes inactivity	+2.56 ± 9.77	+3.74 ± 14.44
40 minutes inactivity	+0.56 ± 11.40	+0.34 ± 17.26
50 minutes inactivity	+5.23 ± 6.84	+8.30 ± 11.15

Table 12: *Absolute (s) and relative (%) LSPT times compared to post warm-up measures.*

<u>7.7 Tympanic Temperature</u>

A significant main effect was found for tympanic temperature [$f(6,66)=36.924$, $p<0.05$] alongside significant pairwise comparisons being obtained between the different periods of inactivity ranging from 20 minutes of inactivity to 50 minutes of inactivity following Pre and Post-WUp measures.

Figure 10

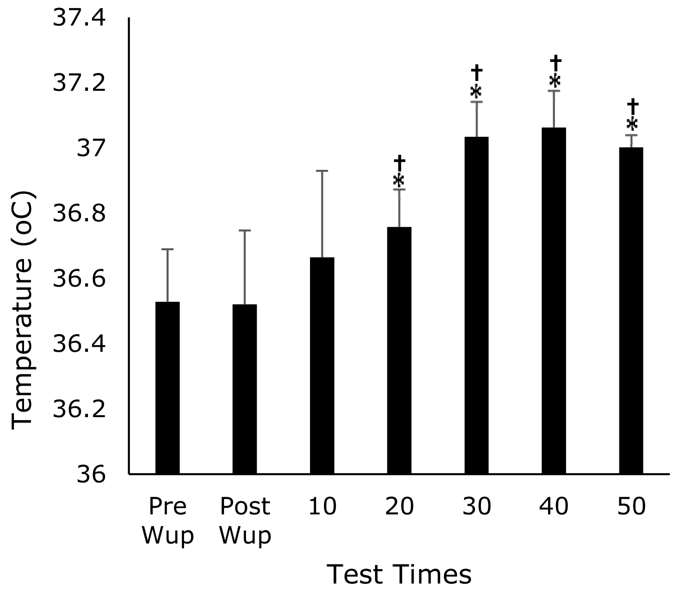

Figure 10: *Comparison of Temperature measurements across all trials. * = Significant difference (p < 0.05) from Pre WUp measures;* **†** *= Significant difference (p < 0.05) from Post WUp measures.*

Table 13

	Tympanic Temperature Relative to Baseline	
	Absolute Values (°C)	**Relative Values (%)**
Post Warm-up	-0.01 ± 0.21	-0.02 ± 0.58
10 minutes inactivity	+0.14 ± 0.30	+0.38 ± 0.82
20 minutes inactivity	+0.23 ± 0.19	+0.63 ± 0.52
30 minutes inactivity	+0.51 ± 0.19	+1.39 ± 0.53
40 minutes inactivity	+0.53 ± 0.19	+1.46 ± 0.51
50 minutes inactivity	+0.47 ± 0.17	+1.30 ± 0.48

Table 13: *Absolute (s) and relative (%) tympanic temperature values compared to baseline measures.*

Table 14

	Tympanic Temperature Relative to Post warm-up	
	Absolute Values (°C)	**Relative Values (%)**
10 minutes inactivity	+0.14 ± 0.27	+0.40 ± 0.75
20 minutes inactivity	+0.24 ± 0.20	+0.65 ± 0.55
30 minutes inactivity	+0.51 ± 0.22	+1.41 ± 0.62
40 minutes inactivity	+0.54 ± 0.19	+1.48 ± 0.54
50 minutes inactivity	+0.48 ± 0.25	+1.32 ± 0.69

Table 14: *Absolute (s) and relative (%) tympanic temperature values compared to post warm-up measures.*

8.0 Discussion

8.1 Overview of Findings

The results from this study show that the performance benefits achieved through completing a pre-match soccer warm-up decline following subsequent extended periods of inactivity. The performance variables measured in this study declined at different rates over the extended durations of inactivity which is an important finding when considering the practical application of these results.

Heart rate, CMVJ, reactive strength and skill performance all significantly improved following completion of the warm-up. However, some of the increases in variables were more robust to the effects of inactivity than others. Heart rate, CMVJ and LSPT performance were the most acutely affected by inactivity with the variables significantly declining from post warm-up levels after 10 minutes. Furthermore, despite seemingly being one of the most acutely affected by inactivity, CMVJ performance still remained significantly elevated in comparison to pre warm-up levels.

