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Title: Practical Cooling Manoeuvres During Simulated Soccer in the Heat

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“Practical Cooling Manoeuvres During Simulated Soccer 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

By

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Declaration

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List of Abbreviations, Symbols and Acronyms

%	Percentage
°	Degrees
°C	Degrees celsius
<	Less than
>	Greater than
~	Approximately
b.min^{-1}	Beats per minute
CHO-E	Carbohydrate-Electrolyte
d	Day
FAM	Familiarisation
FIFA	Federation International Football Association
G	Grams
H	Hour
Hb	Hemoglobin
Hct	Haematocrit
HR	Heart rate
HSD	High-speed distance
Hz	Hertz
iSPT	intermittent Soccer Performance Test
kg	Kilogram
kJ	Kilojoules
km	Kilometre
km.h^{-1}	Kilometre per hour

m	Metre
$m.s^{-1}$	Metre per second
min	Minute
mL	Millilitre
NECK	Neck cooling
$neckT_{sk}$	Neck skin temperature
NECK+VEST	Ice vest and neck cooling
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
SMS	Soccer match simulation
TD	Total distance
T_{re}	Rectal temperature
TS	Thermal sensation
T_{sk}	Skin temperature
TS_{neck}	Neck thermal sensation
UEFA	Union of European Football Associations
UK	United Kingdom
VEST	Ice vest cooling
W	Watts

$\dot{V}O_{2max}$	Maximal oxygen uptake
VRD	Variable run distance
YYIRT1	Yo-Yo Intermittent Recovery Test level 1

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Abstract

The globalisation of soccer match-play has meant that major international and domestic competitions typically occur in hot environments with ambient temperature exceeding 28°C (Taylor and Rollo, 2014). Previous simulated (Aldous et al., 2016) and soccer match-play data (Mohr et al., 2012) in the heat (30 - 43°C) have reported significant reductions in physical performance measures when compared to a temperate environment (18 - 21°C). Practical strategies to reduce these heat-mediated decrements in physical performance whilst fitting in with the time constraints practitioners are faced with in soccer are warranted (Taylor and Rollo, 2014; Russel et al., 2015). Therefore, the aim of the present investigation is to examine the efficacy of practical cooling manoeuvres which can be actively worn during a pre-match warm-up and whilst conducting general changing room preparatory tasks (downtime prior to kick off and half-time) on simulated soccer performance in a hot environment (32°C and 60% rH; WBGT: 28°C). Seven male university level soccer-players completed one Yo-Yo Intermittent Recovery Test level 1, two familiarization sessions, one peak speed assessment and four randomized, counterbalanced experimental trials of the intermittent Soccer Performance Test (iSPT) at 32°C. Four experimental trials consisted of cooling during a soccer-specific pre-match warm-up (~24 min), downtime prior to kick-off (12 min) and half-time interval (10 min) via (1) Ice Vest (VEST); (2) Neck Cooling (NECK); (3) VEST and NECK (VEST+NECK) used concurrently; or with no-cooling (CON). Physical performance [total distance (TD), high-speed distance (HSD), sprint distance, variable run distance (VRD) and low-speed distance (LSD) covered], body temperatures [rectal temperature (T_{re}), mean skin temperature (T_{sk}) and neck temperature ($neckT_{sk}$)], physiological [heart-rate (HR) and change in body-mass] and perceptual response [rate of perceived exertion (RPE), thermal comfort (TC), thermal sensation (TS) and neck thermal sensation (TS_{neck})] were all measured. When compared to CON, sprint distance covered was significantly improved ($P < 0.05$) during the first and last 15 min in NECK, final 15 min in VEST, and final 30 min in VEST+NECK during iSPT, respectively. In

VEST, T_{sk} was significantly reduced ($P < 0.05$) until 15 min of iSPT compared to CON. In NECK and VEST+NECK, TS_{neck} and neckT_{sk} were significantly reduced ($P < 0.01$) prior to the start of iSPT with neckT_{sk} also significantly lower post half-time cooling, compared to CON. Furthermore, VEST+NECK also significantly reduced ($P < 0.05$) TS prior to the start of iSPT, compared to CON. No further significance ($P > 0.05$) was observed for physical performance, physiological or perceptual responses during iSPT for all conditions. Pre- and half-time cooling via VEST+NECK was most ergogenic and significantly improved sprint performance during the final 30 min of iSPT in 32°C, important given the prominence of sprinting prior to goals and assists during soccer match-play (Faude et al., 2012). Further research with a larger sample size is warranted to further elucidate the mechanisms for the enhanced performance.

Chapter 1: General Introduction

1.1. General Introduction

Soccer is a prolonged, high-speed, intermittent team-sport (Stolen et al., 2005), consisting of two 45-minute halves, interspersed by a 15-minute interval (IFAB, 2019). A soccer-player's physical performance is typically characterised by their total distance covered at varying intensities throughout soccer match-play (Mohr et al., 2003). However, high-speed running and sprinting are of higher importance during soccer match-play due to their association with the match outcome (Gregson et al., 2010; Faude et al., 2012). Furthermore, these soccer-specific physical demands rely upon both aerobic and anaerobic energy provision to support the complex interaction between the cardiovascular and muscular systems (Bangsbo, 2014; Taylor and Rollo, 2014).

The globalisation of soccer has meant that major international and domestic competitions have previously been played in countries with typically high ambient temperatures (Nassis et al., 2015), including the 2014 *Fédération Internationale de Football Association* (FIFA) World Cup in Brazil, (22 - 35°C) and *Union of European Football Associations* (UEFA) Champions League in Spain, Portugal, Turkey and Greece (25 - 35°C). Similarly, forthcoming international tournaments are scheduled in countries where high ambient temperatures are expected such as the 2022 FIFA World Cup in Qatar (~24 - 38°C). Both simulated (Aldous et al., 2016) and soccer match-play data (Mohr et al., 2012) in high ambient temperatures (30 - 43°C) demonstrates a significant decrease in several physical performance measures (total, high-speed and sprint distance covered) compared to temperate conditions (18 - 21°C). Furthermore, although the exact mechanisms underpinning these heat-mediated reductions in physical performance are not clear, a complex interplay between peripheral (feedback) and central factors (feed forward) are known to occur during intermittent soccer-specific exercise (Taylor and Rollo, 2014). Furthermore, despite reports highlighting elevated core temperatures (>

39°C) have been shown to impair intermittent and repeated sprint performance (Girard, Brocherie and Bishop, 2015), these reductions in physical performance during soccer match-play are not simply a cause of an individual's absolute core body temperature (Mohr et al., 2012). Instead, simulated soccer data in the heat (30°C and 50% rH) has demonstrated that an absolute rise in both skin temperature and thermal sensation predicted a reduction in both total and high-speed distance covered (Aldous et al, 2016). Thus, both perceptual (thermal sensation and rate of perceived exertion) and physiological factors (core body temperature and skin temperature) amongst other factors, are likely central to decrements in physical performance during soccer match-play in hot environments (> 30°C). Therefore, strategies to reduce these heat-mediated decrements in physical performance are warranted, and thus, could target both of these perceptual and physiological factors.

The most prevalent strategy to alleviate any heat-mediated decrements in physical performance is heat acclimatisation or acclimation (Racinais, et al., 2015). However, this gold standard method can take up to 14 days to be optimal (Périard, Racinais and Sawka, 2015), which lacks practicality in domestic club soccer due to limited time and congested fixture scheduling (Taylor and Rollo, 2014). Therefore, practical strategies such as cooling manoeuvres, which can be actively worn during a pre-match warm-up and whilst seated during the half-time interval without negatively affecting soccer-players ability to conduct generic pre-match or half-time duties would be beneficial to coaches, sport scientists and players in soccer (Towelson et al., 2013; Taylor and Rollo, 2014). Ice vests and neck cooling collars are both practical cooling manoeuvres previously reported to improved exercise capacity (Tyler et al., 2011a; Luomala et al., 2012), endurance (Arngrimsson et al., 2004; Tyler, Wild and Sunderland, 2010) and intermittent performance (Castle et al., 2006; Sunderland et al., 2015) in the heat (30 - 34°C). Previous simulated soccer data in the heat utilising ice vests [31°C and 63% rH (Price, Boyd and Goosey-Tolfrey, 2009)] and neck cooling collars [33°C and 53% rH (Sunderland et al., 2015)] have reported reductions in physiological strain (mean skin temperature and rectal temperature) and/or perceptual stress (neck skin temperature, neck thermal sensation and rate of perceived exertion), respectively. However, the cooling manoeuvres were not utilised during a practical warm-up and changes in key physical performance measures (high-speed distance and sprint distance covered) related to the match outcome were not measured (Gregson et al., 2010), as the soccer-specific simulations were fixed distance protocols (Price, Boyd and Goosey-Tolfrey, 2009; Sunderland et al., 2015). Additionally, a combination approach to cooling is reported to be most beneficial to enhanced exercise performance as per recent meta meta-analysis reviews (Bongers et al., 2014; Bongers et al., 2017), and is further supported during simulated (Aldous et al., 2018) and match-play studies (Duffield et al., 2013).

Therefore, the aim of this thesis was to investigate the effect of three different pre- and half-time cooling maneuvers (ice vest, neck cooling or ice vest and neck cooling) compared with a control (no-cooling) on physical performance, physiological and perceptual responses during simulated soccer in a hot environment (32°C and 60% rH; WGBT: 28°C).

Chapter 2: Literature Review

2.1. Soccer Match-Play Characteristics

Association Football (Soccer) is a prolonged, high-speed, intermittent team-sport (Stolen et al., 2005), consisting of two 45 min halves, with a 15 min half-time interval (IFAB, 2019). Success during soccer match-play is dependent upon a plethora of technical, physical, tactical and physiological factors (Smith, Marcora and Coutts, 2014). Therefore, soccer match-play is multifaceted with the intense physical demands required alongside the repeated execution of complex motor skills under high physiological strain (Rampinini et al., 2009).

2.2. Physical Performance in Soccer Match-play

Soccer-players typically cover between 10 - 13 km during 90 min of soccer match-play (Stolen et al., 2005; Di Salvio et al., 2012). The total distance covered during soccer match-play are typically organised into speed categories including standing (0.0 - 0.6 $km \cdot h^{-1}$), walking (0.7 - 7.1 $km \cdot h^{-1}$), jogging (7.2 - 14.3 $km \cdot h^{-1}$), running (14.4 - 19.7 $km \cdot h^{-1}$), high-speed running (19.8 - 25.1 $km \cdot h^{-1}$) and sprinting [> 25.1 $km \cdot h^{-1}$ (Bangsbo et al., 2006; Di Salvio et al., 2006; Bradley et al., 2009)]. However, total distance covered appears not to be a suitable indicator of physical performance relating to success during soccer match-play (Di Salvio et al., 2012; Paul, Bradley and Nassis, 2015). Di Salvio et al. (2012) supports this notion by highlighting a significant decrease ($P < 0.001$) in total distance covered between elite English players (10,746 ± 964 m), when compared directly to their second division counterparts (11,102 ± 916 m). Although the majority of distance covered during soccer match-play is at low/moderate speed intensities [standing (1.7 - 18.6%), walking (43.6 - 61.3%), jogging (19.1 - 30.3%) and running (6.4 - 9.4%)], high-intensity running (1.9 - 7.1%) and sprinting (0.6 - 2.1%) make up a smaller proportion of soccer match-play but are central to game defining moments (Bradley et al., 2009; Gregson et al., 2010; Carling et al., 2012). Furthermore, the intermittent nature of soccer means players are required to repeatedly sprint throughout match-play (Di Mascio et al., 2013).

This ability to consistently produce sprint throughout match-play is of great significance due to the prominence of straight sprints in the moments preceding goals (61%) and assist (67%) during soccer match-play (Faude et al., 2012). Furthermore, these facets of performance (high-intensity running and sprinting) are markedly reduced ($P < 0.05$) in the second-half (45-90 min) of match-play compared to the first [0-45 min (Mohr et al., 2003)]. Moreover, when compared to moderate standard soccer-players, higher standard soccer-players covered a significantly ($P < 0.05$) greater amount of high-intensity running [28% (2.43 ± 0.14 versus 1.90 ± 0.12 km)] and sprinting [58% (0.65 ± 0.06 versus 0.41 ± 0.03 km)] during soccer match-play (Mohr et al., 2003). Indeed, high speed-running and straight sprinting have been suggested as a valid measurement of physical performance during soccer match-play (Gregson et al., 2010). Therefore, strategies to improve these physical performance measures or offset the decrement between halves would be of great use to coaches, sport scientists and players within soccer (Taylor and Rollo, 2014).

Ascertaining inferences from strategies on physical performance during soccer match-play however, is difficult (Taylor and Rollo, 2014). Numerous studies have reported a high match to match variation between elite soccer matches in multiple performance measures [technical and physical (Mohr et al., 2003; Gregson et al., 2010)]. Although the factors underpinning these variations have been suggested to be as a consequence of multiple match factors including difference in activity profile relating to playing position (Di Salvio et al., 2007), dependent upon the quality of the opposition team (Rampinini et al., 2007), playing standard [elite versus moderate standard professional players (Mohr et al., 2003)], score line (Reilly, Drust and Clarke, 2008), or due to changes within player, the condition of the player, environment or tactical role within the team (Gregson et al., 2010). Therefore, minimising the aforementioned match factors is of imperative importance for predicting statistical power as well as how worthwhile a certain intervention upon soccer-specific physical performance may be (Gregson et al., 2010; Taylor and Rollo, 2014).

2.3. Physiological Responses to Soccer Match-play

The physical demands of soccer match-play are attributed to a complex interaction between both the cardiovascular and muscular systems to support energy provision for both the aerobic and anaerobic energy systems (Taylor and Rollo, 2014). The majority (90.8 - 97.5%) of the total distance covered (10 – 13 km) throughout soccer match-play is at low or moderate intensities (> 19.8 $km \cdot h^{-1}$), from which the aerobic energy system is likely to be highly taxed (Bangsbo, 1994; Bangsbo, Mohr and Krustrup, 2006). However, anaerobic energy provision often contributes to game defining moments (Gregson et al., 2010), thus, highlighting the importance of both energy systems during soccer match-play (Bangsbo et al., 2014).

Aerobic energy provision during bouts of intermittent exercise is imperative, those with a greater capacity for aerobic energy transfer during soccer match-play are more likely to excel (Bangsbo, 1994). Reliance upon the aerobic energy system is demonstrated with average and peak heart-rates during soccer match-play of ~85% and ~98% of their maximal values, respectively (Bangsbo, 1994; Krustrup et al., 2005), corresponding to around 70% of maximum oxygen uptake (Bangsbo, 2014). Anaerobic energy provision initially supports short explosive sprints during soccer match-play through the re-synthesis of stored phosphocreatine and adenosine triphosphate (Buchheit, 2010). Although, when anaerobic exercise exceeds ~90 s there is a greater reliance upon aerobic energy provision to maintain muscle metabolism via an increased oxygen transport to the exercising muscles as a result of reduced regeneration of stored phosphate (Gastin et al., 2001). Indeed, although the anaerobic energy system is capable of responding immediately to high-intensity energy demands, it is limited in its capacity, however, is compensated by an increase in aerobic energy turnover (Gastin et al., 2001). Highlighting that aerobic energy provision may have a greater role during repeated-sprint exercise in the latter stages of soccer match-play, important considering most goals are reportedly scored and conceded during this period (Armatas et al., 2007).

Soccer-players are required to change their given activity every 4 - 6 s which equates to approximately 1,300 actions throughout soccer match-play (Rampinini et al., 2011), with 150 - 250 actions consisting of brief, intense activities (Mohr et al., 2003). Correspondingly, the anaerobic energy systems are highly taxed as a result of these intense activities (tackling, jumping, change of direction, high-speed running and sprinting), especially following the most intense periods of a game (Mohr, Krustrup and Bangsbo, 2005). During intense exercise, the provision of anaerobic energy encompasses two energy systems; i) the adenosine triphosphate-phosphocreatine system and ii) the anaerobic glycolysis system (Bangsbo, 1993; Abt, 2002). During intense and explosive exercise movements in the absence of oxygen, the adenosine triphosphate-phosphocreatine system provides energy for physical performance whereby phosphocreatine is split to provide inorganic phosphate to donate to adenosine diphosphate and adenosine monophosphate (Gastin, 2001; Kreider et al., 2017). During the initial phase of anaerobic activity such as a jump/sprinting action during soccer match-play, the adenosine triphosphate-phosphocreatine system is active as these bouts of activity are short in duration (< 3.5 s) and infrequent (Gastin, 2001; Faude et al., 2012). Adenosine triphosphate production via anaerobic glycolysis does not reach its maximal rate until after ~5 s (Gastin, 2001; Abt, 2002). Which occurs when there is a lack of oxygen via the breakdown of muscle glycogen sourcing the formation of pyruvate, and subsequently lactic acid which is rapidly converted to blood lactate (Krustrup et al., 2006; Spriet, 2006). Both aforementioned anaerobic energy pathways are apparent during soccer match-play and thus, are of great importance due to the prominence of power and speed abilities prior to decisive situations in soccer match-play (Faude et al., 2012).

The rate of anaerobic energy turnover during periods of soccer match-play is high, which leads to a high rate of creatine phosphate breakdown (Bangsbo, 1994). Analysis of creatine phosphate in muscle biopsies have reported only 70% of resting values, due to obvious limitations in the delay in obtaining samples during soccer match-play whereby re-synthesis had undoubtedly occurred (Krustrup et al, 2006). Furthermore, following these highly intense periods, soccer-players require a period of low/moderate intensity activity in order to remove the accumulation of lactate from their working muscles (Mohr et al., 2003; Bangsbo et al., 2014).

However, it is difficult to render inferences upon the physiological responses due to the inherent difficulties in obtaining certain physiological measures (blood samples) during soccer match-play. Therefore, gaining inferences from how worthwhile a certain intervention may be upon the physiological responses to soccer match-play, should utilise a well formulated soccer-specific simulation for greater experimental control (Taylor and Rollo, 2014).

2.4. Heat Stress and Soccer

2.4.1. Instances of Heat and Soccer

Competitive soccer is commonly played within hot environments (Taylor and Rollo, 2014). Additionally, several major international competitions are competed during the European Summer (June and July) where high ambient temperatures are typically experienced [U20 2013 FIFA World Cup in Turkey (25 - 35°C)]. Due to the globalisation of soccer, forthcoming international tournaments are scheduled to be held in climates with expected high ambient temperatures including the 2022 FIFA World Cup in Qatar, Doha (~24 - 38°C) and the 2026 FIFA World Cup in North America, USA, Mexico and Canada, (~24 - 41°C). Furthermore, due to potential temperatures as high as 45 - 50°C being encountered, the 2022 FIFA World Cup in Qatar was rescheduled to the winter months, for the first time in the history of the competition (FIFA, 2018). Although rearranged, average temperatures in November and December are 29 and 24°C, respectively, with temperatures potentially reaching as high as 38°C (BBC Sport, 2015). These high ambient temperatures are also experienced during domestic soccer including UEFA Champions League and Europa League fixtures in Spain

(Madrid and Seville) and Portugal (Porto and Lisbon), respectively (25 - 35°C). Furthermore, these domestic fixtures typically occur during the latter stages of the season when important fixtures occur (e.g. cup semi/finals) and residual fatigue is increased, due to high number of previous matches. The prominence of heat in soccer is further illustrated in figure 2.1.

Decrements in soccer-specific performance measures occur in a somewhat linear fashion as ambient temperature increases above 25°C (Mohr et al., 2003), from which a similar relationship on exercise performance occurs with increasing relative humidity [rH (Maughan et al., 2010)]. Furthermore, the combination of elevated temperatures and rH exacerbate these performance decrements (Taylor and Rollo, 2014). Indeed, when the environmental temperature exceeds skin temperature, heat is inevitably gained in addition to metabolic heat production from the exercising muscles (Periard, Racinais and Sawka, 2015). Although evident that increases in body temperatures play an integral role in the heat-mediated decrements, the precise mechanisms by which exercise-heat stress reduces exercise performance is unclear, with an intricate interplay between peripheral (feedback) and central factors (feed forward) known to occur (Taylor and Rollo, 2014). Previous soccer match-play data from the 2014 FIFA World Cup in Brazil (Nassis et al., 2015) reported decrements in the total number of sprints (~10%) and high-intensity running under high heat-stress (28 - 33°C and 50% rH; 25 - 29°C and 75% rH), important given the association of high-speed running with game defining moments and sprinting prior to decisive situations, combined with upcoming tournaments where high ambient temperatures and rH are likely to be experienced (figure 2.1).

2.4.2. Heat Balance Equation

The fundamental issue during heat-situated soccer match-play, is a compromised heat exchange process (Maughan et al., 2010). Physical exercise is accompanied by metabolic heat production due to skeletal muscle contractions which increased body temperatures (Nybo, Rasmussen and Sawka, 2014). Heat produced by the exercising-muscles is transferred to the surrounding skin and to the body's trunk and head through circulating blood via vasodilation and vasoconstriction (Crandall and Gonzalez-Alonso, 2010; Gonzalez-Alonso, 2012). Heat-dissipation response of sweating and skin blood flow are elicited to sufficiently match heat production and achieve a new thermal balance (Nybo, Rasmussen and Sawka, 2014). However, elevations in skin temperature are proportionate to the environmental temperature (Gagge and Gonzalez, 1973; Adams, 1977), when the environment is warmer than the skin, the body inevitably gains heat (Sawka et al., 2011). This increases the amount of heat that needs to be dissipated for a thermal balance to be maintained between heat gain and heat loss in order to achieve a stable core body temperature (Sawka et al., 2012; Nybo, Rasmussen and Sawka, 2014). Heat exchange between the environment and the body occurs via the following four pathways; convection, radiation, conduction and evaporation (Sawka et al., 2011). These methods of heat loss and gain are defined by the heat balance equation and originate from the first law of thermodynamics (Cheung, 2009) and are defined by the heat balance equation 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.

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

(Sawka et al., 2011)

It is problematic to soccer-player's if the heat balance equation becomes unbalanced during soccer match-play in favour of heat gain, as an increase in resting core temperature ~37°C, by 2-3°C (39 - 40°C) may impair performance (Maughan et al., 2010; Girard, Brocherie and Bishop, 2015) and negatively affect soccer match-play (Taylor and Rollo, 2014).

Figure 2. 1. Locations of soccer matches/tournaments played/scheduled in/for hot environments. A) FIFA World Cup 2014 and Copa America 2019, Brazil (Rio de Janeiro), 28 - 35°C; B) FIFA World Cup 1994 and Copa America 2016, USA (Orlando), and FIFA World Cup 2026, North America (USA, Canada and Mexico), 32 - 41°C; C) UEFA Champions League and UEFA Europa League, Spain (Madrid and Seville), Portugal (Porto and Lisbon) and Greece (Athens), 25 - 35°C; D) The FA Cup and the EFL Championship Play-offs, England (London), 24 - 26°C; E) FIFA World Cup 2022, Qatar (Doha) and Africa Cup of Nations 2019, Egypt (Cairo) 18 - 41°C; F) FIFA U-20 2013 World Cup, Turkey (Istanbul) and 25 - 41°C; G) FIFA Women's World Cup 2019, France (Paris), 22 - 35°C.

2.4.3. Central Factors

Central mediated fatigue has been explored extensively in the last decade, with several theories suggesting underlying mechanisms involved (Nybo, Rasmussen and Sawka, 2014). Elevated brain temperature has been suggested to contribute to reducing central-nervous system motor drive to skeletal muscle, however, these reports were not based on human data (Bruck and Olschewski, 1987). Moreover, core body temperature is widely recognised as a contributing factor to hyperthermia-induced fatigue, although is not a reliable predictor of brain temperature (McIlvoy, 2004). Core body temperatures are usually regulated within a narrow range (35 - 41°C).

Many of the early studies investigating fatigue in the heat aimed to define a singular mechanism for the reduced exercise capacity (Gonzalez-Alonso et al., 1999; Nybo and Nielsen, 2001). Previous research has reported athletes voluntarily terminate exercise at consistent body temperatures during prolonged exercise in hot environments, with trained athletes [~40°C (Gonzalez-Alonso et al., 1999; Pugh et al., 2002)] tolerating higher core temperatures in comparison to their untrained counterparts [38 - 39°C (Cheung and McLellan, 1998). This led to the critical core body temperature hypothesis of ~40°C coinciding with exhaustion during exercise in hot environment as a protective mechanism to prevent heat stroke and cellular apoptosis (Gonzalez-Alonso et al., 1999; Nybo, Rasmussen and Sawka, 2014). Although the critical core temperature concept has been abandoned (Nybo et al., 2015), it is evident that elevated core body temperature has an integral role in the development of fatigue and reduced exercise performance in hot environments (Taylor and Rollo, 2014; Nybo and Gonzalez-Alonso, 2015).

Aughey et al. (2012) reported peak core temperatures exceeding this previously opposed critical value (> 40°C) during Australian Rules Football, highlighting that elite team-sport players can tolerate higher core temperatures. Similarly, Taylor et al. (2018) reported individual peak core temperatures of 39.9 and 39.6°C during men's World Rugby Sevens Series tournaments in Singapore and London, respectively. Moreover, soccer match-play data in 43°C (Mohr et al., 2012) has highlighted peak core temperatures (39.7 ± 0.1°C) approaching previously opposed critical values. However, in contrast to the fixed-paced protocols reporting an attainment of critical core temperatures during exercise in hot environments (Gonzalez-Alonso et al., 1999; Nybo and Nielsen, 2001), team-sport players seem to be able to modulate their exercise intensity to allow completion of game-play (Nassis et al., 2015). This is highlighted with decrements in total and high-speed distance covered during heat-situated soccer match-play (43°C) by Mohr et al. (2012), whilst Aughey et al. (2014) reported Australian rules players reduced total distance covered to preserve sprinting and high-intensity running during Australian rules football (27°C), respectively.

However, elevated core temperatures > 39°C likely reduce maximum voluntary contractions to the active muscles via reduced motor drive in hot environments (Nybo and Nielsen, 2001), in line with the "central governor model" which prevents a failure of homeostasis by causing a voluntary cessation of exercise intensity or effort when homeostasis is challenged (Noakes et al., 2005). Hence core temperatures exceeding 39°C, are observed alongside poorer intermittent-sprint performance (Girard, Brocherie and Bishop, 2015). Additionally, simulated soccer match-play data in 30°C showed sprint distance covered was significantly reduced ($P < 0.05$) in the final 15 min compared to the first 15 min (Aldous et al., 2016), which was accompanied by an elevation in core temperature (39.2 ± 0.2°C). Therefore, it is evident that core temperature has an important role in heat-mediated decrements in soccer performance as previously reported during simulated (Aldous et al., 2016) and soccer match-play studies (Mohr et al., 2012).

