The effect of singular and combined ice vest and neck collar cooling used pre-match and at half-time, during a soccer specific simulation in the heat

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The effect of singular and combined ice vest and neck collar cooling used pre-match and at half-time, during a soccer specific simulation in the heat

A thesis submitted to the University of Bedfordshire, in fulfilment of the requirements for the degree of MSc by Research Degree in Exercise and Environmental Physiology

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Declaration

“I, Charlotte Murphy declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

I confirm that:

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- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
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List of Abbreviations, Symbols and Acronyms

°C – Degrees Celsius

b.min^{-1} - Beats per minute

CON - No cooling conditions

CV- Coefficient variation

FIFA - Federation Internationale de Football Association

HSD - High speed running

HR - Heart Rate

iSPT- Intermittent soccer performance test

kg – Kilogram

km – Kilometres

km.h^{-1}- Kilometres per hour

m – Meters

min – Minutes

mL - Millilitre

LSD - Low-speed distance

MM - Combination of NECK and VEST

NECK$_{TSK}$ - Mean neck temperature

NECK$_{TS}$ - Neck thermal sensation

NMT- Non-motorised treadmill

PSA - Peak speed assessment

PSS - Peak sprint speed

rH - Relative humidity

RPE- Rate of perceived exertion

S - seconds

SD - Standard deviation

SDC - Sprint distance covered

SL - Sweat loss

T_{re} - Rectal temperature

TC - Thermal comfort

TD - Total distance

TS - Thermal sensation

T_{sk} – Skin temperature

UEFA - Union of European Football Associations

W - Watts

WBGT- Wet Buble Globe temperature

VEST – Ice vest cooling

VRD - Variable run distance

VO_{2max} - Maximal oxygen take up

YYIRTI – Yo-Yo Intermittent Recovery Test Level 1

95%CI: - 95% confidence intervals

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Abstract

The globalisation of soccer has seen matches during international tournaments being played at hot environments, where key physical performance variables including high-speed running and sprinting are decreased, due to an elevation in both actual and perceived body temperatures. The singular use of cooling modalities including ice vests and neck cooling collars have been shown to favourably alter these body temperatures when used throughout a simulated soccer match. However, to not interfere with the laws of soccer, these cooling modalities can only be used within a warm-up pre-match and down-time during half-time. Therefore, the current study explored the singular and combined utilisation of these practical cooling modalities, throughout a soccer specific warm-up, downtime before kick-off and at half-time on simulated soccer performance using an environmental chamber at 28°C Wet Bulb Globe temperature (WGBT). Ten male University level soccer players volunteered for this study, completing the Level 1 Yo-Yo Intermittent recovery test, two non-motorised treadmill-based familiarisations, one peak speed assessment and four randomised, counterbalanced, experimental trials of intermittent soccer performance test (iSPT) using (1) Ice vest (VEST); (2) Neck collar (NECK); (3) combination of ice vest and neck collar cooling (MM) and (4) No-cooling (CON). Physical performance (total, high-speed and sprint distance covered), physiological (rectal, skin (T_{sk}) and neck ($NECK_{tsk}$) temperature and heart rate (HR) and perceptual (thermal sensation (TS), thermal comfort (TC), rate of perceived exertion (RPE) and neck thermal sensation ($NECK_{TS}$) responses were all measured during the first (0-45 min) and second (60-105 min) half of each experimental trial. From 0-15 min, both SD ($P < 0.05$) and HSD ($P < 0.05$) covered were significantly increased in NECK and MM compared to CON. These occurred in association with a significant dampening ($P = 0.01$) of thermal sensation and skin temperature following the warm-up until the first 15-min in MM (3.30 ± 1.11) compared to CON. During the second half, both SD (60-105 min) and HSD (75-105 min) covered in MM were significantly increased ($P < 0.05$) by a large effect size (*d* =1.03) compared with CON. Furthermore, there was a significant increase ($P < 0.05$)

to HSD (90-105 min) and SD covered (75-105 min) by a small effect size ($d = 0.3$) during the second half in NECK compared with CON. Half-time cooling significantly decreased ($P < 0.05$) Tsk, T_{NECK} TS, $NECK_{TS}$, however, these were not maintained throughout the second half. The VEST showed no significant improvement ($P > 0.05$) to physical performance throughout the iSPT. Overall, mixed-methods pre-match applied throughout a soccer specific warm-up and downtime before kick-off and at half-time cooling enhanced physical performance and reduced physiological and perceptual strain in the heat (WBGT: 28°C).

Keywords: Soccer, heat, cooling, iSPT, performance.

Chapter 1: Introduction

Soccer is an intermittent team-sport, consisting of two 45-min halves separated by a 15-min half-time interval (Stolen *et al*., 2005). Within soccer match-play, players will typically cover 10-13km at low, moderate and high-speeds (Gregson *et al*., 2010), utilising both the aerobic and anaerobic energy systems to support these physical demands during match-play (Bangsbo, 2014; Taylor and Rollo, 2014). Those distances covered by players at both high- and top-speeds (sprinting) are associated with attacking and defensive plays, which can potentially alter the match outcome during match-play (Gregson *et al*., 2010). For example, high-speed running is associated with game defining moments in soccer (Gregson *et al,* 2010), whilst sprinting was the most seen action prior to an assist (67%), or goal being scored (61%) in elite top division German match-play (Faude *et al*., 2012).

Many soccer events are played at elevated ambient temperatures (>30°C), at both international [Federation international football association (FIFA) World Cup, (e.g., Brazil 2014)], and domestic [Major league soccer (MSL), Australian (A-league)] level (Girard *et al*., 2015). The potential of ambient temperatures exceeding 45-50°C throughout the 2022 FIFA World Cup in Qatar has resulted in rescheduling the competition for mid-season, during the European winter months (November and December). However, temperatures in Qatar during these months can still range between 24-29°C (BBC Sport, 2018). Both match-play (Mohr *et al*., 2012) and simulated (Aldous *et al*., 2016) soccer conducted at high ambient temperatures (30-43°C) have demonstrated a significant decrease to physical performance compared to temperate conditions (18 -21°C). For example, Mohr *et al*. (2012) reported that total distance significantly declined ($P < 0.05$) by 7% and high-speed running by 26% in match-play at 43°C in comparison to 21°C. Aldous *et al,* (2016) also showed a significant decline ($P < 0.05$) in both total (8%) and high-speed (12%) running during simulated soccer at 30 °C when compared with 18 °C, with both decrements predicted by an increase in skin temperature ($r = 0.84$) and thermal sensation ($r = 0.82$). Furthermore, a significant decrement in sprint performance was seen during the final 15 min (76-90 min) of simulated soccer at 30 ^{o}C, when core temperature exceeded 39 ^{o}C at the same period (Aldous *et al,* 2016). Subsequently, these previously reported heat-induced performance decrements within soccer-specific exercise are due to increases in body temperatures, (e.g., core and skin temperature), and their perception (e.g., thermal sensation) during match-play (Taylor and Rollo, 2014). Thus, utilising strategies that target both the actual and perceived body temperatures of players when soccer match-play is conducted in high ambient temperatures is pivotal to prevent the decline in match-play performance (Taylor and Rollo, 2014).

The gold standard strategy to enhance exercise performance in high ambient temperatures is heat acclimation/acclimatisation (Racinais *et al*., 2015). However, this is often not possible as there is typically minimal rest period between matches over a season to enable a full heat adaptation (Racinais *et al*., 2013). Cooling modalities are a feasible and practicable alternative since they are evidenced to decrease the elevated body temperatures, increase heat storage, and decrease thermal perception both prior to and during exercise in hot environments (Bongers *et al*., 2015). Ice vests, and neck cooling collars are examples of practical cooling modalities that can be utilised within a soccer-specific setting, as they can be worn during a warm-up or at the downtime prior to the kick off or at half-time (Towlson *et al.,* 2013). Both ice vests (Parris and Tyler, 2018); Price *et al*., 2009) and neck collars (Sunderland *et al.*, 2015; Zhang *et al.,* 2014) have been used during soccer-specific exercise in the heat, reporting a significant reduction ($P < 0.05$) to physiological (core temperature and skin temperature) and perceptual strain (thermal sensation, neck thermal sensation and RPE). However, these favourable reductions to both physiological and perceptual strain often occurred from the cooling be utilised during the exercise (Towlson *et al.,* 2013), which is not allowed within the laws of soccer. Furthermore, these cooling modalities were not used during a soccer-specific warm-up (Sunderland *et al.*, 2015) and those key physical performance variables (Gregson e*t al*., 2010) which are associated with the match outcome in soccer (high-speed and sprint distance covered) were also not measured (Parris and Tyler, 2018; Price *et al*., 2009). It is also known that combining multiple cooling modalities (mixed methods) can enhance the ergogenic effect of the intervention (Bongers *et al*., 2012) when compared to when used on their own. Both simulated (Aldous *et al*., 2014;2018) and match-play (Duffield *et al.*, 2009) soccer have used mixed-methods cooling with contrasting levels of success. Chaen *et al*. (2019) utilised ice vest and neck collar cooling during an intermittent cycling sprint performance test in the heat (33 ^{o}C; 50% relative humidity) showing a significant increase in peak power output ($P < 0.05$), coinciding with a reduction in core, skin, and neck temperatures ($P < 0.05$) compared to the control. However, further investigation is warranted utilising both a neck cooling collar and ice vest as singular and mixed-methods cooling modalities during soccer-specific exercise in the heat.

Therefore, the aim of this thesis is to investigate the singular and combined use of ice vest and neck collar cooling compared with no-cooling, when applied throughout a soccer specific warm-up, downtime before kick-off and at half-time at a wet-bulb Globe Temperature (WBGT) 28°C during a non-motorised treadmill-based soccer-specific simulation.

Chapter 2: Literature review

2.1 Physical Performance and Physiological Responses in Soccer Match-Play

Soccer is a worldwide played team-sport, known for its high-speed intermittent nature lasting 90-min, which is divided into two 45-min halves and separated by a 15-min half-time break (Stolen *et al.,* 2005). Throughout the match-play, a soccer player will utilise both their aerobic and anaerobic energy systems to support the physical, technical, and tactical demands (Smith, Marcora & Coutts, 2014). Physical performance is typically evaluated via the use of Global Positioning Systems (GPS) during soccer match-play (Bradley *et al*., 2009). The average distance covered by soccer players are between 10-12 km (Gregson *et al.,* 2010), executing 150-250 different actions, with 1,100 changes of direction accomplished throughout soccer match-play (Mohr *et al*., 2003). Standing (0.0-0.6 km·h-^{1}); walking (0.7-7.1 km·h^{-1}); jogging (7.2-14.3 km·h^{-1}) and running (14.4-19.7 km·h^{-1}) (Bangsbo *et al*., 2006; Di Salvio *et al.,* 2006; Bradley *et al.,* 2009) cover up to 91-98% of the total distance covered in soccer match. In comparison, high-speed running (19.8-25.1 km·h^{-1}) and sprinting (>25.1 km·h^{-1}), only account for 2-8% of the distance met throughout soccer match-play (Mohr *et al.,* 2003). Game defining moments in soccer match-play are associated with high-speed running (19.8-25.1 km·h^{-1}) during soccer match-play (Gregson *et al.,* 2010) therefore it is considered as an important indicator in soccer (Stolen *et al*., 2005). Sprinting during soccer match-play have been highlighted to be performed every 90-120s, covering between 10–20 m (Bangsbo *et al*, 2006, Buchheit, 2010) and lasting 2-4 s (Mohr *et al*, 2003, Rampinini *et al*, 2007) per activity. Furthermore, sprinting in soccer match-play have been shown to lead to goals (61%) and assists (67%) which was analysed in the German Premier League (Bundesliga) (Faude *et al*., 2012). Thus, it is vital to consider the importance of sprinting and high-speed running due to their association to match-play outcome.

Soccer match-play heavily relies upon the aerobic energy system throughout the 90 min, as both average and peak heart rates within elite players have been observed to reach up to 85% and 98% of maximum values (Ali & Farally, 1991; Bangsbo, 1994; Krustrup *et al*., 2005), respectively. Although the aerobic energy system is heavily utilised, the anaerobic demands within match-play are also crucial (Thomas *et al*., 2005). Player's blood lactate concentrations are increased as on average there are 150-250 actions short-term high-intensity activities including high-speed running and sprinting which increases the likelihood of lactate accumulating (Mohr *et al*., 2003). For example, blood lactate concentrations reached ~7.0 vs. 2.7 mmol/L in the first half and second half averages ~4.5 vs. 1.0 mmol/L during both elite and sub-elite match-play (Stolen *et al*., 2005) in soccer match-play, respectively. Adenosine triphosphate-phosphocreatine provides energy during anaerobic glycolysis system when the phosphocreatine is divided to produce inorganic phosphate. That is then transported to adenosine diphosphate and adenosine monophosphate (Kreider et al., 2017) and takes ~5-seconds (s) to reach maximal production (Gastin, 2001; Abt, 2002). If not generated, due to the absence of oxygen, it forms a product of pyruvate which is known as lactic acid and then converted into blood lactate (Krustrup *et al*., 2006). Experimental match-play data from Mohr *et al., (*2012) showed that there was no significant difference ($P < 0.05$) within heart rate and blood lactate between hot (43 ^{o}C) and temperate (21 ^{o}C) environments. However, it is evident that even during match-play within temperate conditions (18- 21 ^{o}C), body temperatures including core temperature can increase to hyperthermic levels (38.5-39 ^{o}C) which can be further exacerbated (39-40 ^{o}C when ambient temperature rise (Mohr *et al.*, 2012; Aldous *et al.,* 2016). Thus, it is evident that physiological strain is caused by a plethora of responses having a detrimental effect upon key physical performance (top-speed running) measures during soccer match-play.

2.2 Match to Match Variation to Physical Performance and Soccer-specific Simulations

It is well acknowledged that there is high match-to-match variation to key physical performance variables including both high-speed and sprint distance covered. Gregson *et* *al*., (2010) demonstrated in 1,140 elite matches during three seasons (2003/2004 to the 2005/2006) of the English Premier League large variability in the coefficient variation (CV) percentage to all high-speed activities (16–30%). This high match-to-match variation within soccer match-play is likely due to a plethora of match factors caused by positional roles (Bloomfield *et al*, 2007), playing ability (Mohr *et al*., 2003), tactical play (Bradley *et al*, 2011) and environmental factors (Duffield *et al*., 2010) such as ambient temperature, humidity, and wind speed. Soccer match-play is subsequently, susceptible to these external match factors (Rollo *et al*., 2014) causing both researchers and practitioners vast difficulty, to ascertain changes in physical performance (Stolen *et al.*, 2005; Rollo *et al*., 2014). Thus, methods which minimise the presence of these match factors and the subsequent match-to-match variability to key physical performance measures (high-speed running) are required. Therefore, to ascertain inferences from an intervention.

One solution is to minimise the match-to-match variation is by utilising a soccer-specific simulation to control these match-to-match variations to key physical performance measures (Gregson *et al.*, 2010). There are three diverse types of soccer-specific simulations which have been utilised including field, non-motorised and motorised treadmill based (Drust *et al*., 2007). Field based soccer-specific simulations are the most realistic type of soccer-specific simulation compared with soccer match-play, as they allow for multi-directional movements and the inclusion of technical skills (Harper *et al.*, 2016). An example, of a field-based soccer-specific simulation is the soccer-specific aerobic field test (SAFT$_{90}$), which included both technical skills alongside multi-directional movements and closely reflected the heart rate responses [162 ± 13 b·min $^{-1}$ } (Small *et al.*, 2009)] seen during soccer match-play [168 - 10 b·min $^{-1}$ (Drust *et al.*, 2000)]. The SAFT$_{90}$ also demonstrated high test–retest reliability (CV = 3.8%) for external load, quantified by the vector magnitude of accelerometery, between two repeated trials. However, one limitation of the SAFT$_{90}$ and some other field-based soccer-specific simulations (Drust *et al.,* 2000; Willliams *et al.*, 2010) are the physical performance covered is fixed for all participants, which prompts only the examination of physiological responses for a given physical outcome to be calculated (Abt *et al*., 2003). Furthermore, field-based soccer-specific simulations are normally conducted in a large area, which makes it impracticable in a laboratory setting due to the limited space and therefore are often used outside where, match factors such as temperature, wind speed and humidity cannot be controlled (Athalie *et al.*, 2018). Thus, to distinguish how physical performance within a hot environment is altered by an intervention, a field-based soccer-specific simulation may not be appropriate.

Motorised treadmill-based soccer-specific simulations have been used by multiple researchers to examine soccer performance (Drust *et al*., 2000; Abt *et al.*, 1998; Greg *et al.*, 2006; Page *et al.*, 2015). A recent soccer-specific simulation developed by Page *et al*., (2015) called the contemporary soccer match-play simulation, aimed to validate this against previous notational analysis (Mohr *et al*., 2003; Spencer *et al*., 2004). The protocol consisted of a 90-miniute simulation (2 x 45 min halves) with clusters of repeated sprints. There were a variety of different fixed intensity, such as walking (km·h^{-1}, jogging (8k km·h^{-1}), low speed running (11.6 km·h^{-1}), moderate speed running (15 km·h^{-1}, high speed running (18 km·h^{-1}) and sprinting (25 km·h^{-1}). The findings for total distance covered (12.2 km) were valid compared with soccer match-play (Reilly *et al.,* 1997). Furthermore, a motorised treadmill-based soccer-specific simulation by Drust *et al,* (2000) showed that the heart rate (168 - 10 beats·min -1) were aligned with match-play data (Barrat *et al.,* 2013; Mohr *et al.,* 2003; Mohr *et al.,* 2012), highlighting those physiological responses were approached. Like field-based soccer-specific simulations, the total distance covered seen within motorised treadmill-based simulations is fixed between participants (Drust *et al.,* 2000; Small *et al.*, 2010). Although, motorised treadmill-based soccer-specific simulations do use a laboratory environment where experimental control can be enhanced as match factors can be minimised and allow for the collection of physiological responses can occur throughout the soccer-specific exercise unlike soccer match-play (Page *et al*., 2015). As previously stated in section 2.1, key physical performance measures encompassed within high-speed running are essential to the match outcome (Gregson *et al.,* 2010) cannot be easily measured by a motorised treadmill-based simulation and subsequently not appropriate to for the aims of this thesis.

A non-motorised treadmill (NMT) based soccer-specific simulation can allow participants to demonstrate their true maximal running capacity due to the free-running capability of the treadmill (Aldous *et al.,* 2014). Furthermore, and external match factors to be controlled, alongside the measurement of physiological variables including body temperatures can be collected by the researcher (Page *et al*., 2015). Several NMT soccer-specific simulations have been developed (Nedelec *et al*., 2013; Sirotic, 2008; Drust *et al.*, 1998; Aldous *et al.,* 2014). One non-motorised treadmill-based soccer-specific simulation was validated by (Aldous *et al.,* 2014) called the intermittent Soccer Performance Test (iSPT) which replicated the same intensities observed in match-play per 15-min block and facilitated by the individualised protocol and external cued speed thresholds utilised. The iSPT showed valid and good-to-excellent reliability for physical performance measures [(CV) <10% total (1.4%), variable running (1.4%) high-speed (1.5%), low speed (1.9%) and sprint distance covered (4.5%)] across two experimental trials (Aldous et al., 2014). The iSPT also provides individualisation of each speed threshold for each participant by using each peak sprint speed (PSS) to calculate the participants true performance capacity, as previously used in other Non-Motorised Treadmill (NMT) simulations (Sirotic *et al.,* 2008). The inclusion of the variable running distance within the iSPT is to show high-speed running without any external cues. This is another tool to examine high-speed running which is a key area which effects soccer performance outcomes. Despite one limitation of NMT based soccer-specific simulations being that they are unidirectional reducing its ecological validity, the iSPT has successfully demonstrated changes to key physical performance measures including high-speed running and sprint distances across environments (Aldous *et al*, 2016) and following cooling interventions (Aldous *et al,* 2019) within a controlled laboratory-based environment.