In contrast to the most acutely affected variables, reactive strength determined from a 30cm drop jump height was significantly reduced following 40 minutes of inactivity (-16.22% ± 9.91), and when performed off a 45cm box, it took 50 minutes to significantly decline (15.55% ± 12.88). Although it cannot be determined if sprint performance was significantly increased following completion of the warm-up, participants were found to be significantly slower than post warm-up measures after 40 minutes of inactivity in both the 10m split (2.45% ± 1.73) and 20m sprint times (1.94% ± 1.36). Finally, performance of the arrowhead agility was not significantly affected throughout the extending periods of inactivity. Temperature measured in the study followed an unexpected trend following completion of the warm-up and durations of inactivity and will be discussed.

The results suggest that during the early stages of the match, a substitute's power performance indicated through CMVJ, and HR through BPM is significantly lower than immediate post warm-up levels. This is similar to the findings in other studies examining the effects of performance following passive recovery during the half-time period, where CMVJ was also found to decline after a similar duration of 15 minutes (Edholm, Krustrup and Randers 2014; Zois et al. 2013; Lovell et al. 2013a; Lovell et al. 2013b; Lovell et al. 2007; Mohr et al. 2004).

8.2 Performance Differences between Jump and Sprint

A surprising result of the study is the large differences in the reduced performance following the periods of inactivity when comparing CMVJ to sprint performance, with both activities having previously been found to correlate with each other in both 10m ($r=0.72$, $p=0.001$) and 30m ($r=0.60$, $p=0.01$) sprint times (Wisloff et al. 2004). Considering the correlation, a logical assumption is that changes in one power activity following the warm-up should also mean similar changes in other power activities, but this wasn't found to be the case, with sprint performance taking 40 minutes of inactivity to significantly decrease in both the 10m split (2.45% ± 1.73%) and overall 20m sprint speed (1.94% ± 1.36%). This is in comparison to the significant decrease in CMVJ performance (4.33% ± 4.06%) that occurred after just 10 minutes of inactivity. In addition, although a significant decline in sprint performance did occur, the practical relevance of this decline is likely to be minimal in comparison to that seen in the CMVJ, with performance in the CMVJ continuing to significantly drop to 11.32% ± 5.62 after 50 minutes of inactivity. This finding does however agree with others in the area (Edholm, Krustrup and Randers 2014; Vetter 2007) that also reported differential effects of different warm-up protocols (Vetter 2007) and inactivity (Edholm, Krustrup and Randers 2014) on sprint and CMVJ performance. In the study by Vetter (2007), 6 warm-up protocols were performed with and without stretches. Although there were no significant differences found in sprint performance between all 6 of the warm-ups, significant differences in vertical jump performance was found to occur between protocols. In a walking and running based warm-up, significantly higher jump scores were observed in comparison to a walking and running based warm-up with the addition of static stretches. Furthermore, a walking and running based warm-up with the addition of dynamic stretches and small jumping was also found to significantly increase performance in comparison to the warm-up with static stretches.

Vetter (2007) states that explaining the reason for the differences in the effects on performance was out-with the scope of the research, but did suggest it could be related to the warm-up protocol. The author then elaborates further within the conclusion that warm-ups incorporating the use of static stretching seemingly has a more acute detrimental effect on jump performance in comparison to sprint performance that seems unaffected by it. Although there was a short duration of static stretches performed within the warm-up in this study, it was predominantly dynamic in nature so it is unlikely that this could be a reason for the differences in performance changes observed between sprint and jump performance. In addition to the possibility of the static stretches influencing the results, it is also worth noting the measurement devices used in the study may have caused some inaccuracies. The author suggests that the use of basic data collection methods such as a stopwatch for measuring sprint performance and a jump and reach test for jump height could have impacted the validity of the results. Finally, although the study by Vetter (2007) gives a similar example of performance differences occurring between jump and sprint performance, the results aren't directly comparable to those found in this investigation, given the comparison was drawn between warm-ups rather than performance measures before and after warm-up.