2.4.4. Peripheral and Cardiovascular Factors

Cardiac filling is impaired during exercise in a hot environment as the venous bed of the skin is large and dilates (Gonzalez-Alonso, Crandall and Johnson, 2008). Furthermore, blood vessels of the skin become engorged as skin blood flow increases, resulting in large volumes of blood pools in the skin, which in turn displaces blood from the thorax, reducing central blood volume and cardiac filling (Nybo, Rasmussen and Sawka, 2014). This process is defined as venous compliance and increases with elevated core temperatures (Wenger and Roberts, 1980) and may also with high skin temperatures (Romer and Polkey, 2008). Therefore, during exercise in a hot environment, an increased venous compliance extends blood transit via cutaneous vasculature to improve heat exchange, whilst decreasing central blood volume (via increasing cutaneous volume) which can ultimately reduce cardiac filling (Nybo, Rasmussen and Sawka, 2014). Consequently, an elevated heart-rate is required to maintain cardiac output (Nybo, Rasmussen and Sawka, 2014). This elevation in heart-rate implies a shortening of the cardiac cycle, reducing diastolic filling time, which may further compromise stroke volume and cardiac output will inevitable decline when heart-rate cannot compensate for the reduction in stroke volume (Gonzalez-Alonso, Crandall and Johnson, 2008; Stohr et al., 2011). Heart-rate may compensate for any reduction in stroke volume at rest and during light/moderate intensity exercise (Nybo, Rasmussen and Sawka, 2014). Furthermore, during heat-stress at rest and during light intensity exercise, cardiac output is increased to meet the skin perfusion requirements (Nybo and Nielsen, 2001). However, during prolonged, intense exercise in a hot environment, cardiac output declines as the impairment of cardiac filling becomes profound insufficient and heart-rate approaches maximal values (Gonzalez-Alonso and Calbet, 2003; Nybo, Rasmussen and Sawka, 2014).

Cardiovascular drift is likely apparent during heat-situated soccer match-play due to the prolonged intense physical demands. However, previous soccer match-play data (Mohr et al., 2012) reported no significant difference ($P > 0.05$) between mean heart-rate at 43°C (158 ± 2

$b \cdot min^{-1}$) compared to 21°C (160 ± 2 $b \cdot min^{-1}$), showing synergy with more recent simulated soccer match-play data at 30°C (163 ± 3 $b \cdot min^{-1}$) and 18°C (161 ± 10 $b \cdot min^{-1}$), respectively (Aldous et al., 2016).

Moreover, an elevation in skin temperature is the most immediate physiological event that occurs in high ambient temperatures, resulting in an increase to skin blood flow (Sawka et al., 2011). Skin blood flow transports heat by convection from the active skeletal muscles and other deep tissues to the body surface for heat exchange with the surrounding environment (Sawka et al., 2011). When heat-stress is combined with prolonged high-speed exercise, the primary cardiovascular challenge is to provide sufficient cardiac output to sufficiently supply skeletal muscle to support metabolism whilst simultaneously perfusing the skin to support heat loss (Rowell et al., 1996; Nybo, Rasmussen and Sawka, 2014). Resting skin blood blow is ~8 $L \cdot min^{-1}$ at 33°C, however, during prolonged high-intensity exercise in hot environments, this value will be reduced due to competition of vasoconstriction effects between skin and muscle (Gonzalez-Alonso et al., 2008). Thus, during intense exercise skin blood flow is important for heat dissipation, nonetheless is dependent upon the core to skin temperature gradient (Nybo, Rasmussen and Sawka, 2014).

2.4.5. Perceptual Factors

Perception of thermal stress and the perception of thermal comfort progressively develop during prolonged exercise and become exacerbated in high ambient temperatures (Stevens et al., 2017a). It is now widely recognised that alterations in perceptual measures (rate of perceived exertion and thermal sensation) without effecting core body temperatures can be equally as beneficial to exercise performance (Stevens et al., 2017a). For example, mid-exercise alterations in ratings of thermal sensation have been shown to be as beneficial to 5 km time-trial running performance following facial water spray [without altering core body temperature (24.6 ± 3.3 min)] when compared to pre-cooling via cold water immersion (24.5

± 2.8 min), compared to a control [25.2 ± 3.2 min (Stevens et al., 2017b)]. Indeed, performance is certainly influenced by perception as previously highlighted, combined with enhanced exercise performance in the heat (33°C and 46% rH) following a menthol intervention, which altered perceptual measures without affecting body temperatures (Stevens et al., 2016). Therefore, allowing confirmation of the effect of perception on exercise performance in the heat (Stevens et al., 2017a). Aldous et al. (2016) reported an absolute rise in skin temperature predicted total and high-speed distance covered ($r = 0.82$; $P = 0.02$) with thermal sensation predicting the reduction in total distance covered ($r = 0.82$; $P = 0.02$) during simulated soccer performance in the heat (30°C and 50% rH). As skin temperature and thermal sensation have a strong relationship (Sawka et al., 2012) and have been associated with changes in physical performance during simulated soccer performance in the heat (Aldous et al., 2016). It is likely thermal comfort (thermal skin temperature x thermal sensation) is central to decrements in physical performance in hot conditions (Aldous et al., 2016).

Although evident that increases in body temperatures play an integral role in the heat-induced decrements in soccer-specific performance, multiple factors are suggested to interplay between central, peripheral and perceptual factors (Cheung and Sleivert, 2004). Therefore, strategies should target perceptual measures as well as alleviating physiological strain during soccer-specific performance in hot environments.

2.4.6. Physical Performance During Soccer in the Heat

Özgünen et al. (2010) reported a significant decrement ($P < 0.05$) in total distance covered between first and second-half (4,301 ± 487 versus 3,761 ± 358 m) under high heat-stress (36 ± 1°C and 61 ± 1% rH), whereas there was no significant ($P > 0.05$) decrement between first and second-half (4386 ± 367 versus 4227 ± 292 m) under moderate heat-stress (34 ± 1°C and 38 ± 2% rH). Conversely, moderate heat-stress significantly reduced ($P < 0.05$) sprint distance covered between the first and second-half (75 ± 30 versus 32 ± 22 m) whilst no significant decrement ($P > 0.05$) between first and second-half (45 ± 37 versus 63 ± 34 m) for sprint distance covered was observed under high heat-stress. Indictive of an altered pacing strategy, in contrast to Nassis et al. (2015) who reported a significant reduction ($P < 0.05$) in the number of sprints (~10%) was observed under high (28 - 33°C and 50% rH; 25 - 29°C and 75% rH) compared to moderate (24 - 28°C and 50% rH; 20 - 25°C and 75% rH) and low heat-stress (< 24°C and 50% rH; < 20°C and 75% rH). Although varying standards of soccer-players (elite versus semi-professional) used within these studies, with elite soccer-players reported to cover a significantly greater amount of high-intensity running (Mohr et al., 2003). Highlights with increasing heat-stress, this key physical performance measure related to the match outcome is reduced in both elite and semi-professional soccer-players, respectively. However, no control group in a temperate environment was incorporated in these studies and thus, effects of environmental-mediated changes cannot be fully compared to temperature-like match-play.

The first study to directly compare the heat-mediated effects upon physical performance during soccer match-play to a temperate environment (20°C) was Ekblom et al. (1986) who reported a significant ($P < 0.05$) reduction in total distance covered (4%) in the heat (30°C) in elite male soccer-players. Showing synergy with recent match-play data by Mohr et al. (2012) who also reported a reduction ($P < 0.05$) in total distance covered (7%), although the temperature (43°C) utilised in the latter study lacks consistent external validity to modern day soccer. However, extreme temperatures exceeding 35°C may occur and at the upcoming 2022 FIFA World Cup in Qatar (BBC, 2015). Regardless, unlike high-speed running, total distance covered is not associated with game defining moments. Mohr et al. (2012) was the first to ascertain such important information on soccer match-play data, reporting a significant reduction ($P < 0.05$) in high-speed distance (26%) in a hot (43°C) compared to a temperate environment (21°C). However, it is difficult to ascertain environmentally-mediated changes from soccer match-play data due to confounding game factors (tactics, opposition, playing style) potentially affecting match-play characteristics (Gregson et al., 2010), with variation in physical performance parameters suggested to be even greater in heat-situated soccer match-play due to altered pacing strategies (Nassis et al., 2015), in comparison to studying performance-related parameters in a more controlled environment (Taylor and Rollo, 2014).

During prolonged, intermittent, high-intensity shuttle running to exhaustion in 30°C, Morris et al. (1998) and Morris, Nevill and Williams (2000) reported significantly less ($P < 0.05$) total distance covered by male (28%) and female (25%) team-sport players, when compared to a temperate environment (16 - 21°C). Furthermore, these reductions showed a significant negative correlation with the rate of rise in rectal temperature for both male ($r = -0.94$, $P < 0.01$) and female ($r = -0.93$, $P < 0.01$) participants. Although similar findings, female soccer-players are reported to cover ~30% less distance than their male counterparts (Krustrup et al., 2005), limiting the findings of the latter study to men's soccer. However, Morris et al. (2005) reported male team-sport players ran almost twice the distance ($P < 0.05$) in 17°C (21,644 ± 1629 m) compared to 33°C (11,216 ± 1411 m), with significantly lower ($P < 0.05$) rectal temperature at the point of exhaustion (38.8 ± 1 versus 39.6 ± 0.2°C), also showing a significant negative relationship between the rate of rise of rectal temperature and distance covered ($r = -0.90$, $P < 0.05$). Although the aforementioned field-based studies (Morris et al., 1998; Morris, Nevill and Williams 2000; Morris et al., 2005) highlight the reduced physical capacity during high-intensity shuttle running performance in the heat (30 - 33°C), alongside the negative relation with rectal temperature exceeding 39°C. This field-based protocol lacks external validity with soccer-match-play as players are required to run until exhaustion which meant they ran for up to 105 min, exceeding the 90 min duration of soccer match-play.

Utilising a valid and reliable soccer-specific simulation via a non-motorised treadmill whilst replicating the 90 min duration of soccer match-play (Aldous et al., 2014), Aldous et al. (2016)

reported a significant reduction ($P < 0.05$) in high-speed distance covered (4%) in 30°C compared 18°C (2,156 ± 120 versus 2,316 ± 100 m), with end thermal sensation predicting the high-speed decrement observed at the end of simulated match-play in the hot condition. Indeed, although high rectal temperatures at the end of simulated (Morris et al., 1998; Morris, Nevill and Williams 2000; Morris et al., 2005) and soccer match-play data (Ozgunen et al., 2010; Mohr et al., 2012) have been previously observed, perceptual factors are likely central to decrements in physical performance during soccer performance in hot environments. Furthermore, given the association of high-speed running to game defining moments, and the heat-mediated decrements reported during simulated and soccer match-play. Strategies which can reduce these decrements may have a significant impact on the match outcome, and thus, should target both perceptual and physiological factors.

2.5. Pre and Half-time Cooling

Data which demonstrates the frequency of cooling manoeuvres being utilised both pre-match and at half-time during soccer match-play has not yet been published. However, there are examples in elite competition including the 2014 FIFA World Cup match Netherlands vs Mexico where cooling has been used during the mandatory 3 min break when WBGT > 30 ºC (BBC, 2015). Given the heat-mediated decrements to soccer-specific physical performance that are evident during soccer match-play (Mohr et al., 2012), strategies to offset these decrements should be considered by practitioners. The gold standard intervention for reducing physiological strain and enhancing soccer-specific performance prior to heat situated soccer match-play is via heat acclimatisation/acclimation (Racinais et al., 2012). However, this strategy can be time consuming (6 - 21 days) and may not comply with the congested calendar associated with elite domestic soccer (Taylor and Rollo, 2014). Therefore, various cooling strategies can be utilised with the aim to: i) improve physical performance and ii) alleviate the increased thermal/perceptual strain during soccer match-play in high ambient temperatures.

2.5.1. Opportunities to Cool During Soccer Match-Play

A major constraint of implementing cooling manoeuvres into soccer match-play is the governing body dictated rules, not permitting any additional clothing or garments (Taylor and Rollo, 2014). However, currently there are no governing body dictated restrictions on the use of cooling prior to a match or during the half-time interval. Alternatively, practitioners are presented with a further opportunity during the 3 min water, and cooling break given to players after the 30th min of each half of soccer match-play when WBGT > 32°C (Houssein et al., 2016). As highlighted in section 2.4.6, physical performance decrements during soccer match-play can occur in WBGT < 32°C (Taylor and Rollo, 2014). Therefore, opportunities to use cooling manoeuvres in WBGT < 32°C are limited to pre-match and/or half-time.

In preparation for soccer match-play kick-off, coaches and practitioners traditionally conduct a warm-up for their players (Towlson et al., 2013). The term "warm-up" indicative of not only the physiological (i.e. decrease injury risk) and physical benefits, but also considered mandatory to prepare players for the mental and technical rigours of performance (Impellizzeri et al., 2013). Towlson et al. (2013) reported an average warm-up duration of 30.8 min with 89% of practitioners from professional English League teams administering warm-ups ≥ 25 min. Furthermore, responders within this internet-based questionnaire on practitioners in professional English soccer reported a 12.4 min period of "down-time" between the end of the warm-up and kick-off. Although this period may seem like a potential window of opportunity for interventions, access to players is still limited as tactical and motivational exchanges between players and coaches, alongside general preparatory tasks are typically completed during this period (Towlson et al., 2013). Therefore, due to the limited time and access to players during the pre-match soccer-specific warm-up and during the downtime post warm-up prior to kick-off, any potential cooling interventions must have the ability to be practically worn, not be restrictive or inhibit warm-up procedures, nor be time consuming to apply or hinder any generic downtime duties (receiving instructions and information, preparatory tasks or pre-match fuelling and supplements). Adhering to the practical issues of soccer-specific pre-cooling techniques is a limitation of previous literature which utilized cooling procedures during pro-longed (20-60 min) periods (Price, Boyd and Goosey-Tolfrey, 2009; Clarke et al., 2011; Aldous et al., 2018).

During the 15 min half-time interval between subsequent halves of soccer match-play, a further window of opportunity to cool is presented to practitioners. However, Towlson et al. (2013) highlights that players do not arrive in the dressing room for a further 1.7 min after the initiation of half-time, further reducing the time practitioners have with soccer-players. Of the time remaining during the half-time interval (~13.3 min), the majority is typically utilised in a similar manner to the pre-match downtime period prior to kick-off, with the addition of any necessary medical treatment and rehydration and refuelling. Furthermore, Towlson et al. (2013) highlights a potential ~2.6 min of available time at the end of the half-time period, however this time is frequently used for re-warm-ups (57%) prior to the start of the second-half of soccer match-play due to the previously reported beneficial effects (Russell et al., 2015). Therefore, an extremely aggressive cooling manoeuvre would be required to exert any beneficial effect due to this limited time frame (~2.6 min), which would not be practical post warm-up, prior to kick-off due to potentially reducing muscle temperatures which may negatively impair muscular performance at the start of the second-half due to diminished muscular contractility (Mohr et al., 2004; Gray et al., 2006). Alternatively, a practical cooling manoeuvre which is not invasive, time consuming or would hinder any generic half-time duties would be preferred. Moreover, in a review on strategies to utilise during the half-time period to enhance second-half performance in team-sports, Russell et al. (2015) highlights varies strategies which may be implemented such as half-time re-warm-ups, hormonal priming and nutritional interventions. Therefore, any practical cooling manoeuvres must: i) be considered alongside other strategies being used to enhance second-half performance and ii) adhere to the available time practitioners have to cool (~10 min) players at half-time during soccer match-play.

2.5.2. Cooling Manoeuvres

Interest in cooling practices as a strategy to combat the debilitating effects of heat-stress-induced fatigue on athletic performance has increased greatly over the past three decades (Ross et al., 2013). Cooling manoeuvres can be induced in three alternative methods and are defined below as by Ross et al. (2013):

- *Internal precooling* is defined as taking a cold medium into the body through the mouth (and/or nose in the case of breathing) and can include the inhalation of cold air and the ingestion of cold fluids or ice;
- *External precooling* is defined as the application of a cold medium or material to the surface of the body and can include exposure to cold air, cold water or ice-cold garments;
- *Combining precooling* is defined as combining two or more practical precooling manoeuvres and can include a combination of external approaches or an external and internal approach.

Cold-water immersion is universally referred to as the gold standard method of cooling, despite, lacking practicality to be used successfully prior to soccer match-play (Casa et al., 2007; Taylor and Rollo, 2014). However, logistical issues such as expense, transportation of equipment, access to large volumes of water and electricity in the field [dependent upon location (Jones et al., 2012; Russell et al., 2013)] limit the practical use of this cooling manoeuvre. A further limitation which accompanies cold-water immersion, is the reduction in muscle temperature, as seen by Castle et al (2006) who detailed a significant reduction ($P < 0.05$) in muscle temperature (0.51 ± 0.3°C) following 20 min of cold-water immersion. This is of significant importance given increased muscle temperatures have been shown to enhance sprint performance during soccer match-play in both temperate (Mohr et al., 2012) and hot

(Mohr et al., 2010) environments. Therefore, cold water immersion was not considered a viable and practical cooling manoeuvre to answer the central aim of this thesis.

A practical internal cooling alternative such as ice slurry ingestion, which reduces pre-exercise core body temperature [0.5°C (Jay and Morris, 2018)], elicits a similar ergogenic effect as the impractical cold-water immersion during exercise performance in the heat [34°C and 52% rH (Siegal et al., 2012)]. Indeed, despite a significant reduction ($P < 0.05$) in core temperature (0.51 ± 0.3°C), Gerrett et al. (2017) reported no beneficial effect ($P > 0.05$) of ice slurry ingestion (7.5 g·kg of body mass^{-1}) on self-paced intermittent exercise in 31°C. This is supported by Aldous et al. (2018) reporting no significant improvement in physical performance during a soccer simulation in the heat (30°C and 50% rH) following pre- (7.5 g·kg of body mass^{-1}) and half-time (3.75 g·kg of body mass^{-1}) ice slurry ingestion. Furthermore, only when ice slurry ingestion was combined with 30 min of pre-cooling via ice packs (placed on quadriceps and hamstrings) was physical performance (total, high-speed and variable-run distance covered) during the first-half of a non-motorised based soccer-specific simulation improved. Although Castle et al. (2006) reported the singular use of packs for 20 min prior to intermittent sprint performance in 34°C significantly improved ($P > 0.05$) peak power output by 4%. These findings upon the singular use of packs upon 40 min of intermittent sprint performance were not mirrored during a 90 min soccer-specific simulation (Aldous et al., 2018), likely due to a difference in exercise modality. Thus, limiting the use of these cooling manoeuvres in soccer as internal ice slurry ingestion and external ice packs offer no singular benefit to physical performance, they are not considered viable cooling manoeuvres. Further practical cooling manoeuvres for soccer-players are warranted.

2.5.3. Vest Cooling

Ice-cooling jackets (ice vests) are a practical and effective method of cooling the torso region of the body and have previously been utilised in numerous studies before and/or during exercise in a hot and/or humid environment (Price, Boyd and Goosey-Tolfrey, 2009; Parris and Tyler, 2018). Although this method has been shown to have a small effect at reducing core body temperature (0.2 - 0.7°C) compared with cold-water immersion, it presents a practical method of reducing skin temperature (0 - 0.5°C), without affecting muscle temperature directly (Bongers et al., 2014), which can impair sprint performance (Mohr et al., 2010). Furthermore, ice vests have been shown to have an ergogenic effect on performance (Castle et al., 2006; Brade et al., 2014). Arngrimsson et al. (2004) reported wearing an ice vest during a warm-up prior to a 5 km treadmill time-trial, significantly improved performance by 13 s in competitive male and female runners in 32°C. Additionally, ice vests reduced heart rate (11 $b \cdot min^{-1}$), rectal (0.2°C) and skin temperature (1.8°C) at the start of exercise compared to no cooling during the warm-up, which persisted for the first 3.2 km. Although highlighting the ergogenic effect of ice vest pre-cooling on endurance performance in the heat in line with previous findings (Cotter et al., 2001), the physical demands associated with soccer match-play are vastly different.

Brade et al. (2014) reported a significant benefit ($P < 0.05$) on mean power (972 ± 130 versus 924 ± 188 W) and total work performed (234 ± 31 versus 222 ± 45 kJ), when the ice vest was combined with ice slurry ingestion pre-exercise (7 $g \cdot kg$ of body $mass^{-1}$) and during 10 min at half-time (2.1 $g \cdot kg$ of body $mass^{-1}$) on repeated sprint cycling in comparison no cooling. However, Brade et al. (2014) attributed the majority of the exercise performance benefits to the ice vest [large effect size ($d > 0.8$)] during this repeated cycling protocol in the heat (35°C and 60% rH). Furthermore, Castle et al. (2006) reported a significant increase ($P < 0.01$) in total work done (7.1 ± 0.8 kJ) following 20 min pre-cooling via an ice vest in a hot environment (34°C and 52% rH) during an intermittent cycling sprint protocol compared to no cooling (6.8 ± 0.7 kJ). However, Duffield et al. (2003) reported no significant improvement ($P > 0.05$) in total work done (240 ± 35 versus 230 ± 42 kJ) or power output (928 ± 123 versus 906 ± 155 W) during a 2 x 40 min intermittent, repeated sprint cycling protocol in 30°C following ice vest cooling before (5 min) and during the half-time period (10 min) compared to no cooling. However, cooling may not have been long enough to sufficiently reduce body temperatures which may have influenced these results as no significant difference in core or skin temperature were observed at the start of exercise (37.4 ± 0.3 versus 37.5 ± 0.3°C and 34.2 ± 0.7 versus 34.5 ± 0.6°C). Although contrary findings within these repeated sprint protocols (Duffield et al., 2003; Castle et al., 2006; Brade et al., 2014), different protocols and cooling durations utilised, likely explain the inherent differences. Furthermore, findings from these studies are limited due to the use of intermittent cycling ergometry protocols which lack extremal validity to soccer match-play.

In a four-match soccer simulation study design aimed to investigate the singular and combined effect of ice vest cooling and carbohydrate–electrolyte solution drink, Clarke et al. (2011) reported 60 min of ice vest pre-cooling and placebo-ingestion reduced core body temperature from 37.2 ± 0.1°C to 36.6 ± 0.1°C prior to the start of a 90 min bout of simulated soccer in the heat (30°C and 42% rH), although no significant reductions ($P > 0.05$) in core temperature were observed in the second-half following 15 min of ice vest cooling and placebo-ingestion at half-time, university soccer-players extended (28%) high-intensity running to exhaustion (70.1 ± 7.7 s) post exercise compared to no cooling and placebo-ingestion (57.1 ± 5.3 s), although statistical significance was only achieved when pre- and half-time cooling was combined with a carbohydrate–electrolyte solution drink. Regardless, this improvement in performance observed is more a reflection of exercise capacity, whilst duration of pre-cooling would likely not fit in with the time constraints practitioners are faced with in soccer.

Price, Boyd and Goosey-Tolfrey (2009) pre-cooled for a shorter duration (20 min) via an ice vest resulting in a significantly greater ($P < 0.05$) rise in core temperature in the control trial (no cooling) at 35 min (1.1 ± 0.6°C) compared to pre-cooling (0.7 ± 0.4°C) during simulated soccer in a hot environment (31°C and 64% rH). Although a further 15 min of cooling was undertaken during the half-time period, core temperature remained significantly lower ($P < 0.05$) throughout the second-half of simulated match-play for all eight-elite soccer-players. Although previous research has suggested that there is an inverse relationship between core temperature and intermittent sprint ability (Girard, Brocherie and Bishop, 2015), quantification of physical performance was excluded by Price, Boyd and Goosey-Tolfrey (2009) due to the use of motorised treadmill.

Parris and Tyler (2018) assessed peak sprint speed throughout a 90 min soccer-specific simulation in 35°C whilst wearing an ice vest compared to no ice vest with insignificant findings ($P > 0.05$), despite a moderate effect in reducing core temperature (1.3 ± 0.6°C) throughout the second-half. However, limited findings on sprint performance in the previous study may, in part, be due to the extra ~1.75 kg in mass worn during the ice vest condition which would have increased the energy cost of the exercise bout (Arngrimsson et al., 2004), compared to the control trial which did not wear a vest. Previous studies have reported pre- and half-time cooling via ice vest has little effect on high-intensity, intermittent exercise and that meaningful benefits are only observed when supplemented with other cooling strategies (Duffield and Marino, 2007; Parris and Tyler, 2018). Moreover, a limitation of previous soccer specific studies using ice vests (Price, Boyd and Goosey-Tolfrey 2009; Clarke et al., 2011; Parris and Tyler, 2018) was failing to utilise them during a practical pre-match warm-up and/or quantify key physical performance measures (high-speed and sprint distance covered) related to success during soccer match-play. Furthermore, as ice vests have been reported to have minimal effect on perceptual measures, and how these measures are likely central to heat-mediated decrements (Stevens et al., 2017a), it seems rational to combine ice vests with a strategy that directly targets perceptual stress during exercise in the heat such as neck cooling.

2.5.4. Neck Cooling

An alternative region of the body to cool which has been shown to improve performance is the neck region (Sunderland et al., 2015; Tyler, Wild and Sunderland, 2010; Tyler and Sunderland, 2011a; Zhang et al., 2014), due this region having high alliesthesial thermosenstivity and is in close proximity to the thermoregulatory centre (Cotter and Taylor, 2005). Furthermore, Sunderland et al. (2015) highlighted that the neck is more readily accessible than the torso for cooling manoeuvres to be used prior to and during exercise. However, although physiological responses occur following ice vest cooling on body temperatures, cooling the neck region has minimal effect on body temperatures, instead dampening the perceived magnitude of thermal strain, allowing individuals to tolerate higher core temperatures and heart rates which would have otherwise hindered performance (Sunderland et al., 2015; Bongers et al., 2014). For example, Tyler and Sunderland. (2011a) reported endurance trained male athletes significantly extended ($P < 0.001$) their time to exhaustion in the heat (32.2°C and 53% rH) when a neck cooling collar was worn throughout (43.15 ± 12.82 min) compared to no collar worn (38.20 ± 11.70 min). Additionally, upon completion of exercise, identical levels of perceived exertion and thermal sensation were experienced ($P > 0.05$), however, higher core temperature were tolerated during the neck (39.6 ± 0.5°C) compared to the control (39.2 ± 0.7°C), respectively.