2.3 Instances of Heat in Soccer

The globalisation of major soccer competitions has increased the incidences of hot and humid environments for match-play. The FIFA World Cup held in Brazil (2014) and Russia (2018) saw temperatures exceed 28-33°C and 50% rH; 25-29°C and 75% rH (Lucena *et al*., 2017). High ambient temperatures are likely to be evident in upcoming events including the 2022 FIFA World Cup in Qatar (24-38°C), and the 2026 FIFA World Cup in the USA (24-41°C) (FIFA, 2018). The 2022 FIFA World Cup was originally scheduled in the summer months where temperatures could exceed 45°C (BBC Sport, 2018). This has led to the rescheduling of the competition to be held mid-season during the winter months (November and December), yet ambient temperature is still likely to be between 24-29°C, with highs of 38°C (BBC Sport, 2018). It is not only international tournaments affected by high environmental temperatures. Domestic competitions including the A-League (Australia), La Liga (Spain), Major Soccer League (United States) competitions have reported environmental temperatures which exceed 26-28°C WBGT (Chalmers *et al*., 2019).

2.3.1 Heat Balance Equation

The heat exchange process has been shown to be compromised within soccer match-play, which becomes a fundamental issue (Maughan *et al*., 2010). Metabolic production increases are prominent during physical activity, due to skeletal muscle contractions occurring which leads to elevation in body temperatures (Nybo, Rasmussen and Sawka, 2014). This heat production is transferred via the circulating blood to the surface of the skin (trunk and head) so heat can be dissipated by the process of vasodilation (Nybo, Rasmussen and Sawka, 2014). In response, blood flow is diverted to the skin surface, so heat has a shorter distance to dissipate down the thermal gradient and achieve thermal balance which is known as vasodilation (Cheung and Sleivert, 2004).

$$S = M - (\pm W) \pm (R + C) \pm K - E$$

Equation 1: The Heat Balance Equation (Sawka *et al.,* 2011) where S = rate of heat storage; M = metabolic heat production; W =mechanical work either concentric (positive) or eccentric (negative) exercise; R = rate of radiation; C = convection; K = rate of conduction and E = rate of evaporative loss.

There are four pathways; convection, radiation, conduction, and evaporation which provide heat exchange between the body and the environment (Sawka *et al*., 2011). The heat balance equation formulates the methods of heat loss/gain (Equation 1.0) which implements the first law of thermodynamics (Cheung, 2009). During exercise in the heat, evaporation and conduction mechanisms are utilised to provide passive heat loss and to maintain heat. This is necessary, as an increase in skeletal muscle contractions as seen in physical activity, which elevates the rates of metabolic production which produces heat (Nybo, Rasmussen and Sawka, 2014) and gained via the atmosphere (Sawka *et al*., 2011). Wang *et al*. (2016) explained when heat is generated, due to metabolic reactions, this heat is transferred to the vasodilated capillaries on the skin's surface and the temperature gradient between the environment and the limbs produces a transmission of heat to the surrounding environment via radiation which consists of ~60% of heat loss. Elevated body temperatures can cause heat-mediated decrements during exercise, however, the precise mechanisms which reduce exercise performance is ambiguous, with both central factors (feed forward) and perceptual peripheral (feedback) known to occur.

2.3.2 Central Factors

Central fatigue mechanisms during exercise in the heat has been examined extensively in the last decade (Nybo *et al*., 2014). Core body temperature is a widely established factor of fatigue within hot stress environments, although it is not a reliable predictor of brain temperature (McIlvoy, 2004). When core temperature increases, signals are sensed from the peripheral thermoreceptors then directed to the hypothalamus, which is the centre of temperature regulation (Tucker and Noas, 2009). The hypothalamus role is to sense high skin temperatures and alter thermal perception by regulating exercise intensity to be completed within a range not exceeding the critical limits. Nielsen *et al*., (1993) suggested that critical core body temperature and exercise exhaustion occurred at 38°C and signifies a safety break against catastrophic heat injury or heat illness such as heat stroke. However, Gonzalez-Alonso *et al*., (1999) indicated that exercise in high ambient environments, by trained athletes, voluntarily terminated exercise when body temperatures were at 40°C compared to untrained athletes at 38-39°C (Cheung and McLellan, 1998). Although the critical core temperature concept was later dismissed (Nybo *et al*., 2015), increases in core body temperature has been indicated to have a significant role in the development of fatigue and reduced exercise performance in hot environments (Nybo *et al*., 2014).

Aughey *et al*., (2012) highlighted that elite Australian Rules football players can tolerate higher core temperatures (> 40°C) in the final stages of match-play, without a reduction in high-speed running during the same period of match-play. Furthermore, data from soccer match-play at 43°C saw high core body temperatures (39.7 ± 0.1°C) alongside decrements in both high-speed (26%, $P < 0.05$) and total distance covered (7% $P < 0.05$) in contrast to 21°C (Mohr *et al*., 2012). Laboratory based data reported declines in high-speed running (4%) (2,156 ± 120 versus 2,316 ± 100 m) compared to the control and within the last 15-min compared to the first 15-min with addition to an increase of core temperature (39.2 ± 0.2°C) (Aldous *et al*., 2016). Aldous *et al*., (2016) and Mohr *et al*., (2012) demonstrated that increased core temperature within high ambient temperatures was not directly correlated with a reduction in physical performance. Thus, it is evident that other perceptual and peripheral factors may be associated with the decrements in physical performance in soccer match-play.

2.3.3 Cardiovascular Factors

When exercise intensity and heat production surpass the capacity for heat dissipation into the environment, hyperthermia develops, and this causes the ability to maintain cardiac output to be threatened as there is a decline in stroke volume when core temperature increases (Gonzalez-Alonso 1995). Cardiac filling is impaired during exercise in a hot environment as the venous bed of the skin dilates and enlarges (Gonzalez-Alonso, Crandall, and Johnson, 2008). Rowell *et al*. (1986) noted that a decreased stroke volume coincided with an impaired venous return arising secondary to vasodilation in skin areas. This causes a shortened cardiac cycle reducing diastolic filling, which may further compromise stroke volume and cardiac output as the heart cannot compensate (Gonzalez-Alonso, 2012). Additionally, impairments to cardiovascular function in the heat occurs due to arterial oxygen delivery deterioration and the aerobic energy turnover within the exercising muscles and provokes peripheral fatigue (Gonzalez-Alonso *et al*., 2003).

Heart rate seems to be unaffected during rest, low and moderate- speed running in a high ambient temperature, as any decline to stroke volume is compensated for, by increasing cardiac output to meet the distribution required for the skin blood flow (Rowell, 1986). During high-speed/intense exercise in the heat, cardiovascular drift arises as a response to a reduction in cardiac filling volume due to combination of an elevated heart rate and decreased stroke volume (Nybo and Secher, 2004; Wingo *et al*., 2005; Wingo *et al*., 2012). Therefore, as skin blood flow is increased, the blood vessels within the skin expands causing significant pooling in the vessels which prevent cardiac filling. This process is established as venous compliance, which is increased throughout exercise as the large increments in core and skin temperature (Nybo *et al*., 2014). To complete heat exchange in a hot environment, skin blood flow is increased, however not completely compensated for as central blood volume and cardiac filling are compromised (González-Alonso *et al*., 2008).

Due to the high-speed nature of soccer match-play it is acceptable to predict that cardiovascular drift will occur during soccer match-play (Taylor and Rollo, 2014). Colakoglu *et al*., (2018) analysed the intermittent and cardiovascular exercise and its effect on cardiovascular drift, which is shown via greater stroke volume output. The main outcome was that there was a superior cardiovascular drift pattern observed in continuous exercises, as intermittent condition showed a greater stroke volume response in intermittent modality (138.9 ± 17.9 vs. 144.5 ± 14.6 mL, respectively; $P \leq 0.05$) compared to contentious which reduces the cardiovascular drift risk. However, Mohr *et al*., (2012) revealed that during soccer match-play, there was no reported significant difference between mean heart rate at 43°C (158 ± 2 $b{\cdot}min^{-1}$) in contrast to 21°C (160 ± 2 $b{\cdot}min^{-1}$). Aldous *et al*., (2016) demonstrated no significant difference in heart rate (2 ± 9 $b{\cdot}min^{-1}$, $P = 0.30$, 95%CI: −2 to 8 $b{\cdot}min^{-1}$) at 30°C compared with the control (18°C) during simulated soccer. This process is a reaction to reduced exercise intensity because of pacing strategies, enabling cardiac filling to occur and the intermittent nature of soccer allowing heart rate to be lower due to the variation in intensity and within hot environments players not working as hard thus slowing the heart rate (Rowell, 1993).

Increase in skin temperature is the initial physiological response that occurs in high ambient temperatures, producing an elevation to skin blood flow (Sawka *et al*., 2011). Skin blood flow transfers heat by convection to the body surface from the active skeletal muscles for heat exchange with the surrounding environment (Sawka *et al*., 2011). In soccer simulated there is a rise in skin temperature (34 ± 1°C) (Aldous *et al*., 2016), which emphasises that skin blood flow is increased, and that heat dissipation occurs. As skin temperature increases, there is a correlation with a decline in both high-speed (26%) and total distance (7%) covered (Aldous *et al*., 2016). Soccer simulated statistics in the heat (Aldous *et al*., 2016), showed that an increase in absolute skin temperature was a predictor for total and high-speed distance covered ($r = 0.82$; $P = 0.02$) with thermal sensation calculating the reduction in total distance covered ($r = 0.82$; $P = 0.02$) during simulated soccer performance in the heat (30°C and 50% rH). This data highlights that skin temperature is a key performance predictor, so it is vital for practitioners to identify methods to decrease skin temperature rather than targeting core temperature. It has been highlighted that trained athlete can withstand higher core temperatures (Cheung and McLellan, 1998) however the skin temperature decrease could prevent the negative response to physical performance in hot conditions. Overall, skin temperature (peripheral) is a key area to be controlled to prevent the decline in high-speed running and sprint distances which are both associated to game defining moments in soccer (Aldous *et al,* 2016)

2.3.4 Perceptual Factors

Understanding the role of psychophysiological responses to thermal stimuli and their subsequent influence on exercise performance and tolerance in the heat remains a complex issue (Chueng *et al.*, 2010). Perceptual factors such as thermal comfort, thermal sensation, and rate of perceived exertion (RPE) increases promptly within exercise, alongside physiological aspects in the heat compared to temperate conditions (Périard *et al*., 2011). The perception of the magnitude and the allesthesial quality of thermal stress, plays a key role in human behavioural thermoregulation (Cheung *et al.*, 2010) and exercise performance (Schlader *et al*., 2010). Elevated skin temperatures increase the perception of the effort and exercise intensity (Maw *et al*.1993; Pivarnik *et al.* 1988). This also has links with increased skin blood flow (Rowell, 1974) and sensations of warmth and thermal discomfort (Marcora 2007). This brings attention to protect the perceived exertion response, whilst participants are performing in high ambient temperature, to prevent reduction in exercise intensity (Schlader *et al.* 2010c). Skin temperatures have been shown to elevate throughout exercise (Tatterson *et al.*2000; Tucker *et al.* 2004), and it has been already noted that high skin temperatures have proposed to modulate exercise intensity (Jay 2009; Schlader *et al.,* 2010c).

Match-play in the heat, including both laboratory and field-based study showed that thermal strain elicited a decreased physical performance, especially in the second half (Mohr *et al*., 2012; Aldous *et al*., 2016). Both thermal sensation and skin temperature have a positive correlation in reduction to physical performance (Sawka *et al*., 2012). Aldous *et al.,* (2016) presented that absolute increase in skin temperature is an indicator of high-speed running (r = 0.82; P = 0.02) with thermal sensation predicting the reduction in total distance covered (r = 0.82; P = 0.02) throughout a simulated soccer performance in the heat (30°C and 50% rH). This is in line with previous match-play data (Parris and Tyler, 2018) who also saw reductions in high-speed activities whilst performed in the heat. This is important for coaches and sport scientist to consider regarding the players perception, as high-speed running and sprinting are linked to goal defining moments (Gregson *et al*., 2010), therefore perception will need to be protected to prevent these decrements (Schlader *et al.,* 2010). Nevertheless, it has been shown when there is a deception of temperature (Castle *et al.*, 2012), this leads to a subsequent reduction in RPE, and this overall improves performance. This concludes that perception of temperature is responsible for performance detriments rather than the physiological temperature alone (Gibson *et al.*, 2019). This warrants further investigation to potentially utilise interventions, to produce a deception of the temperature and mask thermal strain, to prevent soccer match-play performance decrements.

2.3.5. Physical Performance during Soccer in the Heat

Decrements in soccer performance have been shown in a linear fashion when both ambient temperatures and rH are increased (Mohr et al., 2003; Maughan et al., 2010; Taylor and Rollo, 2014). When the ambient temperature surpasses skin temperature, heat is increased in addition to metabolic heat production from the exercising muscles (Periard, Racinais and Sawka, 2015). Although it is apparent that core temperature plays an essential role in physical performance decrements in soccer, peripheral (feedback) and central factors (feed forward) can also have an influence (Taylor and Rollo, 2014). In soccer match play, physical performance parameters such as high-speed running and total sprints declined in the 2014 FIFA World Cup tournament in Brazil due to the high heat stress (> 28-33°C and 50% rH; 25-29°C and 75% rH) (Nassis *et al.*, 2015). As both high-speed running and sprinting are crucial to crucial moments in soccer match-play (Faude *et al*., 2012) and the scheduling of soccer tournaments in hot environments and rH are expected, it is important to identify strategies to augment soccer-specific performance.

Soccer in hot conditions has been widely analysed, the very first study examining soccer with elite participants was Ekblom *et al*., (1986). It was informed that there was a significant decline in total distance covered (-4%, $P < 0.05$) at 30°C heat temperatures which were considered temperate. The most up to date studies which examined soccer match play were Özgünen *et al*. (2010), Mohr *et al.*, (2012), Nassis *et al*., (2015) and all showed a common trend of physical performance having a larger detriment in hot conditions compared to moderate and temperate. Özgünen *et al*. (2010) compared high ambient temperatures (36 ± 1°C and 61 ± 1% rH) and moderate ambient temperatures (34 ± 1°C and 38 ± 2% rH) in 11 male soccer players. There was a significant decrement in total distance covered between the first (4,301 ± 487 m) and second half (3,761 ± 358 m) within high ambient temperatures ($P < 0.001$). That said, there was no significant decrement between first (4,386 ± 367 m) and second half (4,227 ± 292 m) under moderate ambient temperatures. Sprinting and high-speed running was significantly lower in hot environments in the first and second half (236 ± 127 m) compared to the low environment (196 ± 80 m). This analysis highlights that under heat stress, there is detrimental effect on high-speed running and sprint distances covered.

As physiological responses are a key component on workload in soccer, analysis on both physical and physiological parameters is essential. This was later examined by Mohr *et al*. (2012) by evaluating responses in match-play in temperate (21°C, 12% RH) and warm (43 °C, 55% RH) conditions. Core temperature was considerably higher in the hot condition compared to the control group ($r = 0.85$, $P < 0.05$), core temperature was also correlated with participants total distance ($r = 0.43$). Although interesting, it has been proposed that to gain inferences from soccer match-play at least 80 players (Gregson *et al*., 2010) are needed due to high variability between matches for significant physical performance measures. Nassis *et al*., (2015) analysed 64 soccer matches during the Brazil FIFA World

Cup (2014) categorising the temperatures of matches based on environmental heat stress, including WBGT and relative humidity (Gonzalez *et al*., 1995); low: 24°C and 50% rH; < 20°C and 75% rH, moderate: 24-28°C and 50% rH; 20-25°C and 75% rH and high: 28-33°C and 50% rH; 25-29°C and 75% rH. The total sprints ($r = -0.37$, $P = 0.003$) and high-speed distance covered ($r = -0.28$, $P = 0.02$) decline throughout match-play in high ambient temperatures. Furthermore, the total sprints performed in match-play under high ambient temperatures (0.36 ± 0.04 sprints/min/player) was drastically lower than the number of sprints within both moderate (0.40 ± 0.05 sprints/min/player) and low (0.41 ± 0.04 sprints/min/player) levels. Nassis *et al*., (2015) concluded that distance covered at high-speed ($r = 0.28$, $P = 0.024$) and number of sprints ($r = 0.37$, $P = 0.003$) were negatively correlated with WBGT. Overall, the is a trend highlighting throughout all the studies (Özgünen *et al*. [2010}, Mohr *et al.*, {2012}, Nassis *et al*., {2015}) show a decline in high-speed running in the second half of soccer match play which is fundamental for game defining moments in soccer and match play outcome (Taylor and Rollo, 2014).

This provides initiative for coaches and sport scientists to prevent this from occurring in soccer match-play. However due to these studies being field based study, match play factors may interfere with the participants workload such as their high-speed running. Several considerations could influence player physical performance parameters in soccer match-play, including the mixture of soccer standards (elite and semi-professional) in Nassis *et al*. (2015) and Özgünen *et al*. (2010) papers. The reduction in physical performance variables in soccer match-play are constantly changing due to confounding game factors such as tactics, opposition, and formation (Gregson *et al*., 2010). The discrepancy could be due to pacing strategies as seen in hot environments in soccer match-play (Nassis *et al*., 2015). Such confounding game factors can be controlled (Taylor and Rollo, 2014) by utilising a 90-min duration protocol, such as a soccer-specific simulation, conducted on a non-motorised treadmill (Aldous *et al*., 2014)

A laboratory-based study, by Aldous *et al*. (2016), utilised the NMT and an iSPT protocol in the heat (30°C; 50% rH) compared to temperate temperature (18°C; 50% rH). A decline in total distance of 4% (321 ± 131 m, P = 0.001) and decreased high-speed running distance by 7% (160 ± 21 m, P = 0.001) in the hot condition was reported compared to data abstracted from the temperate condition. This data was comparable to previous findings from Mohr *et al*., (2012). Although high-speed running decreased, Aldous *et al*. (2016) stated an increase in peak sprint of 4% (3 ± 1 $km \cdot h^{-1}$) compared to the control, like match-play recordings by Mohr *et al*, (2012). It has been proposed that the increments in sprint performance was likely due to the enhanced effect heat has on muscle contractility (Castle *et al*., 2006). It was recognised that there was a reduction in sprint performance (-5.8%) in the final 15-min of iSPT at 30°C, where rectal temperature exceeded 39°C (Girard *et al*, 2015). a Therefore, the main contributing factors for decrements in total distance and high-speed distance covered at 30°C are both skin temperature (r = 0.82, P = 0.02) and thermal sensation (5%).