In a study using methods more closely linked to this investigation, Edholm, Krustrup and Randers (2014) also found dissimilarities between jump and sprint performance following a period of inactivity in 22 male soccer players. Investigating the effects of a passive half-time period in comparison to a re-warm-up strategy, the sprint performance in the passive protocol declined by 2.6% over a 15 minute half-time period in comparison to a 7.6% decline in CMVJ performance. Similar differences were also found in the re-warm-up protocol where although sprint performance was maintained, CMVJ performance declined by 3.1%. From these results, differences in the performance decrements occurring between jumping and sprinting performance were again observed. Considering the results from both the studies discussed, it seems as if CMVJ performance is more acutely effected by inactivity in comparison to sprint performance. A potential reason for this could be related to the energy stores utilised when completing the tests. Although they are both short duration maximal effort tests, the time taken to complete the CMVJ is much less than that of the 20m sprint. It could be the case that the warm-up or periods of inactivity affected the potentially different energy systems used, resulting in the differing effects between sprint and jump performance. Further research in this area may be required to determine the role energy systems may have on performance following periods of inactivity.

8.3 The Effects of Inactivity Following Pre-Match Warm-Ups

A possible reason for the differences in results found between jumping performance and sprint and agility performance could be that sprint and agility performances are relatively unaffected by extended periods of inactivity and do not experience such acute responses following it. It is unlikely that this is the case however, given the magnitude of performance decrements that have been found to occur in other studies after shorter periods of inactivity such as that during the half-time break (Russell et al. 2015; Edholm, Krustrup and Randers 2014; Zois et al. 2013; Kilduff et al. 2013; Lovell et al. 2013b; Lovell et al. 2007; Mohr et al. 2004). Sprint performance during the half-time period has been found to decline between 2.4-10% in previous studies (Zois et al. 2013; Lovell et al. 2013b; Mohr et al. 2004) which is similar to the 2.45% ± 1.73 detriment in 10m sprint performance following 40 minutes of inactivity in this study.

Furthermore, in a similarly designed study to this one, O'Donnell (2013) investigated the effects of recovery duration between warm-up and competition using a sample of 13 male soccer players. The participants were tested after completing a standardised warm-up protocol to gain a baseline measure and also after recovery periods of 5, 10 and 20 minutes. Despite the similarities in the study by O'Donnell (2013) in comparison to this investigation, the results differed quite substantially. O'Donnell (2013) found a trend towards both sprint and agility performance being the most acutely effected performance variables, suggesting that sprint performance in some cases can be affected by inactivity. Despite the contrasting results between the studies on sprint performance, the results found by O'Donnell (2013) with regard to agility performance were similar, with agility between the baseline measurement and all 3 durations of inactivity showing little difference ($p>.017$). Interestingly, when focussing on CMVJ, performance was typically enhanced following 10 minutes of passive recovery in the study by O'Donnell (2013), whereas CMVJ performance had decreased by 4.33% following 10 minutes of passive recovery in this study. In contrast to the results of this study then, O'Donnell (2013) found a trend towards sprint performance being the most adversely affected performance variable by periods of passive recovery, with the same variable being one of the least affected by the extended durations of inactivity in this study. Furthermore, CMVJ performance was actually found to significantly increase following 10 minutes of inactivity in the study by O'Donnell (2013), in comparison to the significant decreases in performance found in CMVJ following the same duration of inactivity in this study.

The conflicting findings between this study and others is interesting, particularly when considering different methods to combat the detrimental effects of inactivity on performance. It might be the case that following periods of inactivity, an active re-warm-up designed to target an increase in power performance might be more pertinent if CMVJ performance is the most acutely affected performance variable. However, if an athletes performance in agility was most acutely affected by inactivity, an active re-warm-up designed to enhance performance in this area may be more appropriate.