Tyler, Wild and Sunderland (2010) investigated the effect of neck cooling on time-trial performance in hot conditions (30°C and 50% rH). In a two-part study, Study A found a significant effect ($P < 0.001$) on 15 min time-trial performance following 75 min at ~60% relative maximal oxygen uptake, with a significant improvement when a neck cooling collar was worn (3,030 ± 485 m) in comparison to an uncooled (2,741 ± 537 m) and no collar (2,884 ± 571 m), respectively. No significant differences ($P > 0.05$) occurred between the uncooled and no collar trials. In stark contrast, Study B elicited no significant performance benefit ($P > 0.05$) of neck cooling on 15 min time-trial performance compared with a control, suggestive that neck cooling only has an ergogenic effect when individuals experience high levels of thermal strain throughout a prolonged period as seen in study A (90 min). These findings are reinforced by Tyler and Sunderland (2011b) who reported time-trial performance in 32°C was significantly improved ($P < 0.01$) following 75 min at ~60% relative maximal oxygen uptake by ~7% when a neck cooling collar was worn throughout exercise (2779 ± 299 m) compared to no cooling collar (2597 ± 291 m). Interestingly, this study highlighted that there was no further significant 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, with similar improvements (~7%) as the neck cooling collar worn continuously throughout exercise. Although, the neck cooling collars significantly lowered ($P < 0.05$) neck temperature and neck thermal sensation, no further alterations in physiological or perceptual values accompanied the enhanced exercise performance, showing synergy with earlier findings (Tyler, Wild and Sunderland, 2010). Conversely, previous research on neck cooling and exercise capacity in 32°C reported a 13.5% increase in time to exhaustion with participants tolerating a high core temperature in the neck cooling condition. However, Tyler and Sunderland (2011b) showed the gain in exercise performance was achieved despite relatively low final core temperatures (38.90 - 38.97°C), and so it is possible that the benefits to self-paced time-trial performance could be greater still in more thermally challenging environment. However, recent findings from Bright et al. (2018) reported exercise performance was unaffected ($P > 0.05$) under greater ambient temperature (34°C and 33% rH) during a fixed rate of perceived exertion protocol (fixed at 16 of a 6 - 20 scale), contrary to previous studies (Tyler, Wild and Sunderland, 2010; Tyler and Sunderland, 2011b). The lack of performance benefit likely stemmed from differences in experimental conditions, with differing trial type (clamped protocol versus time-trial) and the thermal status (no-preload versus preload phase) to previous reports on the beneficial use of neck cooling upon exercise performance (Tyler, Wild and Sunderland, 2010). Nevertheless, although varying degrees of success with neck cooling in previous studies are reported despite differentiation amongst study designs, they lack ecological validity to soccer specific performance.

Zhang et al. (2014) reported neck cooling via wet towels significantly improved Yo-Yo Intermittent Recovery Level 1 test (814 ± 328 m) by 31% compared to no cooling (654 ± 311 m). Additionally, thermal sensation was significantly lower ($P < 0.05$) following 15 min of neck cooling (2.2 ± 0.6) compared to no cooling (3.6 ± 0.7). Findings from this study are limited as soccer-specific performance tests were conducted in a temperate environment (~21°C) whilst only simulating one half of soccer match-play. Although, the Yo-Yo Intermittent Recovery Level 1 test is a measure of exercise capacity, it has been significantly correlated ($r = 0.71$, $P < 0.05$) to the volume of high-intensity running performed during soccer match-play (Krustrup et al., 2003). Moreover, Sunderland et al. (2015) reported wearing a neck cooling collar throughout 90 min of a football specific intermittent treadmill protocol significantly improved ($P < 0.05$) mean (540 ± 99 versus 507 ± 122 W) and peak power output (719 ± 158 versus 680 ± 182 W) during repeated sprint performance in the heat (33°C and 53% rH), compared to no cooling. Interestingly, the significance occurred during the final bout of sprints following simulated soccer performance, with a significantly lower rate of perceived exertion (16.4 ± 0.8) for neck cooling compared to no cooling (15.6 ± 0.8). Although these finding may be of interest to practitioners in soccer given the beneficial effects on correlated high-intensity running and sprint performance, due to their association with the match outcome (Gregson et al., 2010; Faude et al., 2012). Neither study utilised a 90 min soccer-specific simulation which could quantify for decrements in physical performance measures during simulated match-play, as these studies used performance tests following one (Zhang et al., 2014) or two 45 min exercise bouts (Sunderland et al., 2015). Therefore, this provides a rationale to investigate the benefits of neck cooling on a soccer-specific simulation which can quantify for key measures of physical performance within a controlled environment.

2.5.5. Combining Cooling Manoeuvres

Combining two or more practical methods can provide mutually potentiating effects upon exercise performance through increased heat storage and reduced thermoregulatory and cardiovascular strain (Ross et al., 2013). Indeed, it has been reported that there is an improved exercise performance and reduced physiological load, dependent upon pre-cooling volume, with pre-cooling larger surface areas providing the greatest benefit (Minett et al., 2011). Furthermore, Minett et al. (2012) highlighted that a longer duration of mixed-method pre-cooling (10 < 20 min) provided a greater augmentation of performance and blunting of physiological loads during an intermittent-sprint shuttle running protocol in the heat (33°C and 33% rH). Moreover, combination of pre-cooling manoeuvres has been reported by Bongers et al. (2014) in a meta-analysis as the most effective cooling technique to improve exercise performance, with an ice vest highlighted as the most effective per-cooling strategy (Bongers et al., 2017). Thus, it was hypothesised that combining a combination a pre- and per-cooling approach would be most beneficial to exercise performance (Bogers et al., 2017).

Duffield and Marino (2007) reported large effect sizes ($d > 0.8$) for total amount of hard running in the first (1,232 ± 129 m) and second-half (1,156 ± 139 m) during an intermittent sprint protocol following a combination of ice vest and cold water immersion, as opposed to the singular use of ice vests (1,143 ± 114 and 1,043 ± 148 m) pre-exercise (15 min) and at half-time (5 min) compared to the first (1,104 ± 112 m) and second-half (1,020 ± 108 m) of the no cooling trial, respectively. Highlighting the larger ergogenic effect of a combination of cooling manoeuvres as opposed to their singular use, this exercise protocol did not simulate soccer match-play whilst using rugby players as opposed to soccer-players, thus, limiting the findings in context to soccer. Moreover, soccer match-play and training data utilising a combination approach of 20 min pre-cooling (ice vest, ice towel and 350ml ice slurry) and 5 min half-time cooling (ice vest and ice towel) reported equivocal findings on physical performance during training and match-play in 29 - 30°C. Large effect sizes (*d* > 0.08) were reported for distance covered during training (6,996 ± 296 versus 6,789 ± 423) alongside reduced perceptual exertion and thermal stress, compared to no cooling. However, gaining inferences from match-play data is difficult due to the inherent variability (Gregson et al., 2010), hence why simulated soccer match-play designs are typical recommended to gain reliable empirical data on interventions (Taylor and Rollo, 2014).

Aldous et al. (2018) utilised a valid and reliable soccer-specific simulation to investigate the effect of 30 min pre- and 15-min half-time internal (ice slurry), external (ice packs placed on the quadriceps and hamstrings) and combination approach (ice slurry and ice packs) cooling on soccer performance in the heat (30°C and 50% rH). Moderate-large effect sizes (*d* > 0.06) indicated increases in high-speed (56 ± 46 m), variable run (15 ± 5 m) and total distance covered (108 ± 57 m) in the first-half of this simulation following 30 min of combination pre-cooling, however, physical performance was unaltered in the second-half following the 15 min of half-time. An enhanced first-half performance was accompanied with similar moderate-large (*d* > 0.06) reductions in core body temperature (0.86 ± 0.35°C), skin temperature (0.88 ± 0.42°C) and thermal sensation (0.91 ± 0.36), whilst these measures were unchanged in the second-half compared to the control trial. This study highlights further half-time cooling manoeuvres are required to improve second-half performance, as physical performance decrements are further exacerbated during this period in the heat (Mohr et al.,2012; Aldous et al., 2016). The author attributed these physical performance benefits to peripheral and central thermoregulatory factors favourably influencing first-half performance, highlighting a greater benefit upon soccer-specific performance when multiple factors are targeted. However, Aldous et al. (2018) failed to utilise a throughout soccer-specific warm-up replicating the duration commonly used in soccer, whilst the pre-cooling duration utilised may not fit in with the time practitioners have with soccer-players prior to match-play (Towlson et al., 2013). Indeed, cooling manoeuvres seem to have a greater ergogenic effect upon performance when combined

(Bongers et al., 2014). Furthermore, a greater benefit seems to occur when multiple factors are targeted to combat the heat-mediated reductions in soccer-specific performance (Aldous et al., 2018). Therefore, combining two or more practical cooling manoeuvres whilst targeting multiple factors is most likely to enhance soccer performance in the heat to the greatest extent.

Table 2. 1. Pre- and/or Half-time Cooling on Soccer Performance

Reference	Level and Participants	Study Design	Temperature	Pre-cooling	1st Half	Half-time - Cooling	2nd Half
Drust et al., 2000a	6 Male University SP	3 SMS	20.5°C and 68.3% rH	60 min PC SHOWER	No improvement	N/A	No improvement
Price, Boyd and Goosey-Tolfrey, 2009	8 Female Elite SP	3 SMS	30.6°C and 63.4% rH	20 min PC VEST	↓ T_{re} and T_{sk} from 35 min onwards	15 min VEST	↓ T_{re} and T_{sk}
Clarke et al., 2011	12 Male University SP	4 SMS	30.5°C and 42.2% rH	60 min PC VEST +/ CHO-E	↓ T_{re} and HR	15 min VEST	↓ HR ↑ 22.5% TTE and 2.5% SSRS
Duffield et al., 2013	10 Male Elite SP	2 SM	29.3°C and 78% rH	20 min PC VEST, TOWEL and SLURRY 350ml	No improvement	5 min VEST, TOWEL and SLURRY 350ml	No improvement
Sunderland et al., 2015	7 Male Team-Sport Players		33°C and 53% rH	PER NECK	↓ TS_{neck}, RPE	PER NECK	↓ RPE (90 min) neckT_{sk} (45-60 min) ↑ final MPO and PPO

Table 2.1. Pre- and/or Half-time Cooling on Soccer Performance

Reference	Level and Participants	Study Design	Temperature	Pre-cooling	1st Half	Half-time - Cooling	2nd Half
Aldous et al., 2018	8 Male University SP	4 SMS	30.7°C and 50.9% rH	30 min PC SLURRY, PACKS or MM	↑TD, HSD and VRD covered in MM ↓T_{re} T_{sk} and TS in MM	15 min of PC manoeuvre	No improvement
Parris and Tyler, 2018	10 Male SP	2 SMS	35.1°C and 50.2% rH	PER VEST	No improvement	PER VEST	↓$T_{re,}$ T_{sk}, RPE and TS

Abbreviations: SP = Soccer-players; SMS = Soccer Match Simulation; SM = Soccer Match; rH = Relative Humidity; PC = Pre-Cooling; PER = Per-Cooling; VEST = Ice Vest; TOWEL = Ice Towels; SLURRY = Ice Slurry ($7.5\ g \cdot kg^{-1}$); PACKS = Ice Packs; MM = Mixed Method (PACKS and SLURRY); NECK = Neck Cooling Collar; CHO-E = Carbohydrate Electrolyte Drink; SHOWER = Cold Shower; LC = leg cooling by water immersion in about 25°C; T_{re} = Rectal Temperature; T_{sk} = Skin Temperature; $neckT_{sk}$ = Neck Skin Temperature; TS = Thermal Sensation; TS_{neck} = Neck Thermal Sensation; TD covered = Total Distance covered; HSD covered = High-speed Distance covered; VRD covered = Variable Run Distance covered; TTE = Time to Exhaustion; SSRS = Self-selected Running-speed; PPO = Peak Power Output; MPO = Mean Power Output

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2.5.6. Pre and Half-time Cooling in Soccer

Pre-cooling aims to reduce body temperatures pre-exercise to increase both heat storage capacity and exercise intensity (Ross et al., 2013; Bongers et al., 2017; Bongers et al., 2014). For example, Booth, Marino and Ward (1997) reported a significant reduction ($P < 0.05$) in core temperature (0.7°C) at the start of exercise following pre-cooling via cold water immersion, significantly increased ($P < 0.05$) the distance run by 304 ± 166 m during a 30 min exercise bout at 32°C. Conversely, exercise performance and capacity in the heat can also be enhanced without alterations to thermoregulatory measures including core and skin temperature, due to a favourable change in the level of perceived strain (thermal sensation, comfort and rate of perceived exertion) experienced by the exercising individual (Tyler, Sunderland and Cheung, 2015; Stevens, Taylor and Dascombe, 2017). Although a large reported beneficial effect of pre-cooling upon exercise performance (5.7%), this benefit typically decreases after 20-25 min of exercise (Bongers et al., 2014). Therefore, the desired physiological and heat storage capacity alterations induced via pre-cooling would only be sufficient enough to have an ergogenic affect upon the first-half (0 - 45 min) of soccer match-play performance, leaving the second-half of soccer match-play relatively unaffected (Taylor and Rollo, 2014). However, the use of cooling manoeuvres during exercise have become of particular interest to practitioners as the magnitude of heat-stress experienced during exercise is greater in comparison to before (Kenefick, Cheuvront and Sawka, 2007). Although cooling is not permitted during soccer match-play, it can be used during the half-time interval to not only alleviate the increases in thermal strain achieved from the first-half of soccer match-play, but also attenuate some of the decrements in physical performance previously reported in the second-half of simulated (Aldous et al., 2016) and soccer match-play (Mohr et al., 2012) in hot environments.

Due to the prominence of heat within elite soccer, numerous simulated (Drust et al., 2000a; Price, Boyd and Goosey-Tolfrey, 2009; Clarke et al., 2011; Sunderland et al., 2015; Aldous et al., 2018; Parris and Tyler, 2018) and match-play (Duffield et al., 2013) studies have assessed the effect of pre-cooling with or without half-time cooling on soccer performance with varying levels of success reported (table 2.1). Drust et al. (2000a) was the first to investigate pre-cooling on simulated soccer performance reporting no significant reductions ($P > 0.05$) upon the physiological responses to this soccer-specific simulation following 60 min of pre-cooling via a cold shower. Although this cooling manoeuvre failed to achieve any substantial changes in thermoregulatory responses or physical performance changes, likely due to the magnitude of heat-stress (20°C and 68% rH) not being sufficient to permit an ergogenic effect of the cooling on increasing body temperatures. A further limitation is the practicality of this cooling manoeuvre, similar to cold water immersion, it would require large amounts of time to effectively cool the players, physical limitations of cooling multiple players at the same time combined with reducing muscle temperatures which is important to sprint performance during soccer match-play (Mohr et al., 2004). Conversely, Duffield et al. (2013) utilised a more practical approach to cooling as highlighted in section 2.5.3, although equivocal findings were reported in professional soccer-players during training and match-play in 29°C. However, it is widely acknowledged that inferences from interventions within match-play designs are difficult to obtain due to the variable nature of soccer match-play (Rampinini et al., 2007; Rampinini et al., 2009). As highlighted in section 2.5.3, simulated soccer data has reported a reduced thermal strain following pre-cooling via ice vests (Price, Boyd and Goosey-Tolfrey, 2009; Clarke et al., 2011; Parris and Tyler, 2018). However, the cooling periods utilised by Clarke et al. (2011) and Price, Boyd and Goosey-Tolfrey (2009) prior to (60 and 20 min) and at half-time (15 min) during simulated soccer match-play do not fit in with the time constraints practitioners are faced with in soccer. Furthermore, these studies did not utilise the cooling manoeuvre during a pre-match warm-up, which would be of great practical benefit to practitioners due to the limited access to soccer-players on match-day (Taylor and Rollo, 2014). Parris and Tyler (2018), reported thermoregulatory strain (core and skin temperature) was significantly reduced during the second-half of simulated match-play in 35°C when an ice vest was worn throughout exercise. Furthermore, a significant improvement in repeated sprint performance following a simulated soccer match-play in 33°C when a neck cooling collar was worn throughout exercise (Sunderland et al., 2015). Although these studies highlight reduced thermoregulatory strain (Parris and Tyler, 2018) and enhanced sprint performance (Sunderland et al., 2015), these studies both utilised their respective cooling manoeuvre throughout exercise, which is not permitted is competitive soccer due to the governing body dictated rules of the sport (Taylor and Rollo, 2014). Moreover, neither studies utilised a valid and reliable soccer-specific simulation which can quantify for decrements in physical performance during each half as opposed to performance tests utilised after fixed distance protocols used in the previous studies (Clarke et al., 2011; Sunderland et al., 2015). However, utilising the valid and reliable intermittent Soccer Performance Test, Aldous et al. (2018) reported a significant increase in total, high-speed and variable-run distance covered during the first-half. However, the half-time duration of cooling utilised in this study (15 min) is not realistic in soccer match-play (Towlson et al., 2013) nor had any significant effect on any physical performance measure during the second-half of this individualised, soccer-specific simulation at 30°C, where further heat-mediated decrements in physical performance have been reported to occur during simulated (Aldous et al., 2016) and match-play data (Mohr et al., 2012). Furthermore, the ice packs placed on the quadriceps and hamstrings as part of this combination cooling manoeuvre utilised would be too restrictive to be worn during a pre-match warm-up, whilst also directly reducing muscle temperatures and potentially affecting initial sprint performance at the start of the second-half of match-play. Although a re-warm-up could offset these decrements (Lovell et al., 2009), a more practical solution which could reduce body temperatures without reducing muscle temperatures would be of greater benefit to soccer-players.

As varying degrees of success have been reported in the pre- and/or half-time cooling studies (table 2.0), the level of heat-stress (20.5 - 30.7°C and 42.2 - 78% rH) in the majority of studies (Drust et al., 2000a; Clarke et al., 2011; Duffield et al., 2013; Aldous et al., 2018) may have not been extreme enough to permit reducing bodily temperature to have any further ergogenic effect on soccer-specific performance. As higher ambient temperatures can be experienced within heat-situated soccer match-play (figure 2.1), future research should evaluate pre- and half-time cooling manoeuvres on simulated soccer performance under greater heat-stress (≥ 32°C and 60% rH).

2.6. Summary

In summary, there is a prominence of heat in elite-soccer, with decrements in physical performance measures apparent within previous soccer (Mohr et al., 2012; Nassis et al., 2015) and simulated soccer match-play studies (Aldous et al., 2016) within hot environments (30 - 43°C). Physical performance during soccer-match-play is important due to its association with game defining moments (Gregson et al., 2010). However, the mechanisms underpinning heat-mediated decrements in physical performance are complex, with an interplay amongst multiple factors apparent (Nybo et al., 2014). Therefore, interventions which can augment these decrements in physical performance via reducing physiological strain or perceptual stress are warranted in soccer.

Due to the congested calendar within soccer match-play (Racinais et al, 2015) and limited access to players prior to and during half-time in soccer, practical interventions such as cooling manoeuvres are typically most suited (Taylor and Rollo, 2014). Ice vests offer a practical, and effective method at reducing body temperatures, without affecting muscle temperature directly (Bongers et al., 2014). Neck cooling collars offer an alternative practical method of improving simulated soccer performance within a hot environment (Sunderland et al, 2015). However, any improvements from neck cooling collars within previous studies (Tyler, Wild and

Sunderland, 2010; Sunderland et al., 2015) stem from a reduction in perceptual measures (rate of perceived exertion, thermal sensation and neck thermal sensation). However, aforementioned studies for both ice vests and neck cooling collars are limited as they did not cool during a practical warm-up or allow any key physical performance measures to be quantified, due to fixed distance protocols being utilised within these studies (Price, Boyd and Goosey-Tolfrey, 2009; Sunderland et al., 2015).

As ice vests target reducing physiological strain (Price, Boyd and Goosey-Tolfrey, 2009; Duffield et al., 2013) and neck cooling collars target reducing perceptual stress (Tyler, Wild and Sunderland, 2010; Sunderland et al., 2015), an additive effect may occur from combining both practical cooling manoeuvres (Bongers et al., 2014). Therefore, this provides a rationale to investigate the singular and combined effect of these practical cooling manoeuvres during a pre-match warm-up and at half-time, utilising the valid and reliable iSPT in a hot environment (32°C and 60% rH; WBGT: 28°C).

2.7. Aims and Hypothesis

The aim of the current study was to investigate the effect of three different pre- and half-time cooling maneuvers (ice vest, neck cooling or ice vest and neck cooling) compared with a control (i.e. no-cooling) on physical performance, physiological and perceptual responses during simulated soccer in a hot environment (32°C and 60% rH; WBGT: 28°C). It was therefore hypothesised that;

1. Ice vests, neck cooling and mixed-method pre-cooling will significantly improve each 15 min period of simulated soccer performance during the first-half of iSPT at 32°C and 60% rH, compared with no cooling.
2. Ice vests, neck cooling and mixed-method pre-cooling will significantly improve each 15 min period of simulated soccer performance during the second-half of iSPT at 32°C

and 60% rH, compared with no cooling.

3. The mixed method pre- and half-time cooling will significantly improve each 15 min period of simulated soccer performance, compared with ice vest and neck cooling during iSPT at 32°C and 60% rH.

Chapter 3: Methods

3.1. Participants

Seven male soccer-players [mean ± SD; age 22 ± 1 y, body mass 77 ± 7 kg, height 178 ± 8 cm, predicted maximal oxygen uptake ($\dot{V}O_{2max}$) 48 ± 2.2 mL.kg^{-1}.min^{-1}] volunteered to participate in the study. The study was approved by the Research Ethics Committee at the University of Bedfordshire (Approval number: 2018ISPAR003) and conformed to the declaration of Helsinki. An a *priori* power calculation (G*Power 3.1, University of Keil, Germany) demonstrates that a sample size of 8 soccer-players is required following a repeated measures design assuming an effect size of $d = 0.7$ for HSD covered (Aldous et al., 2018), at a statistical power of 80% and an alpha level of 5%. One participant withdrew from the study due to injury and was therefore not used for data analysis.

To demonstrate some parity to elite soccer-players, all participants adhered to the following criteria: ≥ three years' experience playing soccer and a $\dot{V}O_{2max} \geq 45$ mL.kg^{-1}.min^{-1} (Bloomfield, Polman and O'Donoghue, 2007; Tonnessen et al., 2013). Participants trained ≥2 times per week for the Men's University 1st team competing in the British Universities and Colleges Sport Midlands 3B Division. All participants were provided with an information sheet (appendix A) detailing the expectations and risks of the study before providing written informed consent (appendix B).

3.2. Experimental Controls

All participants refrained from the supplementation of ergogenic aids outside their normal diet throughout the study (Taylor et al., 2012) and from hot baths seven days before and throughout experimental testing (Zurawlew et al., 2016). Participants abstained from alcohol, cigarettes, caffeine and strenuous activity $<$ 48 h prior to all experimental trials. In the 24 h prior to all experimental trials, participants standardised their food and water consumption and consumed

2 - 3 L of water (Sawka et al., 2007; Taylor et al., 2012). Adherence to all control measures was assessed via a training log for the preceding 7 days (appendix K), and a food diary (appendix L) for the preceding 24 h before experimental testing. Participants were provided with a weighting scales (Scales, Tanita, BWBO800, Allied Weighing) to measure food intake prior to experimental trials (24 h), with a violation occurring if an equal or a greater amount of food was not consumed. No violations of control measures were reported.

All experimental trials took place at the same time of day to minimise circadian variation upon rectal temperature [T_{re} (Racinais et al., 2012)] and physical performance (Drust et al., 2005). All participants started the iSPT at 1:00 pm (mean ± SD; 1:08 ± 0:19). This time being the earliest kick-off time experienced during the 2014 and 2018 FIFA World Cup in Brazil and Russia, respectively. It is anticipated that 1pm will be the earliest kick-off time during the 2022 FIFA World Cup in Qatar, where the highest ambient temperature (24-38°C) will likely be experienced (BBC Sport, 2015). All familiarisation [FAM (18°C and 50% rH; WBGT: 14°C)] trials, peak speed assessment [PSA (18°C and 50% rH; WBGT: 14°C)] and experimental trials (32.1 ± 1.7°C and 57.3 ± 4.4% rH; WBGT: 28°C) were completed on the same calibrated non-motorised treadmill [NMT (Force3.0, Woodway UK, Birmingham)], in an environmental chamber (T.I.S.S. Services UK, Hampshire). The WBGT was calculated from a bespoke Microsoft Excel Spreadsheet and was calculated from the ambient air temperature, relative humidity and wind speed in the environmental chamber (Liljegren et al., 2008; Brice and Hall, 2009). The laws of association football state that if WBGT $\geq$ 32°C is experienced during soccer match-play, a 3 min water and cooling break must be enforced at the 30th min of each half (Houssein, et al., 2016; IFAB, 2018). However, as a WBGT of 28°C was used in the present study design, no water and cooling breaks were included. A tether belt and harness were attached around participants waist to secure them to the NMT, with the harness attached at an angle of 8° from horizontal (Lakomy 1987). Airflow was present in all experimental trials via a large fan (655-mm diameter blade; Imasu IMS International, Tsuen Wan, Hong Kong) placed 1 m in front of the participant on the NMT. The fan height was adjusted to include airflow over the torso, both arms and the upper legs, covering as much surface area as possible in the standing position. The maximum average wind velocity from 1 m was 1.4 m/s. Hydration status was assessed via urine osmolality (Atago-Vitech-Scientific, Osmocheck Pocket-PAL-OSMO, Southam), with euhydration deemed when urine osmolality is < 600 $mOsm.kg^{-1}$ H_2O (Hillman et al., 2013). All participants wore a football kit (Dry-Fit, Nike, Georgia) consisting of a short-sleeved shirt, shorts and stockings combined with their own running trainers during all experimental trials. All equipment worn was kept consistent for each individual throughout experiential testing.