It is evident that soccer match play (Ozgunen *et al*., 2010; Mohr *et al*., 2012) and simulated soccer performance (Aldous *et al*., 2016) have resulted in high core temperatures when performed in hot environments. Furthermore, peripheral, and perceptual factors also are negatively impacted; these factors are key determinants to physical performance during soccer performance. Strategies should be used to reduce these physical performance decrements by targeting both perceptual and physiological factors to have an enhanced impact on the match-play outcome.

2.4 Pre-match and Half-time Cooling

Heat acclimation/acclimatisation are considered the gold standard method of preparing athletes for performance within hot environments (Buchheit *et al.*, 2011). Heat acclimatisation, although effective, can be time consuming and these protocols can last up to

>14 days (Garrett *et al.,* 2011) and may not comply with a high demanding calendar associated with elite soccer (Taylor & Rollo, 2014). Athletes with intense training schedules would benefit from protocols with a short duration (Zurawlew *et al*., 2016), but adaptation to the heat is subsequently compromised (Guy *et al*., 2015).

Cooling modalities are used to attenuate increased body temperatures during soccer match-play and therefore relative to soccer match play (Mohr *et al*., 2012) and player's safety (Armstrong *et al*., 2007). Since both simulated and match-play soccer physical performance is impaired in high ambient temperatures (Nassis *et al*., 2015; Mohr *et al*., 2012) the use of cooling manoeuvres in the heat may have an enhanced impact on psychophysiological responses (perceptual and physiological mechanism) in soccer match-play in the heat (Gregson *et al*., 2010; Faude *et al*., 2012; Aldous *et al*., 2018) and player safety (Armstrong *et al*., 2007). Interventions should target skin temperature and thermal sensation to maintain 'temperate-like' match play soccer performance and stop the reduction in physical performance parameters.

2.4.1 Opportunities to Cooling Prior to and at Half-time in Soccer

Pragmatic cooling manoeuvres have been considered both prior to exercise (pre-cooling), and/or at half-time to improve performance and reduce the thermal strain of athletes in hot and/or humid conditions (Bongers *et al*., 2014). Examples of soccer tournaments utilising breaks when WBGT reached 30°C (BBC, 2015) were shown in the 2014 FIFA World Cup match of Netherlands versus Mexico, where a mandatory 3-min break following the 30th-min of each half of match-play was applied. Within soccer, there are pre-match warm-ups which lasted ~30-min, with a ~12-min conversion between the execution of the warm-up and the start of the match (Towlson *et al*., 2013). Warm-up are included to prepare soccer players physically and physiologically (preventing injury) and is used to prepare players mentally and technically (Impellizzeri *et al*., 2013). Throughout international competitions (e.g., UEFA

Champions League), teams' presentation and official anthems allow players to passively rest for approximately 15-min before the match. As a result, the warm-up short-term effects are dependent on adjustments in muscle temperature, may be lost (Russell *et al*., 2015). In fact, it has been highlighted that every 1°C decline in muscle temperature results to a 3% reduction in lower-body power output (Sargeant, 1987). Consequently, a decrease in muscle temperature in response to passive durations may contribute to the deterioration of key physical performance variables, including sprint capacity (Sargeant. 1987; Castle *et al*., 2006). Therefore, practitioners working with soccer players in hot environments should consider utilising cooling modalities that would not have a negative direct impact on sprint performance where the main locomotive muscles are not targeted.

The half-time provides another opportunity for practitioners to utilise cooling modalities in soccer match-play (Towlson *et al*., 2013). Players take 1.7 min to arrive in the changing room and have approximately 13 minutes within the changing room before heading back to the pitch for the second half to commence (Towlson *et al*., 2013). A 5-min duration of mixed-methods half-time cooling is extremely practical (Minett *et al*., 2011) as soccer practitioners tend to only have 2-6-min accessible duration to implement interventions at half-time due to medical treatment, rehydration and refuelling also needing to take place (Russell *et al*., 2015b). Using practical cooling manoeuvres like neck cooling collar and an ice vest singularly or combined before they are entering the changing rooms and throughout the duration of half-time. Furthermore, applying these practical cooling modalities within the warm-up will not restrict exercise and would be a beneficial way to increase heat storage while warming up and keeping whole body temperatures not exacerbating (Gray *et al*., 2006).

2.4.2 Cooling modalities

Cooling modalities can be applied externally (on the body) or internally (ingested), via a singular or combined mixed methods approach pre-match and/or at half-time in soccer (Grantham *et al*., 2010). External cooling garments can be used to cool the face/neck area which has a high proximity of altheisial sensitivity (Cotter and Taylor, 2005). Although the gold standard of pre-cooling is water immersion, it is not practical for soccer (Quod *et al*., 2006).

Castle *et al*., (2006) analysed the differences of pre-cooling methods (water immersion, ice vest and ice pack covering upper leg) against no cooling, within a cycling intermittent sprint protocol performed in hot conditions of 33°C and 51% rH. Results stated that precooling via ice packs offered an ergogenic effect on peak power output unlike whole body water immersion due to Castle *et al*., (2006) emphasised a substantial drop in muscle temperature (0.51 ± 0.3°C) following a 20-min water immersion which approves the idea that elevated muscle temperature has shown to significantly improve sprint performance, also shown in soccer match play within temperate and hot conditions (Mohr *et al*., 2011; 2012). This creates a hypothesis on not utilising water immersion or any cooling modalities which targets locomotive muscle areas, as it is deemed not viable and practical which is essential for the current thesis aim. Cooling modalities which should be considered are those that target reducing skin temperature and thermal sensation, to reduce the risk of decrements in high-speed running (Aldous *et al.*, 2018) occurring. However, the application should be practicable and accessible to be applied in active parts of preparation for soccer such as warmups, downtime and/ or at half time periods so we can utilise these given times to cool the individuals, as the magnitude of cooling is crucial to gain the true effect (Minnet *et al*., 2012).

2.4.3 Ice Vest Cooling

Wearing an ice cooling vest cools the torso region of the body by lowering skin temperature and thermal perception, and in relieving thermal and cardiovascular strain sent from the peripheral thermoreceptors to the hypothalamus increases exercise intensity (Faulkner *et al*., 2015; Schmit *et al*., 2017; House *et al*., 1996). This can be explained due to ice possessing a significantly greater capacity to absorb heat (Seigel *et al*., 2012) providing a heat sink around the torso area, which could lead to a decrease in the core temperature. When core temperature increases, signals are sensed from the peripheral thermoreceptors then directed to the hypothalamus, which is the centre of temperature regulation (Tucker and Noas, 2009). The hypothalamus role is to sense high skin temperatures and alter thermal perception by regulating exercise intensity to be completed within a range not exceeding the critical limits. This is essential for soccer-specific exercise performance to reduce increases in body temperatures and thermal strain to prevent these heat-induced decrements occurring (Aldous *et al*., 2016; Mohr *et al*., 2012). Numerous studies have demonstrated the effectiveness of the ice vest in hot and/or humid environment (Arngrimsson *et al*., 2004; Price *et al*., 2009; Clarke *et al*., 2011; Parris and Tyler, 2018) on performance in 5 km time trial, intermittent running, and later studies on soccer specific protocol. The first study to examine this was Arngrimsson *et al*., (2004), who compared the use of an ice vest during a ~42 min warm-up prior to a 5 km time trial compared to no-cooling. Wearing an ice vest provided a 13 s improvement (1.1%) in 32°C within competitive male and female runners. In the first 3.2 km of the 5 km time trail, core temperature remained significantly lower (0.2 °C, P = 0.05), but by the end of the 5 km there were no significances (0.15 ± 0.33 °C, P = 0.07) in the cooling group in relation to the control. Heart rates were reduced by 3 ± 5 b.min^{-1} at point ‘1.6 km’ into the time trial, but there was no significant difference thereafter. Skin temperature was significantly lowered in the warm-up within the cooling condition, and at the start of the 5 km time trial (1.79 ± 1.20°C). These improvements to the 5km time trial could have been due to the reduction in skin temperature in response to the application of the ice vest reducing thermal stress, which allowed the efforts of the participants to thrive rather than decline as seen in the control condition. However, due to the nature of the protocol being continuous and not intermittent like soccer match-play, it is difficult to transfer these data and conclude whether there would be performance increments in soccer match play. We also can only hypothesise that the reason there was enhancement in the time trial was due to the known link between reduced skin temperature and thermal sensation as stated by Aldous *et al.,* (2016).

A later study by Price *et al.,* (2009) analysed intermittent running using a soccer specific protocol in 31°C and 64% rH comparable to Arngrimsson *et al*., (2004) study. All trials were performed in a warm environment (30.6 ± 0.2°C and 63.5 ± 2.1% relative humidity). Ice vest cooling was implemented at either both pre-match (20-min) and at half-time (15-min) or just at pre-match, compared with a control (non-cooling). The intermittent protocol consisted of several 15-min bouts of exercise based on match analysis data derived from FA's Women's Premier League (FAWPL) matches (The Football Association 1999, unpublished observations). The study aim was to analyse the thermal strain rather than physical performance neglecting; total distance, sprinting and high-speed running. Price *et al.,* (2009) concluded that both cooling protocols (pre- and combined pre-and mid-cooling) were beneficial when compared with the control (CON). In the PRE- and mid-cooling intervention, lowered T_{re} by 0.2 ± 0.1°C for PRE and 0.1 ± 0.2°C for PRE- and mid-cooling, however the control group was unaltered (0.0 ± 0.0°C). T_{re} was significantly lower until the 35th-min then increased in CON, PRE and combination of PRE and mid-cooling (1.1 ± 0.6°C, 0.7 ± 0.4°C, and 0.7 ± 0.3°C, $P < 0.05$).This is important to consider as lowered skin temperature has been notified as a performance predictor in high-speed running (Aldous *et al*., 2016) and high-speed running being associated to game defining moments, makes the value crucial to maintain (Gregson *et al*., 2010). We can assume that high speed running was not maintained due to the failure of decreasing skin temperature throughout, and not enhancing soccer performance further. Limitations of the Price *et al.,* (2009) study that it did not include a soccer specific warm up and this allows extra available time for participants to be cooled, as the ice vest would not hinder the warmup due to it not restricting the participants movements, making it an admirable cooling garment to utilise. The study did not feedback perceptual responses which would have been ideal to examine to see if the reduction in high-speed running was due to the relationship between skin temperature and thermal sensation as known predictors.

The most recent study which looked at the benefits on ice vest on a soccer simulation and peak speed performance in the heat (35°C and 50% rH) was performed by Parris and Tyler (2018). Two 90-min bouts of soccer-specific intermittent running were completed; one trial had an ice cooling vest applied and one trial without. Trials contained two 45-min periods, divided by a 15-min of seated rest in cool conditions (23°C, 50% rH). Results only established a moderate effect in declining core temperature (-1.3 ± 0.6°C) within the second half. However, the laws of soccer do not authorize players to wear cooling vests during competition, but if such garments are deemed safe and effective, they could be applied during warm-ups, training sessions, and non-competitive soccer games held in hot, humid conditions (Parris and Tyler 2018). Limitations of the soccer data is that it utilised on a fixed distance protocol, this reduces ecological validity as a true of the participants maximal running capability cannot be expressed (Taylor and Rollo, 2014). As previously outlined, wearing an ice vest throughout the protocol is impractical as it is against the FIFA rules and regulations to what players can wear within match play so therefore research is needed to calculate the effects of the ice vest within times the players are able to utilise the garments such as half-time and warm up. The magnitude of change from the cooling vest may be augmented with combination with another cooling strategy via a mixed methods approach (Bongers, 2014). Further, ice vests have a small effect on perceptual strain (e.g., thermal sensation) so it could be combined with something like neck cooling provide that dampening of thermal stress and an increase in high-speed running.

2.4.4 Neck Cooling

The neck is an alternative region of the body that can be targeted for cooling, as this is an area of high alliesthesia thermosensitivity (Cotter *et al*., 2005). There are temperature-sensitive areas located in the hypothalamus which release inhibitory signals when there is an increase in brain temperature which impairs motor activity (Nybo, 2012) and alter neurotransmitter release (Meeusen and Roelands, 2010). Neck cooling is unlikely to reduce human brain temperature during exercise (Sukstanskii and Yablonskiy, 2007) and has no effect on core body temperature (Tyler *et al*., 2010; Tyler and Sunderland, 2011a, b). The mechanism of the neck cooling collar is to dampen the perceived magnitude of thermal strain, allowing individuals to tolerate increased core body temperatures and heart rates before volitional termination (Tyler and Sunderland, 2011a). The efficiency of dampening effect is dependent on magnitude of thermal strain (Tyler *et al*., 2010), therefore most beneficial when core temperatures exceed 39°C (Aldous *et al*., 2019) as seen during intermittent activity in the heat (Sunderland and Nevill, 2003, 2005; Morris *et al*., 2005; Sunderland *et al*., 2008).

Numerous studies have analysed the effect of neck cooling collar cooling in hot conditions (Tyler *et al*., (2010); Tyler and Sunderland (2011b); Zhang *et al*. (2014); Sunderland (2015). Tyler, Wild and Sunderland (2010) analysed the influence of a neck cooling collar during a 75-min submaximal treadmill run at 60% VO_{2max} followed by a 15-min self-paced time-trial compared to no cooling collar and one with the collar uncooled. Eight participants also completed a 15-min time trial twice with and without the neck cooling collar omitting the submaximal run. When the neck cooling collar was utilised, a significant effect was highlighted ($P < 0.001$) in the 15 min time-trial performance following 75 min at ~60% relative maximal oxygen uptake. There was also a significant improvement in total distance when a neck cooling collar was applied and replaced (3,030 ± 485 m, $P < 0.001$) in comparison to one use of neck cooling collar cooling (2,741 ± 537 m, $P = 0.008$) and no-cooling (2,884 ±

571 m, $P = 0.04$). When no submaximal run was completed prior to the 15-min time-trial no significant performance improvement was evident compared with a control. It could be argued that the vast differences in duration of exercise is why the neck cooling collar did not elicit an enhancement on performance when the submaximal run was not completed prior to the time trial. This is comparable to the Tyler and Sunderland (2011b) study, as there was a significant improvement ($P < 0.01$) utilising neck cooling collar cooling on total distance (2779 ± 299 m) compared to no cooling (2597 ± 291 m) as relative maximal oxygen uptake increased by 7% when a neck cooling collar was applied throughout exercise. Interestingly there was no further improvement ($P > 0.05$) in performance detected when the neck cooling collar was replaced every 30-min throughout exercise (2776 ± 331 m) compared to no cooling. Therefore, despite the favourable data supporting the use of a neck cooling collar during endurance exercise performance in the heat, these studies have limited application to soccer performance, warranting further research.

Zhang *et al*. (2014) stated that neck cooling collar cooling via wet towels significantly enhanced Yo-Yo Intermittent Recovery Level 1 test (814 ± 328 m) by 31% compared to no cooling (654 ± 311 m). Significant reductions were also apparent in thermal sensation following 15-min of neck cooling (2.2 ± 0.6) compared to no cooling (3.6 ± 0.7; $P < 0.05$). However, the study was conducted at an ambient temperature of 21°C which is not deemed as a thermally challenging environment. The Yo-Yo Intermittent Recovery test has been shown to show true value of exercise capacity and similarities of high-speed running values highlighted in soccer (Krustrup *et al*., 2003), the protocol only replicates one period half of soccer match-play. Therefore, the true effective of neck cooling on soccer specific performance in the heat cannot be concluded. Sunderland *et al*., (2015) conducted a study using a soccer specific intermittent motorised treadmill protocol which followed with sprints (5 x 6s) before and after each 45-min halves at 33°C and 53% rH, wearing either a neck cooling collar throughout or with no neck cooling collar. Neck temperature ($P < 0.001$) was significantly reduced by the neck cooling collar garment coinciding with increased mean power output mean (540 ± 99 versus 507 ± 122 W, P = 0.03) and peak power output (719 ± 158 versus 680 ± 182 W, P = 0.002) during the final bout of sprints during the cooling condition compared to no cooling. The limitation of the study is that the protocol consisted of the cooling modalities were worn throughout the protocol which does not pass the soccer guideline (Parris and Tyler, 2018) and that decrements in performance between halves cannot be measured, warranting further research.

2.4.5 Mixed Methods Cooling

Combining cooling modalities together is referred to as mixed methods cooling and provides ecological validity and practical replacements to cold water immersion (Duffield *et al*., 2009). Minett *et al*., (2011) initially looked at the pre-cooling implementation of a mixed method approach when examining medium fast bowling in the heat (33 ± 0.9°C) and humid (33.9 ± 0.9%) environment. Participants were cooled at varied body parts such as, head cooling via iced water towel (5.0 ± 0.5°C), head and hand cooling which was cold water towel with hand immersed in cold water (9.0°C ± 0.5°C) or mixed method approach which consisted of both cooling modalities and an ice vest covering the torso and application to ice packs on quadriceps, compared to no cooling condition. Cooling was applied for 20-min before (pre-cooling) the protocol commenced. It was found that mean peak sprint was greater in the precooling trails (P = 0.03; *d* = 0.75) in contrast to the control. Greater maintenance of sub-maximal sprints has been linked to previous research on performance benefits, in self-paced intermittent sprint exercise in the high ambient temperatures (Castle *et al*., 2006; Duffield *et al*., 2007; 2009). All cooling conditions had a positive effect on core temperature (*d* = 0.91 – 3.44) and on the performance in the intermittent sprint exercise. This is an important consideration for soccer performance since cooling needs to be effective on high-speed running due to its association to goal scoring opportunities (Faude *et al*., 2012).

Minett *et al*., (2012) then analysed the duration (20 or 10 minutes) of cooling affected performance, reporting a positive significance in total distance covered within the cooling which lasted 20 mins (4,801 ± 375 m), compared with cooling of 10-min (4,584 ± 373 m; P = 0.03; *d* = 0.82) compared to no cooling (4,584 ± 411 m; P = 0.01). Core temperature remained lowest within the condition of cooling for 20-min compared to the 10-min cooling (P = 0.02; *d* = 1.32) and the control (P = 0.003-0.04, *d* = 0.82-1.20). In both pre-cooling in 10-min (P = 0.01-0.03; *d* = 1.72-7.60) and in 20-min (P = 0.001; *d* = 3.89–7.47) a decrease in skin temperature was highlighted compared to the control, creating greater reductions in thermal strain. Overall, it was concluded that higher self-paced, sub maximal running, and maintenance of repeated sprint ability were shown to be withheld in the 20-min cooling compared to the 10-min cooling and the control. This coincides with the effectiveness of pre-cooling and its ability to increase heat storage reserve (P < 0.001; *d* = 3.66–8.18) compared to the control and in turn, accommodate high levels of heat stress and elongated periods of increased exercise intensity (Duffield *et al*., 2008). However, due to the cooling duration and volume of Minett *et al*., (2012) study compared to the current study, it could lose its effectiveness in managing heat stress as the protocol being specific to fast-bowling exercise and the current study being focused on soccer. There is a greater load on the participants physically, physiologically, and perceptually due to the duration and demands of soccer (Bangsbo *et al*., 2014). The pre-cooling intervention would not be practical in a soccer specific warm up due to the hand being immersed in water and the quadriceps being covered with ice packs which makes it impractical and not ecologically valid.