8.4 Inactivity During the Half-Time Period

Although there is limited research on the effects of inactivity on sprint and agility performance following pre-match warm-ups, previous research has highlighted significant detrimental effects of a passive half-time period in soccer on sprint, CMVJ and soccer specific endurance performance in as little as 15 minutes (Edholm, Krustrup and Randers 2014; Zois et al. 2013; Lovell et al. 2013a; Lovell et al. 2013b; Lovell et al. 2007; Mohr et al. 2004). After just 15 minutes of inactivity simulating the passive nature of a half-time period in soccer, sprint performance declined by 2.6% in the study by Edholm, Krustrup and Randers (2014), 2.4% by Mohr et al. (2004) and 6.2% by Lovell et al. (2013b). Although the results in this study (10m split - 2.45% ± 1.73%, overall 20m sprint speed - 1.94%±1.36%) are similar to the performance declines found by Edholm, Krustrup and Randers (2014) and Mohr et al. (2004), the performance decrements took an extra 25 minutes to occur. One possible reason for the differences in results in comparison to this study could be that the period of inactivity used in these studies was preceded by longer periods of actual soccer performance or simulated soccer performance. This activity is much more likely to have been performed at a higher intensity, placing greater physical demands on the participants. Comparing this to the warm-up activity that preceded inactivity in this study, perhaps more acute responses occur following higher intensity exercise during periods of inactivity in comparison to the sort of preparatory exercise included in a warm-up. A potential reason for these more acute responses could be reduced energy substrates also playing a contributing factor in the reduced performance output. In addition to this, other methodological differences within the studies including the protocol for assessing sprint performance exist. Whilst Mohr et al. (2004) measured repeated sprint ability through 3 X 30m sprints separated by 25 seconds, Lovell et al. (2013b) measured the average of 3 X 10m sprints using a 3m rolling start within a simulated soccer activity protocol. Finally, Edholm, Krustrup and Randers used 2 X 10m maximal sprints using a 0.5m rolling start, separated by 90 seconds of rest. These different methods of measuring sprint performance could also have played a part in the varied results inactivity has on sprint performance.

8.5 Sprint and Agility Performance Unaffected by Warming up

An alternative reason that could explain the differences between sprint and CMVJ performance could be that sprint performance was relatively unaffected by the warm-up used in this study, meaning there was less scope for performance decrements to occur following the subsequent periods of inactivity. This is something that cannot be determined with the results from this study however, given the absence of baseline pre warm-up measures for these tests. Having noted this, previous research does exist highlighting similar results to this study, with no performance benefits being gained through completing a warm-up (Zois et al. 2011b; Gregson et al. 2005; Gregson et al. 2005; Bishop, Bonetti and Dawson 2001; Stewart and Sleivert 1998). Zois et al. (2011b) found that in comparison to baseline measures, a traditional team sport warm-up lasting approximately 23 minutes had no effect on CMVJ, reactive agility and 20m sprint performance. This result could be considered unexpected, given that it was based on a warm-up similar to one used by a premier league soccer club, with the intensity adapted to suit the fitness levels of the participant group. However, similar findings have also been found in previous research using warm-ups lasting 15-30 minutes and at similar intensities of 60-80% VO_2 max (Gregson et al. 2005; Gregson et al. 2005; Bishop, Bonetti and Dawson 2001; Stewart and

Sleivert 1998). Bishop et al. (2003b) suggests that warm-ups of between 5-10 minutes at 40-70% of VO_2 max is appropriate for improving long term performance (fatiguing effort for ≥5 minutes), and longer duration warm-ups may reduce subsequent performance by fatigue through reduced glycogen stores and a prematurely elevated core temperature (Gregson 2005). Furthermore, a reduction of force output of the quadriceps of around 30% has been said to occur following high intensity exercise lasting 13.2 minutes, with a recovery period of 70 minutes required to return to original levels (Romer et al. 2006).

Although research suggests that warm-ups performed for too long at too high an intensity can be detrimental to performance, it is unlikely that this was the case in this study. The time to complete the warm-up was approximately 12.5 minutes long which is less than any of other studies finding little to no change in performance. In addition to this, had the warm-up been too physically demanding on the participants, it is likely that no performance improvements would have been found in CMVJ, with it being the first test following the warm-up meaning participants would have had minimal recovery prior to completing this test.

