“Effect of extreme environmental conditions on decision making ability of active referees and Goal Line Officials”

Professor John Brewer

John.Brewer@beds.ac.uk

Institute of Sport and Physical Activity Research

Department of Sport and Exercise Science

University of Bedfordshire

Introduction

Football match officials are tasked with up-holding the laws of the game and the decisions they make can affect the outcome of a fixture. This considered it is important that match officials are able to judge incidents correctly.

UEFA competitions are played out in varying environmental conditions, for example temperatures as cold as -5 ^{o}C in Moscow and as high as 30 ^{o}C in Madrid. The exercise carried out by a match official is specific to the officiating role they are assigned to, thus varying environmental conditions will affect the specific match officials differently.

Referees are required to keep up with play so they are close enough to judge an incident or infringement correctly. The speed of the modern game means that referees cover large distances during a game, causing significant strain on the various physiological systems at work. A by-product of intense exercise is heat (metabolic heat production), endogenous heat production will increase the bodily temperatures of a referee during a game. Exercise induced temperature will be further intensified during exposure to hot conditions (a fixture in Madrid). It is suggested that elevation of bodily temperatures may negatively affect the decision making performance of referees.

Goal line officials are tasked with judging whether the football has crossed the goal line and aiding referees with incidents in the penalty area. Goal line officials spend the entire match stood next to a goal carrying out minimal movements. Unlike referees, goal line officials will produce minimal amounts of heat because they are not expected to exercise intensely. Thus, during exposure to hot conditions (Madrid, 30 ^{o}C) the decision making performance of goal line officials is not expected to suffer any decrement. In contrast, during exposure to cold conditions (Moscow, -5 ^{o}C) a goal line official's decision making performance may suffer. Because goal line officials produce little heat one would expect their body temperatures to reduce drastically during exposure to cold conditions. It is suggested that this drop in body temperatures may negatively affect the decision making ability of goal line officials.

No current work exists investigating the effects of extreme hot and cold on the decision making ability of referees and goal line officials. The present study aims to elucidate on the cognitive performance of match officials during exposure to both hot and cold.

Active Referees- Thermoregulation and Decision Making

The aim of the following sections are to provide an understanding of the topics that are relevant to an intermittent sprint exercise protocol in hot and cold environments in referees' decision making abilities.

Football is considered to be the most popular sport in the world (Reilly 1997) and it is estimated that around 400-500 million people play football (Castagna, Abt et al. 2007). Football is characterized as an intermittent sport, making physiological demands more complex than continuous sports such as running (Drust, Reilly et al. 2000). Football includes a lot of high intensity running, therefore calls for high levels of physical fitness for players (Reilly 1997). In every football match there must be a referee, two assistant referees and a fourth official (Castagna, Abt et al. 2007). It has been reported that total distance covered and high speed running were consistent between referees and players, demonstrating that referees are able to keep pace with the players (Weston, Drust et al. 2011). It is important for referees to keep pace as being a considerable distance away from infringements may lead to incorrect decisions being made (Krustrup and Bangsbo 2001). Research has shown that top-class referees make approximately 137 observable decisions throughout a match (Helsen and Bultynck 2004). Therefore in order to make accurate decisions during match play, positioning and cognitive focus is very important from the beginning to the end of the match (Helsen and Bultynck 2004).

Many football competitions such as the Champions League take place in hot climates such as the Mediterranean where temperatures reach 30-31°C (MetOffice 2011). Hot climates will decrease the body's ability to dissipate heat and therefore compromise performance (Morris, Nevill et al. 1998). Cognitive performance may also be affected by performance in the heat. When there is an increase in core temperature, cognition can be adversely affected (Gaoua 2010). Previous research also agree in that an increase in deep body temperature will breakdown cognitive performance (Hancock and Vasmatzidis 2003). They also point out that more cognitive demanding tasks are more vulnerable to heat stress. Football competitions also take place in cold climates such as Moscow where temperatures can fall to -9°C (MetOffice 2011). These cold temperatures can cause severe discomfort and lead to a drop in body temperature (Parsons 2003). There are some cold weather scenarios such as low temperature and wind chill, where thermal balance cannot be maintained and therefore decrease exercise performance (Castellani, Young et al. 2006). Cold environments may have an effect on the referee as they might start shivering, experience a change in behaviour and feel confused, therefore effecting cognition (Castellani, Young et al. 2006). It has been found that cold environments do have an effect on cognitive performance due to distraction (Makinen, Palinkas et al. 2006). However this may only be relevant to goal line officials and not active referees, which are of interest in this study.