Cooling Modalities utilised within a soccer field-based study by Duffield *et al*., (2013), implemented pre-cooling between training sessions and soccer games in an environment of 30°C, 75% rH (28°C WBGT). The precooling consisted of 30-min bouts of cooling prior to the warmup, consisting of mixed-method cooling procedures as seen in Minett *et al*., (2011; 2012); ice-vest (Arctic Heat, Brisbane, Australia), and placing a cold towel that had been soaked in 5°C cold water over their head and neck. The nine players consumed a standardised 350 mL ice-slushie that consisted of frozen sports drink (Gatorade, Chicago, USA). In the control condition, players continued their regular pre-training or match routine and consumed 350 mL of room temperature sports drink (Gatorade, Chicago, USA). Throughout the half-time break of the match, the cold towels and ice-vest were allocated for a further 5-min. Training outcomes showed no significant variations found between conditions for total distance, intensities (high, moderate, or low) speed distance or the number of peaks of speeds reaching above 23 kmh^{-1} ($P = 0.28$, $d = 0.93$). The pre-cooling method prevented any rise in core temperature during pre-training preparation and declined the core temperature following the warm-up ($d = 1.00$; $P = 0.01$). However, the reduction of core temperature after pre-cooling did not continue for an expanded duration, due to it being dissipated within the first 10-min, with no alterations between conditions for the remainder of the session. Mean skin temperature was reduced ($d > 1.00$, $P = 0.01-0.09$) following pre-cooling only up until the 10th min and no significant modifications were found after the 20th minute.

No significant differences were found in match play and training outcome ($P = 0.26$). Between the conditions for match-play physical performance measures. However, there was a moderate effect size ($d = 0.60$), demonstrating a tendency for increased relative total distance after cooling. The emphasised increase in total distance occurred in the second half ($d = 0.77$; $P= 0.27$). The increments in moderate and low speed relative distances were prominent in the second half with the application of cooling ($d = 0.80-0.95$), however total high-speed running did not differ ($d < 0.30$; $P= 0.55$) amongst conditions for the match. There was no significant difference between peak speeds over 23 km h^{-1} between conditions, although increased amounts of efforts and peak speeds were highlighted ($d = 1.5$; $P = 0.15$) in the control in contrast to the cooling conditions. The results emphasised a reduced benefit via pre-cooling regarding soccer performance, physiological and perceptual measures throughout a soccer orientated study and were less explicit than previous laboratory evidence (Duffield *et al.*, 2009; Price *et al.*, 2009). Although the practicality in a soccer stetting has demonstrated, however the mixed method cooling did not show any significances. It could be argued that this was because the duration of the cooling was not efficient enough and therefore including cooling in the warmup may be beneficial. The study shows high ecological validity; however, it does prevent physiological and perceptual measurement to be taken consistently throughout (apart from core temperature in this study). Using soccer-specific simulations could provide the opportunities to closely monitor the physiological, perceptual, physical increments and decrements and prevent match-play factors having an influence on participants physical performance.

Aldous *et al*., (2019) conducted a laboratory-based study in which mixed method cooling was applied pre-match (30-min before ‘kick off’) and within half-time (15-min) during a soccer specific simulation (iSPT) in a hot (30.7 ± 0.3°C) and rH (50.9± 4%) environment. Cooling manoeuvres were either ice packs, ice slurry, a combination of both or no-cooling at all. In the first half, a reasonable increase in total distance (108 ± 57 m, most likely 0.87 ± 0.31), high speed running (56 ± 46 up to 0.68 ± 0.38 m, very likely 0.68 ± 0.38) and variable run (15 ± 5 0.81 ± 0.47 m, highly likely 0.81 ± 0.47) within the mixed method control compared to the control. Additionally, within pre match there were decrements in thermal sensation (-1.0 ± 0.5, and up to –0.91 ± 0.36) and core temperature (–1.0 ± 0.5, and up to, –0.91 ± 0.36) throughout the first half of the ISPT, however physical performance was unaltered following the ice pack and ice slurry conditions compared to the control. Rectal temperature was moderately elevated in ice slurry at the 45th-min (0.2 ± 0.1°C, very likely, 0.67 ± 0.36°C). Within the second half there was no significant differences between any parameters in any conditions compared to the control. Cooling modalities appeared to have no effect on the second half of the iSPT protocol, which can be assumed that the cooling approach not aggressive enough and did not provide enough volume, as previously identified as a key determent in success of effectiveness of the cooling modalities (Minett *et al*., 2011). The study highlights that a change in half-time cooling is essential to increase the second-half performance, as physical performance reductions are elevated throughout this period in the heat (Mohr *et al*., 2012; Aldous *et al*., 2016). Furthermore, the study did not demonstrate a typical soccer game, as it did not utilise a soccer-specific warm-up and did not apply pre-cooling during this duration. Therefore, it is essential that investigations demonstrate utilisation of an application cooling strategy within a soccer specific warm up, downtime before kick-off and at half times which increases the duration of cooling but still abiding to the laws of soccer (Parris and Tyler 2018).

Chaen *et al*., (2019) demonstrated the positives of applying a cooling vest which also covered the neck area, throughout half-time improves intermittent exercise on a cycle ergometer in a hot and humid environment (33°C and 50% humidity). Two 30-min halves separated by a 15-min half time was the designed protocol. The results showed that peak power output in the second half increased in the condition of the ice vest ($P < 0.05$) compared to no cooling. Core temperature within the cooling condition decreased by 0.13°C and skin temperature decreased by 2.8°C and neck temperature by 5°C, in addition to an increased performance. The decreasing skin temperature causes a reduction in peripheral skin blood flow, and it declines cardiovascular strain and elevates blood supply to the skeletal muscles due to an advanced oxygen uptake and cardiac output resulting in a greater venous return (Sleivert *et al*., 2001). Perceptual parameters such as thermal sensation was highlighted to decrease in the second half in the ‘cooling’ compared to no cooling. The study concluded that wearing the ice vest covering the torso and neck during half-time significantly improves intermittent exercise performance in the heat, with decreased neck and mean skin temperature as well as improved subjective response.

2.5 Summary

In conclusion, it is emphasised that soccer physical performance decrements are apparent in soccer (Mohr *et a*l., 2012) and simulated soccer match-play studies (Aldous *et al.,* 2016) within high ambient temperatures (30-43°C). Previous literature has highlighted how crucial it is to maintain high-speed running and sprint distances within the final 15-min of soccer-match play, due to its relationship to match-play outcome (Faude *et al*., 2012). It is pivotal that coaches and trainers utilise cooling intervention which are feasible and practicable to augment these decrements in physical performance (Nybo *et al*., 2014). The optimal intervention is acclimation or acclimatisation, but due to congested calendars soccer players have (Racinais *et al.,* 2015) it would be more so practical to utilise cooling manoeuvres (Taylor and Rollo, 2014). As highlighted ice vests provide practicality and covers an extensive surface area which targets core and skin temperature (physiological strain) without affecting temperature in the locomotive muscles (Bongers *et al*., 2014) and neck cooling collar cooling targets perceptual stress (Tyler *et al.,* 2010; Sunderland *et al.,* 2015). A combination of these may provide an enhancement to soccer performance when utilised before kick-off and within half-time. This provides a rationale to observe the unknown thermo-physiological and performance effects of neck collar cooling, ice vest cooling and the combination of the two (mixed methods), within a warm-up, downtime before kick-off and at half-time during an iSPT soccer specific protocol in the heat (32°C and 60% rH).

It was hypothesised that:

1. There will be a significant improvement in performance throughout the iSPT in the heat and physiological and perceptual strain will be significantly reduced when utilising a neck cooling collar, ice vest and mixed method pre-cooling compared to non-cooling

2. There will be a significant improvement in performance in a simulated soccer performance of the iSPT in the heat, when utilising the mixed method pre-cooling compared with ice vest and neck collar cooling.

Chapter 3: Methods

The present study continued upon the data collection of a previous Masters' student (Peter Mcdonald). I (Charlotte Murphy) was involved in the data collection of five extra participants.

3.1 Participants

Ten University level male soccer players (mean ± SD; age 22 ± 1 years, body mass 74 ± 9 kg, height 177 ± 9 m, $VO2_{max}$: 50 ± 5 $kg^{-1} \cdot mL \cdot min^{-1}$) volunteered for the study which received ethical approval (Approval number: 2018ISPAR003) from the University of Bedfordshire Research Ethics Committee and confirmed to the declaration of Helsinki. Participants were expected to have a minimum of three years' experience playing soccer and participated in two training sessions and at least one 90-min soccer match per week. A priori power calculation (G*Power 3.1, University of Kiel, Germany) calculated a minimum sample size of ten was required at a statistical power of 80% and an alpha level of 5% (Aldous *et al*., 2019). To prevent circadian variations, all testing commenced at the same time of day [1pm] (Waterhouse *et al*., 2005). The kick-off time was undertaken at 1pm as this is anticipated to be when the temperature would be the warmest at the Qatar 2022 World Cup (Sky Sports, 2018).

3.2. Experimental design and controls

Participants standardised their intake of water and food prior to each experimental trial (Sawka *et al*., 2007). Dietary intake was observed via a food diary (Appendix A) 24 h prior to each experimental trial. Participants also were expected to be refrained from the consumption of alcohol, caffeine, and not to partake in strenuous exercise for 48 h prior to testing, whilst maintaining their normal diet prior to and between all experimental visits (Borg *et al*., 2018). It was essential that participants completed a training log (Appendix B) seven days prior to all experimental trials to monitor their training load. To reduce the onset of heat acclimation, sevens day prior to testing hot baths were avoided and participants were not to be exposed to temperatures >30°C three months prior to this study (Aldous *et al*., 2016; Zurawlew *et al*., 2016). The participants also wore the same soccer clothing (Dry-fit, Nike, and Georgia) during each experimental trial (running shoes, sports sock up to just below the knee, short-sleeved soccer shirt and shorts).

Before experimental trials began, participants were informed with the details of the study via a detailed information sheet of experimental procedures. A health screen questionnaire, informed consent, training log (Appendix B) and food diary (Appendix A) were completed prior to testing. All participants visited the Sport and Exercise Science Laboratories at the University of Bedfordshire, Bedford Campus on seven separate occasions (one preliminary testing session; two familiarisation sessions; and four experimental trials). All familiarisation and experimental trials related to the iSPT were consistently performed on the same non-motorised treadmill (NMT; Woodway Force 3.0, Woodway, Waukesha, WI 53186). Participants wore a tether belt and harness which was attached around the waist to be secured onto the NMT. The harness was positioned horizontally at an optimal angle of 8°C, (Lakomy, 1987). Visits one, two and three (Preliminary test and familiarisations) were all performed in a temperate environment (~18°C ~50% rH).

The iSPT protocol was performed on four instances via a randomised and counterbalanced, repeated measures design; (1) no-cooling (CON); (2) Vest (VEST); (3) Neck collar cooling (NECK) and (4) mixed method of NECK and VEST (MM) in an environmental chamber (Custom Made, T.I.S.S) at 32.1 ± 1.7°C, 57.3 ± 4.4% rH and a wind speed of 4 m/s (WGBT 28.5°C) Figure 3.1). For all experimental visits, the wind speed of 4 m/s was created via the use of a 50 cm fan (655- diameter blade; Imasu IMS International, Tsuen Wan, Hong Kong) being placed 1 min front of each participant (Stevens *et al*., 2017). Microsoft Excel spreadsheet was utilised to input the wind speed, ambient temperature and rH to determine the WBGT for all experimental trials (Liljegren *et al*., 2008; Brice and Hall, 2009).

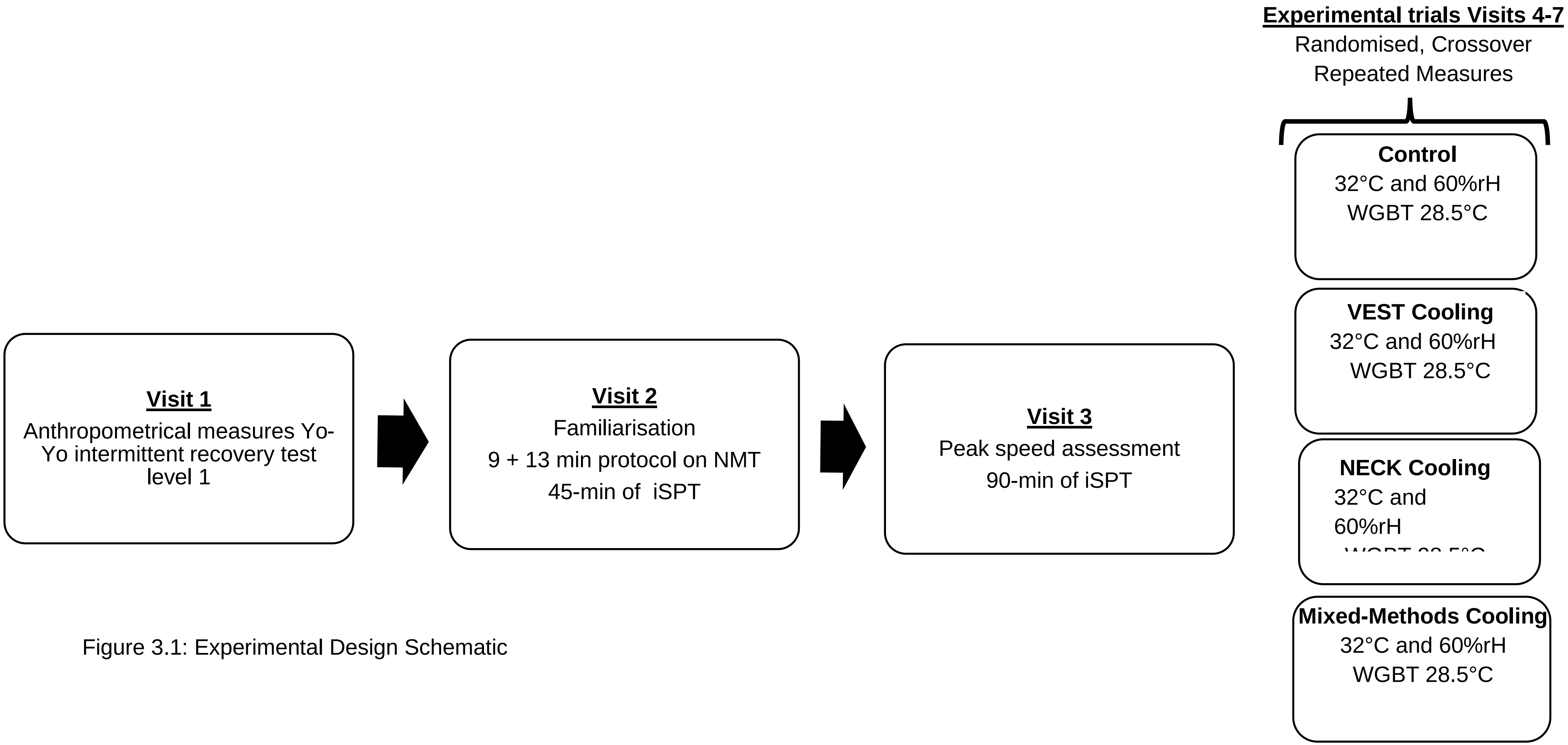

Figure 3.1: Experimental Design Schematic

3.3 Yo-Yo Intermittent Recovery Test Level 1

Visit One: Prior to the initial visit, the health screening questionnaire and formal consent were both completed by participants. Once they completed a short warm-up, along with dynamic stretches and sub-maximal running participants then completed the Yo-Yo Intermittent Recovery Test Level 1 (YYIRT1) (Krustup *et al*., 2003) in the University of Bedfordshire Sports Hall. The YYIRT1 required the participants to undertake incremental runs in between 2 x 20 m cones, from the start and finish line. All increments in levels were controlled by an audio sound, the starting level of the YYIRT1 was 10 $km \cdot h^{-1}$. Active recovery was utilised within the 2 x 5m area at the start/finished which lasted 10 seconds, between each running bout. The level announcements of the YYIRT1 were amplified by a portable CD player (Phillips, CD player, Netherlands) and speakers (Soundplus, TRAMP PC-30, Korea) in the Sports Hall at the University of Bedfordshire. Reaching volitional exhaustions were expected from all participants while performing the YYIRT1. Total distances completed was used to predict VO_{2max}, after the participants failed to reach the start/finish line on the beep twice. The VO_{2max} for each participant was estimated using the equation:

$$VO_{2max}\ (kg^{-1} \cdot mL \cdot min^{-1}) = YYIRT1\ distance\ (m) \times 0.0084 + 36.4$$

Equation 2: Calculation of VO_{2max} regarding distance covered (Bangsbo et al., 2008).

3.4 Familiarisation

Visit Two: Two intermittent protocols lasting 9 and 13 min were included in the first familiarisation (visit 2) followed by the completion of the first 45 min of the iSPT, as per Aldous *et al*., (2014). Participants rested between each bout of exercise until their heart rate (HR) returned to their baseline value. Participants were required to perform a peak speed assessment (PSA) prior to the first 45-min of the iSPT to set their individualised speed thresholds. The PSA involved a 4 min protocol consisting of four sprints lasting 6 s, each separated by a 54s active rest periods on the NMT. The peak sprint speed (PSS) was defined as the fastest speed recorded during the PSA for each participant (Aldous *et al*., 2014). Visit Three: Seven days after completing the initial familiarisation participants then completed the second familiarisation session. Participants firstly completed the PSA to set their individualised speed thresholds, before completing the full 90-min (2 x 45-min halves with a 15-min interval) of the iSPT. Participants then rested for a further 7 days prior to the completion of the first of their four experimental trials.

3.5 Experimental Procedures (Experimental Trials)

Pre-Exercise (-60 min): When participants arrived at the laboratory, blood pressure, body mass and urine osmolality were all obtained (Section: 3.2.2 Height, Blood Pressure, Body Mass, and Sweat Loss). Participants then rested for 5-min whilst a heart rate monitor was applied, and resting baseline value was obtained. A single-use rectal thermistor was also fitted by the participant to measure core body temperature (T_{re}) (Section 3.2.5) and skin thermistors (were then allocated to the right side of the body and on the back of the neck to measure skin (T_{sk}) and neck temperature ($NECK_{TSK}$) (section 3.2.6').

A warm-up was executed (Section; 3.7 Warm Up) on the NMT lasting approximately 24-min, within the environmental chamber at 32.1 ± 1.7°C and 57.3 ± 4.4% rH (WBGT: 28.5°C) (with or without the Neck and Vest Cooling), and wind speed of 4 m/s. A total of 500ml of water was provided to the participant during all conditions. The water was consumed within the 2-min rest period after the first and second section of the warm-up, and after the third phase prior to commencing on the iSPT. Drinking period was allowed in the 12-min downtime before kick-off and at half-time. All fluid ingested was recorded and considered when measuring post-body mass.

Post Warm up (-17 min): The participants were then seated for 12-min to replicate obtaining management/coaching instructions prior to a soccer match within a temperate (18°C) environment. Post warm-up measurements were also recorded in this period. This period was also utilised to apply the second application of cooling modalities Figure 3.2)

First-half exercise (-5-45-min): Participants were harnessed to the NMT and secured to this via a belt, which was placed around the waist, and connected to the harness at 8° degrees from the horizontal (Aldous *et al*., 2019). Every physiological and perceptual measurements as seen in Figure (3.5) were noted down. Once the completed, the first half (45-min) of the iSPT commenced with this replicating a 1 pm kick off.