Although there is some research that suggests sprint (Zois et al. 2011b; Vetter 2007; Bishop, Bonetti and Dawson 2001; Stewart and Sleivert 1998), and agility (Zois et al. 2011b) performance can be relatively unaffected by warming up, these results are likely to be the cause of ineffective warm-up protocol related to the intensity or content of the activity. Furthermore, there is also contrasting research showing increased sprint (Anderson, Landers and Wallman 2014; Alikhajeh et al. 2012; Alikhajeh, Ramenzanpour and Moghaddam 2011, Gelen 2010; Needham, Morse and Degens 2009) and agility (Chaouachi et al. 2010;McMillian et al. 2006) performance following warm-up of 0.6-3% and 1.73-2.51% respectively. These studies show enhanced sprint and agility performance using a variety of different warm-up methodologies including intensity and stretch protocol. One particular element of warming up discussed by Anderson, Landers and Wallman (2014) was the intensity used, finding that in team sport athletes, an active warm-up lasting 10 minutes that was equal to around 90% of an individual's HR max was most effective at enhancing subsequent intermittent sprint performance. The intensity of the warm-up in this study was not measured, however considering the results of the study by Anderson, Landers and Wallman (2014), a potential reason for the differences in the magnitude of improvements in sprint performance compared CMVJ in this study could be that the warm-up used was not performed at a high enough intensity. This is a possibility, as the risk of the warm-up inducing fatigue on the participants from being performed over too long a duration was earlier dismissed given the 12.5 minute duration of the warm-up used. However, although the 10 minute duration of the warm-up used in the study by Anderson, Landers and Wallman (2014) was not largely different to that used in this study, the content of the warm-ups differed greatly with the one in this study being comprised of dynamic movements/exercises and skill elements, in comparison to the treadmill based warm-ups used by Anderson, Landers and Wallman (2014).

Given the results of these studies highlighting enhanced sprint performance following warming up, a logical assumption for the results of this study could be that sprint and potentially agility performance was enhanced following the 12.5 minute warm-up protocol, and this would have been reflected in the post warm-up measurement results (Alikhajeh et al. 2012). As previously mentioned however, this is something that cannot be identified with the results of this study without the baseline measures for these performance variables.

<u>8.6 Re-Activation Effect Caused by PAP</u>

One possible reason for the differences in improvements in performance in this study may be a result of a re-activation effect being caused within the test battery. Following the periods of inactivity, participants were tested in the order of temperature, CMVJ, drop jump RSI, sprint, agility and LSPT. It is possible that performing the two CMVJ's and two drop jumps prior to the 20m sprint induced a PAP effect on the participants, enhancing performance following the periods of inactivity and thus dulling any potential detrimental effects that the inactivity may have had on 20m sprint performance. The potential for this re-activation effect has also been suggested to occur in other studies. McGowan et al. (2015) investigated the effects of passive, active and a combined warm-up strategy over a 30 minute transition period following a pool based warm-up. The active warm-up strategy in the form of a dryland based circuit involving activities such as medicine ball throws, simulated butterfly kicks and box jumps, all performed at maximal effort was found to improve 100m freestyle time trial performance by 0.7% and by 1.1% when combined with the passive heat strategy. The proposed mechanism for these improvements were the attenuated decline in core and muscle temperature as well as the dry land activity potentially playing a role in inducing a 'priming' or 're-activation' effect on performance. Although there is a chance the 15 minute marshalling period following this active warm-up could have restricted the potential for a PAP effect occurring from these activities, improved power production has been found to occur up to 18.5 minutes following a PAP inducing exercise (Chiu et al. 2003).

8.7 Ballistic Movements Inducing PAP

Having considered the potential for the jumps within the test battery causing a re-activation effect, it is important to determine the extent of which ballistic style activities such as CMVJ and drop jump activity has on inducing a PAP effect, as well as the effect of time following this PAP inducing activity. Although PAP inducing activity tends to involve maximal effort exercise at an intensity of between 75-95% 1RM (Tillin and Bishop 2009), McGowan et al. (2015) explains that increasing attention is being paid towards the use of more practical ballistic-style pre-loading activities such as drop jumps and weighted jumps to induce this PAP effect (Byrne, Kenny and O'Rourke 2014, Lima et al. 2011; Hilfiker et al. 2007; Thompsen et al. 2007; Faigenbaum et al. 2006). In a study by Byrne, Kenny and O'Rourke (2014), the addition of 3 drop jumps to a dynamic warm-up protocol was investigated and compared to a cardiovascular, and dynamic stretch only warm-up protocol using 20m sprint performance. 20m sprint performance was improved following all warm-up protocols, however, the greatest improvement was observed in the dynamic warm-up protocol including drop jumps, with an increase in performance of 5.01% when compared to the cardiovascular warm-up and 2.93% when compared to the dynamic stretch protocol. These results seem favourable for the use of drop jumps in enhancing performance via PAP. An interesting point to consider in the study is the 1 minute transition duration used between the warm-up and sprint performance. This duration is very similar to that used in this study, with 1 minute being the amount of time players took to change their footwear from trainers to boots to complete the 20m sprint performance following completion of the drop jumps.