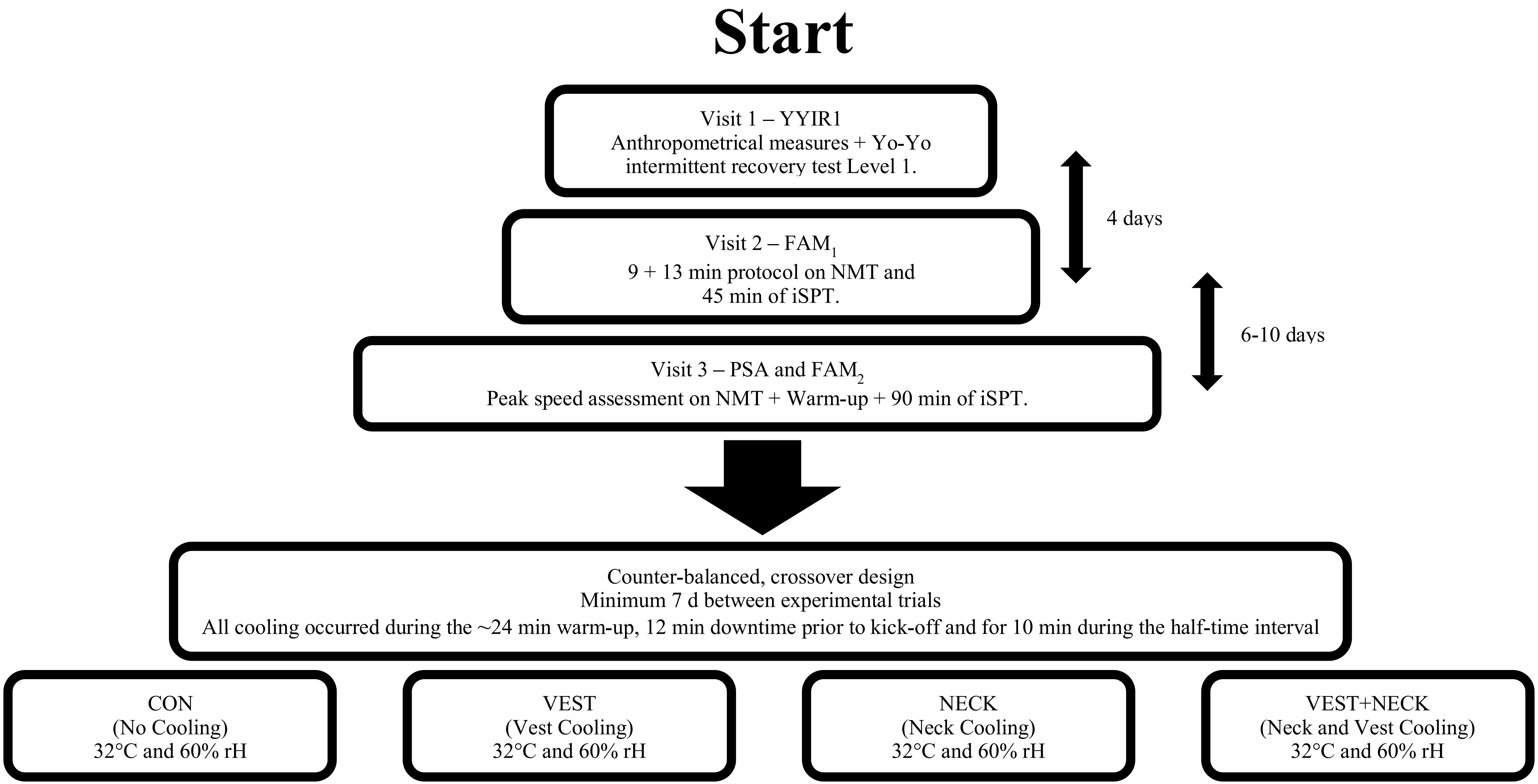

Figure 3. 1. Schematic for experimental design.

3.3. Experimental Design

Visit 1 required participants to visit the University of Bedfordshire Sports Hall to complete the the Yo-Yo Intermittent Recovery Test, Level 1 [YYIRT1 (Krustup et al., 2003)]. Upon arrival, anthropometric measurements (height and body mass) were collected prior to attaching a heart rate (HR) monitor (Polar FS1, Electro, Kempele, Finland). After a standardised soccer specific warm-up consisting of aerobic continuous running and dynamic stretching exercises (see section 3.3.4), participants performed the YYIRT1 until volitional exhaustion. Cones were marked with a width of 2m, the YYIRT1 consisted of repeated 2 x 20 m runs back and forth between the start and finish line at a progressive speed increase controlled by audio beeps. The audio cues of YYIRT1 were played via a portable CD player (Phillips, CD player, The Netherlands) with portable amplifier (Soundplus, TRAMP PC-30, Korea). The YYIR1 consists of 4 running bouts at 10 - 13 km·h^{-1} (0 - 160 m) and another 7 runs at 13.5 - 14 km·h^{-1} (160 - 440 m), following this the YYIR1 continued with stepwise increments (0.5 km·h^{-1}) in speed after every 8 running bouts (i.e. after 760, 1080, 1400 m etc.) until volitional exhaustion. Between each running bout, participants had 2 x 5m of active recovery after the start/finish line lasting 10s in duration. When the participant failed twice to reach the start/finish line on time, the test was terminated. Total distance covered was used as the test result to calculate the $\dot{V}\mathrm{O}_{2\mathrm{max}}$ of the participant using the following equation:

$$YYIR1\ estimated\ \dot{V}O_{2max}\ (mL.min^{-1}).kg^{-1]}) = YYIRT1\ distance\ (m) \times 0.0084+36.4$$

(Bangsbo, Iaia and Krustrup, 2008).

The YYIRT1 was used to either include (≥ 45 mL.kg^{-1}.min–1) or exclude (< 45 mL.kg^{-1}.min^{-1}) the participant in the study (Krustrup et al., 2003). Participants completed the YYIR1 individually to eliminate any competitive motivation factors. All participants were familiarized with the test before completion via walking practice runs until competent.

Participants then completed a thorough familiarisation to the NMT due to its novel running mechanics (Lakomy et al, 1987) as per previous studies utilizing iSPT (Aldous et al., 2014; Coull et al., 2015; Aldous et al., 2016; Aldous et al., 2018). **Visit 2 (FAM_1):** A minimum of 4 days after visit 1, participants were required to complete two short intermittent protocols on the NMT lasting 9 and 13 min, followed by the first 45 min of the iSPT. Between each bout of exercise, participants rested until their HR returned to their previously measured resting value. **Visit 3 (FAM_2 and PSA):** Participants rested for 6 - 10 days after the completion of FAM_1, before completing FAM_2 which consisted of the three-phase soccer-specific warm-up (see section 3.4.1) prior to 90 min of the iSPT in a temperate environment (18°C and 50% rH; WBGT: 14°C). Following the warm-up in FAM_2, participants rested for 12 min before entering the chamber to complete a PSA before the 90 min protocol. The PSA protocol was completed on the NMT which consisted of 3 sprints lasting 6 s separated by 3 rest periods. The peak sprint speed was defined as the fastest speed recorded during the PSA and was used to individualise the iSPT for all participants.

In a randomized and counterbalanced repeated measures design, experimental trials were completed on four occasions separated by a minimum of 7 days; (1) Ice Vest (VEST); (2) Neck Cooling (NECK); (3) VEST and NECK (VEST+NECK) used concurrently; or with no-cooling (CON). *-90 min - PreWU:* Upon arrival to the laboratory a HR monitor was attached and pre-exercise body-mass (Tanita, BWB0800, Allied Weighing, Abergele) was obtained. Following this, participants entered the toilet to provide a urine sample (see section 3.5.2), insert the single use rectal thermistor (see section 3.2) and changed into the provided football kit. Upon return to the labs, skin and neck thermistors were attached (see section 3.5.2). Pre-iSPT blood lactate and plasma volume samples were then taken (see section 3.5.2). Participants then rested for 5 minutes before resting measure for all measures were taken. *PreWU - 0 min:* Participants were given 500 mL of room temperature water for the duration of this period. Participants entered the chamber for the three-phase soccer-specific warm-up. No cooling/ cooling garment(s) were applied prior to entering the chamber. Once in the chamber, participants completed a ~24 min modified three-phase soccer-specific warm-up (see section 3.4.1), the average duration of a warm-up protocol in elite soccer (Towlson et al., 2013). Upon completion of the warm up, participants left the chamber and entered the laboratory room (18°C and 50% rH; WBGT: 14°C). Participants removed any cooling garment(s), where applicable, and replaced them with new ones as pilot testing found they had melted by this time. During all experimental trials, participants rested in a seated position for 12 min prior to entering the chamber again for the start of the iSPT, to simulate the time spent receiving pre-match instructions from the management/ coaching team prior to soccer match-play in the changing room (Towlson et al., 2013). Participants then removed any cooling garment(s) before entering the environmental chamber (32.1 ± 1.7°C and 57.3 ± 4.4% rH) 5 min prior to the first-half of the iSPT commenced to simulate the time taken for kick-off to occur once players enter the pitch (national anthems, team huddle, coin toss etc.). *0 - 45 min:* Participants completed the first-half of the iSPT, with all physiological and perceptual measures recorded every 15 min. *45 - 60 min:* Participants entered the laboratory for the 15 min half-time interval. Participants were given a further 500 mL of room temperature water for the duration of this period. Participants rested for 2 min before no cooling/cooling garment(s) were applied as previous research reported an average time of 1.7 min for players to return to the changing room following the half-time whistle (Towlson et al., 2013). No cooling/cooling garment(s) were worn for a total duration of 10 min during the half-time interval, with the garments removed 3 min prior to the end of half-time as previous research reported players typically leave the changing room 3 min early to ensure they are ready for the start of the second-half of match-play (Towlson et al., 2013). Participants rested whilst seated for a further 2 min prior to entering the environmental chamber in the final min of the half-time interval to commence with the second-half of the iSPT. *60 - 105 min*: Participants completed the second-half of the iSPT with all measures collected as per the first-half of iSPT. *105 - 115 min*: Upon completion of the iSPT, participants exited the environmental chamber to the laboratory room where a post-exercise finger prick blood sample and nude body mass measurement was obtained. All fluid consumed was measured and used to calculate post body-mass [pre-body mass – post body-mass + fluid consumed (Siegal et al., 2012)]. The study design and schematic are illustrated in figure 3.1 and 3.2, respectively.

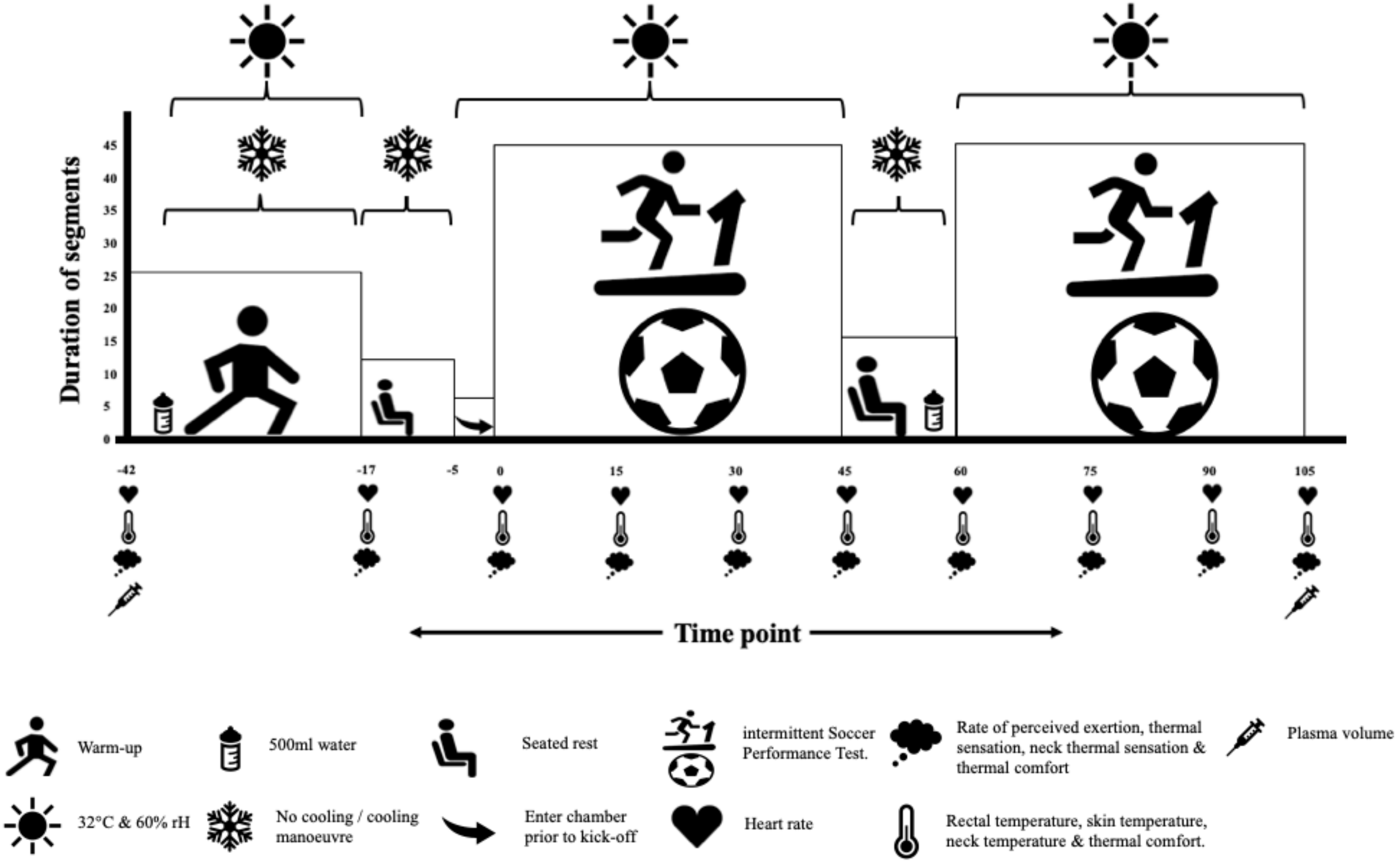

Figure 3. 2. Schematic for experimental protocol

3.4. Experimental Procedures

3.4.1. Three Phase Soccer-Specific Warm-Up

Prior to the iSPT, participants completed a standardized three phase ~24 min soccer-specific warm-up. This has been adapted from the FIFA11+ warm up (Impellizzeri et al., 2013), due to the environmental chamber size and omission of technical skills within this study design. The full duration of the warm-up was conducted in the environmental chamber (32.1 ± 1.7°C and 57.3 ± 4.4% rH; WBGT: 28°C) and consists of three phases. ***Phase 1:*** Participants completed 8 min at a self-selected pace on the NMT. Following this, participant stood resting for 2 min before prior to phase 2. ***Phase 2:*** Participants then completed a total of 16 dynamic exercises (appendix M) in the environmental chamber and was completed diagonally (6 m) across the 4 x 4.5 m chamber. Participants started at the first cone and performed the instructed exercises at each cone, for both legs towards the final cone, where they turned and completed the same exercises back to the starting cone. After each exercise, participants completed a gentle jog to the end cone and back. Total time to complete this section of the warm-up was recorded (06:44 ± 00:41 mm:ss). Participants rested again for 2 min prior to moving onto the final phase of the warm-up. ***Phase 3:*** The final phase of the warm up consisted of a 5 min high intensity NMT based warm-up (Oliver, Armstrong and Williams, 2007). consisting of three runs (6 s) and two sprints (6 s) at the end of each min interspersed with short bouts of walking, standing, and jogging. The 500 mL of room temperature water given to participants at the start of the warm up and was available during each period of rest between phases. Fluid consumption was consistent for each participant throughout all experimental conditions (761 ± 244 mL).

3.4.2. The intermittent Soccer Performance Test (iSPT)

The iSPT is a non-motorised treadmill-based soccer-specific simulation consisting of two 45 min halves, each comprised of three identical 15 min blocks of intermittent exercise.

Participants interacted with a computer program by following a red line on the screen (which displays their target speed) and the current (actual) speed (green line) throughout each 15 min block for all target speeds except for the variable run. Participants were instructed to match their current speed with the target speed as closely as possible throughout the iSPT for standing, walking, jogging, running, fast running and sprinting but not for the variable run component. Audio cues specific to each movement category (e.g. jog) were also presented by 3 audible tones which are played and subsequently followed by an audible command to inform the participant of the upcoming activity (e.g., "beep", "beep", "beep", "run"). Finally, four self-selected high-speed 'variable runs' were included in the 13th–14th min of each 15-min block. The variable run has been used elsewhere in a valid and reliable manner and has been previously described in detail (Aldous et al., 2014). The variable run component of the iSPT involved four self-selected high-speed runs during the 13th - 14th min of each 15 min block, where the participants were instructed to cover as much distance as possible whilst not sprinting. This enabled the quantification of high-speed distance covered at a self-selected running speed (without an external cue) above the second ventilatory threshold. The iSPT has been previously used in four published studies to date (Aldous et al., 2014; Coull et al., 2015; Aldous et al., 2016; Aldous et al., 2018). The iSPT has a high test-retest reliability, with the coefficient of variation <10% [TD (1.4%), VRD (1.4%), HSD (1.5%), LSD, (1.9%) and sprint distance covered (2.2%)] for within-subject values for all performance measures and physiological responses.

3.4.3. Cooling Manoeuvres

Ice vests (Arctic Heat, Brisbane, Australia; www.arcticheat.com.au) and neck collars (model CCX; Black Ice LLC, Lakeland, USA; www.blackicecooling.com) were purchased online for ~ £112 (price for one ice vest) and ~ £40 (price for one neck collar plus neoprene wrap). Cooling garments were stored in a freezer at -20°C and removed 5 min prior to their use so that any excess water/frost was removed from the products. All cooling garments were worn throughout the ~24 min soccer-specific warm-up, 12 min downtime period prior to the completion of the iSPT first-half and during a 10 min period at half-time. As pilot data indicated that both cooling garments had nearly melted following the soccer-specific warm-up, the ice vests and neck collars were both replaced for the 12 min cooling prior to kick-off. The ice vest was worn directly on top of the participants' clothing, whereas the neck collar was worn directly upon the skin, during the pre-match warm-up, downtime period and half-time interval. Participants completed a 2 min period of rest whilst seated, following this period cooling garments were applied from which participants wore for a total duration of 10 min whilst rested in a seated position. Following a further 2 min of seated rest, participants entered the chamber upon the final minute of the half-time interval (14th – 15th min), ready for the second-half of iSPT to commence. The cooling part of the collar was held in place by a 600 mm neoprene wrap with a hook and loop to fasten around the neck. Chest and mean neck skin temperature (neckT_{sk}) were measured throughout to monitor the T_{sk} to assess for signs of frost nip at the designated cooling areas. Thermal sensation was also monitored whilst any cooling garment were worn and throughout exercise to assess the participants perception of thermal stress. The proposed intensity and duration of cooling is in line with previous ethically approved work within the field (Arngrimsson et al., 2003; Tyler and Sunderland, 2011a).

3.5. Physical Performance, Physiological and Perceptual Measures

3.5.1. Physical Performance Measures

All physical performance variables were sampled at a rate of 100 Hz from the NMT via the software provided by the manufacturer (Innervation, Pacer Performance System Software). Total distance (TD) covered comprised of all movement categories, with percentage of PSS, frequency and total time spent detailed below (table 3.1). High-speed distance (HSD) covered was derived from fast run, variable run distance (VRD) and sprint distance (SD) covered, while low speed distance (LSD) covered consisted of walking, jog and run distances covered as per Aldous et al. (2014). Performance changes were calculated in distance covered (m) and computed for TD, HSD, VRD, SD and LSD for each half and 15 min block.

Table 3. 1. Movement categories and the percentage of intensity, frequency and total time spent during iSPT obtained from Aldous et al. (2014).

Movement Category	% of PSS	Frequency	Total Time (s)
Stand	0	240	960
Walk	20	456	1968
Jog	35	300	1296
Run	50	192	624
Fast run	60	72	192
Variable run	Unset	48	144
Sprint	100	72	216
Total		690	5,400

Abbreviations: iSPT = intermittent soccer performance test; % = percentage; PSS = peak sprint speed; s = seconds.

3.5.2. Physiological Measures

Prior to the FAM, height (cm) was measured via a Stationmaster (Harpenden Stadiometer, HAR 98.602, Holtain, Crymych, Wales). Nude body Mass (kg) was also measured pre- and post-iSPT, during all experimental trials using a digital scale (Tanita, BWB0800, Amsterdam, The Netherlands) to quantify for the fluid loss. Heart-rate was recorded beat-by-beat and averaged every 1 min using a telemetric HR monitor (Polar FS1, Electro, Kempele, Finland) throughout the experimental protocol. A single use rectal thermistor (Henleys, 400H, Henleys Medical, Welwyn Garden City, UK) was used to assess T_{re} from a depth of 10 cm past the anal sphincter and connected and read from a data logger (Measurement, 4600, Henley-medical, Welwyn Garden City, UK). A researcher awaited outside an unlocked bathroom with a HR watch to monitor HR as a safety precaution for anaphylactic shock, whist the participant inserted the rectal thermistor. Skin temperature (T_{sk}) was measured via skin thermistors (Grant, EUS-U-VS5-0, Wessex-Power, Dorset, UK) attached to the right side of the body at the centre of the pectoralis major, tricep, rectus femoris, and gastrocnemius as per the Ramanathan (1964) equation.

$$T_{sk} = 0.3\ (T_{chest} + T_{arm}) + 0.2\ (T_{thigh} + T_{calf})$$

(Ramanathan, 1964)

Mean neck skin temperature was calculated as the mean temperature of four skin thermistors spaced equally across the posterior aspect of the neck in line with Tyler, Wild and Sunderland (2010). Two skin thermistors were placed either side of the spinal midline, at approximately the 3rd - 4th cervical vertebrae, with the remaining two skin thermistors placed superior to the anterior aspect of both the left and right carotid arteries which was located via palpation (Tyler, Wild and Sunderland, 2010; Tyler and Sunderland, 2011a). All thermistors were attached via waterproof tape (Transpore; 3M Health Care, United States). Data for T_{sk} and neckT_{sk} was recorded separately from a data logger (Eltek/Squirrel, Squirrel Series/model 451, WessexPower, Dorset, UK). The T_{re}, T_{sk} and neckT_{sk} were recorded pre- and post the warm-up (PreWU and PostWU) and every 15 min throughout the iSPT (0, 15, 30, 45, 60. 75, 90 and 105 min).

3.5.2. Perceptual Measures

Rating of perceived exertion (RPE), thermal comfort (TC), TS and neck TS (TS_{neck}) were recorded pre- and post the warm-up (PreWU - PostWU) and every 15 min throughout the iSPT

(0, 15, 30, 45, 60. 75, 90 and 105 min) via the Borg 6 - 20 scale (Borg, 1998), 0 - 8 TS scale [TS and TS_{neck} (Young et al., 1987)] and 1 - 10 TC scale (Stevens et al., 2016), respectivley.

3.6. Statistical Analyses

Statistical analysis was performed using IBM SPSS statistics version 23 (SPSS Inc. Chicago, USA). Physical performance data from the NMT was exported to a bespoke spreadsheet on Microsoft Excel 2010 for analysis (Windows Microsoft, Washington, USA). All graphs were produced via Microsoft Excel 2010 (Windows Microsoft, Washington, USA). Quantile-quantile (Q - Q) plots were used to check data is normally distributed and was deemed plausible in all instances. Therefore, all data is presented as mean ± SD. A two-way ANOVA (condition x time) with repeated measures was used to analyse differences between conditions (CON, VEST, NECK and VEST+NECK) for physiological (HR, T_{re}, T_{sk}, $neckT_{sk}$) perceptual (RPE, TC, TS TS_{neck}) and physical performance (TD, HSD, VRD, SD and LSD covered between halves, and 15 min blocks) data. A one-way ANOVA was used to analyse changes in body mass pre- and post-iSPT. Mauchley's test was used to test the assumption of sphericity. When violated ($P > 0.05$), the correction Greenhouse-Geisser was applied to the degrees of freedom for the F ratio. When a significant main and/or interaction effect was identified, a bonferroni post-hoc comparisons were used to identify specific differences across time between conditions. Two-tailed statistical significance was accepted at $P < 0.05$. Effect sizes (Cohen's *d*) of all significant differences were calculated based on the following scale: < 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. Physical Performance

4.1.1. Between Conditions and Halves

4.1.1.1. Total Distance Covered

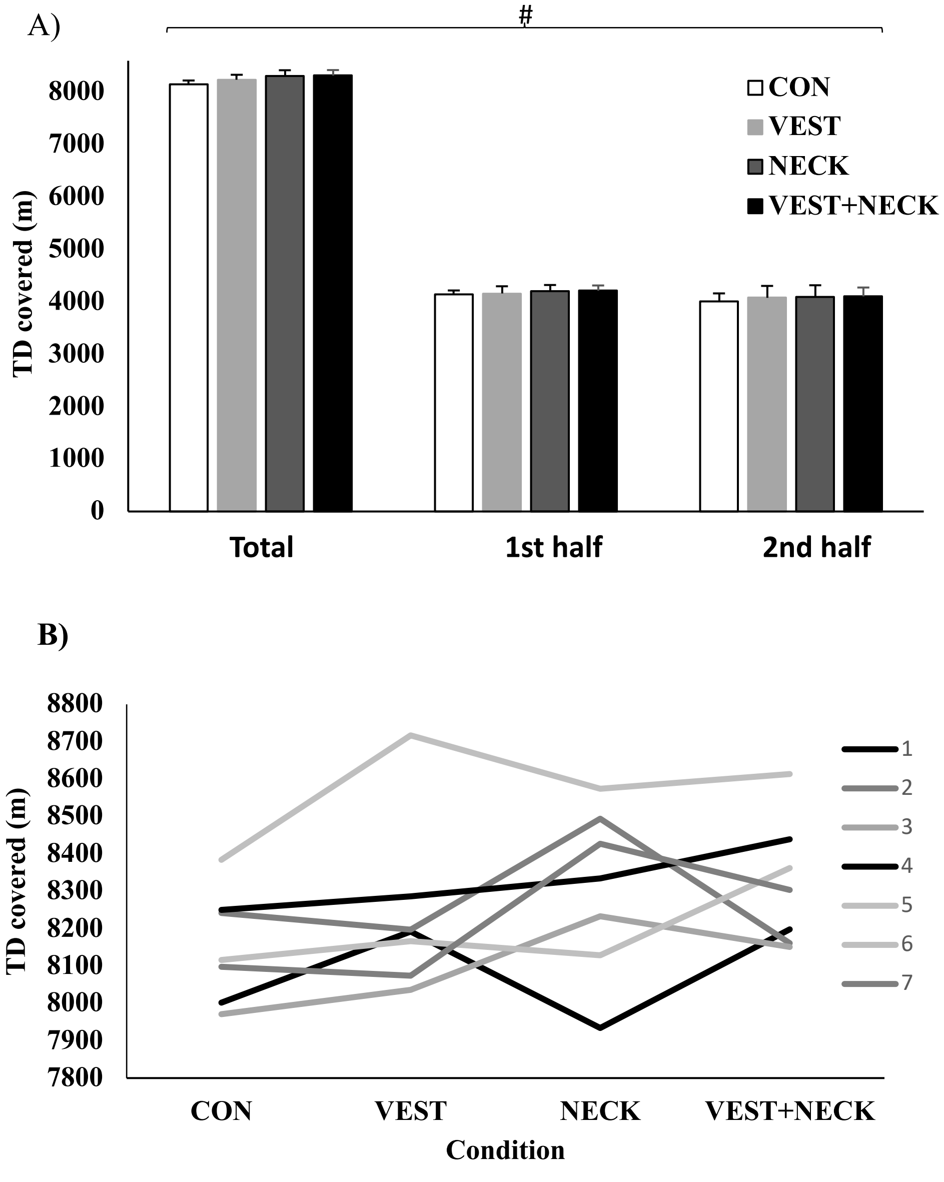

Figure 4. 1. The (A) TD covered in total (0 - 105 min) and each half [0 - 45 min and 60 - 105 min) and (B) the individual scores for total TD covered during iSPT for CON, VEST, NECK and VEST+NECK (n = 7). Data presented as mean ± SD. # = Significant main effect for time ($P < 0.02$).