Half-time (interval) (46 – 60-min): Participants exited from the environmental chamber to a temperate environment (18°C) for a 15-min period, replicating a half-time in a temperate condition changing room. During this time participants were administered 500mL of room temperature water for the duration of the rest period, (Aldous *et al*. 2016). Apart from in the control experimental trial, after the primary 2-min participants wore the appropriate cooling garments (see ‘cooling intervention’). Two minutes before re-entering the environmental chamber, cooling garments were removed from the participants, and they re-entered the environmental chamber to begin the second half of iSPT.

Second-half exercise (61 – 105-min): Participants were then re-harnessed to the NMT and performed the second half (45-min) of the iSPT in the given experimental condition.

Post-exercise (106 – 115-min): Participants finalised the iSPT on the NMT and exited the environmental chamber safely into air-conditioned room, resembling temperate environment seen in changing rooms (18°C, 50% rH)

Post-exercise (115-min): Before participants completed a 10-min self-selected cool down to minimise injury between experimental trials, for 10 min, a post body mass (Section: 3.2.2) was recorded. Finally, rectal temperature was monitored until they were at the baseline value before participants were safe to leave the laboratory (as per the relevant risk assessments).

Table 3.1: The percentage of intensity, repetitions and total time spent of each movement category during the 90-min of the intermittent soccer performance test (Aldous *et al*., 2014)

Movement category	***Peak Sprint Speed (%)***	***Repetitions per 90 min***	***Total Time (s)***	***Total Time (%)***
Stand	0	240	961	17.8
Walk	20	456	1966	36.4
Jog	35	300	1296	24.0
Run	50	192	626	11.6
Fast Run	60	72	194	3.6
Variable Run	Unset	48	146	2.7
Sprint	100	72	216	4.0
Total		**690**	**5405**	**100**

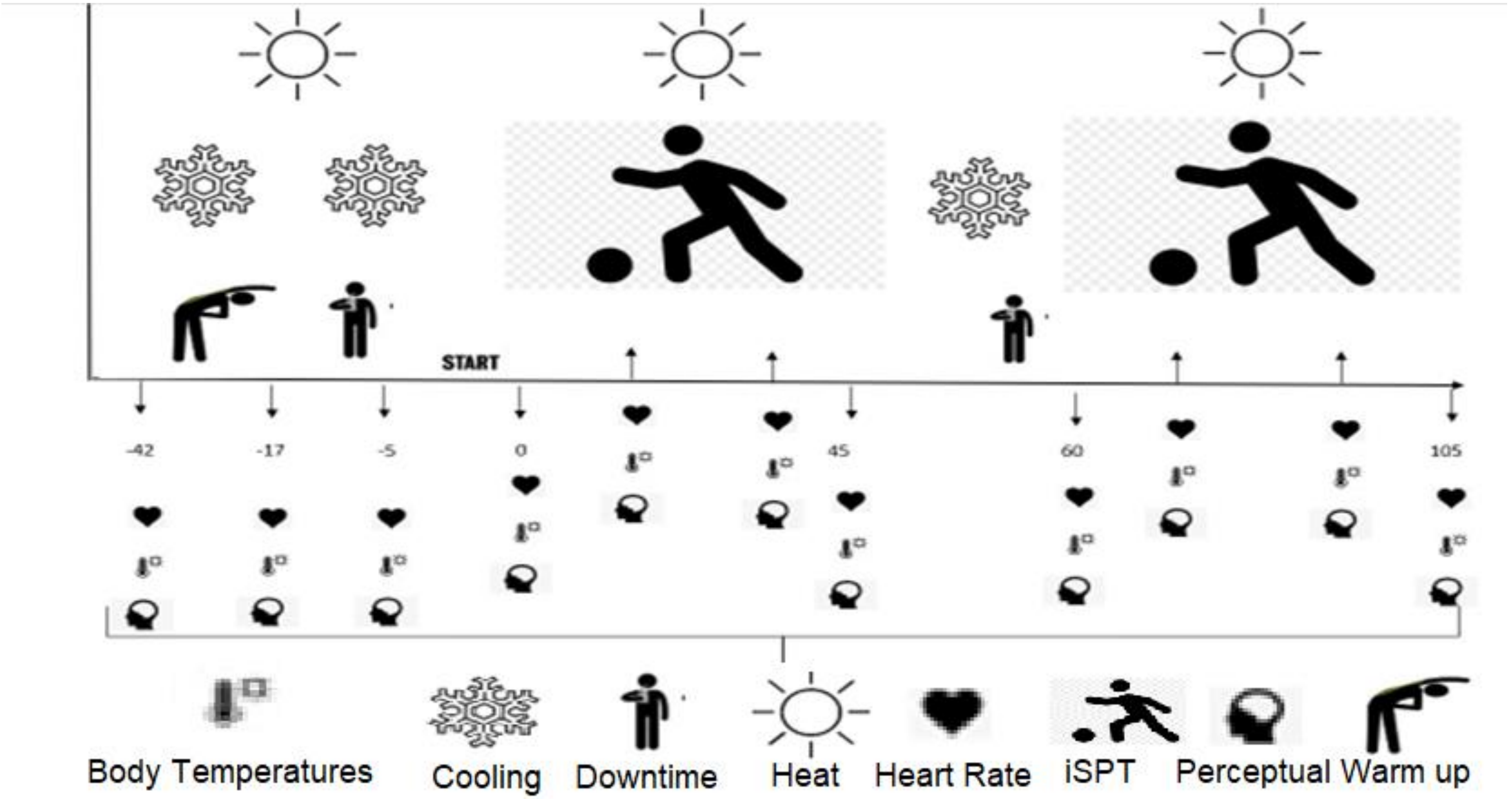

Figure 3.2: Experimental Protocol Schematic: Representing time points of the experiment and when measures were taken place in chronological order - from Warm up (-42 min), when kick off is commencing (0 min), individual 15 min bouts where measurements were taken, half time (45-60 min) and the end of the simulation (105 min)

3.6 The intermittent Soccer Performance Test and Physical Variances

The iSPT consisted of two 45-min halves, each comprising three duplicated 15-min intermittent exercise blocks as validated by Aldous *et al*., (2014). Each 15-min block included objective speeds apart, for the variable run, and the participant imitated the speed given via the computer program which instructs the participant to meet a red line on the screen (which displays each participant target speed) and the participants speed represented by a green line and a target red line which was individualised by peak sprint speed assessed in the PSA. The variable running distance (VRD) was recorded, no matched line was presented, and this took place throughout the 13-14th min of each 15-min block. The VRD required the participants to cover as much distance at a speed not exceeding a sprinting pace, without external cues, above the second ventilatory threshold.

The aim is for the participants to meet all target speed throughout the iSPT, such as stand, walk, jog, run, fast run and sprint. Audio cues and instruction were used to inform the participant of the upcoming activity, for example “beep”, “beep”, “beep”, and “jog”. The iSPT was used in line with four previous studies (Aldous *et al*., 2014; Coull *et al*., 2015; Aldous *et al*., 2016; Aldous *et al*., 2018) and duration of intensity iSPT was based on time and motion of previous studies of soccer (Bangsbo *et al*., 1991). The iSPT evaluates the numerous soccer performance variances; total distance (TD); High speed running (HSD); VRD; sprint distance covered (SD); and low speed running (LSD). All physical performance variables were recorded of 100 Hz utilising the Innervation Pacer Performance System Software. Microsoft Excel (2010 [Windows Microsoft, Washington, USA]) was utilised for further analysis. The ISPT has been highlighted as suitable quantification tool of soccer performance alongside calculating the efficiency of cooling modalities which will conclude the research question (Aldous *et al*., 2019).

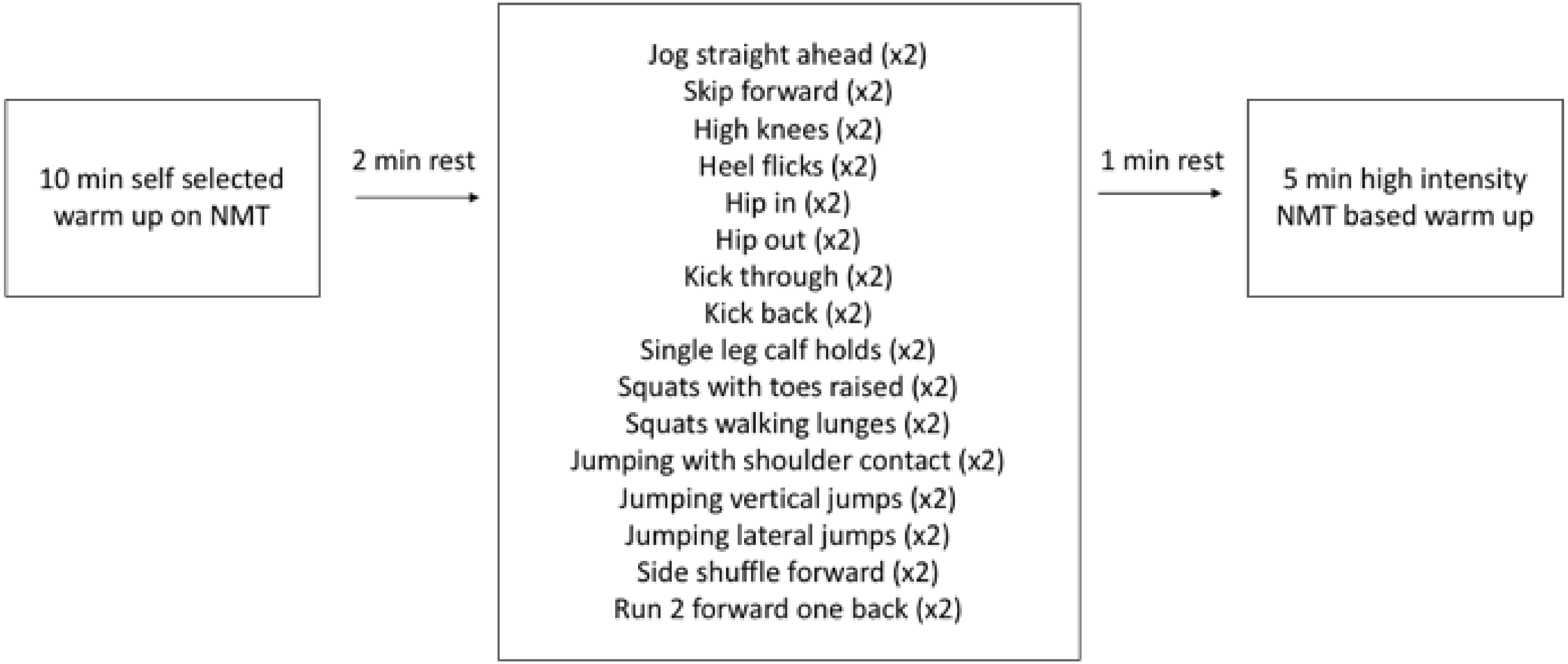

Figure 3.3: Schematic of the soccer-specific warm up protocol adapted from the FIFA 11+ (Impellizzeri *et al*., 2013; Mcdonald *et al*., 2019)

The warm-up was modified from the FIFA11+ warm-up (Impellizzeri *et al*., 2013), due to the dimension and practicality of technical skills within the environmental chamber. The duration of the warm-up was conducted in the same environmental chamber (hot condition with cooling or no cooling). Water was provided at the 2-min rest period bouts between each phase of the warmup. All fluids consumed were recorded and considered when measuring post-body mass.

Phase One: A 10-min self-selected pace warm up was conducted on the NMT where intensity, time and distance were recorded in the second familiarisation and replicated in both experimental trials. **Phase Two:** Participants completed 16 dynamic exercises (Figure 3.3) within the environmental chamber, this was displayed diagonally (6 m) across the 4 x 4.5 m chamber. Participants performed each exercise at each cone set out on a diagonal line twice through. Participants then completed an easy jog back to the first cone. **Phase Three:** individualised 5-min NMT based warm-up, adapted from Oliver *et al*. (2007). The 5-min protocol consisted of four 6 sec sprints interspersed with short bouts of different movements found in soccer such as walking, standing, jogging, and running.

3.7 Physiological measures

3.7.1 Height, Blood Pressure, Body Mass, and Sweat Loss

Blood pressure was recorded via a blood pressure monitor (Omron, M5-I, Cranlea). Measurements were recorded while seated in an upright position and relaxed, for 5-min before the first blood pressure measurement. The arm cuffs were applied on the left upper arm 1-2cm above the elbow and on a bare arm. The air tube was placed on the inside of the arm, aligned with the middle finger. The experimenter pressed the Start/Stop button to inflate the cuff automatically. Pulse rate and Blood Pressure were displayed after 1-min. Two measurements were required before the familiarisations were executed, if measurements were not found a further 2-3-min wait was granted before taking another measurement. The lowest value was recorded and if blood pressure exceeded 140/90, the participant was excluded from the study.

To measure the participants' height, they were instructed to stand with their feet together in contact with the Holtain Stationmaster (Holtain Stationmaster (Stadiometer, Harpenden, HAR 98.602, Holtain) while looking straight ahead. Participants were asked to inhale whilst keeping their heals on the floor. The researcher lowered the sliding scale on top of the head of the participant and noted the final measurement. Body Mass (kg) was calculated via the digital scale (Tanita, BWB0800, Allied Weighing), this was measured to the nearest 0.1 kg with minimal clothing and no footwear. The digital scale was set to zero prior to the participant being measured. Pre- and post-iSPT body mass was measured, during all experimental trials to analyse the loss in fluid ingestion and urine excretion to estimate sweat rate through the following equation.

$$Sweat\ rate = \frac{(\Delta\ mass + fluid - urine - blood)}{exercise\ time}$$

Equation 3: Sweat rate (Stevens et al., 2017)

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3.7.2 Urine Osmolality

Both Pre-and post-iSPT, hydration status was measured using a urine osmometer (Pocket PAL-OSMO, Vitech Scientific Ltd., HaB Direct). Participants were reminded to drink 500ml (minimum) of water 2 hours prior to exercise (Aldous *et al*., 2018). Urine was checked using the urine osmometer by placing droplets of water on the osmolality refractometer platform to calibrate the device, following this the water was removed and pipetted on to the platform was a few drops of the given participants urine, after a short wait a result appeared. Participants did not partake in the study if urine osmolality is >600mOsm.kg^{-1} (Hillman *et al*., 2011).

3.7.3 Heart rate

Heart rate monitors (HR; Polar FS1, Electro, Kempele, Finland) were fitted prior to all testing for the safety of the participants and for the collection of data throughout the protocol. The HR was analysed throughout utilising a telemetric HR monitor (Polar, FS1, Polar Electro, Oy), which was fitted around the chest of the participant. Throughout each experimental trial HR was measured at baseline, pre/post warm-up, and every 15-min throughout both halves and during the half-time period of iSPT.

3.7.4 Rectal Temperature

A rectal thermistor (Henleys, 400H, Henleys Medical, Welwyn Garden City) was implemented to a depth of 10 cm past the anal sphincter and a data logger (Measurement, 4600, Henley-medical, Welwyn Garden City) was connected to analyse temperature throughout. Analysing T_{re} was a mandatory measurement when exercising in a hot and/or humid environment as emphasised in the environmental chamber risk assessment. The safety cut off value for T_{re} was set as 39.7°C as noted in the general ethics document. Experimental testing was terminated if Tre increased over 39.7°C. This was continually recorded throughout the experiment from baseline, pre/post warm up and every 15-min throughout both halves and during the half-time period of iSPT.

3.7.5 Skin Temperature

Skin thermistors (Grant, EUS-U-VS5-0, Wessex-Power, Dorset) were used during this study to assess T_{sk}. Skin thermistors were attached by waterproof tape (Transpore; 3M Health Care) on the pectoralis major, tricep, rectus femoris, and gastrocnemius to measure T_{sk} on the right side. Four skin thermistors were also attached across the posterior part of the neck, like Tyler *et al*., (2010) to measure $NECK_{TSK}$. Two skin thermistors were planted on either side of the spinal midline at the 3rd-4th cervical vertebrae. The further two skin thermistors were allocated on the superior, to the anterior aspect of both the left and right carotid arteries, which was situated via palpation (Tyler, Wild and Sunderland, 2010; Tyler and Sunderland, 2011a). Data for both T_{sk} and $NECK_{TSK}$ was recorded individually to a data logger (Eltek/Squirrel, Squirrel Series/model 451, WessexPower, Dorset). The T_{sk} was measured (Equation 4) as per Ramanathan (1964). The $NECK_{TSK}$ was calculated as the mean value from all four-measurement site on the participant's neck. At baseline, pre/post warm-up, and every 15-min throughout both halves and during the half-time period of iSPT, T_{sk} were measured.

$$0.3 \text{ X (chest temp + arm temp)} + 0.2 \text{ x (thigh temp + calf temp)}$$

Equation 4: Skin temperature calculation (Ramanathan, 1964).

3.8 Perceptual measures

3.8.1 Thermal sensation (TS)

Perceptions of thermal comfort were assessed during this study using a thermal sensation (TS) scale 0-8. 0 as if the participant were extremely cold and 8 being overly hot. (Young *et al*, 1987) (Appendix C). At baseline, pre/post warm-up, and every 15-min throughout both halves and during the half-time period of iSPT, TS was measured.

3.8.2 Rating of Perceived Exertion (RPE)

Rating of perceived exertion (RPE) was measured via Borg scale (RPE; Borg 6-20 scale [Borg, 1998) (Appendix D). A score of 6 resembled very light work and 20 was very hard intensity. At baseline, pre/post warm-up, and every 15-min throughout both halves and during the half-time period of iSPT, RPE was measured.

3.8.3 Thermal Comfort

Thermal Comfort (TC) was predicted by using the thermal comfort scale (Stevens and Russ, 2017) (Appendix F) throughout the protocol, ranging from comfortable (1.0) to extremely uncomfortable (10.0). At baseline, pre/post warm-up, and every 15-min throughout both halves and during the half-time period of iSPT, The TC was measured.

3.9 Cooling Interventions

The cooling modalities were utilised at three time points: warm-up, another set of cooling modalities at the 12-min down time before kick and half time. The hybrid cooling vests (Arctic Heat, Brisbane, Australia; www.arcticheat.com.au) and neck collars (model CCX; Black Ice LLC, Lakeland, USA) were all stored within a freezer cooled at -20°C. Prior to using these cooling garments, the experimenter removed the garments from the freezer 5-min prior to being worn. Both the ice vest and neck collar were worn for the warm-up and then a new set was applied for the 10-min period after the warm-up in the rest period prior to the start of iSPT(the pilot research highlighted that after the warm-up the cooling modalities had melted and provided no further effect). At half time, the cooling modalities were applied to the participant for 10 min. After leaving the environmental chamber into the temperate environment (18°C; 50% rH, the participant did not wear the cooling modalities for the first and last 2-min of half time, to replicate the time which players would walk off and, on the pitch, and into to the changing rooms (Towlson *et al*., 2013). The neck cooling collar was fixed in position by a 600 mm neoprene wrap with a hook and loop to fasten around the neck. The ice vest was applied on the participants’ short-sleeved shirt during the active warm-up and whilst in a seating rest before pre-match and half-time period. This has been chosen to minimise the chance of frostnip of the exposed skin. The T_{sk} of the chest and $NECK_{TSK}$ was measured throughout to monitor or see signs of frostnip at the designated cooling areas.