Having reviewed this research then, despite the literature regarding the onset of PAP suggesting that the transition duration between the warm-up and sprint performance in this study is likely to be too short for the participants to have benefited from a re-activation effect, the potential for this having an effect on the subsequent sprint and agility performance cannot be completely ruled out considering the results of Byrne, Kenny and O'Rourke (2014).

Having considered that a PAP response could have occurred through completing the drop jump tests prior to the sprint and agility performance, there is a chance that a re-activation effect may have occurred thus attenuating the reduction in performance. Although the re-activation effect would have been able to improve performance following periods of inactivity once the physiological benefits of the warm-up have had the opportunity to diminish, it is likely that the jumps in the test immediately following the warm-up wouldn't have been able to increase performance any further. As discussed, many of the physiological responses that occur through warming up act to increase performance via increased power output. Given that increased power performance would already have occurred through warming up, it is unlikely a PAP effect would have been able to enhance power performance any further with the already elevated levels. One way of testing the hypothesis of a re-activation effect occurring the jumps in the test battery would be to alter the order of the test battery, with sprint and agility measures preceding CMVJ and drop jump RSI measures. This would mean a true effect of the warm-up and periods of inactivity on sprint and agility performance could be assessed, without other performance measures influencing their performance output.

8.8 Skill Performance

The results in this study also found that although skill performance was increased following completion of the warm-up, and did show a trend towards a decline in performance following this, no significant changes were observed during the periods of inactivity. Previous research has highlighted that soccer skill performance, also measured using the LSPT, can be enhanced through completion of a SSG re-warm-up with improvements of 14.7% in comparison to a control condition (Zois et al. 2013). Zois et al. (2013) makes the point that this is an important benefit, specifically for that study, as a 15% decrease in passing performance is said to occur following the first half of a soccer match and similarly during short periods of high intensity activity as a result of fatigue (Rampinini et al. 2008). This finding seems to be in agreement with the results from this study, as when players are on the bench, fatigue will be unlikely to occur, meaning performance decrements in skill performance occur at a slower rate, perhaps alongside the decline in core and muscle temperature. Zois et al. (2013) also suggests that a possible reason behind no improvement in skill performance following the no re-warm-up condition in the study is related to a decline in muscle temperature, however this was not investigated in the study. Another consideration for the skill performance results in this study must be that LSPT was the final test to be performed by participants following the periods of inactivity. This means that the physical activity the participants completed in the tests leading up to the LSPT could, much like the sprint and agility performance, have had a re-activation effect, dulling the effects of the inactivity on skill performance. Although the slow decline in skill performance following periods of inactivity could have been affected by the points raised above, it is an important finding as substitute players are often limited to warming up without the ball whilst on the bench. This means substitutes will only have the opportunity to warm-up with the ball prior to the match as well as during the half-time period. It may be the case that although substitute players do have the opportunity to rehearse skill activities during the half-time period, this period may be better suited to completing a re-warm-up that focuses on enhancing the physical performance attributes that have significantly declined, rather than skill performance.