There was a significant main effect for time (F = 60.965; P < 0.001), but no significant main effect for condition (F = 2.958; P = 0.06), or significant condition x time interaction effect (F = 0.469; P = 0.708) for TD covered between halves. Mean TD covered during iSPT for VEST+NECK, NECK, VEST and CON was 8318 ± 169, 8304 ± 223, 8328 ± 227 and 8152 ± 148 m, respectively (figure 4.1).

4.1.1.2. High-Speed Distance Covered

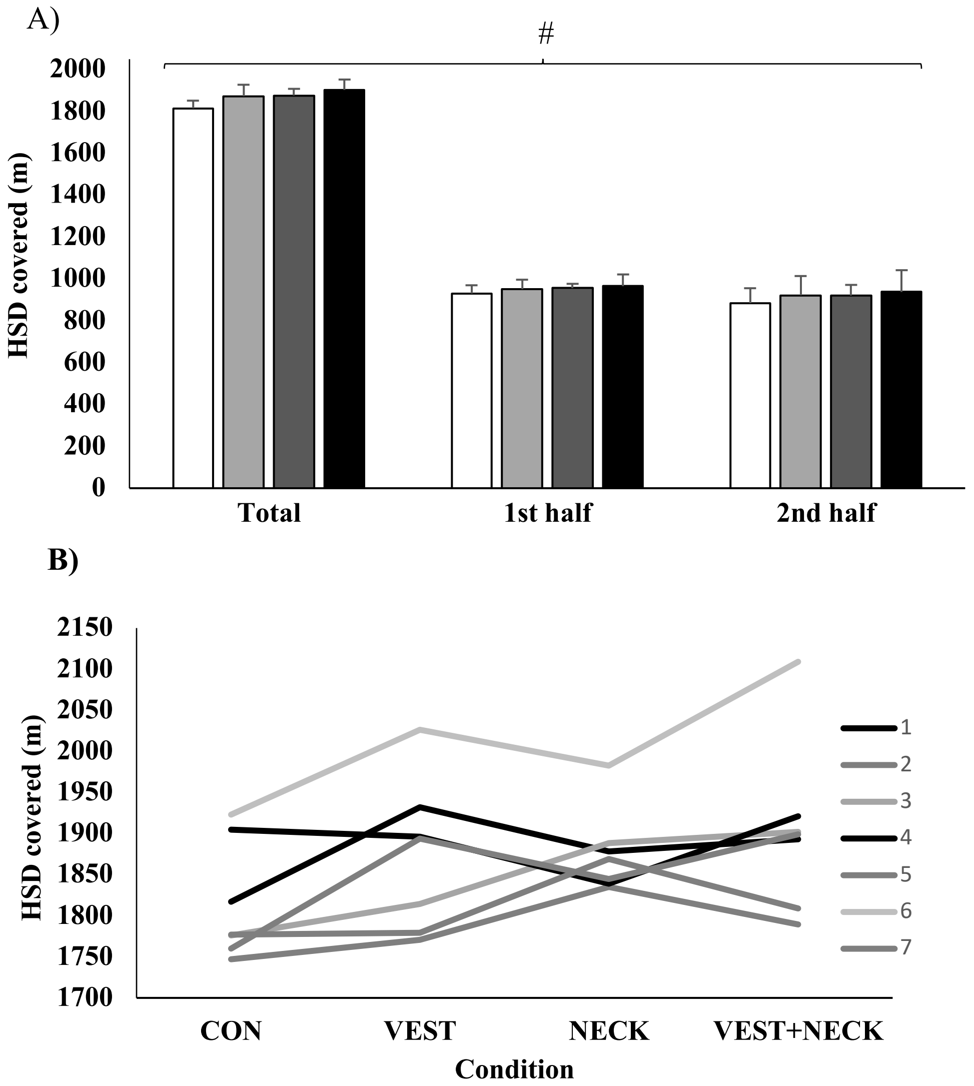

Figure 4. 2. The (A) HSD covered in total (0 - 105 min) and each half [0 - 45 min and 60 - 105 min) and (B) the individual scores for total HSD covered during iSPT for CON, VEST, NECK and VEST+NECK (n = 7). Data presented as mean ± SD. # = Significant main effect for time (P < 0.01).

There was a significant main effect for time (F = 25.065; P = 0.002), but no significant main effect for condition (F = 5.274; P > 0.05), or significant condition x time interaction effect (F = 0.908; P = 0.457) for HSD covered between halves. Mean HSD covered during iSPT for VEST+NECK, NECK, VEST and CON was 1903 ± 104, 1877 ± 51, 1873 ± 92 and 1815 ± 71 m, respectively (figure 4.2).

4.1.1.3. Variable Run Distance Covered

There was a significant main effect for time (F = 10.696; P = 0.017), but no significant main effect for condition (F = 3.282; P = 0.055), or significant condition x time interaction effect (F = 4.65; P = 0.710) for VRD covered between halves. Mean VRD covered during iSPT halves for VEST+NECK, NECK, VEST and CON was 429 ± 40, 414 ± 36, 413 ± 23 and 394 ± 28 m, respectively (figure 4.3).

4.1.1.4. Low Speed Distance Covered

There was a significant main effect for time (F = 22.017; P = 0.003), but no significant main effect for condition (F = 1.447; P = 0.262), or significant condition x time interaction effect (F = 4.37; P = 0.729) for LSD covered between halves. Mean LSD covered during iSPT for VEST+NECK, NECK, VEST and CON was 6415 ± 171, 6427 ± 255, 6365 ± 224 and 6337 ± 169 m, respectively.

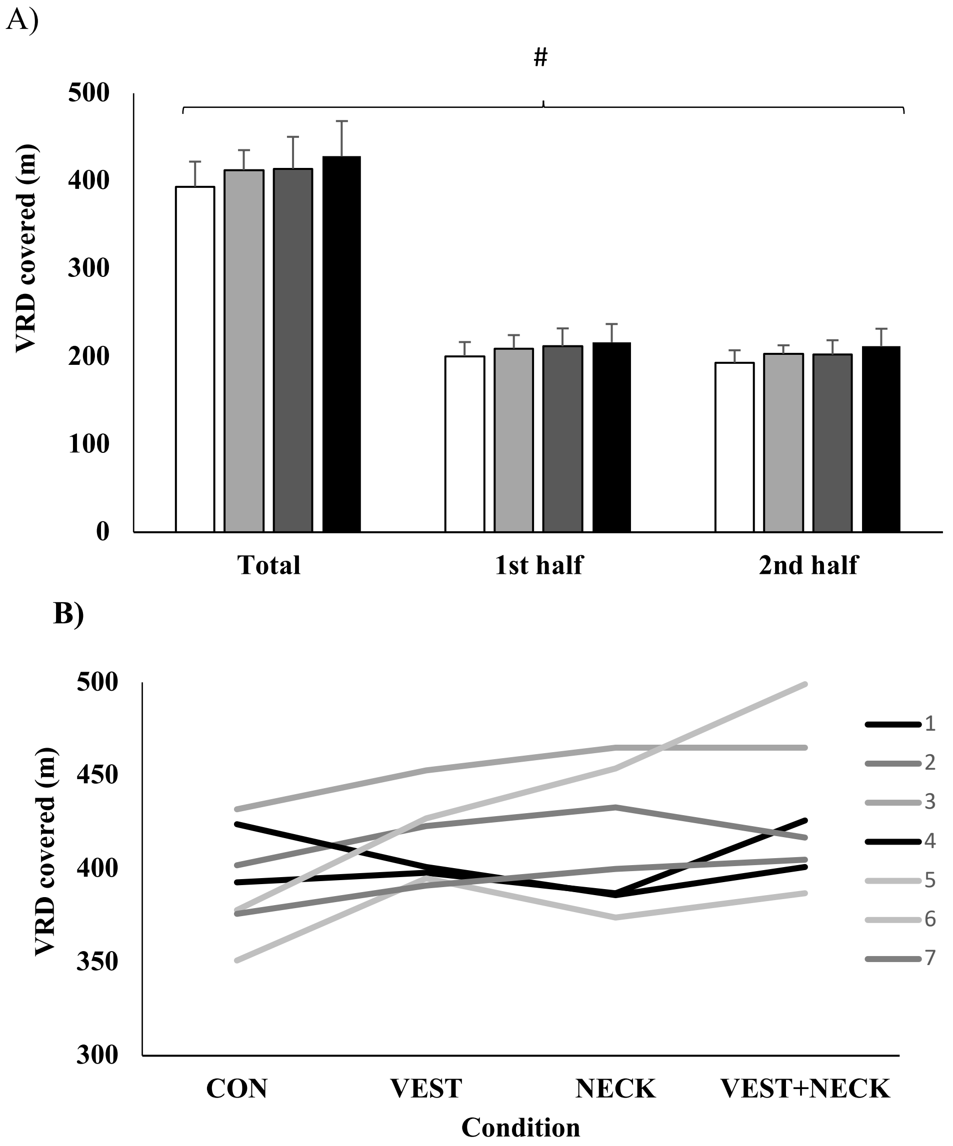

Figure 4. 3. The (A) VRD covered in total (0 - 105 min) and each half [0 - 45 min and 60 - 105 min) and (B) the individual scores for total VRD covered during iSPT for CON, VEST, NECK and VEST+NECK (n = 7). Data presented as mean ± SD. # = Significant main effect for time (P < 0.02).

4.1.1.5. Sprint Distance Covered

There was a significant main effect for condition (F = 6.877, P = 0.003), time (F = 27.044, P = 0.02) but no significant interaction effect (F = 2.717, P = 0.075) for sprint distance covered. Throughout iSPT, sprint distance covered was significantly greater by a large magnitude in VEST+NECK (448 ± 11 m, P = 0.012, *d* = 0.9, 95% CI: 7 to 50 m) and NECK (440 ± 9 m, P = 0.031, *d* = 0.8, 95% CI: 2 to 40 m) compared to CON (419 ± 12 m). There was no significant difference in VEST compared to CON (443 ± 15 m, P = 0.077, 95% CI: -3 to 51 m), NECK (P = 1.0, 95% CI: -27 to 34 m) and VEST+NECK (P = 1.0, 95% CI: -39 to 30 m), respectively.

4.1.2. Between Conditions and 15 min Blocks

4.1.2.1. Total, High-Speed, Variable-Run and Low-Speed Distance Covered

There was no significant interaction effect for TD (F = 1.71; P = 0.349), HSD (F = 1.511, P = 0.227), VRD (F = 0.799, P = 0.519) and LSD covered (F = 0.867, P = 0.478) between 15 min blocks (table 4.1).

4.1.2.2. Sprint Distance Covered

There was a significant condition x time interaction effect (F = 1.856, P = 0.039) for sprint distance covered between 15 min blocks. There was a significant decrease in sprint distance covered by a large magnitude from 90 - 105 min (131 ± 5 m, P = 0.013, *d* = 1.5, 95% CI: 4 to 31 m) compared to 0 - 15 min of iSPT in CON (148 ± 4 m). There was a significant decrease in sprint distance covered by a large magnitude during 90 - 105 min (142 ± 4 m, P = 0.025, d = 1.4, 95% CI: 2 to 25 m) and 75-90 min (141 ± 3 m, P = 0.005, *d* = 1.6, 95% CI: 5 to 23 m) compared to 0 - 15 min of iSPT for NECK (155 ± 3 m). There was a significant decrease in sprint distance covered by a large magnitude during 75-90 min (146 ± 3 m, P = 0.019, *d* = 0.9, 95% CI: 2 to 17 m) compared to 0 - 15 min of iSPT for VEST+NECK (155 ± 4 m). There were no further significant differences (P > 0.05) evident in conditions between 15 min blocks for sprint distance covered during iSPT (table 4.1).

When compared to CON (131 ± 5 m), there was a significant increase in sprint distance covered by a large magnitude during 90 - 105 min of iSPT for VEST+NECK (145 ± 5 m, P = 0.02, *d* = 1.2, 95% CI: 3 to 27 m), NECK (142 ± 4 m, P = 0.021, *d* = 1.0, 95% CI: 2 to 20 m) and VEST (145 ± 5 m, P = 0.049, *d* = 1.1, 95% CI: 0 to 29 m). There was also a significant increase in sprint distance covered by a large magnitude during 75 - 90 min of iSPT for VEST+NECK (146 ± 4 m, P = 0.034, *d* = 1.4, 95% CI: 1 to 21 m) compared to CON (135 ± 4 m). For NECK (155 ± 3 m), there was a significant increase in sprint distance covered by a large magnitude compared to CON (148 ± 4 m, P = 0.02, *d* = 2.3, 95% CI: 3 to 12 m) during 0 - 15 min of iSPT. There were no further statistical differences (P > 0.05) evident between conditions and 15 min blocks during iSPT (table 4.1).

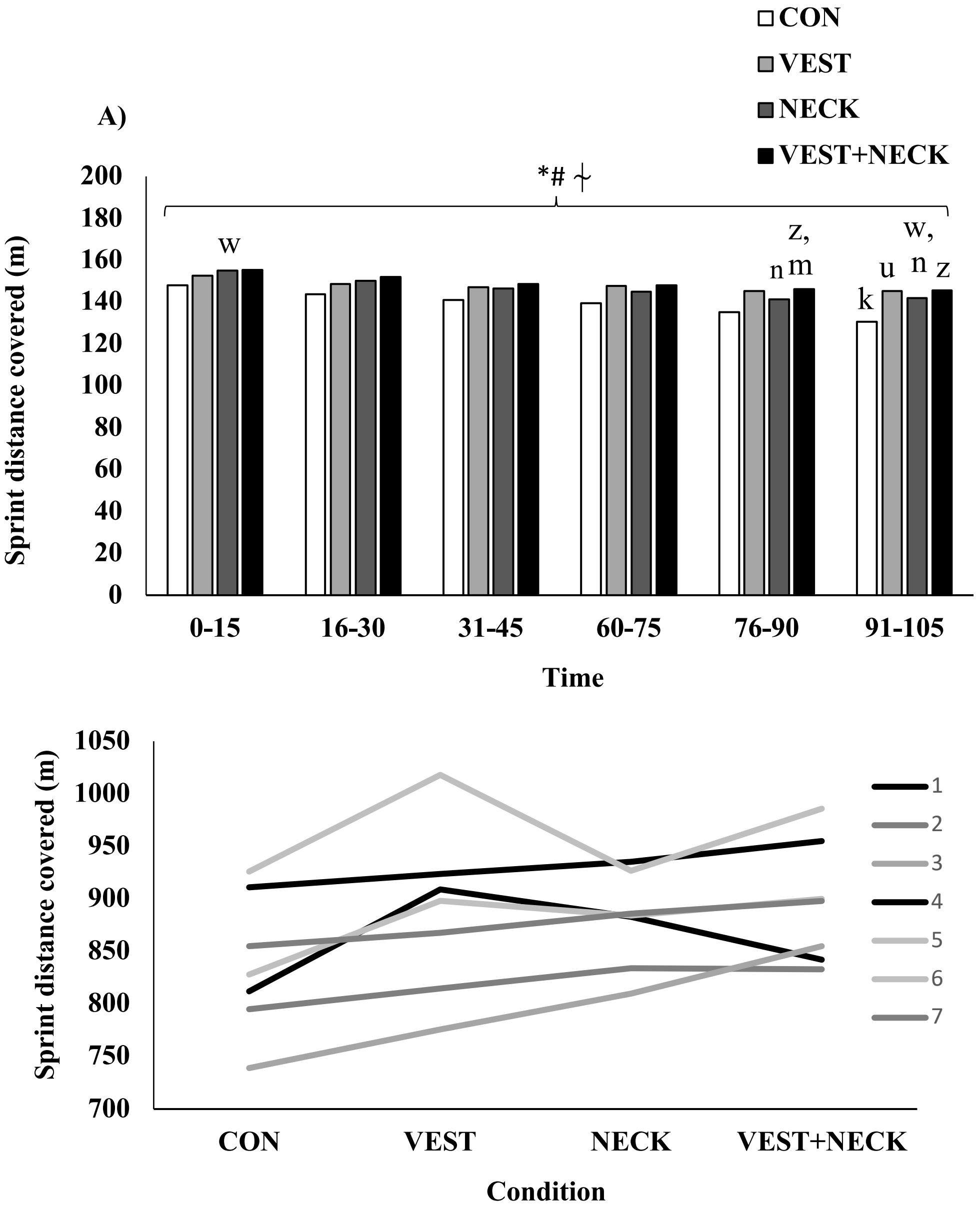

Figure 4. 4. The (A) sprint distance covered in each 15 min block and (B) the individual scores for total sprint distance covered during iSPT for CON, VEST, NECK and VEST+NECK (n = 7). Data presented as mean ± SD. * = Significant main effect for condition ($P < 0.01$); # = Significant main effect for time ($P < 0.02$); † = Significant interaction effect [condition x time ($P < 0.05$)]; k = Significant difference from first 15 min block in CON ($P < 0.02$); n = Significant difference from first 15 min block in NECK ($P < 0.03$); m = Significant difference from first 15 min block in VEST+NECK ($P < 0.02$); z = Significant difference between identical 15 min block in CON for VEST+NECK ($P < 0.04$); w = Significant difference between identical 15 min block in CON for NECK ($P < 0.03$); u = Significant difference between identical 15 min block in CON for VEST ($P < 0.05$).

Table 4. 1. The Overall HSD Sprint Distance Covered and VRD Covered in Each 15 min Block Throughout iSPT for CON, VEST, NECK and VEST+NECK (n = 7).

		0 - 15 min	15 - 30 min	30 - 45 min	60 - 75 min	75 - 90 min	90 - 105 min
HSD covered (m)							
	CON	316 ± 5	310 ± 5	304 ± 5	304 ± 5	295 ± 5	286 ± 5
	VEST	322 ± 8	316 ± 8	313 ± 6	315 ± 7	302 ± 6	305 ± 5
	NECK	327 ± 6	319 ± 4	310 ± 3	310 ± 3	307 ± 3	303 ± 2
	VEST+NECK	329 ± 7	323 ± 6	315 ± 6	316 ± 7	313 ± 7	311 ± 7
Sprint distance covered (m)							
	CON	148 ± 4	144 ± 4	141 ± 4	139 ± 5	135 ± 4	131 ± 5^{k}
	VEST	153 ± 5	149 ± 5	147 ± 5	148 ± 6	145 ± 5	145 ± 5^{u}
	NECK	153 ± 5^{w}	150 ± 2	146 ± 3	145 ± 3	141 ± 3^{n}	142 ± 4$^{w, n}$
	VEST+NECK	155 ± 4	152 ± 4	149 ± 3	148 ± 3	146 ± 3$^{z, m}$	145 ± 5^{z}
VRD covered (m)							
	CON	69 ± 2	67 ± 2	66 ± 2	67 ± 2	63 ± 2	63 ± 2
	VEST	71 ± 2	69 ± 2	69 ± 2	70 ± 2	66 ± 2	67 ± 1
	NECK	71 ± 3	70 ± 3	70 ± 3	67 ± 2	67 ± 2	68 ± 3
	VEST+NECK	74 ± 3	72 ± 3	71 ± 2	72 ± 3	70 ± 2	70 ± 2

Data presented as mean ± SD. CON = No Cooling; VEST = Vest Cooling; NECK = Neck Cooling; VEST+NECK = Vest and Neck Cooling; HSD = High-speed Distance; VRD = Variable Run Distance; k = Significant difference from first 15 min block in CON ($P < 0.02$); n = Significant difference from first 15 min block in NECK ($P < 0.03$); m = Significant difference from first 15 min block in VEST+NECK ($P < 0.02$); z =

Significant difference between identical 15 min block in CON for VEST+NECK ($P < 0.04$); w = Significant difference between identical 15 min block in CON for NECK ($P < 0.03$); u = Significant difference between identical 1min block in CON for VEST ($P < 0.05$).

4.2. Body Temperatures

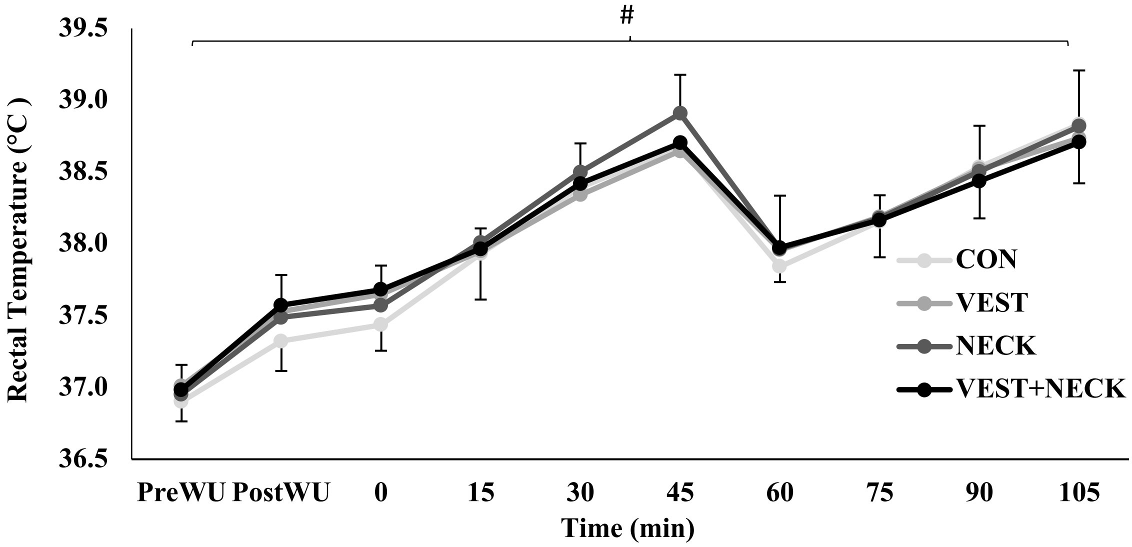

Figure 4. 5. Rectal temperature during the warm-up (PreWU - PostWU), downtime/pre-cooling period (PostWU - 0 min), iSPT first-half (0 - 45 min), half-time cooling (45 - 60 min) and iSPT second-half (60 - 105 min) for CON, VEST, NECK and VEST+NECK (n = 7)**.** Data presented as mean ± SD. # = Significant main effect for time ($P < 0.001$).

4.2.1. Rectal Temperature

There was a significant main effect for time ($F = 132.791$; $P < 0.001$), but no significant main effect for condition ($F = 0.313$; $P = 0.313$) or interaction effect ($F = 2.237$; $P = 0.09$) for T_{re}. From PreWU (36.96 ± 0.04°C, 95% CI: 36.86 to 37.07°C), T_{re} significantly increased PostWU (37.48 ± 0.03°C, $P < 0.001$, $d = 6.6$, 95% CI: 0.25 to 0.78°C) and throughout iSPT halves ($P < 0.05$), with the exception of the half-time period where it significantly decreased (37.93 ± 0.05°C, $P = 0.025$, $d = 8.8$, 95% CI: 0.10 to 1.49°C) compared to the end of the first-half by 0.8 ± 0.1°C (figure 4.5).

4.2.2. Neck Skin Temperature

There was a significant main effect for condition ($F = 135.217$; $P < 0.001$), time ($F = 104.173$; $P < 0.001$) and a significant condition x time interaction effect ($F = 77.087$; $P < 0.001$) for neckT_{sk} (figure 4.6).

Warm-up (PreWU - PostWU)

The neckT_{sk} was significantly reduced by a large magnitude in VEST+NECK at PreWU ($P < 0.001$, $d = 6.2$, 95% CI: 6.4 to 11.1°C) and PostWU ($P < 0.001$, $d = 13.4$, 95% CI: 7.6 to 11°C) compared to CON by 8.8 ± 0.6 and 9.3 ± 0.5°C, respectively. Similarly, neckT_{sk} was significantly reduced by a large magnitude in NECK at PreWU ($P < 0.001$, $d = 6.4$, 95% CI: 5.6 to 10.8°C) and PostWU ($P < 0.001$, $d = 9.5$, 95% CI: 7 to 11.2°C) compared to CON by 8.2 ± 0.7 and 9.1 ± 0.6°C, respectively. The neckT_{sk} was significantly reduced by a large magnitude in VEST+NECK at PreWU ($P < 0.001$, $d = 6.4$, 95% CI: 5.7 to 11.2°C) and PostWU ($P < 0.001$, $d = 6.2$, 95% CI: 7.6 to 10.2°C) compared to VEST by 8.4 ± 0.7 and 8.9 ± 0.3°C, respectively. Similarly, neckT_{sk} was significantly reduced by a large to large magnitude in NECK at PreWU ($P < 0.001$, $d = 6.4$, 95% CI: 5 to 10.8°C) and PostWU ($P < 0.001$, $d = 10.1$, 95% CI: 7 to 10.4°C) compared to VEST by 7.8 ± 0.8 and 8.7 ± 0.4°C, respectively. There was no further significance ($P > 0.05$) evident during the warm-up to iSPT between all conditions (figure 4.6).

First-half (0 - 45 min)

There was a significant reduction in neckT_{sk} by a large magnitude in VEST+NECK at 0 min compared to CON ($P < 0.001$, $d = 8.6$, 95% CI: 4.9 to 8.4°C) and VEST ($P < 0.001$, $d = 6.5$, 95% CI: 5.7 to 6.9°C) by 6.7 ± 0.5 and 6.3 ± 0.2°C, respectively. Furthermore, there was a significant reduction by a large magnitude in neckT_{sk} in NECK at 0 min compared to CON ($P < 0.001$, $d = 7.0$, 95% CI: 4.9 to 10.5°C) and VEST ($P < 0.001$, $d = 5.6$, 95% CI: 5 to 9.6°C) by 7.7 ± 0.7 and 7.3 ± 0.6°C, respectively. No further significant differences ($P > 0.05$) in neckT_{sk} were evident throughout the remainder of first-half of iSPT between conditions (figure 4.6).