3.10 Statistical Analysis

IBM SPSS statistics version 26 (SPSS Inc. Chicago, USA) was utilised for all statistical analysis. Physical performance results from the NMT were exported onto a spreadsheet on Microsoft Excel 2010 to obtain the raw data (Windows Microsoft, Washington, USA). The data was then transferred to SPSS to obtain both descriptive statistics and for inferential analysis. Quantile-quantile (Q-Q) plots were utilised to check that the data for all variables was normally distributed. All data was represented in a mean ± SD format alongside 95%CI where necessary. To examine the differences between conditions and physical performance measures amongst 45-min halves and 15-min blocks, a two-way repeated measures ANOVA (Condition x Time) were utilised. Furthermore, the repeated measures Two-way ANOVA was also completed for all physiological (T_{re}, T_{sk}, HR, $NECK_{TSK}$) and perceptual (RPE, TC, TS, $NECK_{TS}$) variables pre- and post-warm-up and at each 15-min block including at half-time. The examination between urine osmolality among conditions was completed via a repeated one-way ANOVA. The Mauchley's test was used to test the assumption of sphericity within each One- and Two-Way Repeated Measures ANOVA. When sphericity was violated ($P > 0.05$), the Huyhn-Feldt correction was applied to determine a main or interaction effect. A Bonferroni post-hoc test was used when a significant main and/or interaction effect was highlighted, and then used to identify specific differences across time and between the experimental conditions. Two-tailed statistical significance was approved at $P < 0.05$. Effect sizes (Cohen's *d*) of all significant differences were calculated using a bespoke Microsoft Excel Spreadsheet using the following thresholds: < 0.2 (trivial effect), 0.2-0.49 (small effect), 0.5-0.79 (moderate effect) and ≥ 0.80 (large effect) (Cohen, 1992).

Chapter 4: Results

4.1. Urine Osmolality and Sweat loss

Pre-iSPT urine osmolality was not significantly different between all conditions (F = 0.48, P = 0.70). Furthermore, no significance differences were found between all conditions for sweat loss (F = 0.31, P = 0.82), as demonstrated in Table 4.1.

Table 4.1: Mean and standard deviation PRE-iSPT Urine osmolality and sweat loss during a 90-min intermittent soccer specific protocol, between conditions; no-cooling, ice vest, neck collar cooling and a combination of the two cooling modalities.

	Osmolality ($Osm.kg^{-1}$)	**Sweat loss (L)**
CON	294 ± 231	-1.14 ± 0.48
VEST	202 ± 171	-1.04 ± 0.53
NEC	269 ± 203	-1.07 ± 0.58
MM	220 ± 202	-0.95 ± 0.67

CON, no-cooling; VEST, ice vest; NECK, neck collar cooling; MM, combination of VEST and NECK.

4.2. Physical Performance

4.2.1. Between Halves

4.2.1.1 Total Distance Covered

There was a significant main effect for Time (F = 31.20; P = 0.001), but there was no significant main effect for Condition (F = 3.48; P = 0.06) and interaction effect for condition x time (F = 1.13; P = 0.35) for TD covered between halves.

4.2.1.2. High-Speed Distance Covered

There was a significant main effect for time (F = 19.84, P = 0.002) and condition (F = 6.48, P = 0.002) but no significant interaction effect between condition x time (F = 2.69, P = 0.14) in HSD. There was a significant improvement in HSD in MM (1909 ± 103 m, P = 0.009, *d* = 0.7, 95%CI: 10 to 72 m) with a large effect size compared to CON (1,827 ± 73 m) throughout the iSPT.

4.2.1.3. Sprint Distance Covered

There was a significant main effect for time (F = 19.06, P = 0.002) and condition (F = 9.06, P = 0.001) and a significant interaction effect found between condition x time (F = 3.02; P = 0.05) for sprint distance covered between conditions. There was significant increase in SD found in MM (456 ± 26 m, P = 0.01, *d* = 0.7, 95%CI: 4 to 35 m) by a large effect size compared to CON (436 ± 29 m) in the first half. There was also a significant increase in SD in NECK (428.400 ± 26.692m, P = 0.025, *d* = 0.57, 95%CI: 2 to 35m) and MM (440 ± 30 P = 0.01, *d* = 0.8, 95%CI: 6 to 55 m) by a large effect size compared to CON (409 ± 39 m) in the second half Table 4.1).

4.2.1.4. Variable Run Distance Covered

There was a significant main effect in time (F = 627.20; P = 0.01) and Condition (F = 5.06; P = 0.02) however there was no significant interaction effect in Condition x Time (F = 2.26; P = 0.10) for VRD covered between halves. There was a significant decrease in VRD in CON (2197 ± 33 m) by a moderate effect size to VEST (422 ± 38, P = 0.003, *d* = 0.4, 95%CI: 3 to 14 m) throughout the iSPT. There was a significant increase in VRD in NECK (420 ± 42 m) by a small effect size compared to CON (2198 ± 33, P = 0.006, *d* = 0.4, 95%CI: 4 to 36 m) throughout the ISPT.

4.2.1.5. Low-Speed Distance Covered

There was a significant main effect evident for time (F = 16.09; P = 0.003) however there was no significant main effect for condition (F = 1.17; P = 0.33) and no significant interaction effect between condition x time (F = 1.24; P = 0.32).

Table 4.2: The overall total distance covered for high-speed running, variable running distance and sprint distance covered, in the first half vs second half within the iSPT for Control, Ice vest, Neck collar cooling, and Mixed method. Data presented as mean ± SD

Condition		**HSD Covered**	**VRD Covered**	**SD Covered**
CON	1st half	936 ± 33	207 ± 16	207 ± 16
	2nd half	891 ± 40	199 ± 17	199 ± 17
	Overall	1827 ± 68	406 ± 31	843 ± 62
VEST	1st half	949 ± 53	214 ± 19	214 ± 19
	2nd half	933 ± 59	209 ± 20	209 ± 20
	Overall	1871 ± 105	423 ± 37[c]	881 ± 73
NECK	1st half	952 ± 37	215 ± 23	215 ± 23
	2nd half	919 ± 39	205 ± 20	205 ± 20[a2]
	Overall	1840 ± 130	421 ± 42[b]	877 ± 46
MM	1st half	964 ± 4	221 ± 21	221 ± 21[a1]
	2nd half	945 ± 58	221 ± 25	221± 25[a1]
	Overall	1909 ± 101[a1]	443 ± 45	898 ± 53

CON = No Cooling; VEST = ice vest cooling; NECK = neck collar cooling; MM = combination of both VEST and NECK; HSD = High speed running; SD = Sprint distance; a= Significant difference found between MM and CON. b = Significant difference between NECK and CON. c= Significant difference between CON and VEST. 1= Effect size between MM and CON. 2= Effect size between NECK and CON

4.2.2 Between 15-min Blocks

4.2.2.1 Total, variable run and Low-Speed Distance Covered

There was no significant interaction effect for condition x time for TD covered (F = 1.18, P = 0.29), VRD (F = 1.29, P = 0.22) and LSD covered (F = 1.00; P = 0.46) at each 15-min block.

4.2.2.2 High-Speed Distance Covered

There was a significant interaction effect between condition x time (F= 2.07, P = 0.02). At 0-15-min, there was a significant increase by a large effect size in MM (332 ± 17 m, P = 0.007, *d* = 0.9, 95%CI: 3 to 22m) compared to CON (318 ± 11.6 m). Within the second half, there was significant increase in HSD covered in MM compared to CON (298 ± 14 m) at 76-90-min (315 ± 18 m, P = 0.004, *d* = 1.18, 95%CI: 5 to 29 m) and 91-105-min (312 ± 25 m, P = 0.009, *d* = 0.7, 95% 5 to 40 m) by a large effect size. Also, a significant increase was evident in HSD covered for NECK (303 ± 15 m, P = 0.018, *d* = 0.9, 95%CI: 2 to 25 m) by a large effect size at 91-105-min compared to CON (289 ± 17 m) Table 4.3). There were no differences between VEST and CON at any 15-min block.

4.2.2.3 Sprint Distance Covered

There was a significant interaction effect for condition x time (F = 1.95, P = 0.02). During the first half at 0-15-min a significant increase in SD covered was evident in NECK (154 ± 8 m, P= 0.017, *d* = 0.6, 95%CI: 4 to 9 m) and MM (158 ± 10, P = 0.001, *d* = 0.8, 95%CI: 4 to 13m) by a moderate and large effect size, respectively compared to CON (149 ± 9 m). Throughout the second half, a significant increase by a large effect size to SD covered in MM at 61-75-min (148 ± 9 m, P = 0.05, *d* = 0.7, 95%CI: 0 to 15 m), 76-90-min (147 ± 9 m, P = 0.014, *d* = 1.10, 95%CI: 2 to 19 m) and 91-105-min (146 ± 14 m, P = 0.02, *d* = 1.03, 95%CI: 1 to 23 m) compared to CON. Furthermore, at 61-75-min (141 ± 9 m, P = 0.01, *d* = 0.5, 95%CI: 1 to 10 m) by a moderate effect size and at 91-105th-min (142 ± 10 m, P = 0.009, *d* = 0.3, 95%CI= 2 to 15m) by a small effect size, SD covered significantly increased in NECK compared with CON Table 4.3).

Table 4.3: The overall high-speed running and sprint distance covered in each 15-min block throughout the iSPT for CON, VEST, NECK, and MM (n = 10)

Variable	Condition	0-15 min	16-30 min	31-45 min	61-75 min	76-90 min	91-105 min
HSD Covered	CON	319 ± 12	313 ± 12	305 ± 12	304 ± 13	298 ±14	289 ± 17
	VEST	323 ± 18	315 ± 20	311 ± 18	314 ± 20	304 ± 21	304 ± 22
	NECK	326 ± 14	318 ± 11	308 ± 16	310 ± 12	306 ± 13	303 ± 16[b2]
	MM	332 ± 17[a1]	321 ± 16	312 ± 19	317 ± 18	315 ± 18[a1]	312 ± 25[a1]
SD covered	CON	149 ± 10	145 ± 11	142 ± 11	139 ± 13	136 ± 11	131 ± 12
	VEST	152 ± 10	148 ± 12	146 ± 13	146 ± 14	145 ± 13	144 ± 14
	NECK	154 ± 8[b2]	149 ± 6	144 ± 9	146 ± 8	141 ± 9[b2]	142 ±10[b2]
	MM	158 ± 10[a1]	152 ± 9	148 ± 8	148 ± 9[a1]	147 ± 9[a1]	146 ± 14[a1]

Data represents as mean ± SD. CON = No Cooling; VEST = ice vest cooling; NECK = neck collar cooling; MM = combination of both VEST and NECK; HSD = High speed running; SD = Sprint distance. a = Significant difference MM and CON), b = Significant difference NECK and CON. 1= effect size between MM and CON 2= Effect size between NECK and CON.

4.3. Body Temperatures and Physiological Responses

4.3.1. Rectal Temperature

There was no significant main effect for condition (F = 0.59; P = 0.63) however there was a significant main effect in time (F= 165.81, P= 0.001). There was a significant interaction effect between condition x time (F = 2.61; P = 0.001), however, no significant differences between conditions throughout the warm-up and both halves of iSPT were evident from the post-hoc analysis.

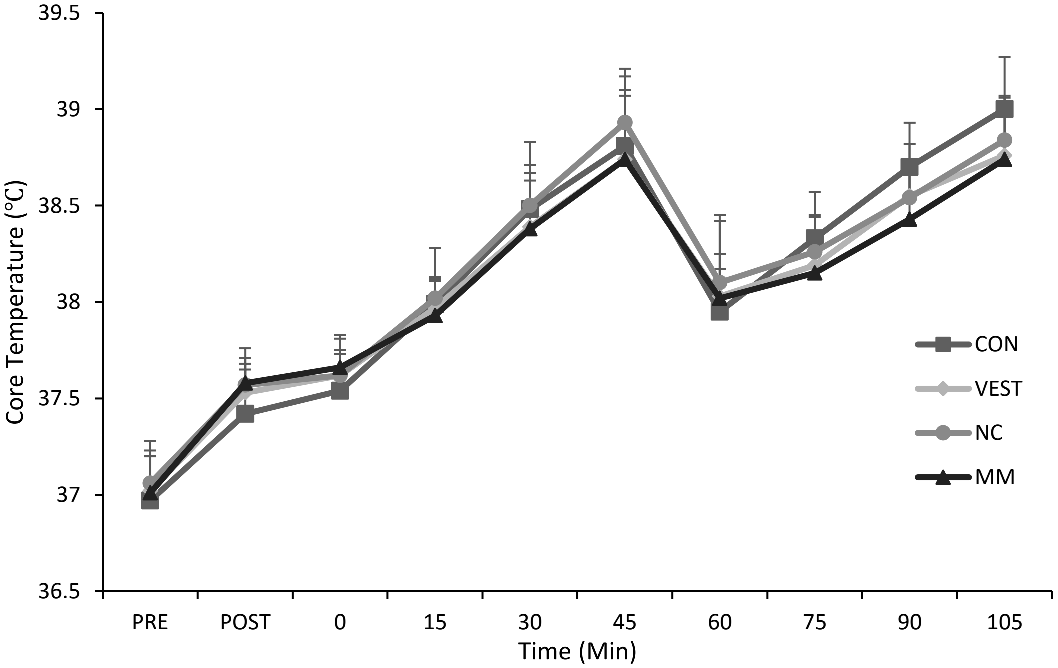

Figure 4.1: Absolute Core temperature during the warmup (PRE and POST), iSPT first half (0-45 min), half-time (45-60 min) and Second half (60-105 min) for Control, Ice vest, Neck collar cooling, and Mixed method (n = 10). CON = No Cooling; VEST = ice vest cooling; NECK = neck collar cooling; MM = combination of both VEST and NECK. Data presented as mean ± SD.

4.3.2. Skin Temperature

There was a significant main effect in condition (F = 17.46; P = 0.001) and time (F = 110.95; P = 0.001) and an interaction main effect within condition x time (F= 8.03; P = 0.001). Upon application of the VEST, there was a significant decline by a large effect size to T_{sk} post-warm-up (31.72 ± 1.9°C, P = 0.005, *d* = 1.7, 95%CI: 1 and 4°C) compared to CON (32.08 ± 1.1°C). In MM, post-warm-up T_{sk} was significantly decreased (31.68 ± 1.29°C, P= 0.003, *d* = 1.7, 95%CI: 1 to 4°C) by a large effect size compared to CON (34.32 ± 0.90°C). The T_{sk} remained significantly reduced until 30 min of the iSPT first half in both VEST (33.92 ± 0.32°C, P = 0.006, *d* = 3.1, 95%CI: 0 to 2℃) and MM (35.07 ± 0.41°C, P = 0.029, *d* = 0.9, 95%CI: 1 to 4°C) by a large effect size compared to CON (35.41 ± 0.31°C). There was a significant decline by a large effect size in T_{sk} following the half-time cooling in MM (31.46 ± 1.01°C, P = 0.017, *d* = 1.4, 95%CI: 0 to 2°C) compared with CON (33.09 ± 1.22°C) and NECK (33.28 ± 1.17°C). Also, in VEST (31.95 ± 1.29°C, P = 0.036, *d* = 0.8, 95%CI: 0 to 2°C) T_{sk} was significantly lower compared with NECK (33.28 ± 1.17°C) post half-time cooling. There were no significant differences evident between all conditions throughout the second half (figure 4.2).

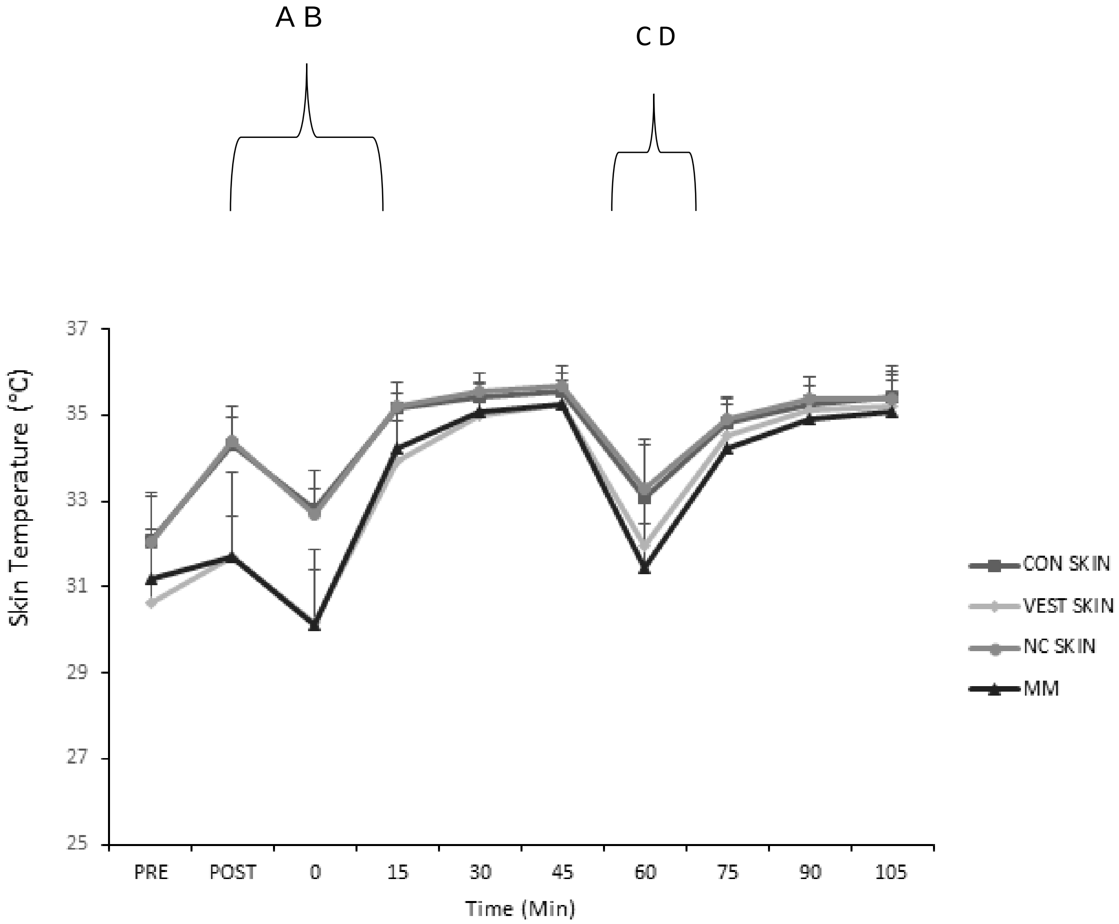

Figure 4.2: Absolute skin temperature during the warmup (PRE and POST), iSPT first half (0-45 min), half-time (45-60 min) and second half (60-105 min) for Control, Ice vest., Neck collar cooling, and Mixed method (n = 10). CON = No Cooling; VEST = ice vest cooling; NECK = neck collar cooling; MM = combination of both VEST and NECK. Data presented as mean ± SD. A = A significant difference between Ice vest and Control. B = A significant difference between mixed method and Control. C = Significant difference between Mixed method and Neck collar cooling. D= Significant difference between Neck collar cooling and Ice vest.