8.9 Heart Rate

As expected, BPM was significantly increased following the warm-up and significantly declined following 10 minutes of inactivity. In addition to this, BPM continued to decline throughout the extending durations of inactivity but only returned to baseline levels following 50 minutes when using the minimum resting, maximum WUp and minimum inactivity responses, and average resting, average WUp and average inactivity responses. This result is in accordance with other studies also investigating the effects of recovery durations following performance (O’Donnell 2013; Kannankeril, Kadish and Goldberger 2004). These results provide an understanding of the participant’s physiological state of readiness to perform within the study, with previous research highlighting a link between increased HR, increased VO_2 kinetics and the ability to maintain repeated sprint performance (Dupont et al. 2010). Although VO_2 was not measured in this study, having considered its association with HR, it is possible that if a player was to be substituted in to play following 10 minutes of inactivity, greater demands could be placed on the player's anaerobic capacity (Bishop, Bonetti and Dawson 2001). This is potentially a disadvantage, as it may be more beneficial for players to store this anaerobic capacity and save it for later stages in the match during periods of high intensity activity that place demands on the anaerobic energy system (Reilly, Bangsbo and Franks 2000). This was also proposed to occur in the study by Zochowski, Johnson and Sleivert (2007), where participants had significantly higher HR's prior to a 200m time trial in a 10 minute passive recovery duration in comparison to a 45 minute duration following warm-up. Zochowski, Johnson and Sleivert (2007) stipulated that less initial work could have been completed anaerobically following the 10 minute recovery duration when compared to the 45 minute duration meaning it could be used towards the end of the time trial, perhaps resulting in the quicker split times reported in the final 100m of the performance.

8.10 Temperature

With regard to the results of temperature measured throughout the study, the findings conflict with well-established results found in multiple other studies with regards to core (Kilduff et al. 2013; Lovell et al. 2007) and muscle temperature (Lovell et al. 2013; Mohr et al. 2004). In this study, tympanic temperature used as an indicator of core temperature dropped, all be it minimally, by 0.02% ± 0.58 following completion of the warm-up. This is a surprising result given that one of the primary responses from warming up is to increase core and muscle temperature in order to gain further physiological and performance benefits prior to performance (Bishop 2003b). In addition to this, the trend towards temperature gradually increasing throughout the periods of inactivity was also an unexpected result, with a 1.30% ± 0.48 increase in temperature following 50 minutes of inactivity. Both these findings are in contrast to the results of other studies investigating the effect of 15 minutes of inactivity during the half-time period in soccer and the same length of time between warming up and start of competition in rugby, suggesting there is a link between reduced performance and a reduction in both core (Kilduff et al. 2013; Lovell et al. 2007) and muscle temperature (Lovell et al. 2013; Mohr et al. 2004). An example of this is in the study investigating the effects of muscle temperature on sprint performance in soccer by Mohr et al. (2004). The study found that core temperature in a control group (passive half-time period) at rest was 37.2°C and following the completion of the warm-up increased to 38.2°C (2.68%). Furthermore, temperature at the end of the first half had been found to further increase to 38.9°C (1.83%), but rather than increasing during inactivity as found in this study, temperature fell to 37.8°C (-2.82%) over the 15 minutes.

Taking these results in to consideration, it is possible that some form of error occurred while taking the temperature measurements in this study. This is despite the tester and testing device being used as indicated on the manufacturer guidelines as well as kept the same throughout all the experimental sessions to minimise the risk of any potential error occurring. Although the possibility of error cannot be ruled out, previous research by Garcia-Concepcion, Peinado and Hernandez (2012) found similar results to that in this study whilst also using the same tympanic temperature measuring device. Garcia-Concepcion, Peinado and Hernandez (2012) explain that a relationship between temperature of the head (hypothalamic temperature) and heat production is inversed. Temperatures above 37 °C cause a constant decrease on the amount of heat produced and results in increased heat loss by sweat evaporation (Benzinger 1963). It is possible that temperature increased in this study following the warm-up which resulted in heat loss in the head thus reducing tympanic temperature.

It is also worth noting that this measure of temperature was selected as it is typically regarded as the 'best' field measure of core temperature for its speed and acceptance of subjects (Lim, Byrne and Lee 2008). Further research in this area may look to include other methods of measuring temperature that has been successful in previous research, such as rectal temperature using an electronic clinical rectal thermometer, or muscle temperature using a needle thermistor (Mohr et al. 2004). Although it would have added to the strength of the study having more accurate measurements of temperature, given the large body of research associating the decline in core and muscle temperature with performance, it is a possibility that temperature was a contributing factor to the reduced performance following the periods of inactivity.

9.0 Limitations

The study was not without its limitations. As has been discussed, the results gained through use of the tympanic thermometer are likely to be caused by some form of error with the device. However, given the resources available for this study, the need for a non-invasive measure and the complications associated with other potentially more valid measures of temperature, this was considered the best option.