Football and Active Referees

Football is considered to be the most popular sport in the world (Reilly 1997) and it is estimated that around 400-500 million people play football (Castagna, Abt et al. 2007). It is characterized as intermittent sprint activity, therefore physiological demands are more complex than sports with continuous exercise (Drust, Reilly et al. 2000) and the demand for high levels of physical fitness for the players is of great importance (Reilly 1997). The intensity of the exercise performed by a player can be determined by the distance covered during a 90 minute match (Reilly 1997). According to Reilly (1997), players cover between 8-12 km during a match, which is made up of low intensity (walking and jogging) and high intensity (running and sprinting) activities. Low intensity activities (including rest periods of 3 s rest every 2 minutes) increase towards the end of a match due to fatigue (Reilly 1997; Mohr, Krustrup et al. 2005). High intensity activities occur approximately every 30 s and occur less, nearer the end of a game (Reilly 1997).

During every football match there must be a referee, two assistant referees and a fourth official (Castagna, Abt et al. 2007). The physiological stresses experienced by referees during a competitive match are very similar to that of a midfield football player (Casajus and Castagna 2007). Weston et al. (2011) were interested in the relationship between exercise intensities of elite referees with elite players and found that total distance covered and high speed running were consistent between referees and players. Therefore referees are able to keep pace with players during matches (Weston et al*.* 2011). Referees are also required to carry out intermittent sprint activity, consisting of short periods of high intensity and low intensity activity (Weston et al. 2011).

Distance Covered

High intensity running is directly related to the referees ability to keep up with the tempo of the game (Krustrup, Helsen et al. 2009) and remain alert, therefore high levels of physical fitness are needed (Catterall, Reilly et al. 1993). Physical fitness is needed to sustain proximity to infringements, if fitness is not high then the referee is likely to fatigue quicker and thus their distance from any infringements will be increased (Galanti, Pizzi et al. 2008).

As mentioned previously, referees and players performance during a match is very similar and distances covered during a match average 8-12 km (Reilly 1997; Castagna, Abt et al. 2007) of which 4444 m was spent jogging and 1109 m was spent sprinting (Catterall, Reilly et al. 1993).

Reilly (1997) points out that for players, distance covered in the second half of a match was less than in the first half, this was also found in referees (Catterall, Reilly et al. 1993). The decrease in distance covered was over 400 m (Catterall, Reilly et al. 1993). This decrement is thought to be as a result from fatigue due to diminished energy within the muscles (Catterall, Reilly et al. 1993). Another reason distance covered in the second half is decreased may be due to less high intensity running in the first 5 minutes of the second half compared to the first 5 minutes of the first half (Mohr, Krustrup et al. 2005). Mohr et al. (2005) believe the decrease in high intensity running to be due to to a drop in muscle temperature following the 15 minute rest period. Recent research has also shown that referees' performance during the initial 15 minutes of the second half of match play decreased when compared with the initial 15 minutes of the first half of match play (Weston, Batterham et al. 2011). They believe this could be due to a slower tempo of play rather than a physiological impairment.

Age and Performance

There is a negative relationship between referee's age and physical performance as referees are on average 10-15 years older than players (Caballero et al. 2011). Aging has a negative effect on physiological aspects of performance which has been found in referees (Castagna, Abt et al. 2005). The purpose of their study was to examine the effects of age on physical match performance in referees and found that total distance covered and high intensity running decreased as referees age increased. However this did not have an impact on their ability to keep up with the pace of the match. Further research proposed this may be due to the older referees being more economical with their movements due to years of experience (Weston, Castagna et al. 2010).