Second-half (60 - 105 min)

There was a significant reduction in neckT_{sk} by a large magnitude in VEST+NECK at 60 min (start of the second half) compared to CON (P = 0.009, *d* = 3.1, 95% CI: 1 to 5.6°C) and VEST (P = 0.015, *d* = 2.5, 95% CI: 0.7 to 5.7°C) by 3.3 ± 0.6 and 3.2 ± 0.7°C, respectively. Furthermore, there was a significant reduction in neckT_{sk} by a large magnitude in NECK at 60 min compared to CON (P = 0.002, *d* = 4.9, 95% CI: 1.5 to 4.8°C) and VEST (P = 0.007, *d* = 3.5, 95% CI: 1 to 5.1°C) by 3.1 ± 0.4 and 3.1 ± 0.5°C, respectively. There were no further significant differences (P > 0.05) found throughout the second-half (75 - 105 min) of iSPT between conditions in neckT_{sk} (figure 4.6).

4.2.3. Skin Temperature

There was a significant main effect for condition (F = 10.279; P = 0.007), time (F = 151.801; P < 0.001) and a significant condition x time interaction effect (F = 8.425; P < 0.001) between conditions for T_{sk} (figure 4.6).

Warm-up (PreWU - PostWU)

The T_{sk} was significantly reduced by a large magnitude in VEST at PreWU (P = 0.037, *d* = 1.9, 95% CI: 0.1 to 3.7°C) and PostWU (P = 0.011, *d* = 2.6, 95% CI: 0.9 to 5.3°C) compared to CON by 1.9 ± 0.5 and 3.1 ± 0.6°C, respectively. Similarly, the T_{sk} was significantly reduced by a large magnitude in VEST at PreWU (P = 0.01, *d* = 2.5, 95% CI: 0.5 to 3.2°C) and PostWU (P = 0.013, *d* = 2.9, 95% CI: 0.8 to 5.8°C) compared to NECK by 1.9 ± 0.5 and 3.3 ± 0.7°C, respectively. The T_{sk} was significantly reduced by a large magnitude in VEST+NECK compared to NECK at PostWU (P = 0.02, *d* = 2.6, 95% CI: 0.5 to 5.1°C) by 2.6 ± 0.6. There was no further significance (P > 0.05) evident during the warm-up to iSPT between all conditions (figure 4.6).

First-half (0 - 45 min)

The T_{sk} was significantly reduced by a large magnitude in VEST at 0 min ($P = 0.013$, $d = 2.7$, 95% CI: 0.7 to 5.4°C) and 15 min ($P = 0.027$, $d = 2.1$, 95% CI: 0.2 to 2.7°C) compared to CON by 3.1 ± 0.6 and 1.4 ± 0.3°C, respectively. Similarly, a significant reduction by a large magnitude in T_{sk} was seen by VEST at 0 ($P = 0.015$, $d = 2.8$, 95% CI: 0.7 to 5.3°C) and 15 min ($P = 0.029$, $d = 2.0$, 95% CI: 0.2 to 3°C) compared to NECK by 3 ± 0.6 and 1.6 ± 0.4°C, respectively. The T_{sk} was significantly reduced by a large magnitude in VEST+NECK at 0 min compared to CON ($P = 0.039$, $d = 2.2$, 95% CI: 0.1 to 5°C) and NECK ($P = 0.016$, $d = 2.1$, 95% CI: 0.5 to 4.4°C) by 2.6 ± 0.6 and 2.5 ± 0.5°C, respectively. No further statistical changes ($P > 0.05$) were evident between conditions during the first-half of iSPT (figure 4.6).

Second-half (60 - 105 min)

At the start of the second-half (60 min), T_{sk} was significantly reduced by a large magnitude in VEST+NECK ($P = 0.038$, $d = 1.0$, 95% CI: 0.68 to 2.3°C) compared to NECK by 1.2 ± 0.3°C, respectively. No further statistical significance ($P > 0.05$) were evident throughout the second-half of iSPT (60 - 105 min) for T_{sk} between conditions, or during the rest of the second-half (75 - 105 min) for VEST+NECK (figure 4.6).

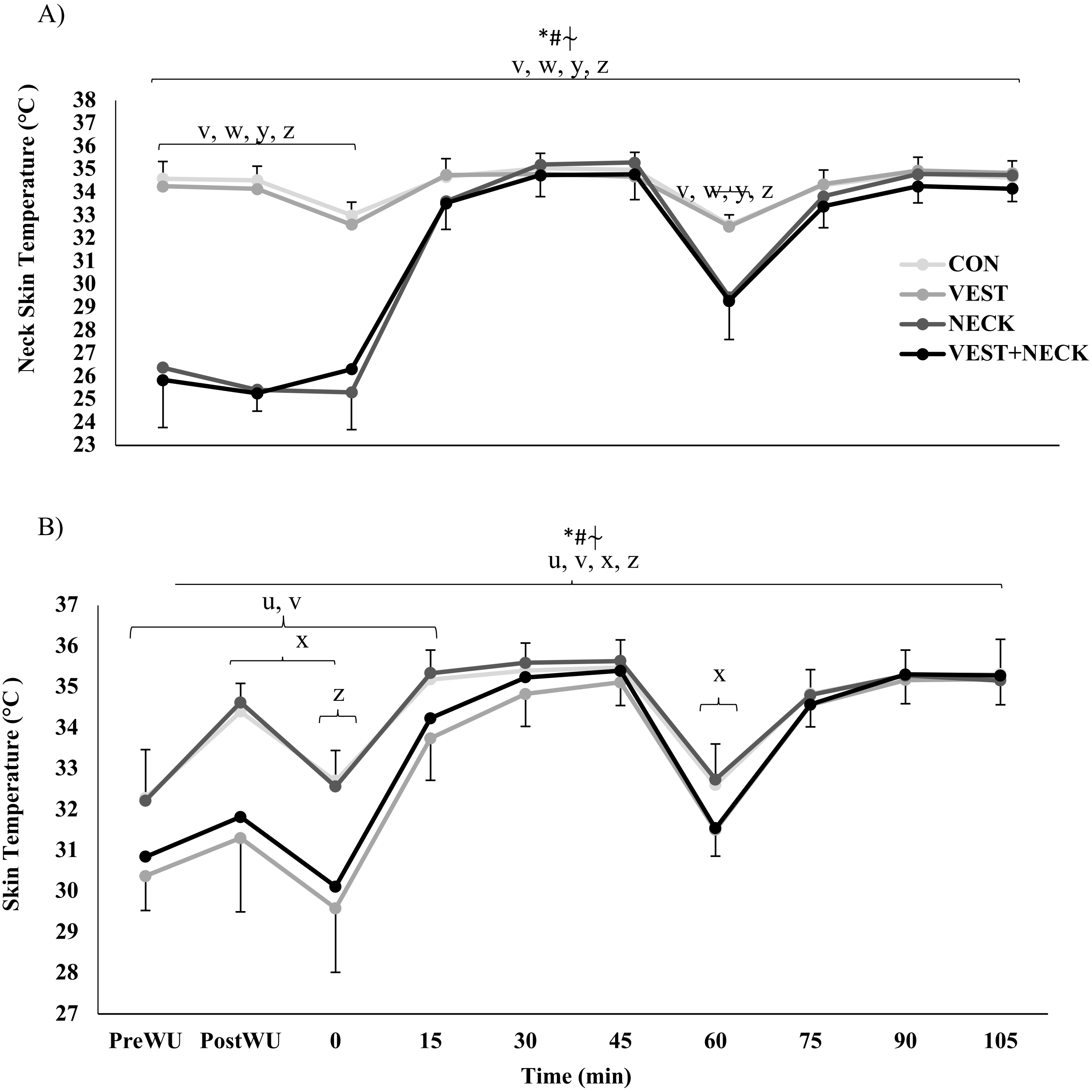

Figure 4. 6. Mean neck skin temperature (A) and mean skin temperature (B) during the warm up (PreWU to PostWU), downtime/pre-cooling period (PostWU - 0 min), iSPT first-half (0 - 45 min), half-time cooling (45 - 60 min) and iSPT second-half (60 - 105 min) for CON, VEST, NECK and VEST+NECK (n = 7)**.** Data presented as mean ± SD. * = Significant main effect for condition (P < 0.01); # = Significant main effect for time (P < 0.001); † = Significant interaction effect [condition x time (P < 0.001)]; z = Significant difference between CON and VEST+NECK (P < 0.04); y = Significant difference between VEST and VEST+NECK (P < 0.02); x = Significant difference between NECK and VEST+NECK (P < 0.04); w = Significant difference between CON and NECK (P < 0.003); v = Significant difference between VEST and NECK (P < 0.03); u = Significant difference between CON and VEST (P < 0.04).

4.3. Perceptual Responses

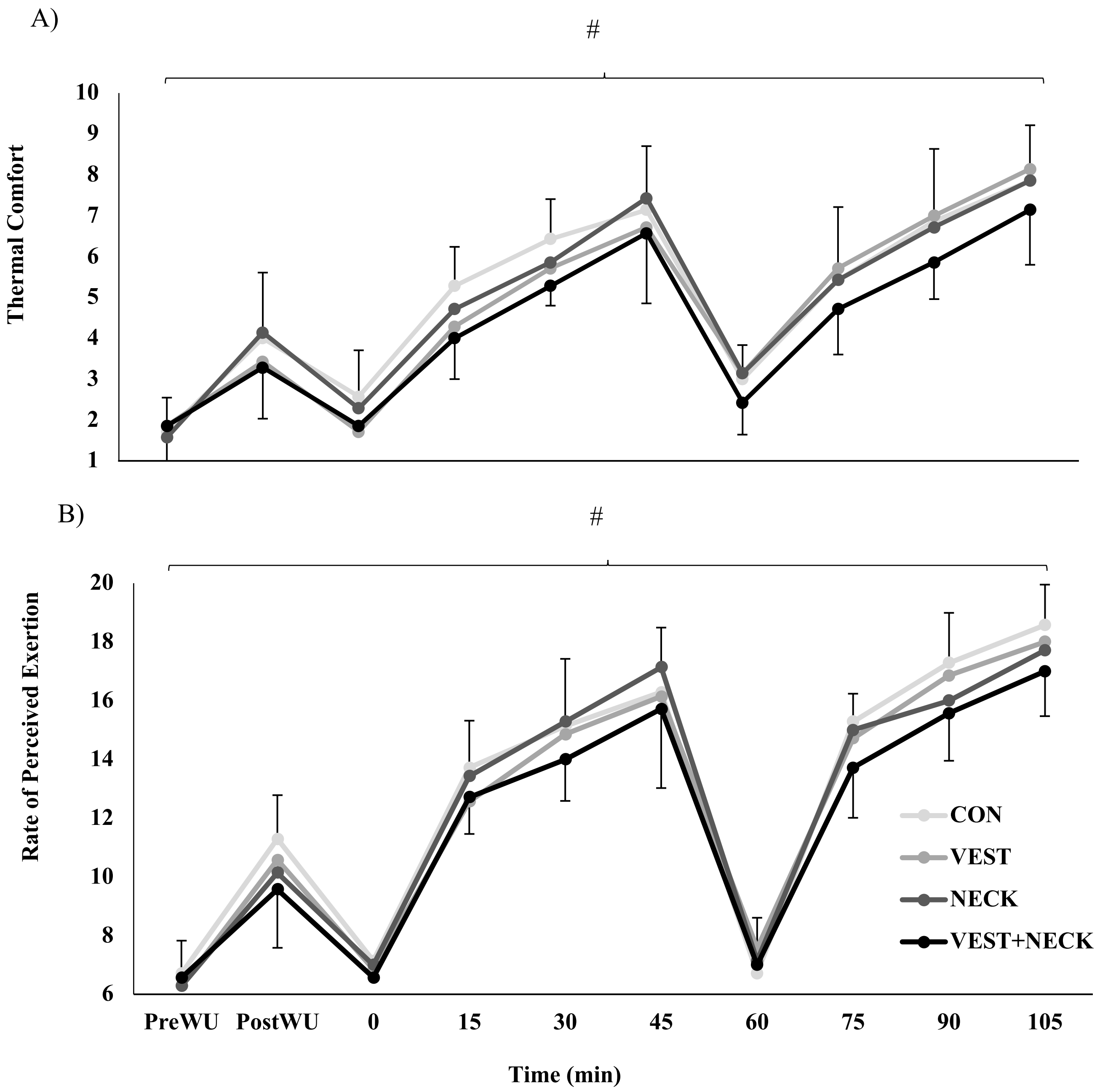

Figure 4. 7. Thermal comfort (A) and rate of perceived exertion (B) during the warm up (PreWU - PostWU), downtime/pre-cooling period (PostWU - 0 min), iSPT first-half (0 - 45 min), half-time cooling (45 - 60 min) and iSPT second-half (60 - 105 min) for CON, VEST, NECK and VEST+NECK (n = 7)**.** Data presented as mean ± SD. # = Significant main effect for time (P < 0.001).

4.3.1. Thermal Comfort

There was a significant main effect for time (F = 71.805; P < 0.001), but no significant main effect for condition (F = 1.373; P = 0.283) or interaction effect (F = 0.917; P = 0.481) for TC. From PreWU (95% CI: -0.7 to 1.5), TC was significantly increased by a large magnitude PostWU (P = 0.007, *d* = 6.6, 95% CI: 0.29 to 2.9), and throughout iSPT halves (P < 0.05), with the exception of the half-time period where TC significantly decreased (P = 0.008, *d* = 11.0, 95% CI: 1.1 to 6.9) compared to the end of the first-half by 4 ± 0.5 (figure 4.7).

4.3.2. Rate of Perceived Exertion

There was a significant main effect for time (F = 169.309; P < 0.001), but no significant main effect for condition (F = 1.457; P = 0.26) or interaction effect (F = 1.0; P = 0.472) for RPE. From PreWU (95% CI: 95% CI: -1.65 to 0.8), RPE was significantly increased by a large magnitude PostWU (P = 0.004, *d* = 8.4, 95% CI: 1.5 to 6.4), and throughout iSPT halves (P < 0.05), with the exception of the half-time period where RPE significantly decreased (P < 0.001, *d* = 19.3, 95% CI: 5.3 to 13.1) compared to the end of the first-half by 9.2 ± 0.7 (figure 4.7).

4.3.3. Neck Thermal Sensation

There was a significant main effect for condition (F = 8.954; P < 0.001), time (F = 49.046; P < 0.001) and a significant interaction effect (F = 4.009; P = 0.01).

Warm-up (PreWU - PostWU), First-half (0 - 45 min) and Second-half (60 - 105 min)

There was a significant reduction in TS_{neck} by a large magnitude in VEST+NECK at PreWU compared to VEST (P < 0.001, *d* = 2.7, 95% CI: 1.3 to 3.1) and CON (P < 0.001, *d* = 4.5, 95% CI: 1.5 to 4.1) by 2.2 ± 0.2 and 2.8 ± 0.3, respectively. Similarly, TS_{neck} was significantly reduced by a large magnitude in NECK at PreWU (2 ± 0.6) compared to VEST (P = 0.034, *d* = 1.8, 95% CI: 0.2 to 3.8) and CON (P = 0.013, *d* = 2.8, 95% CI: 0.6 to 4.5) by 2 ± 0.5 and 2.6 ± 0.5, respectively. The TS_{neck} was significantly reduced by a large magnitude in VEST+NECK at PostWU (P = 0.023, *d* = 2.3, 95% CI: 0.3 to 3.7) compared to CON by 2 ± 0.4. The TS_{neck}

was significantly reduced by a large magnitude in NECK at PostWU (P = 0.021, *d* = 2.4, 95% CI: 0.5 to 4.7) compared to CON by 2.6 ± 0.6. No further significant differences (P > 0.05) were evident during the warm-up prior to iSPT, or during the first (0 - 45 min) or second-half (60 - 105 min) of iSPT for TS_{neck}, respectively (figure 4.8).

4.3.4. Thermal Sensation

There was a significant main effect for condition (F = 8.503; P < 0.001), time (F = 46.295; P < 0.001) and a significant interaction effect (F = 2.086; P = 0.003) between conditions for TS.

Warm-up (PreWU - PostWU), First-half (0 - 45 min) and Second-half (60 - 105 min)

There was a significant reduction in TS by a large magnitude in VEST+NECK at PreWU (P = 0.036, *d* = 1.8, 95% CI: 0.1 to 2.9) and PostWU (P = 0.026, *d* = 1.5, 95% CI: 0.2 to 2.9) compared to NECK by 1.5 ± 0.5 and 1.5 ± 0.4, respectively. Similarly, TS was significantly reduced by a large magnitude in VEST+NECK at PreWU (P = 0.003, *d* = 3.5, 95% CI: 0.9 to 3.1) and PostWU (P = 0.038, *d* = 2.6, 95% CI: 0.1 to 4) compared to CON by 2 ± 0.3 and 2.1 ± 0.4, respectively. The TS was significantly reduced by a large magnitude in VEST at PreWU (2.9 ± 0.4, P = 0.032, *d* = 2.2, 95% CI: 0.2 to 3) compared to CON by 1.6 ± 0.4. No further significant differences (P > 0.05) were evident during the warm-up prior to iSPT, or during both halves of iSPT (0 - 105 min) for TS, respectively (figure 4.8).

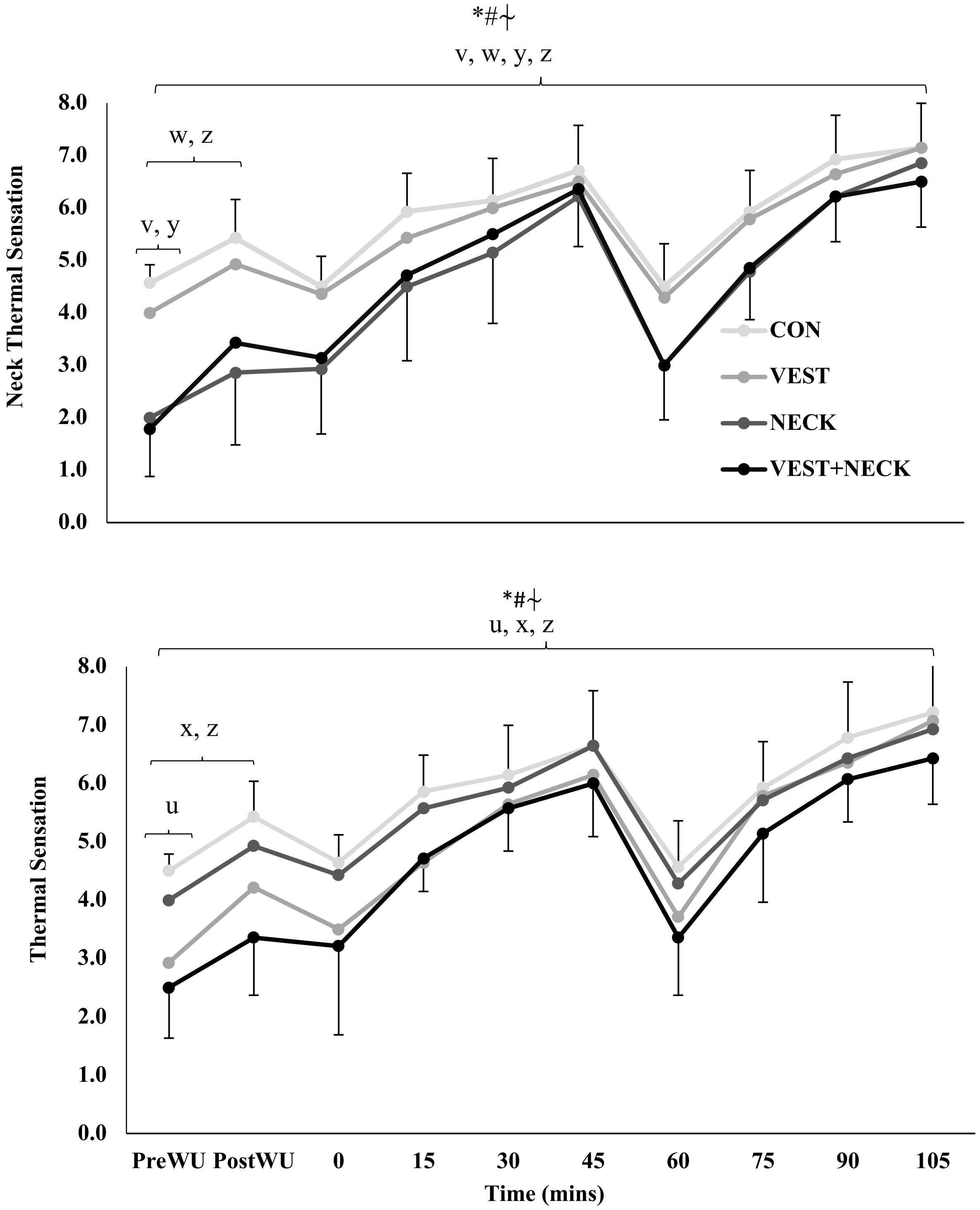

Figure 4. 8. **Neck thermal sensation (A) and thermal sensation (B) during the warm up (PreWU to PostWU), downtime/pre-cooling period (PostWU to 0 min), iSPT first-half (0 to 45 min), half-time cooling (45 to 60 min) and iSPT second-half (60 to 105 min) for CON, VEST, NECK and VEST+NECK** (n = 7)**.** Data presented as mean ± SD. * = Significant main effect for condition ($P < 0.001$); # = Significant main effect for time ($P < 0.001$); † = Significant interaction effect [condition x time ($P < 0.01$)]; z = Significant difference between CON and VEST+NECK ($P < 0.04$); x = Significant difference between NECK and VEST+NECK ($P < 0.04$); y = Significant difference between VEST and VEST+NECK ($P < 0.001$); u = Significant difference between CON and VEST ($P < 0.04$); w = Significant difference between CON and NECK ($P < 0.03$); v = Significant difference between NECK and VEST ($P < 0.04$).

4.4. Physiological Responses

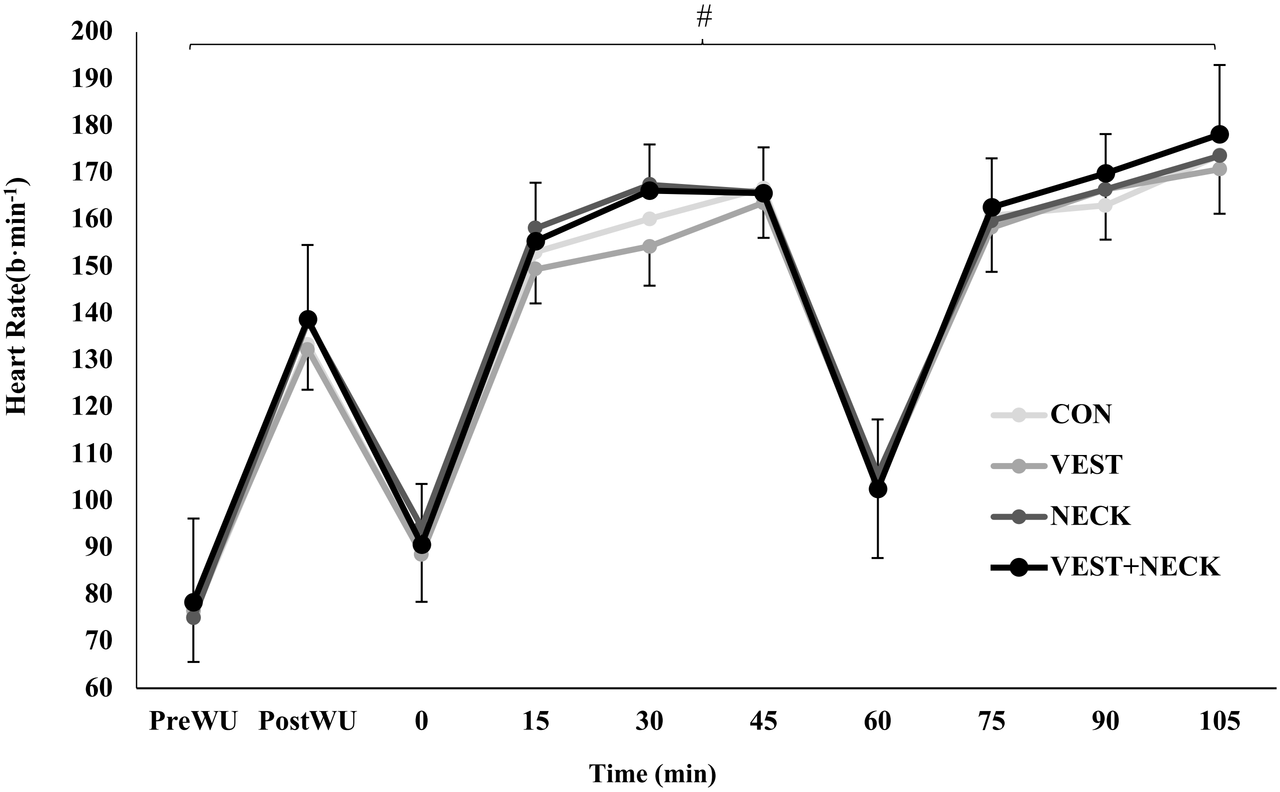

Figure 4. 9. Heart-rate during the warm-up (PreWU - PostWU), downtime/pre-cooling period (PostWU - 0 min), iSPT first-half (0 - 45 min), half-time cooling (45 - 60 min) and iSPT second-half (60 - 105 min) for CON, VEST, NECK and VEST+NECK (n = 7)**.** Data presented as mean ± SD. # = Significant main effect for time ($P < 0.001$).

4.4.1. Heart-Rate

There was a significant main effect for time (F = 298.255; $P < 0.001$), but no significant main effect for condition (F = 0.664; P = 0.585) or interaction effect (F = 0.622; $P > 0.05$) for HR. From PreWU (76 ± 3 b·min^{-1}, 95% CI: 68 to 85 b·min^{-1}), HR was significantly increased at PostWU ($P < 0.001$, $d = 24.4$, 95% CI: 31 to 89 b·min^{-1}), and throughout iSPT halves ($P < 0.05$), with the exception of the half-time period where it significantly decreased ($P < 0.001$, $d = 46.5$, 95% CI: 38 to 85) compared to the end of the first-half by 62 ± 4 b·min^{-1}, respectively (figure 4.9).

4.4.2. Body Mass

There was no significant main effect for condition (F = 0.279; P = 0.840) for change in body mass (table 4.2).