Another limitation could be the influence of the initial tests within the test battery dulling the effects that inactivity had on the tests at the end of the battery. To completely eradicate this, 5 separate experimental sessions for each test would have to be conducted, where just one test was performed following the warm-up and subsequent periods of inactivity. This is an unrealistic option considering the number of experimental sessions and time that would have been required to retrieve data for all the performance variables tested within this study. In addition to this, further complications could occur using this method from the longer period of time required to complete testing. There would be the potential for training adaptation to occur in participants that could influence the results. As well as this, there would be a greater risk of participants sustaining injury during this time, resulting in missing data. Another simpler option of preventing this would have been to reduce the number of variables used to assess performance following the periods of inactivity. Although this was considered, the variables included within the test battery were selected as they are believed to be main physical attributes associated with performance in soccer and would provide a greater insight in to the effects of inactivity on soccer performance following a warm-up (Stolen et al. 2005; Little and Williams 2005).

10.0 Practical Application of Results

The results from this study make it challenging for a single recommendation to be made on the length of time the performance benefits of a soccer warm-up lasts that applies to all variables measured. However, the results do suggest it is possible that a substitute player brought on to play may not be immediately able to perform at their optimal levels. Performance of the CMVJ declined by as much as -4.33% ± 4.06 following a 10 minute period of inactivity and by -8.35% ± 4.76 following 20 minutes of inactivity. In addition, HR BPM declined between -28.35% ± 4.46 and -45.99% ± 4.51 after 10 minutes of inactivity and declined between -34.39% ± 6.63 and -50.23% ± 6.14 following 20 minutes of inactivity, dependent on the method of analysis. Finally, after skill performance significantly improved through completion of the warm-up, LSPT performance dropped to baseline levels after 10 minutes of inactivity taking +6.07 ± 11.52 longer to complete the test. Despite the large declines in these variables after a short duration, other performance measures including the reactive strength and sprint performance took 40 minutes or 50 minutes to significantly decline dependent on the height of the box or distance of the sprint. In addition to this, agility didn’t show any significant reductions in performance over the 50 minute period following the warm-up. Although some performance variables did take longer to decline than others, the significant decline observed in the CMVJ performance, LSPT and BPM following 10 minutes of inactivity indicates that there may be a need for a short duration re-warm-up following this period of time. However, taking in to consideration the even greater performance decrements observed following 20 minutes of inactivity after the pre-match soccer warm-up, a more robust re-warm-up may be better suited somewhere between 10 and 20 minutes of inactivity. Performing a re-warm-up following this amount of time after cessation of the pre-match soccer warm-up will ensure that substitutes are at their optimal condition and can be included in play whenever required by the team. As this re-warm-up would need to be completed every 10-20 minutes to maintain this peak condition, it is important that it is kept brief and specific to increasing the performance variables that are likely to have declined. In doing this, the chance of fatigue occurring through repeatedly performing re-warm-ups that are longer than necessary is reduced.

Having made the above findings, further research should look to establish the effects of extended durations of inactivity following the warm-up on actual soccer performance, rather than using performance measures. In addition, investigations with an increased number of participants and a more valid and reliable measure of core or muscle temperature would provide further insight in to how temperature may effect performance following extended periods of inactivity. This will help to further inform those working in the applied setting of the optimal time substitutes should be warming-up following completion of the pre-match soccer warm-up.

11.0 Summary and Conclusion

Following completion of a typical pre-match soccer warm-up, a player's HR, power and skill performance seem to be the most acutely affected variables to decline during inactivity. Other variables such as reactive strength and sprint performance were also negatively affected by inactivity but took a longer duration to have a significant impact. Finally, agility performance was the most robust variable, with 50 minutes of inactivity having little impact on performance. Taking this in to consideration, in the initial stages of a match, substitutes should complete short duration re-warm-ups with an emphasis on improving power and increasing HR. As the match progresses towards the half-time period, increased emphasis in re-warm-ups should be placed on improving sprint performance and reactive strength performance. In addition to this, the half-time period also gives substitute players the opportunity to perform a re-warm-up with the ball, something that they are unlikely to get the opportunity to during the match. Throughout this half-time break, players should look to complete a re-warm-up that includes practicing of skills with the ball such as passing and dribbling to re-elevate skills levels prior to the start of the second half.

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