Aerobic Fitness

Aerobic fitness is one of the most important factors that determines distance covered during a match. Reilly (1997) states that there is a predominant reliance on aerobic energy during a match. According to Mohr et al. (2005) aerobic loading is around 75% of maximal oxygen uptake which allows performance to continue at a higher work rate before fatigue sets in (Reilly 1997). The anaerobic pathway also plays an important role, and is highly taxed during high intensity periods (Armstrong 2000).

Cognitive Performance and Decision Making: An Introduction

As well as physical demands, referees are also required to make decisions regarding the match as they are responsible for applying the laws of the game correctly and consistently (Catteeuw, Gilis et al. 2010). Therefore, in order to make accurate decisions during match play, positioning and cognitive focus is very important from the beginning to the end of the match (Helsen and Bultynck. 2004). Krustrup and Bangsbo (2001) found that decisions made in the first half of a match were made 15 m away from the infringement whereas in the second half, this distance was increased to 17 m away. In the final stages of a match, performance often declines due to fatigue (Royal, Farrow et al. 2006) which may explain the increase in distance from infringements seen by others (Krustrup and Bangsbo 2001). However previous research has found that strenuous exercise does not have an effect on cognitive performance therefore some literature within the area remains equivocal (Hogervorst, Riedel et al. 1996).

Cognitive function

The main responsibility of a referee involves perception and making decisions, however, research on this area has only emerged in the last 10 or so years (Catteeuw, Helsen et al. 2009). Decision making is defined as the process of selecting the correct response to the stimuli presented in any given situation (Royal, Farrow et al. 2006). Making the correct decision depends on skills such as choosing only one of several options and selecting the correct response from the given options (Frank and Claus 2006). These decisions will be made quicker due to experiences (Frank and Claus 2006).

Refereeing is a challenging role as they have high physical stress as well as high mental stress (Casajus and Castagna 2007). According to Helsen and Bultynck (2004) research showed that top-class referees make approximately 137 observable decisions throughout a match. Referees will also make non-observable decisions, such as deciding to not interfere with match play, taking decisions made up to approximately 200 of which 3-4 are made per minute (Helsen and Bultynck 2004).

Due to high physical stress, there may be a negative effect of exercise on cognition (McMorris and Graydon 1997). Early research supports this as high intensity exercise decreased cognitive performance (Easterbrook 1959). This decrease in cognitive performance during high intensity exercise is due to the changes in arousal levels (Brisswalter, Collardeau et al. 2002). The higher the exercise intensity, the higher the arousal levels (Brisswalter, Collardeau et al. 2002). When arousal levels increase, attention narrows and only relevant cues are processed. If there is a further increase in exercise intensity and therefore a further increase in arousal, relevant cues will be missed (Brisswalter, Collardeau et al. 2002).

As well as exercise intensity, exercise duration may have an effect on cognitive performance. During prolonged exercise, such as a football match, decrements in cognitive performance are rarely observed. This has been found to be as a result of an increase in brain neurotransmitters such as catecholamines (Brisswalter, Collardeau et al. 2002). However the effects of prolonged exercise, catecholamine levels and cognitive performance are still relatively unknown (Brisswalter, Collardeau et al. 2002). Prolonged exercise under heat stress may affect cognitive performance due to factors such as a change in thermal homeostasis or dehydration. These factors could lead to central fatigue and thus a decrease in cognitive performance (Brisswalter, Collardeau et al. 2002).

Thermoregulation

The human body's internal temperature is kept constant due to physiological regulations known as thermoregulation (Wilmore, Costill et al. 2008). Thermoregulation has a very important role in homeostatic balance and if it fails, it can result in death (McArdle, Katch et al. 2006). To maintain core temperature (around 37ºC) there needs to be a steady state between heat production and heat loss to the environment (Talavera, Nilius et al. 2008). There are four ways in which heat exchange between the body and environment can happen: radiation, conduction, convection and evaporation. Radiation is the net exchange of heat from the body to solid, cooler objects via electromagnetic waves and conduction transfers heat via direct contact of a liquid, solid or gas from one molecule to another. Convection is the transfer of heat from the body to a liquid (air near the body) and evaporation transfers heat energy in a liquid form on the skins surface to a gaseous form into the environment (McArdle, Katch et al. 2006). Heat exchange and the maintenance of a thermal equilibrium can be calculated using the heat balance equation.