4.4.3. Fluid Consumption

There was no significant main effect for condition (F = 1.169; P > 0.5) for change in total fluid consumed between conditions.

Table 4. 2. Pre- to Post Changes in Body Mass and Total Fluid Consumed (n = 7)**.**

	Pre- to Post Change in Body Mass (%)	Total Fluid Consumed (mL)
CON	-1.37 ± 0.39	773 ± 299
VEST	-1.17 ± 0.52	683 ± 246
NECK	-1.20 ± 0.67	815 ± 196
VEST+NECK	-1.16 ± 0.67	773 ± 260

Data presented as mean ± SD. CON = No Cooling; VEST = Vest Cooling; NECK = Neck Cooling; VEST+NECK = Vest and Neck Cooling; % = Percentage; mL = Millilitre.

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Chapter 5: Discussion

The main aim of the present study was to investigate the effect ice vest cooling (VEST), neck cooling (NECK) and ice vest and neck cooling (VEST+NECK), compared with no cooling (CON) during a soccer-specific warm-up (~24 min), downtime prior to kick-off (12 min) and half-time interval (10 min) on simulated soccer performance in a hot environment (32.1 ± 1.7 °C & 57.3 ± 4.4% rH; WBGT: 28°C). The main findings from this study are; although the first experimental hypothesis for enhanced simulated soccer performance for each 15 min period in the first-half of iSPT was rejected, pre-match cooling during a warm-up and downtime prior to kick-off via NECK significantly improved sprint distance covered during the initial 15 min period of iSPT. Secondly, the second experimental hypothesis for enhanced simulated soccer performance for each 15 min period in the second-half of iSPT was rejected, despite VEST, NECK and VEST+NECK significantly improving sprint distance covered during the final 15 min period of the second-half of iSPT, with VEST+NECK also significantly enhancing sprint distance covered during the penultimate 15 min period. Lastly, no statistical significance was observed for VEST+NECK compared to the singular effect of VEST or NECK during iSPT, rejecting the third, and final experimental hypothesis. Although VEST significantly reduced mean skin temperature until the 15th min of iSPT compared with CON, no further significant reductions in physiological or perceptual responses were observed throughout both halves of iSPT.

5.1. Physical Performance

The present study found no significant improvement in TD covered following any pre and half-time cooling manoeuvre, showing parity with previous match-play data (Duffield et al., 2013) in elite soccer-players during training and match-play at 29°C, where a combination of pre and half-time cooling manoeuvres (ice vest, ice towel and 350 ml ice slurry) were used. However, ascertaining inferences from an intervention utilised in a soccer match-play design are difficult due to a plethora of match factors [score line, tactics etc. (Gregson et al., 2010)] in addition to the altered pacing strategy soccer-players are reported to adopt during heat-situated soccer match-play (Nasiss et al., 2015). Utilising the iSPT means both pacing strategies and match factors are minimised due to three identical 15 min blocks of exercise in each-half with the same individualised externally parameterised speed thresholds. Indeed, recent finding using this soccer-simulation (Aldous et al., 2018) reported a significant improvement in TD covered (3%) alongside HSD and VRD covered during the first-half of simulated soccer match-play in 30°C, following 30 min of combination pre-cooling (ice packs on quadriceps and hamstrings and 7.5 $g{\cdot}kg^{-1}$ ice slurry ingestion). This elevation in TD covered during the first-half of iSPT was accompanied by a moderate decrease in TS, which was not observed during the second-half where no significant improvement in TD covered was reported. Indeed, simulated soccer match-play data in 30°C (Aldous et al., 2016) has reported end TS predicted the decrement in TD covered (5%), which may explain the insignificance for TD covered reported in the present study as no cooling manoeuvre significantly reduced TS in either half of iSPT.

Participants willingness to perform high-speed running at a self-paced speed was measured via the variable run component during iSPT, aimed to quantify high-speed running without an external que. Interestingly, simulated soccer match-play data in 30°C reported reductions in HSD covered were predicted by elevated T_{sk} on university level soccer-players (Aldous et al., 2016), which were also used in the present study. However, no significant improvements were evident throughout both halves of iSPT in all cooling conditions compared with CON. However, Aldous et al. (2018) reported participants chose a faster self-selected running speed following a combination of internal and external pre-cooling manoeuvres during the first-half of iSPT, compared to no cooling. The author attributed this improvement to a sensory effect as T_{sk} and TS were significantly reduced throughout the first-half of iSPT. Indeed, reductions in T_{sk} and TS on occasions can be beneficial to exercise performance without any alterations in T_{re} (Stevens et al., 2018). Therefore, the lack of improvement in HSD and VRD covered in the present study likely stems from the cooling manoeuvres utilised not significantly altering either these measures (T_{sk} or TS) during both halves of iSPT. Furthermore, the ice packs used as part of the combination cooling manoeuvre (alongside ice slurry ingestion) by Aldous et al. (2018) are not viable to be practically utilised during a soccer-specific warm-up, with few other options to practically cool available (Duffield et al., 2013).

In comparison to the same time period in CON, sprint distance covered was significantly improved by VEST from 90 - 105 min (11.2%), by NECK from 0 - 15 (4.8%) and 90-105 min (8.5%), and by VEST+NECK from 75 - 90 (8.1%) and 90 - 105 min (11.3%), respectively. In contrast, Parris and Tyler (2018) reported no significant improvement in sprint performance when an ice vest was worn throughout a soccer-specific simulation in the heat (35°C and 50% rH), However, limited findings on sprint performance in this study (Parris and Tyler, 2018) may be due to the extra ~1.75 kg in mass worn during the ice vest condition which would have increased the energy cost of the exercise bout (Arngrimsson et al., 2004), compared to the control trial which did not wear a vest. Moreover, the present findings on NECK builds upon data demonstrating improved exercise performance and capacity (Tyler, Wild and Sunderland, 2010; Tyler and Sunderland 2011a) in hot environments. Sunderland et al. (2015) reported mean and peak power output was significantly enhanced during 5 x 6 s repeated sprint performance following a 90 min soccer-specific intermittent treadmill protocol in 33°C. Although neck cooling failed to significantly enhance the initial bout of repeated sprints in this study (Sunderland et al., 2015) in contrast to the present improvement in sprint distance covered from 0 - 15 min, is likely due to the inadequate warm-up duration (5 min) compared to the present study (~24 min). However, the significant improvement in sprint performance during the latter stages within the present and Sunderland et al. (2015) study for NECK, without alterations in perceptual measures (TC, RPE, TS or TS_{neck}) could be as consequence of a dampening of the sensory cues which are combined to form this perceptual rating because more work was completed for a similar perceptual rating (Sunderland et al., 2015). Indeed, it seems apparent that NECK cooling during the half-time interval is as beneficial to sprint performance as wearing during exercise, which as highlighted previously is not permitted during soccer match-play (Taylor and Rollo, 2014).

Although mixed-method cooling (VEST+NECK) utilised in the present study significantly enhanced sprint distance covered during the final 30 mins of iSPT, dissimilar to Aldous et al. (2018). However, this is likely due to the ice packs placed on the quadriceps and hamstrings as part of this combination cooling manoeuvre by Aldous et al. (2018) significantly reducing the mean muscle temperature (35.2 ± 1.0°C) compared to no cooling (35.6 ± 1.0°C), thus affecting subsequent sprint performance during iSPT. Furthermore, despite Aldous et al. (2018) reporting a greater total sprint distance covered during the penultimate (173 ± 13 versus ± 146 ± 3 m) and final 15 min period (172 ± 13 versus 145 ± 5 m) of iSPT in comparison to the present study for the respective mixed method cooling manoeuvres, this difference may be partly explained by the greater aerobic capacity of participants (52 ± 4 versus 48 ± 2.2 $mL.kg^{-1}.min^{-1}$), combined with the reduced environmental stress (30.7 ± 0.3°C and 50.9 ± 4.2% rH versus 32.1 ± 1.7°C and 57.3 ± 4.4% rH) between study designs, with a decrease in sprinting during soccer match-play previously reported with increasing heat-stress (Nassis et al., 2014). The significant improvement to sprint distance covered during VEST+NECK compared with CON was evident in all seven participants (figure 4.4) and may be pivotal to the outcome in heat-situated (≥ 32°C) soccer match-play. For example, Armatas et al. (2007) highlighted that most goals are scored and conceded during the final 15 mins during soccer match-play, with straight sprinting being the most prominent action prior to goals and assists (Faude et al., 2012). Therefore, coaches may look to utilise VEST+NECK to enhance sprint performance during the final 30 mins of soccer match-play, to take advantage from a tactical point of view with sprinting a key component during counter attacking situations.

5.2. Physiological and Perceptual Responses

The present study revealed no significant reduction in T_{re} during the warm-up or half-time for NECK, showing synergy with previous findings (Sunderland et al., 2015; Tyler and Sunderland 2011b). Conversely, pre-cooling via VEST or VEST+NECK did not significantly reduce T_{re}, dissimilar to previous studies [0.2 - 0.6°C (Price, Boyd and Goosey-Tolfrey 2009; Clarke et al., 2011)]. However, the differing findings are likely due to the production of metabolic heat during the soccer-specific warm-up in the present study design, as opposed to pre-cooling whilst resting for 20 (Price, Boyd and Goosey-Tolfrey, 2009) and 60 min (Clarke et al., 2011), respectively. However, Arngrımsson et al. (2004) reported a significant reduction in T_{re} prior to the start of exercise (0.21 ± 0.20°C) when utilising ice vest cooling during a warm-up, although this reduction was only significant after 20 min. As a more intense, soccer-specific warm-up was used in the present study design in comparison to the aforementioned simulated long distance-warm-up, dissimilar findings are likely due to the longer total duration (38 versus 24 min), greater rest periods (10 versus 4 min) and lighter intensity warm-up employed by Arngrımsson et al. (2004). Moreover, Parris and Tyler (2018) reported a slower rate of rise of T_{re} during the latter stages of the second-half (60 - 90 min) of simulated soccer match-play, which was not observed in the present study. However, wearing an ice vest throughout exercise as done so by Parris and Tyler (2018), is not within the governing body dictated rules of soccer match-play (Taylor and Rollo, 2014). Indeed, although no significant reduction in T_{re} accompanied the increased sprint performance for VEST and VEST+NECK in the present study, it is likely the localised cooling induced via VEST resulted in vasoconstriction, reducing cutaneous blood flow and cooling of the tissues beneath which increase throughout exercise in the heat, increasing skin blood flow which would be cooled and thus, reduce core temperature upon return to the core via venous circulation (Price, Boyd and Goosey-Tolfrey, 2009). However, it is possible it may have been delayed until during exercise as previously reported by Price, Boyd and Goosey-Tolfrey (2009) where a reduction in T_{re} was observed from 35 min onwards during a soccer-simulated in 30°C following 20 min pre-cooling via VEST. However, the soccer simulation utilised within the previously described study (Price, Boyd and Goosey-Tolfre, 2009) was completed on a motorised treadmill, thus likely players could not express their true maximal running capacity due to fixed running speeds and the reduction in core temperature may be as a result of players not being able to compete more work, which was permitted in the present study design due to the use of an NMT based soccer-specific simulation.

Although pre-cooling via VEST is suggested to enhance performance via a lowering of T_{re} before exercise has begun, therefore delaying thermally induced fatigue (Bongers et al., 2014). It is apparent in the literature that enhanced exercise performance can occur without reductions in T_{re} (Stevens, Taylor and Dascombe, 2017; Tyler, Sunderland and Cheung, 2015). Indeed, Stevens et al. (2017) found no significant effect upon 3 km self-paced time-trial performance in 33°C, following 30 min of cold-water immersion (23 - 24°C) combined with ingestion of ice slurry ($7.5 g \cdot kg^{-1}$), albeit a significant reduction in T_{re} (0.5°C). Whereas in the same study, mid cooling via facial water spray and menthol mouth rinse significantly enhanced performance without any reductions in T_{re}, which the author attributed to attenuated perceptual stress due to a significantly lower TS. Furthermore, Mohr et al. (2012) reported no correlation between absolute rise in core temperature and reduction in high-speed distance covered during match-play in 43°C. Indeed, it is likely heat-mediated alterations in physical performance are not simply a function of core temperature, therefore, targeting peripheral body measures (e.g. T_{sk}) is likely to be most ergogenic

As previously highlighted within this thesis, peripheral body temperatures such as T_{sk} predict decrements in TD and HSD covered during simulated soccer performance in hot environments (Aldous et al., 2016), with end TS predicting the decrement in TD covered. Due to the larger surface area targeted by VEST in comparison to NECK, T_{sk} was significantly lower in VEST from PreWU (30.37 ± 0.84 versus 32.29 ± 1.18°C) until the 15 min (33.75 ± 1.03 versus 35.18 ± 0.37°C) compared with CON, in line with findings from Price, Boyd and Goosey-Tolfrey (2009) who reported 20 min of pre- and 15 min half-time cooling via VEST significantly reduced T_{sk} until 5 min of each half of simulated soccer match-play in in the heat (30°C ± 63% rH). However, TS was unaffected by VEST alone, and was only significantly reduced when combined with NECK PostWU (3.4 ± 1.0 versus 5.4 ± 0.6), compared to CON. Indeed, as there were no further significant reductions during the first-half, with no significant alterations in T_{sk} or TS in the second-half of iSPT, likely due to the cooling manoeuvres incorporated not being aggressive enough to reduce these measures (T_{sk} or TS), which may aid to explain why no significant findings on TD and HSD covered were established. Moreover, participants were required to differentiate the levels of thermal sensation they experienced at the neck (TS_{neck}) from the rest of their body (TS), and this was used as an additional measure. Unsurprisingly, NECK significantly reduced TS_{neck} along with VEST+NECK at PreWU (2.0 ± 1.5 and 1.8 ± 0.9) and PostWU (2.9 ± 1.4 and 3.4 ± 1.0), compared to CON (4.6 ± 0.3 and 5.4 ± 0.7), respectively. However, despite the alliesthesial thermosensitivity of this region (Cotter and Taylor, 2005), NECK did not have a similar effect on TS. In NECK, TS_{neck} was not altered during iSPT, contrasting to previous studies reporting reductions in TS during exercise (Tyler and Sunderland, 2011a; Sunderland et al., 2015), although differences in methodology whereby participants wore the NECK throughout the bout of exercise or replaced during, as opposed to during a pre-match warm-up or half-time interval within the present study, is a plausible explanation for this disparity. Indeed, it is well documented that improvements in thermal sensation offer a benefit to exercise performed in a hot environment (Stevens et al., 2017), Tyler and Sunderland (2011a) reported a significant increase in time to exhaustion for NECK compared to a control, however, at the point of exercise termination, no difference in thermal comfort or rating of perceived exertion existed. Despite this exercise protocol lacking ecological validity to that of the present soccer-specific simulation, there was also no significant difference in perceptual measures (RPE, TC, TS and TS_{neck}) observed at the end of iSPT despite a significant improvement in sprint performance during the final 15 and 30 min in NECK and VEST+NECK, respectively.

The application of NECK significantly reduced $neckT_{sk}$ from PreWU to 0 min when compared to CON, however, no further reductions were observed until 60 min where it was significantly reduced again following the 10 min half-time cooling period. These findings show synergy with previous studies utilising NECK (Sunderland et al., 2015; Tyler and Sunderland, 2011a), however, further reductions in $neckT_{sk}$ throughout exercise have been previously reported which were not seen during the present investigation. Likely due to these studies utilising the cooling manoeuvre throughout the exercise bout, which is not permitted during soccer match-play (Taylor and Rollo, 2014). Although previous studies reporting a significant improvement in exercise performance with NECK (Tyler and Sunderland, 2011a; Tyler and Sunderland 2011b; Sunderland et al., 2015), which is accompanied with a significant reduction in $neckT_{sk}$. However, there does not seem to be a direct relationship as highlighted by Tyler and Sunderland (2011b) where no cumulative benefit on time-trial performance when the cooling collar was replaced every 30 min throughout exercise (6.9%), compared to a cooling collar worn throughout exercise (7.3%), compared to no collar. Despite a significantly greater reduction in $neckT_{sk}$ compared to the cooling collar worn continuously.

The half-time cooling period in the present study design (10 min) failed to significantly alleviate physiological or perceptual responses during the second-half of iSPT, despite reductions following half-time cooling (60 min), likely due to a larger volume of cooling not utilised (Minett et al., 2011). A large proportion of the heat is produced in the first-half of soccer match-play, which is still situated within the body's periphery's (Minett et al., 2012). Furthermore, although cooling was utilised for a longer duration than the 2-6 min practitioners are reported to have with soccer-players at half-time (Russel et al., 2015), the cooling manoeuvres utilised in the present study can be worn for a longer duration as they do not interfere with a soccer-players ability to conduct generic half-time duties. Furthermore, following 5 min of whole-body half-time cooling (ice vest, packs on upper legs, iced towel on head and neck), Minett et al. (2011) reported a significant reduction in T_{re}, whilst T_{sk} was significantly reduced during the entire second-half of this self-paced intermittent sprint exercise protocol (2 x 35 min) in 33°C, coinciding with a 12% increase in total distance covered compared to no cooling. Indeed, it may be most ergogenic to combine practical cooling manoeuvres during the half-time period (10 min) with a shorter period (2 - 6 min) of more aggressive cooling (e.g. whole body-cooling). However, a re-warm-up may likely be required to offset significant reductions in the locomotive muscles as decreased muscle temperature can negatively-effect subsequent exercise performance by diminishing muscle contractility (Gray et al., 2006).

5.3. Experimental Limitations and Direction for Future Research

Limitations of the present study include the use of sub-elite soccer-players and the omission of technical skills and sideways and backwards movements during iSPT (Aldous et al., 2014). Although there was statistical significance and moderate to large effect sizes present in the current investigation, the sample size required from an a *priori* power calculation of 8 soccer-players was not met due to an injury to the final participant prior to completing all four experimental trials. Further, research is warranted with a larger sample size to further elucidate the mechanisms for the performance enhancement.

Future research should look to examine the effectiveness of mid-cooling strategies such as facial water spray or menthol mouth rinse during the 3 min water break during simulated soccer match-play under greater heat-stress (WBGT > 32°C). Furthermore, although imperative that a pre-match cooling manoeuvre is practical and not invasive, future research should look to add a more aggressive approach with increased volume to half-time cooling.

5.4. Practical Applications

The practical application of the present cooling manoeuvres offers a practical method of cooling during a pre-match warm-up and half-time interval without further disrupting soccer-players generic routines. It also offers a method to alleviate some of the heat-mediated decrements associated with heat-situated soccer match-play to coaches and sport scientists from elite soccer teams competing in hot environments, without sufficient time to complete an appropriate acclimation protocol. Which may be the case with the upcoming 2022 FIFA World Cup in Qatar as this tournament has been moved to the winter months with the dates for the winter break in domestic club soccer not yet released.

Indeed, due to the prominence of straight sprints preceding goals and assists (Faude et al., 2012), and the beneficial effect of the practical cooling manoeuvres utilised within this study. Coaches could use this greater sprint distance covered to their advantage by orchestrating a higher-intensity game throughout the latter stages of soccer match-play. Potentially increasing the number of goals scored during the latter stages of soccer match-play, when they are most commonly scored (Armatas et al., 2007). Furthermore, neck cooling collars and ice vests can be worn with little restriction to body movement, although some participants in the present study reported them to be slightly uncomfortable. There are currently no governing body dictated rules against pre and or half-time cooling in soccer (Taylor and Rollo, 2014). Therefore, coaches and sport scientists may include the current cooling manoeuvres within their practise to enhance heat-situated soccer performance.

5.5. Conclusion

To conclude on the investigation above, cooling during a pre-match warm-up and half-time interval via a combination of ice vest and neck cooling significantly improved sprint distance covered in the final 30 min of simulated soccer match-play in 32°C. Furthermore, pre- and half-time neck cooling alone significantly improved sprint distance covered from 0 - 15 min and 90 - 105 min during iSPT, whereas pre- and half-time ice vest cooling only significantly improved sprint distance covered during the final 15 min of iSPT in 32°C. Lastly, although the combination effect of ice vest and neck cooling was most ergogenic compared to their singular effect, it was not statistically significant in direct comparison, rejecting the third experimental hypotheses. Besides ice vest cooling significantly reducing mean skin temperature until 15 min of iSPT, physiological and perceptual measures were not significantly altered by conditions during both halves of iSPT in 32°C. Therefore, further research is warranted.

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Appendices

Appendix A: Information Sheet

Research Title:

Does the addition of neck cooling to vest cooling improve physical performance, physiological responses and cognitive performance during simulated soccer performance in a hot environment?

Dear Participant,

Thank you for showing an interest in participating in the study. Please read this information sheet carefully before deciding whether to participate. If you decide to volunteer, we thank you for your participation. If you decide not to take part, there will be no disadvantage to you of any kind and we thank you for considering our request.

What is the aim of the project?

Due to the globalisation of elite soccer match-play for tournaments including the 2022 FIFA World Cup in Qatar and the 2020 Olympic Games in Tokyo, Japan, players and officials are likely to compete in temperatures and relative humidity exceeding 30°C and 50%, respectively. It is well acknowledged within the literature that physiological stress is increased during soccer match-play in the heat putting players and/or officials at risk to heat induced illnesses (e.g. heat exhaustion, cramps etc.). Thus, highlighting the need for strategies to minimise the physiological strain and improve player safety in these environments. Cooling interventions such as neck and vest cooling have been shown to improve soccer-specific performance in the heat and can be easily used by players during the warm up and/or at half-time. However, the information regarding the use of both cooling interventions simultaneously in a soccer-specific environment is unknown

Therefore, the purpose of this study is to quantify the effect of neck and vest cooling upon simulated soccer-specific performance during a hot environment (32°C; 60% rh). This study is being undertaken as part of the requirements of a MSc by research degree.

What type of participant is needed?

To participate in this current study, you must meet all of the following criteria.

- VO2max > 55mL.kg^{-1}.min^{-1}.
- Age = 18-40.
- Playing experience ≥ 3 years.
- Body mass = 70-85kg.
- Gender = male.
- Participants must also be injury free before taking part in the study in order to perform maximally in each trial.

What will participants be asked to do?

You will visit the sports hall once, and the sport science laboratory at the University of the Bedfordshire on six separate occasions. The visits will consist of;

- Visit 1 – Yo-Yo Intermittent Recovery Test Level 1 (sports hall).
- Visit 2 (familiarisation 1 and peak speed assessment) – Familiarisation 1 will include two short intermittent protocols lasting 9 and 13 minutes, respectively. A peak speed assessment will be conducted, consisting of four sprints lasting 6 seconds separated by three rest periods. The peak sprint speed will be defined as the fastest speed recorded during the peak speed assessment. Following this, the first 45 minutes of the iSPT protocol will be completed.
- Visit 3 (familiarisation 2 and peak speed assessment): Participants will rest for 6 – 10 days after completing familiarisation 1 before completing visit 2, which involves another peak speed assessment to confirm the peak sprint speed followed by a full 90 min of the iSPT.
- Visits 3, 4, 5 and 6 (Trials 1, 2, 3 and 4) - A randomised, counterbalanced, controlled repeated measures design will be used in the outlined study design. Each participant will then complete four randomised experimental trials of the intermittent soccer performance test (iSPT), following one of three pre-match and half-time cooling interventions: (1) Ice Vest (VEST) (2) Neck Cooling (NECK); (3) VEST and NECK (VEST+NECK) used concurrently; or with no-cooling (CON). The pre-match cooling will be used for 37 min during a 25 min soccer-specific warm-up and the 12 min post-warm up prior to commencing the first-half of iSPT. At half-time, participants will the same cooling garment used pre-match during the half-time interval in a temperate environment (18 ºC). The environmental temperature and relative humidity for all experimental trials at the laboratory will be 32 oC and 60% rh, respectively.

What are the possible risks of taking part in the study?

A possible risk of taking part in this study include illnesses that can occur when exercising in the heat such as heat cramps, heat stroke and heat exhaustion. The risk of these heat illnesses will be minimized by monitoring the core body temperature, skin temperature, heart rate, and the rate of perceived exertion and thermal sensation felt by the participant, combined with ensuring participants are appropriately hydrated before exercising. The laboratory at the University of Bedfordshire has cut off values for rectal temperature of 39.7 °C to ensure safety to all participants.

Other risks involve exercising in the lab on the non-motorised treadmill with the chance of slipping on unfamiliar equipment, this risk will be minimised through the use of familiarisation sessions to familiarise yourself with the laboratory and protocols, combined with the participant being attached to a harness whilst running on the non-motorised treadmill.

Whilst exercising in the heat, participants are required to insert a rectal thermistor. Possible risks of using a rectal thermistor include impractical use of the rectal thermistor, penetration of rectum wall or anaphylactoid shock. Risks will be reduced by a full explanation on how to use a rectal thermistor, instructions to insert thermistor slowly to avoid bending and damage to rectum. Participants will insert the rectal thermistor themselves in the bathroom whilst its unlocked, in the case of anaphylactoid shock, assistance will be waiting outside the unlocked bathroom door. Also, a heart rate monitor will be attached and monitored whist insertion is taking place, in the case of anaphylactoid shock the extend can be assessed. Also, a first aider must be present in the labs during all experimental testing in the case of an emergency.

During cooling interventions participants may be at risk of frostnip and hyperthermia. The risks of these illnesses will be reduced by monitoring rectal temperature and skin temperature in combination with the participants perceived thermal sensation whilst cooling and throughout the experimental protocol. Participants will be at risk of skin burns. However, these will be minimised by using cooling garments as opposed to applying ice directly on the skin, also the garments will not be worn for longer than 30 minutes at one time.

Whilst at rest and exercising during experimental trials, finger prick blood samples will be taken by a researcher or member of staff who has been fully trained and signed off on their training log to reduce the risk of any associated hazards. Those responsible for taken blood during exercise and at rest must work towards the departments standard operating procedures at all times, receive and be signed off on appropriate training in collection and disposal of clinical waste.

What if you decide you want to withdraw from the project?

Participants are able to withdraw from the study at any time without a reason. There will be no disadvantage or prejudice to yourself should you wish to withdraw.

What will happen to the data and information collected?

Everyone that takes part in the study will receive their own results for the tests that they complete. All information and results collected will be held securely at the University of Bedfordshire and will only be accessible to related University staff. Results of this project may be published, but any data included will in no way be linked to any specific participant. Your anonymity will be preserved.

What if I have any questions?

Questions are always welcomed, and you should feel free to ask myself, Peter McDonald or Dr. Jeff Aldous (Director of Study) at any time. See details below for specific contact details.

Should you want to participate in this study, please complete the attached consent form, which needs to be returned before commencing the study.