4.3.3. Neck Skin Temperature

There was a significant main effect for condition (F = 72.77; P = 0.001) and time (F = 121.15; P = 0.001) and there was a significant interaction effect within condition x time (F = 47.30; P = 0.001). Throughout the warm-up there was no significant difference in $NECK_{TSK}$ between CON and VEST (P > 0.05). However, there was a significant reduction in $NECK_{TSK}$ by a large effect size in NECK (25.70 ± 1.25°C, P = 0.001, *d* = 6.1, 95%CI: 6 to 10°C) and MM (26.26 ± 2.35°C, P = 0.001, *d* = 3.9, 95%CI: 4 to 10°C) compared with CON. There was a significant decline in $NECK_{TSK}$ in NECK (25.70 ± 1.25°C, P = 0.001, *d* = 5.8, 95%CI: 5 to 10°C) and MM (26.26 ± 2.35°C, P = 0.001, *d* = 3.8, 95%CI: 4 to 10°C) by a large effect size compared to VEST (33.75 ± 1.47°C). At both 0-min and 15-min of ISPT first half there was a significant decrease in $NECK_{TSK}$ in NECK (0-min: 25.42 ± 1.36°C, P = 0.001, *d* = 4.8, 95%CI: 5 to 9°C; 15-min: 33.43 ± 0.88 °C, P = 0.001, *d* = 1.07, 95%CI: 5 to 9°C) and MM (0-min: 26.74 ± 1.30°C, P = 0.001, *d* = 4.9 95%CI: 4 to 7°C; 15-min: 33.59 ± 0.97°C, P = 0.001, *d* = 0.9, 95%CI: 4 to 7°C) by a large effect size compared to CON (33.02 ± 1.11°C). No other differences were evident throughout the first half. During the second half there was a significant decline in $NECK_{TSK}$ by a large effect size in NECK (29.79 ± 0.96°C, P = 0.001, *d* = 2.3, 95%CI: 2 to 4°C) and MM (29.54 ± 1.61°C, P = 0.001, *d* = 2.1, 95%CI: 2 to 5°C) compared to CON (33.14 ± 1.10°C) after the half-time cooling at 60-min. No other significant differences were evident throughout the remainder of the second half.

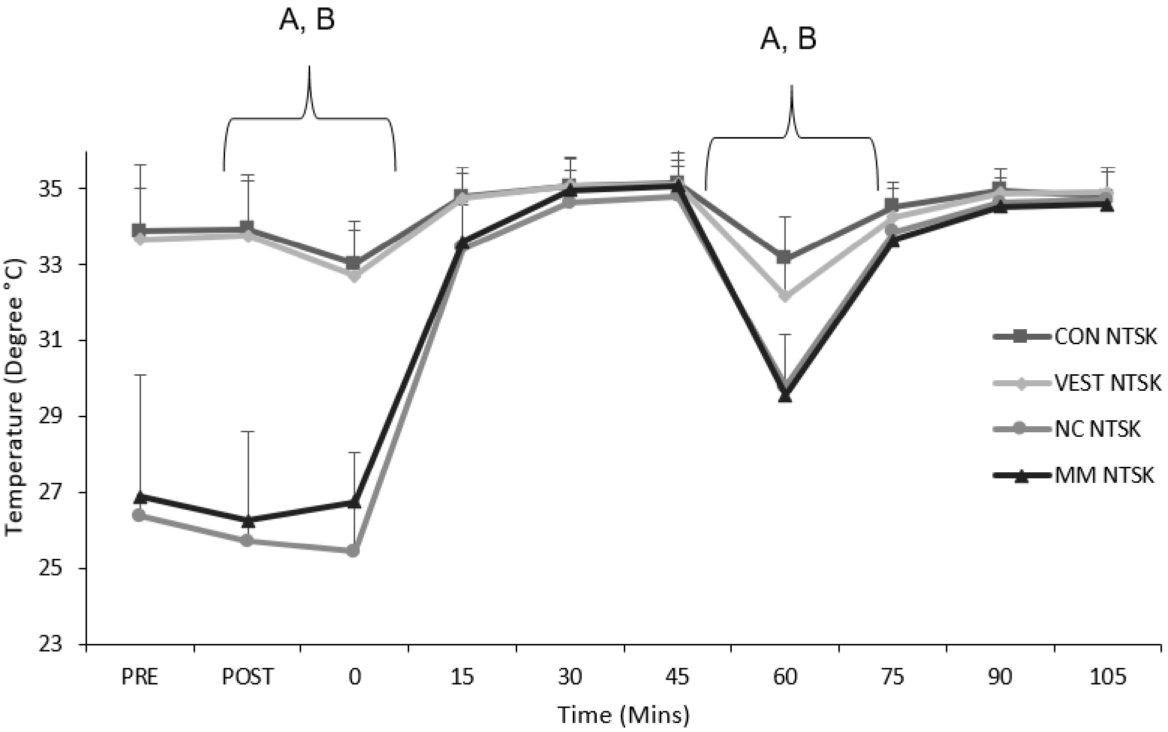

Figure 4.3: Absolute neck skin temperature during the warmup (PRE and POST), iSPT first half (0-45 min), half-time (45-60 min) and second half (60-105 min) for Control, Ice vest, Neck collar cooling, and Mixed method (n = 10). CON = No Cooling; VEST = ice vest cooling; NECK = neck collar cooling; MM = combination of both VEST and NECK. Data presented as mean ± SD. A = Significant difference between both mixed method application and Neck collar cooling to Control. B = A significant difference between Neck collar cooling and Control.

4.3.4. Heart Rate

There was no significant main effect for condition (F= 0.16 P=0.92), however a significant main effect for time (F = 162.86, P= 0.001) and no interaction effect for condition x time (F= 0.72, P = 0.84) for HR.

4.4 Perceptual Responses

4.4.1 Thermal Sensation

There was significant main effect in condition (F = 11.74; P = 0.001), time (F = 71.15, P = 0.001) and significant interaction effect in condition x time (F = 2.716; P = 0.001) for TS. Following the warm-up until the first 15-min there was a significant decline by a large effect size in TS in MM (3.30 ± 1.11) compared to CON (5.10 ± 0.73, P = 0.014, *d* = 1.9, 95%CI: 0.18 to 2.71) and by a small effect size in NECK (4.75 ± 0.92, P = 0.023, *d* = 0.4, 95%CI: 0

to 1) but only following the warmup. Following the half-time break (60-min), a significant decrease in TS by a large effect size was evident in MM (3.30 ± 0.85, P = 0.0015, *d* = 1.7, 95%CI: 0 to 2) and NECK (4.25 ± 0.75, P = 0.027, *d* = 0.5, 95%CI: 0 to 2) by a moderate effect size compared to CON (4.65 ± 0.66). At 105th-min there was a significant decline in TS in MM (6.4 ± 0.65, P = 0.031, *d* = 0.8, 95%CI: 0 to 1) by a large magnitude compared to VEST (7.00 ± 0.70). No other significant differences were evident throughout the remainder of the second half.

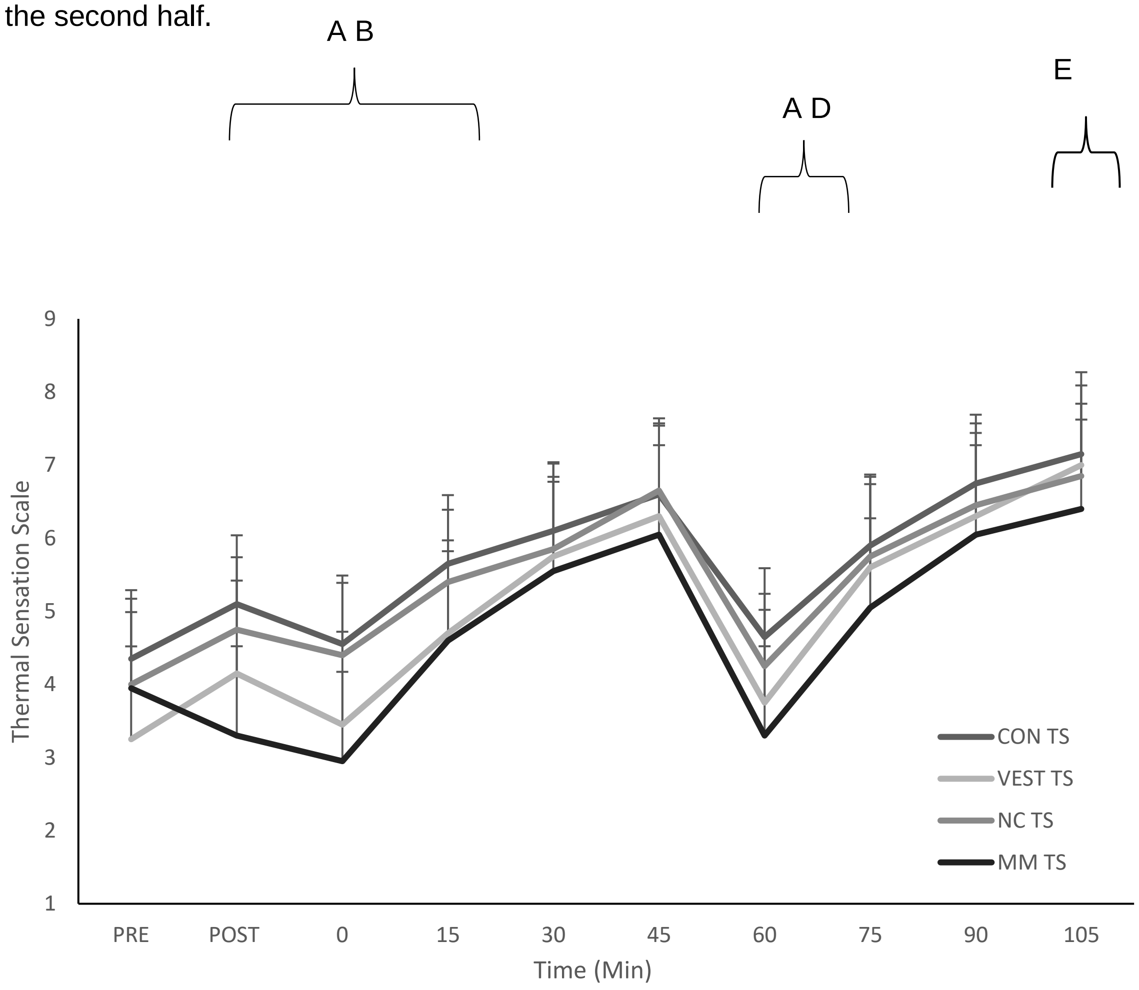

Figure 4.4: Thermal sensation during the warmup (PRE and POST), iSPT first half (0-45 min), half-time (45 – 60-min) and second half (60 – 105-min) for Control, Ice vest, Neck collar cooling, and Mixed method application (n = 10). Data presented as mean ± SD. A= Significant difference between Mixed method and Control. B = Significant Difference between Mixed method application and Neck collar cooling. C = Significant difference between Ice vest and Control. D = Significant difference between Neck collar cooling and Control. E= Significant difference between Mixed method application and Ice vest.

4.4.2. Neck Thermal Sensation

There was a significant main effect for condition (F= 12.47, P= 0.001), time (F= 74.34, P= 0.001) and there was an interaction effect for condition x time (F= 3.72, P=0.001) for $NECK_{TS}$. There was a significant decrease in $NECK_{TS}$ in NECK (2.60 ± 1.57, P = 0.004, *d* = 1.3, 95%CI: 0.041 to 3.55) and MM (2.35 ± 1.20, P = 0.008, *d* = 1.6, 95%CI: 1 to 4) by a large effect size compared to CON (4.40 ± 0.39) post-warm-up. Within the first 15-min of iSPT first half, there was a significant decrease in $NECK_{TS}$ within MM (2.85 ± 1.35, P = 0.045, *d* = 1.6, 95%CI: 0 to 3) by a large effect size compared to CON (4.55 ± 0.55). No other significant differences were evident in the first half. Following half-time at the beginning of the second half (60-min), the only significant reduction found in $NECK_{TS}$ was evident in NECK (3.2 ± 1.25, P = 0.01, *d* = 1.3, 95%CI: 0 to 2) and MM (3.1 ± 0.91, P = 0.008, *d* = 1.9, 95%CI: 0 to 3) by a large effect size compared to CON (4.65 ± 0.70). No other significant differences were evident throughout the remainder of the second half.

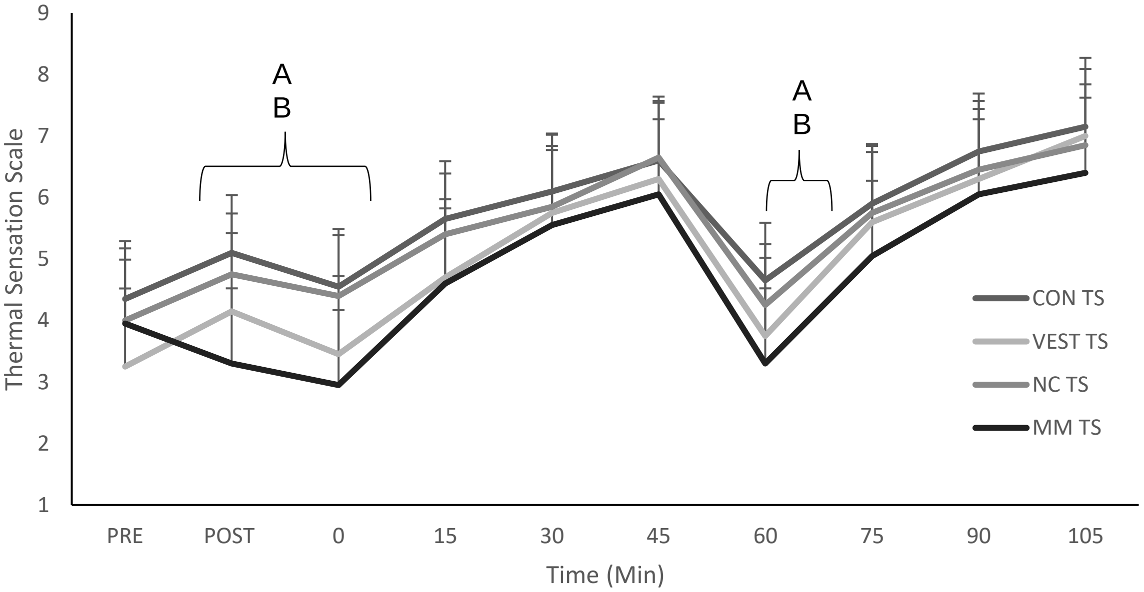

Figure 4.5: Neck thermal sensation during the warmup (PRE and POST), iSPT first half (0-45 min), half-time (45-60 min) and Second half (60 – 105 min) for Control, Ice vest, Neck collar cooling, and Mixed method (n = 10). CON = No Cooling; VEST = ice vest cooling; NECK = neck collar cooling; MM = combination of both VEST and NECK. Data presented as mean ± SD. A= Significant difference between Neck collar cooling and Control. B= Significant difference between Mixed method and Control.

4.4.3. RPE and Thermal Comfort

There was no significant main effect for condition (F= 1.50, P= 0.24), but no significant main effect for time (F = 191.65, P = 0.001), However there was an interaction effect in condition x time (F = 0.86, P = 0.66) for RPE. There was a significant main effect in time (F = 94.34, P = 0.001), however, there was no significant main effect for condition (F = 2.037, P = 0.150) and significant interaction effect in condition x time (F = 0.98, P = 0.50) for TC.

Chapter 5: Discussion

The aim of this study was to investigate the effect of ice vest (VEST), neck collar cooling (NECK) and the simultaneous use of both cooling manoeuvres (MM) compared to no cooling (CON) used within a warm-up, 12-min down time before kick-off, and at half-time physical performance and associated physiological and perceptual responses during a 90-min soccer-specific simulation, in a hot and humid environment (WBGT: 28°C). The first hypothesis was accepted as both HSD and SD covered was significantly improved in NECK and MM during the first 15 min (Table 4.2). Furthermore, SD covered was significantly improved throughout the second half in MM and during the final 30 min in NECK compared with CON (Table 4.2). Both TS and T_{sk} were significantly reduced during the first 15 min and 30 min, respectively in MM. Furthermore, only TS was significantly reduced at the end of the second half in MM, despite a reduction to all other thermoregulatory and perceptual measures being reduced at the start of the second half following the half-time cooling. Lastly, no significant differences in physical performance and its associated physiological and perceptual responses were evident in MM compared to NECK and VEST during the ISPT, which rejects the second experimental hypothesis.

5.1 Physical Performance

The TD covered throughout iSPT was not significantly improved within pre-match and half-time cooling strategy compared with CON Tables 4.1 and 4.2). This data is in line with previous soccer match-play (Duffield *et al*., 2013) at 29°C, using an ice vest, ice towel and 350ml of ice slurry ingested simultaneously. However, Duffield *et al*., (2013) utilised a soccer match-play design which demonstrates elevated match-to-match variability to key physical performance measures including high-speed running (Gregson *et al*., 2010). This could be caused by external match factors including tactics, opposition, score line etc. likely altering a player pacing strategy, particularly in a hot environment (Nassis *et al*., 2015). However, evidence from a soccer-specific simulation by, Aldous *et al*., (2019) demonstrated a moderate effect size increase in TD covered (d = 0.87 ± 0.31) during the first half of a simulated soccer match play at 30.7 ± 0.3°C and 50.9 ± 4% rH when mixed-methods cooling was applied via ice packs on quadriceps and hamstrings alongside 7.5 $g \cdot kg^{-1}$ ice slurry ingestion. This increased TD covered was attributed to a reduction in T_{re}, T_{sk} and TS throughout the first half (Aldous *et al*, 2019), which was not seen in the present study. Furthermore, Nassis *et al*., (2015) showed no significant difference in TD covered between low, moderate, and high heat stress during the 2014 FIFA World Cup in Brazil. Instead, both SD and HSD covered, were reduced at high heat stress, with TD covered being preserved by an increase to LSD covered (Nassis *et al.,* 2015). Thus, cooling strategies should not primarily focus on increasing the TD covered during match-play and instead on variables that have a relationship with the match outcome in soccer including HSD and SD covered (Faude *et al*., 2012).

The variable run during the iSPT is measured to calculate the willingness of a participant to perform high-speed running at a selected self-pace, without an external cue. However, the current study demonstrated no significant improvement to VRD covered throughout the iSPT via all cooling strategies compared to CON. Aldous *et al*., (2019) demonstrated that participants chose an increased self-selected running speed during the first half compared to CON after applying cooling modalities (internal [ice slurry] and external [ice packs]), coinciding with a reduction to both T_{sk} and TS at the same period. This caused a sensory effect, by decreasing T_{sk} and TS (Stevens *et al*., 2018) to augment exercise capacity without alterations to T_{re}. In the present study, TS was decreased only throughout the warm-up and the initial 15-min of the first half and the second half in MM compared to CON. It can be concluded that due to the sensory effect being prominent factor for increased HSD, the decline in VRD within both halves was due to TS not being significantly reduced. This could be down to the cooling modalities not providing a beneficial volume (Minett *et al*., 2011) to dampen the sensory effect consistently. Furthermore, the increased rate of HSD was likely due to the increased large magnitude in SD covered in MM at 0-15-min and during the concluding 15-min (76-105 min) in NECK compared with CON Table 4,2).

In the present study, HSD covered increased throughout the first 15-min of the first half and throughout the second half in MM compared to the CON Table 4.3), similar to previous simulated soccer data (Aldous *et al*., 2019). In the present study, locomotive muscles were not directly targeted by the cooling strategies. Intermittent sprint performance in soccer match-play has declined in both temperate and hot environments (Mohr *et al.*, 2012) as muscular activation is negatively associated by a decrease in muscle temperature (Castle *et al*., 2005). Regarding the present study, there was significant increase in SD in the first 15-min likely due to muscle temperature of the main locomotive muscles being unaffected by the vest and neck collar cooling. The significant increase to SD covered in MM and NECK continued within the second half which is likely pivotal for soccer match-play outcome, as goals are likely to be scored and conceded in the last 15-min (Armatas *et al*., 2007), and straight sprinting has been positively correlated to goals and assist (Faude *et al*., 2012). Therefore, coaches could look to use these cooling strategies in high ambient temperatures to reduce the risks of these performance indicators decreasing and therefore prevent performance to decline.