This project has been reviewed and approved by the Ethics Committee of the Department of Sport and Exercise Sciences.

Many Thanks,

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Appendix B: Consent Form

CONSENT FORM

TO BE COMPLETED BY PARTICIPANT

NAME: …………………………………………………… (Participant)

I have read the Information Sheet concerning this study and understand what is required. All my further questions have been answered to my satisfaction. I understand that I am free to request further information at any stage.

I know that:

- My participation in the study is entirely voluntary, and I am free to withdraw from the project at any time without disadvantage or prejudice.

- I will be required to attend one preliminary testing session, two familiarisations and four experimental sessions to complete this study.

As part of the study I will have to:

- Wear an ice-jacket and/or neck cooling garment during the warm up and at half-time in at least three experimental trials.
- Complete soccer-specific exercise in a hot, humid environment [WGBT: 32°C (32°C and 60% rh)
- For visit 1, you will be required to attend the sports hall to complete a Yo-Yo Intermittent recover test, level 1.
- Visits 2 and 3 will require you to perform two familiarisation (understanding the protocol) sessions to understand the running mechanics of the non-motorised treadmill.
- A peak speed assessment will be conducted during visit 2 and 3, on the non-motorised treadmill consisting of four sprints lasting 6 seconds separated by three rest periods
- Perform 3 different types of cooling interventions pre-match for 37 min (during a 25 min soccer-specific warm-up and the 12 min post-warm up) and for 12 min at half-time prior to both halves of a 90 min, individualised (based upon peak sprint speed) soccer-specific simulation upon the non-motorised treadmill called the intermittent soccer performance test (2 x 45 min halves; 15 min break)
    - Ice Vest cooling
    - Neck cooling collar
    - Mixed methods (Ice Vest and Neck cooling)
- Complete a 30 min, individualised (based on peak sprint speed) warm up protocol on the non-motorised treadmill prior to the intermittent soccer performance test.
- Give a sample of urine before and after experimental testing so that hydration status can be assessed pre and post exercise.
- Insert a rectal thermistor to measure rectal temperature.
- Attach skin thermistors to the chest, arm, quad and calf to measure skin temperature.
- Exercise with a rectal thermometer inserted and skin thermistors attached to the chest, arm, quad and calf.
- Complete four cognitive tests (dual-tasking, vigilance and reaction time) on a laptop before the warm up, before the intermittent soccer performance test first-half, at half-time and after the full protocol.
- Have a finger prick blood sample taken during the 12th, 27th and 42nd min during each half of the intermittent soccer performance test in order for analyse lactate and glucose.
- Plasma volume will be measured from finger prick blood sample and post exercise
- Avoid vigorous and cognitively demanding activities and refrain from caffeine and alcohol consumption in the 48 hours prior to experimental testing.
- Avoid exposure to the heat 3 months prior to participation in this study

- Complete a 24h food log and 7 day training diary.
- Have heart rate, rate of perceived exertion and thermal sensation measured via a heart rate monitor, rate of perceived exertion scale (6-20) and thermal sensation scale, respectively.
- I am aware of any risks that may be involved within this study.

All information and data collected will be held securely at the University indefinitely. The results of the study may be published but my anonymity will be preserved.

Signed: ………………………………… (Participant) Date: ………………

Appendix C: Health Screen and Physiological Testing Questionnaire

Name/Number ....

Male/Female ....

Date of Birth ....

Health Screen and Physiological Testing Questionnaire

As an individual participating in physical activity, it is important that you are currently in good health. This is to ensure your well-being and to try and prevent confounding data.

Please complete this brief questionnaire to confirm your ability to participate:

1. **At present,** do you have any health problem for which you are:

(a)	on medication, prescribed or otherwise...........	Yes ☐	No ☐
(b)	attending your general practitioner..................	Yes ☐	No ☐
(c)	on a hospital waiting list	Yes ☐	No ☐
(d)	recovering from an illness or operation	Yes ☐	No ☐

2. **In the past two years,** have you had any illness or injury which required you to:

(a)	consult your GP...	Yes ☐	No ☐
(b)	attend a hospital outpatient department...........	Yes ☐	No ☐
(c)	be admitted to hospital	Yes ☐	No ☐

3. **Have you ever** had any of the following:

(a)	Convulsions/epilepsy	Yes ☐	No ☐
(b)	Respiratory conditions such as asthma/bronchitis/ Turburculosis…………………..	Yes ☐	No ☐
(d)	Eczema	Yes ☐	No ☐
(e)	Diabetes	Yes ☐	No ☐
(f)	A blood disorder	Yes ☐	No ☐
(g)	Head injury	Yes ☐	No ☐
(h)	Digestive/ Gastrointestinal problems	Yes ☐	No ☐

(i)	Heart problems/chest pains/ angina/heart attack/varicose vein/ embolism/aneurysm	Yes	☐	No	☐
(j)	Problems with muscles, bones or joints (for example arthritis/back pain)	Yes	☐	No	☐
(k)	Disturbance of balance/coordination	Yes	☐	No	☐
(l)	Dizziness / black outs / fainting	Yes	☐	No	☐
(m)	Disturbance of vision	Yes	☐	No	☐
(n)	Ear/hearing problems	Yes	☐	No	☐
(o)	Thyroid problems	Yes	☐	No	☐
(p)	Kidney or liver problems	Yes	☐	No	☐
(q)	Problems with blood pressure (low or high)	Yes	☐	No	☐
(r)	A pacemaker	Yes	☐	No	☐
(s)	Chronic obstructive pulmonary disease (COPD)	Yes	☐	No	☐

(t)	Anaphylactic shock symptoms to needles, probes or other medical-type equipment	Yes	☐	No	☐
(u)	Any allergies or food intolerances	Yes	☐	No	☐
(v)	A history of heart disease in the family	Yes	☐	No	☐
(w)	Been pregnant or given birth in the last 6 months	Yes	☐	No	☐

If YES to any question, please describe in more detail if you wish (for example, was the problem short lived, if it is controlled, if it is re-occurring, if your doctor has given you specific information/instructions regarding the problem).

……

……

……

……

4. Please state what medication (if any) you are currently taking, explain briefly what the medication is for and how long you have been taking it.

……

……

……

5. Do you have any other condition or disability that you feel we should be aware of?

Yes ☐ No ☐

If yes, please briefly explain below:

……

……

6. Physical activity

(a) Are you physically active (30 min of moderate intensity, physical activity on at least 3 days each week for at least 3 months)? Yes ☐ No ☐

(b) Please circle your present level of activity:

Sedentary *Moderately Active* *Active* *Very active* (c) Please circle your current level of fitness

Unfit *Moderately Fit* *Trained* *Highly Trained*

7. Do you smoke, and if so, how much each day do you smoke?

………

8. Please describe your sport and your sport classification

………

9. How long have you been involved in this sport?

………

10. How many hours a week do you train for sport / to keep fit?

………

11. Do you participate in aerobic training (if yes how many hours)?

………

12. Do you participate in anaerobic training (if yes how many hours)?

……
………

13. Do you participate in strength training (if yes how many hours)?

……
………

14. Are you currently involved in any other lab activity at the University or elsewhere?

Yes ☐ No ☐

If yes, please provide details.

…………………………………………………………………………………………………
……………

15. Please provide contact details of a suitable person for us to contact in the event of any incident or emergency.

Name: Relationship to Participant:

……………………………………………
…………………………….

Telephone Number: Work ☐ Home ☐ Mobile ☐
……………………………………………………

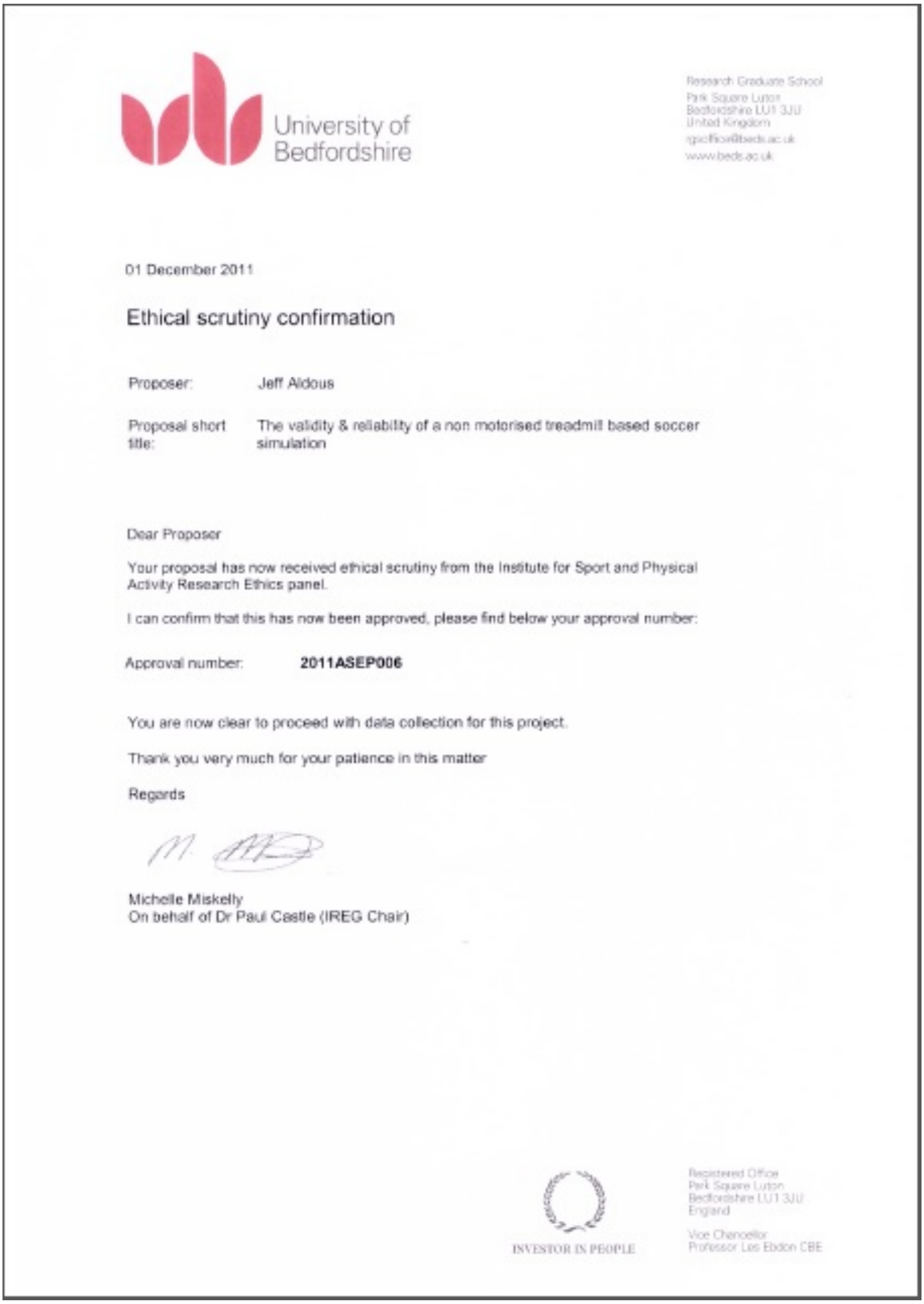
I declare that this information is correct, and is for the sole purpose of giving the tester guidance as to my suitability for the test.

As far as I am aware, there is nothing that might prevent me from successfully completing the tests

This completed questionnaire will be held in a locked filing cabinet in the Sport and Exercise Science Laboratories for a period of three years. After this time it will be shredded. Please ask for a photocopy of this questionnaire if you require one.

Appendix D: Previous Ethical Approval letters

“The Validity and Reliability of a non-motorised treadmill-based soccer simulation”



University of
Bedfordshire

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Park Square Luton
Bedfordshire LU1 3JU
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rgsoffice@beds.ac.uk
www.beds.ac.uk

01 December 2011

Ethical scrutiny confirmation

Proposer:	Jeff Aldous
Proposal short title:	The validity & reliability of a non motorised treadmill based soccer simulation

Dear Proposer

Your proposal has now received ethical scrutiny from the Institute for Sport and Physical Activity Research Ethics panel.

I can confirm that this has now been approved, please find below your approval number:

Approval number: **2011ASEP006**

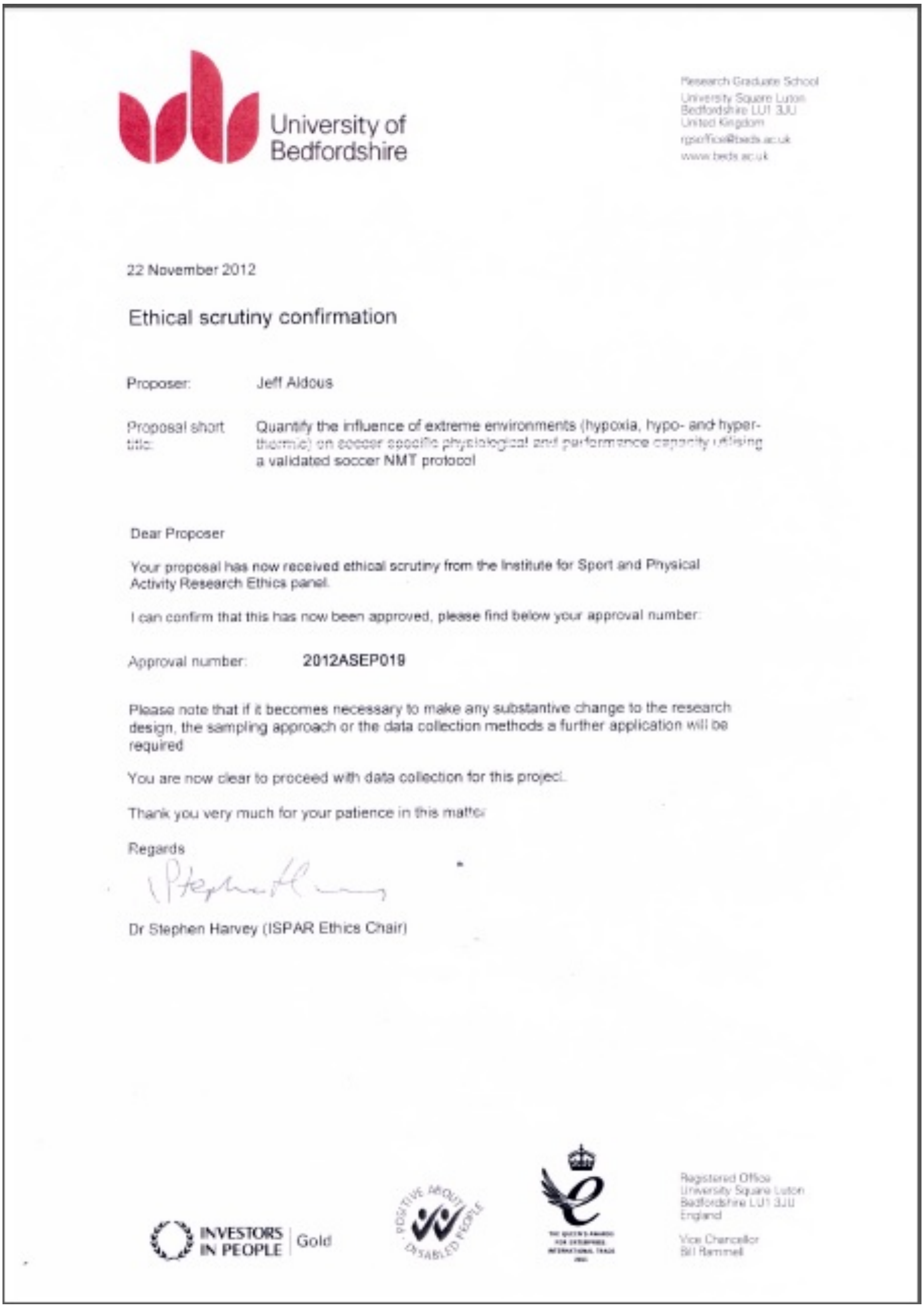
You are now clear to proceed with data collection for this project.

Thank you very much for your patience in this matter

Regards

Michelle Miskelly
On behalf of Dr Paul Castle (IREG Chair)

“Quantify the influence of extreme environments (hypoxia, hypo- and hyper-thermic) on soccer-specific physiological and performance capacity utilising a validated soccer NMT protocol



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22 November 2012

Ethical scrutiny confirmation

Proposer: Jeff Aldous

Proposal short title: Quantify the influence of extreme environments (hypoxia, hypo- and hyper-thermic) on soccer specific physiological and performance capacity utilising a validated soccer NMT protocol

Dear Proposer

Your proposal has now received ethical scrutiny from the Institute for Sport and Physical Activity Research Ethics panel.

I can confirm that this has now been approved, please find below your approval number:

Approval number: **2012ASEP019**

Please note that if it becomes necessary to make any substantive change to the research design, the sampling approach or the data collection methods a further application will be required.

You are now clear to proceed with data collection for this project.

Thank you very much for your patience in this matter

Regards

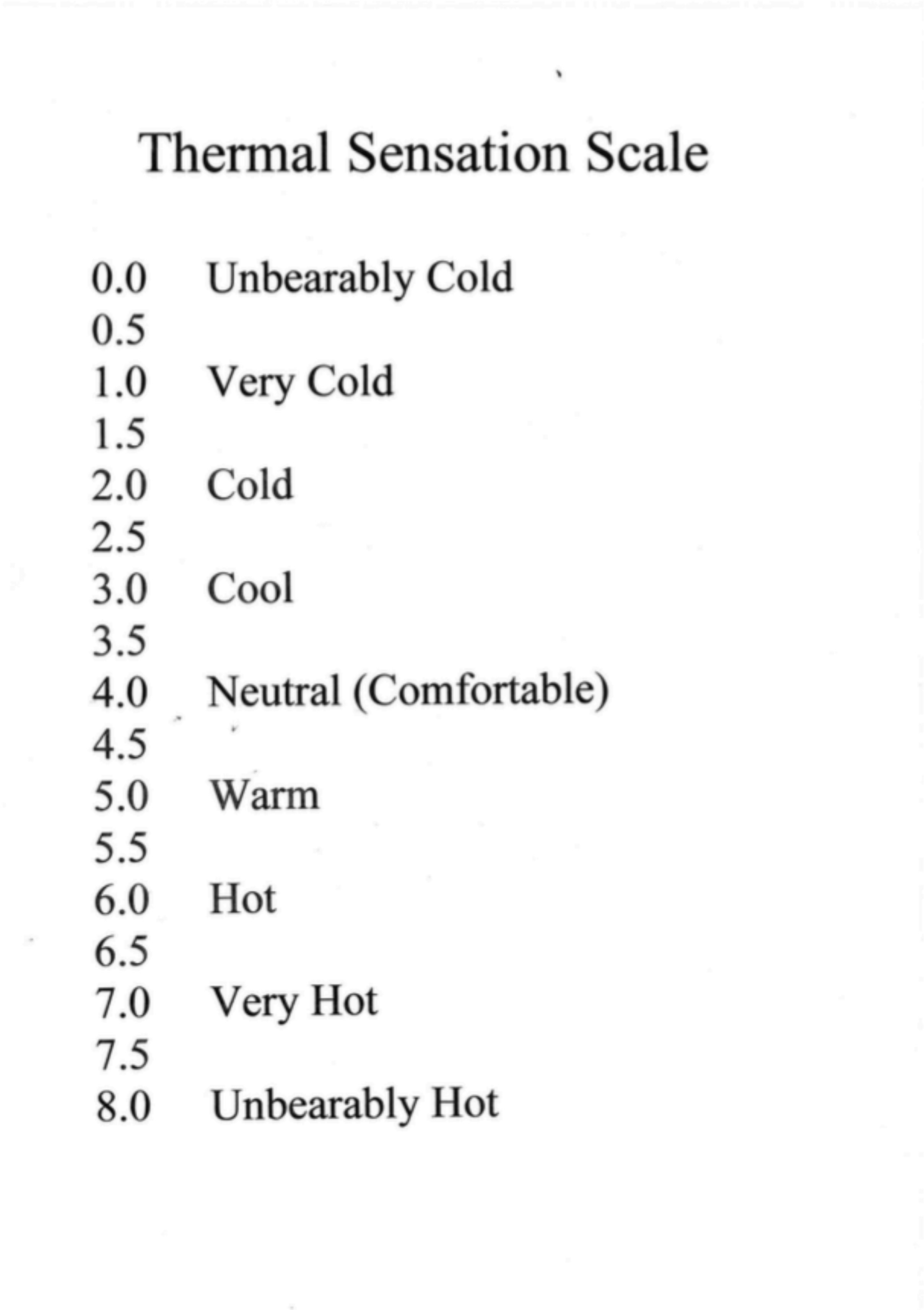
Stephen H

Dr Stephen Harvey (ISPAR Ethics Chair)

Registered Office
University Square Luton
Bedfordshire LU1 3JU
England

Vice Chancellor
Bill Rammell

Appendix E: Thermal Sensation Scale



Thermal Sensation Scale

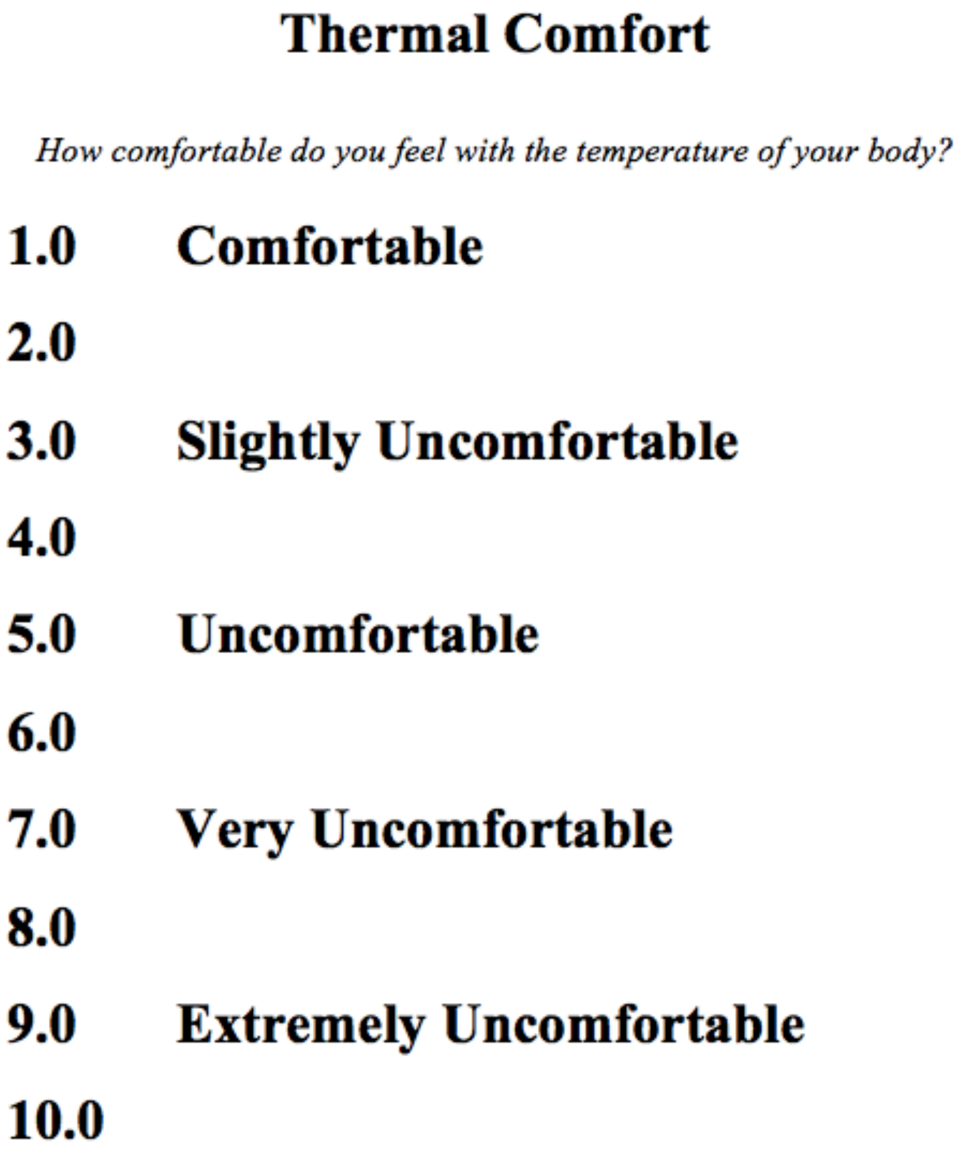
0.0	Unbearably Cold
0.5	
1.0	Very Cold
1.5	
2.0	Cold
2.5	
3.0	Cool
3.5	
4.0	Neutral (Comfortable)
4.5	
5.0	Warm
5.5	
6.0	Hot
6.5	
7.0	Very Hot
7.5	
8.0	Unbearably Hot

Appendix F: Rate of Perceived Exertion Scale

PERCEIVED EXERTION

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

Appendix G: Thermal Comfort



Thermal Comfort

How comfortable do you feel with the temperature of your body?

1.0	**Comfortable**
2.0	
3.0	**Slightly Uncomfortable**
4.0	
5.0	**Uncomfortable**
6.0	
7.0	**Very Uncomfortable**
8.0	
9.0	**Extremely Uncomfortable**
10.0	

Appendix H: Training Log

The effect of neck and vest cooling on simulated soccer performance in the heat			
TRAINING DIARY			
Name:	Age:		
Height:	Weight:		
Type of exercise:			
Resting Heart Rate (HRrest) / Maximal Heart Rate (HRmax)			
Day 1	Date / /	Time:	HR_{rest} bpm
Exercise completed			HR_{max} bpm
			Duration min
			RPE:
Comments:			
Day 2	Date / /	Time:	HR_{rest} bpm
Exercise completed			HR_{max} bpm
			Duration min
			RPE:
Comments:			
Day 2	Date / /	Time:	HR_{rest} bpm
Exercise completed			HR_{max} bpm
			Duration min
			RPE:
Comments:			
Day 4	Date / /	Time:	HR_{rest} bpm
Exercise completed			HR_{max} bpm
			Duration min
			RPE:
Comments:			

Day 5	Date / /	Time:	HR$_{rest}$ bpm
Exercise completed			HR$_{max}$ bpm
			Duration min
			RPE:
Comments:			
Day 6	Date / /	Time:	HR$_{rest}$ bpm
Exercise completed			HR$_{max}$ bpm
			Duration min
			RPE:
Comments:			
Day 7	Date / /	Time:	HR$_{rest}$ bpm
Exercise completed			HR$_{max}$ bpm
			Duration min
			RPE:
Comments:			

Appendix I: Food Diary

Day 1				
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 J: Warm-up