There were no significant increments to physical performance in VEST within the present study Tables 4.1 and 4.2). This shows parity with Parris and Tyler (2018) where participants wore an ice vest throughout the 90-min soccer specific protocol at 35°C and 50% rH, however, physical performance was fixed between conditions as a motorised treadmill-based soccer-specific simulation was used. Within the present study, the ice vest was utilised during both during the warm-up and organised breaks (e.g., pre-match and half-time) showing good ecological validity with soccer match-play (Taylor and Rollo). In the present study, NECK increased SD covered in the first 15-min of the first half of iSPT compared with

CON. Sunderland *et al*., (2015) study who utilised a neck cooling throughout a soccer-specific intermittent exercise protocol at 33°C and 53% rH showed that mean peak output (539.9 ± 98.8 W) and peak power output (718.8 ± 158.0 W) was increased compared to CON (MPO, 506 ± 121.7, *d* = 0.32; PPO: 680.2 ± 182, *d* = 0.21) by neck cooling in the latter stages of the protocol. The increased warm-up duration within the present study (24-min) compared to the shorter warm up (5-min) used by Sunderland *et al*, (2015) could have provided significance, as an increase muscle temperature has been shown to be beneficial on sprinting performance (Gray *et al*., 2006) hence the initial increments in SD earlier in the present study compared to Sunderland *et al*., (2015). Furthermore, Sunderland *et al*., (2015) demonstrated a lowered $NECK_{TS}$ from neck collar cooling compared with no-cooling ($P < 0.001$ $d = 1.34$) when both PPO and MPO were significantly increased. However, the application of the neck cooling collar was throughout the full exercise protocol which is contradiction to laws of soccer match-play and lacks ecological validity.

5.2 Physiological and perceptual responses

The T_{re} was not significantly different throughout the warm-up and both halves of iSPT, aligned with previous research using neck cooling (Sunderland *et al*., 2015). The neck collar cooling does not target an area where core temperature is manipulated meaning it did not implement a sufficient volume of cooling to reduce T_{re} (Minett *et al*., 2011). In contrast, Price *et al*., (2009) analysed the effect of ice vest cooling on PRE (20-min cooling) and mid-cooling (15-min at half time) within an intermittent protocol, with two 45-min halves in the heat. Results found a 0.2°C decline ($P < 0.05$) in T_{re}, but the cooling strategy was utilised 20-min prior to a 10-min warm-up, whereas the present study utilised a 24-min soccer-specific warm-up which increased metabolic heat production and damped the effect of the cooling due to the increase temperature in T_{sk} and T_{re}. Parris and Tyler (2018) also demonstrated a reduction to T_{re} with the use of an ice vest from the 60th to the 90th min of a soccer-specific protocol. The ice vest targets a large surface area, which decreases both T_{re} and T_{sk}

simultaneously and increases the heat storage capacity due to an increased gradient between T_{sk} and T_{re} (Nybo *et al*., 2014). However, the ice vest was utilised throughout both halves of the exercise protocol, and this demonstrates disparity with the laws of association football (Taylor and Rollo, 2014).

An increase in T_{re} during soccer match-play in hot environments are no correlated ($r = -0.53$, $p = 0.05$) with any decrements in physical performance (Mohr *et al*., 2012). Furthermore, Aldous et al., (2019) highlighted that TD and HSD covered are both predicted by changes in T_{sk} and TS. Therefore, cooling interventions may target both peripheral (T_{sk}) and perceptual (TS) measures rather than T_{re} due to their association with the match outcome (Faude *et al*., 2012). Within the present investigation, VEST decreased T_{sk} throughout the warm-up (37.72 ± 1.9°C, P = 0.005) compared to CON (32.08 ± 1.1°C). Alongside VEST, MM reduced T_{sk} in the first 30-min of the first half (Figure 4.2). This is consistent with Price *et al.,* (2009) who found pre-cooling and 15-min half-time cooling concluded to a reduced T_{sk} in the first 5-min of both halves. Furthermore, TS was unaffected in VEST alone but there was significant decline in MM (3.30 ± 1.11, P = 0.014) and NECK (4.75 ± 0.92, P = 0.023) in the both first 15-min in first and second half ({MM} 3.30 ± 0.85, P = 0.0015, {NECK} 4.25 ± 0.75, P = 0.0027). This was due to the MM and NECK both targeting areas of high allesthesial thermosensitivity which dampens the perceptual strain. The MM only decreased TS in the last 15-min in the second half (6.4 ± 0.65, P = 0.031) which corresponds with why there was an increased HSD and SD in the last 15-min due larger skin surface area targeted combined with the NECK dampening the sensory effect.

The use of NECK and MM significantly reduced $NECK_{TS}$ and $NECK_{Tsk}$ throughout the warm-up, first 15-min of the first half and at the start of the second half (Figure 4.3). The current findings show comparability with previous studies which utilised NECK (Sunderland *et al*., 2015; Tyler and Sunderland 2011a), but these reductions continued further within these studies which is inconsistent to the present investigation. The result of this could be in response of neck cooling collar being applied throughout the exercise protocol which contradicts soccer match-play laws. However, the benefit of a neck cooling collar being replaced after every 30-min (6.9%) versus continual neck collar use throughout (7.3%), (Sunderland and Tyler, 2011b) found no collective effect on time trial performance even though there was a significant reduction to $NECK_{Tsk}$.

Half-time cooling within the current study has shown to be successful due to the increase in SD covered throughout the 2nd half of the ISPT, despite the physiological and perceptual measures only being reduced at the start of this time. It needs to be considered that increased heat production occurs not only within the warm-up but continued through into the first half which is in the body periphery's (Minett *et al*., 2012). Thus, an increased volume and duration may be required to reduce these physiological and perceptual variables throughout the second half (Minett *et al.,* 2011; 2012). Minett *et al*., (2011) has shown that 5-min of whole-body cooling (VEST), ice packs on quadricep, ice towel on neck and head) significantly reduced T_{re} and T_{sk} throughout the second half of the intermittent sprint protocol (2 x 35-min) in an ambient temperature of 33°C. However, expansive cooling could potentially prevent the increase in SD covered, as a reduction in locomotive muscle temperature has a relationship with decrements in SD performance (Gray *et al.*, 2006). Therefore, expanding the cooling may cause detriment to soccer performance rather than the enhancement coach's desire.

5.3 Limitations and Directions for future research

The use of a non-motorised treadmill-based soccer-specific simulation promotes players to express their true maximal capacity without being fixed to cover the same distance as other participants (Barrat *et al.*, 2013). However, during sprinting opportunities within the iSPT, the heaviness and resistance of the treadmill belt could have prevented true maximal speed occurring during each experimental condition (Aldous *et al.*, 2014). As peak sprint speed was used to individualise (Aldous *et al.*, 2014) as opposed to setting the running speeds to the work rate of the average player, participants with a greater maximal speed were able to demonstrate their maximal capacity (Lakomy *et al,* 1987). However, players with increased maximal sprint speed and a lower aerobic capacity, may demonstrate fatigue responses increased within the latter stages, further exacerbated within hot environments (Aldous *et al,* 2016).

Following this investigation, further research is needed regarding utilising cooling modalities on cognitive function which is known to deteriorate at T_{re} of 39°C and causes decline in complexity tasks (decision making) , crucial with soccer match-play outcome (Taylor *et al*., 2015) Furthermore, Chalmers *et al*., (2019) analysed the effect of introducing 3-min water break at the 30th-min of each half, with cooled water or ice towel around the neck and an elongated half-time break (extra 5-min). The rationale to conduct the study was through acknowledgement of increasing T_{re} in the 30th-min of soccer match-play, shown by FIFA (Ozgunen *et al*., 2010). The T_{re} significantly reduced when the 3-min water breaks were applied and during the cold-water condition (-0.25°C), cold towel (-0.28°C) and an extended half-time (-0.21°C) compared to CON ($P < 0.05$). This intervention could work alongside the present study cooling modalities to also target T_{re} during the exercise performance potentially minimising the risk of an exertional heat illness occurring during the latter stages of match-play (Chalmers *et al*., 2019).

5.4 Practical implications

Overall, the study indicates that the simultaneous use of neck cooling collars and ice vests during a soccer specific warm-up, downtime before kick-off and at half-time can augment soccer performance in WBGT of 28°C. This is crucial for team sports coaches to consider as T_{re}, T_{sk} and perceptual responses exacerbate in high ambient temperatures of 30-43°C as witnessed in both soccer match-play (Mohr *et al*., 2012) and simulated soccer protocols (Aldous *et al*., 2016). Future competitions such as the upcoming 2022 and 2026 FIFA World

Cup in Qatar and North and Central America, respectively where ambient temperatures are prominent, the MM approach should be utilised to prevent negative match-play outcome. This would be essential as there are currently no restrictions of applying cooling throughout the warm-up and at half-time periods (Aldous *et al*., 2019).

5.5 Conclusion

To conclude, cooling during a warm-up, downtime before kick-off and half-time via neck collar cooling and an ice vest used simultaneously in MM significantly improved SD and HSD in the first 15 min of the first half and showed a significant improvement to SD covered throughout the second half, accepting the first experimental hypothesis. There was no significant difference between MM, NECK, and VEST, rejecting the third hypothesis. The significant improvement to SD and HSD covered during the first 15 min in NECK and MM, coincided with a decrease with thermal sensation until 15 min and T_{sk} until 30 min. However, only TS was significantly reduced at the end of the second half in MM, with no other differences in physiological and perceptual strain being evident during the second half. Therefore, the mixed methods cooling via the simultaneous use of an ice vest and neck cooling collar was the most effective strategy to enhance key physical performance variables during soccer performance in the heat when used throughout a warm-up, prior to kick off and at half time in the heat.

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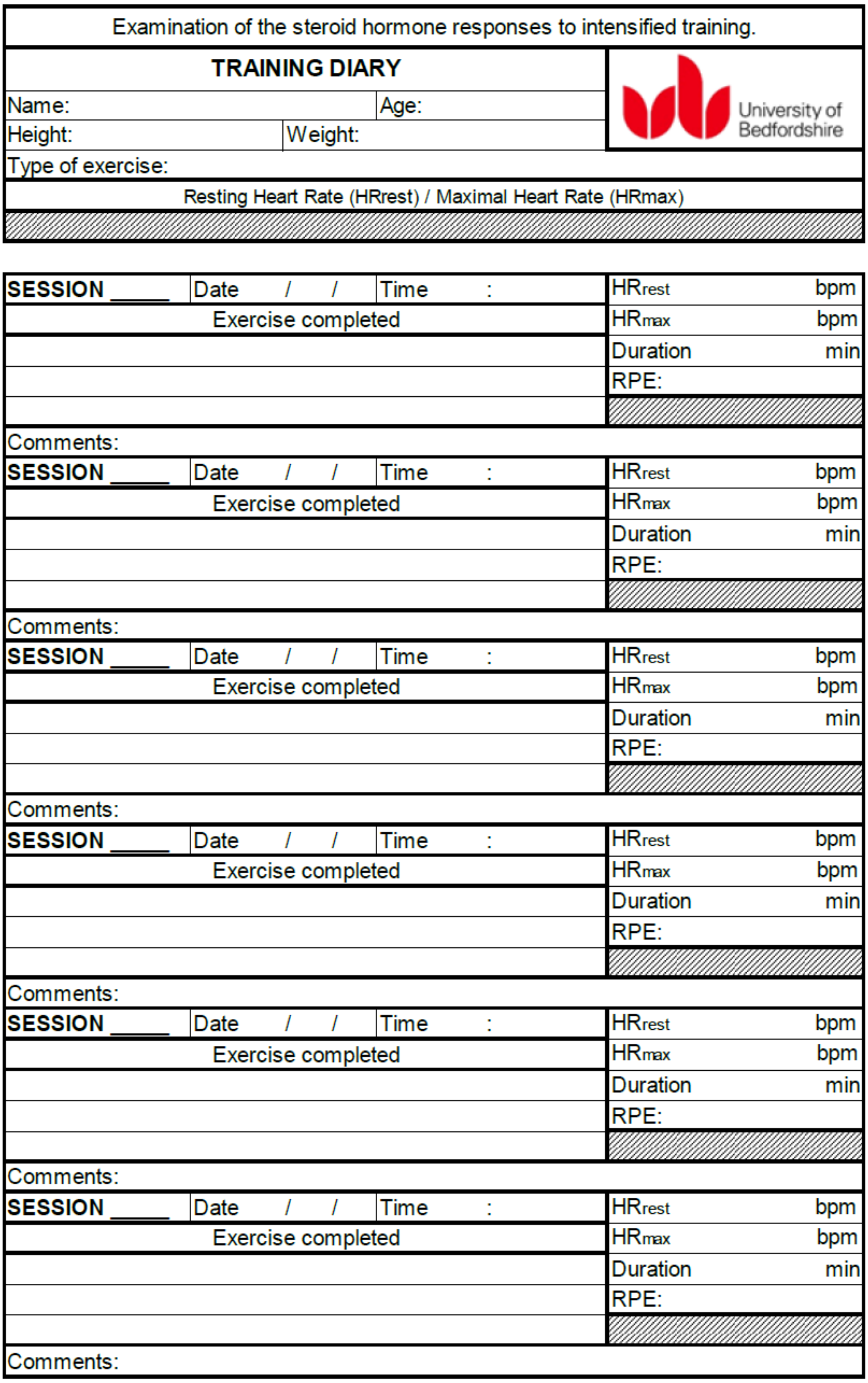
Day 1

Appendix

Appendix A. A 24-hr food diary

Date and time of day	Brand name	Detailed description of food/drink and cooking method (e.g. boiled potatoes, canned sweetcorn, bacon fried in sunflower oil)	Amount served (grams/ approx. portion)	Did you leave any? How much did you leave?

Appendix B. A 7-day training log



Examination of the steroid hormone responses to intensified training.		
TRAINING DIARY		University of Bedfordshire
Name:	Age:	
Height:	Weight:	
Type of exercise:		
Resting Heart Rate (HRrest) / Maximal Heart Rate (HRmax)		

SESSION _____	Date / /	Time :	HRrest bpm
Exercise completed			HRmax bpm
			Duration min
			RPE:
Comments:			

SESSION _____	Date / /	Time :	HRrest bpm
Exercise completed			HRmax bpm
			Duration min
			RPE:
Comments:			

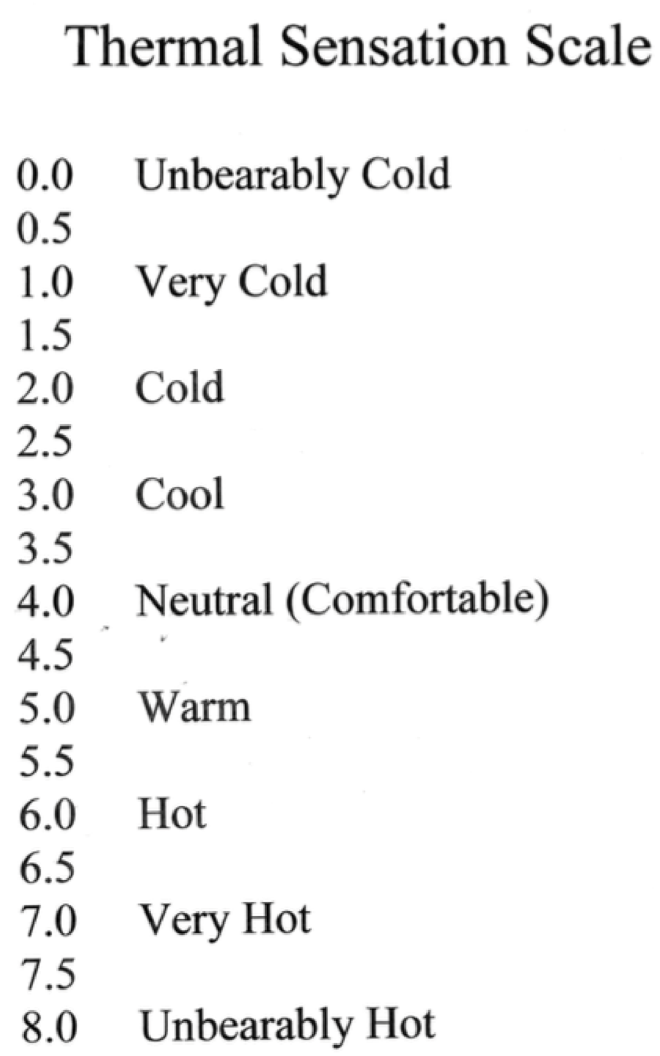
SESSION _____	Date / /	Time :	HRrest bpm
Exercise completed			HRmax bpm
			Duration min
			RPE:
Comments:			

SESSION _____	Date / /	Time :	HRrest bpm
Exercise completed			HRmax bpm
			Duration min
			RPE:
Comments:			

SESSION _____	Date / /	Time :	HRrest bpm
Exercise completed			HRmax bpm
			Duration min
			RPE:
Comments:			

SESSION _____	Date / /	Time :	HRrest bpm
Exercise completed			HRmax bpm
			Duration min
			RPE:
Comments:			

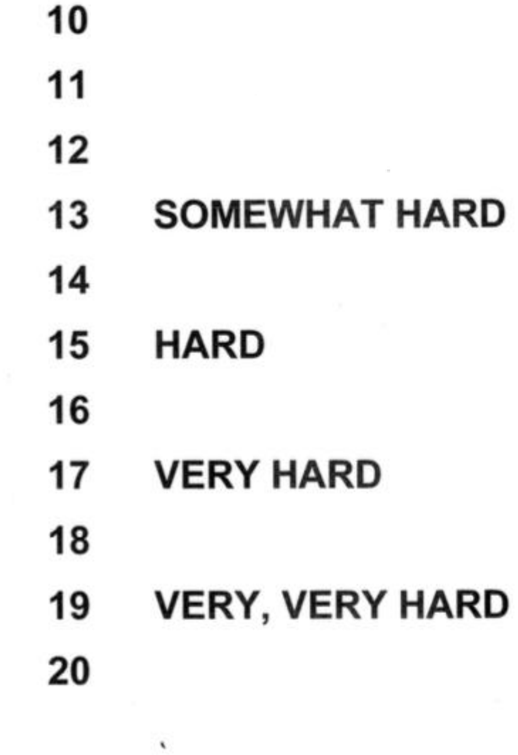
Appendix C: Thermal Sensation Scale and Thermal Comfort



Thermal Sensation Scale

0.0	Unbearably Cold
0.5	
1.0	Very Cold
1.5	
2.0	Cold
2.5	
3.0	Cool
3.5	
4.0	Neutral (Comfortable)
4.5	
5.0	Warm
5.5	
6.0	Hot
6.5	
7.0	Very Hot
7.5	
8.0	Unbearably Hot

Appendix D: Rate of Perceived Exertion Scale



P

6	
7	
8	
9	
10	
11	
12	
13	SOMEWHAT HARD
14	
15	HARD
16	
17	VERY HARD
18	
19	VERY, VERY HARD
20	