Equation. The heat balance equation

$$M \pm C \pm R - E = S$$

where M = metabolic heat production, C = convective + conductive heat loss or gain, R = radiant heat loss or gain, E = evaporative heat loss and S = rate of heat storage (Piantadosi 2003).

For these processes to happen, permanent monitoring of thermal information from the skin and core will promote heat production or heat loss (Talavera, Nilius et al. 2008). Changes in temperature are sensed by the somatosensory system, which is initiated when sensory nerve fibres at the periphery are activated (McKemy, Neuhausser et al. 2002). Thermal stimuli are converted into action potentials and sent to the spinal cord and the hypothalamus in the brain which is the thermoregulatory controller (McKemy et al. 2002; Sessler 2009). Mechanisms into temperature sensation have come from cloning of the vanilloid receptor (VR1) which belongs to the transient receptor potential (TRP) family of ion channels (McKemy et al. 2002). Temperature dependent TRP are activated via different temperature thresholds, detected by the periphery, allowing us to sense different temperatures (Voets, Talavera et al. 2005). TRPV3 is one of the TRP channels that senses heat and is activated by temperatures >31ºC and are mostly found in the skin (Clapham 2003). TRPM8 is one two TRP channels that senses cold temperatures (8-20ºC) and also responds to agonists such as icillin (Clapham 2003). When these channels are activated, cell depolarisation occurs opening Na^+ and $Ca2^+$ channels which excite sensory nerves via unknown paracrine signals (Talavera, Nilius et al. 2008). The sensory nerves then send a signal via either C-type fibres, that are unmelinated and react to slow conduction velocities, or ADelta-type fibres which are myleinated and react to quicker conductions (Talavera, Nilius et al. 2008). The signals are then transmitted to either the anterior or posterior hypothalamus and the correct physiological response is performed. The anterior hypothalamus controls vasodilation and sweating and the posterior hypothalamus controls vasoconstriction and shivering (Parsons 2003)

Skin blood flow is very important for thermoregulation as it is essential for the maintenance of core body temperature (Charkoudian 2010). There are two branches of the sympathetic nervous system that are responsible for the maintenance of body temperature. These are sympathetic noradrenergic vasoconstrictor system and sympathetic active vasodilator system (Charkoudian 2010) which receive signals from either the anterior or posterior hypothalamus, depending on which response is required.

The sympathetic vasodilator system is activated when body temperature increases above resting level (around 37ºC). Blood flow to the skin increases which leads to an increase in skin blood volume therefore, vasodilation occurs. Thus, more blood is available at the skins surface for heat transfer (Charkoudian 2010). Heat transfer occurs via sweating and vasodilation. Vasodilation is described as vascular smooth muscle relaxation (Lowenstein, Dinerman et al. 1994). The main vasodilator to bring about this relaxation is nitric oxide (NO) which is released from the endothelium. It is a lipid soluble gas, therefore can diffuse freely across membranes (Di Francescomarino, Sciartilli et al. 2009). When there is an increase in blood flow and pressure, acetylcholine binds to the NO receptor on endothelial cells, increasing intracellular calcium. This then activates nitric oxide synthase which makes nitric oxide. It then diffuses out of the cell into smooth muscle cells and binds with guanylate cyclase and induces relaxation of the smooth muscle (Lowenstein, Dinerman et al. 1994).

As mentioned previously, evaporation transfers heat energy in a liquid form on the skins surface to a gaseous form into the environment (McArdle, Katch et al. 2006) and is therefore important in the maintenance of core body temperature. Sweat is secreted by eccrine sweat glands that cover most of the body and are activated by sympathetic nerve fibres when signals are sent from the hypothalamus (Wendt, van Loon et al. 2007). The pathway of which the signals are sent from the hypothalamus to the sweat glands is unknown but the thermal receptor afferent pathway including the dorsal horn is thought to be the path used (Nakamura and Morrison 2008). Evaporation of sweat cools the skin, creating a thermal gradient allowing heat dissipation from the blood to the skin and finally to the environment. The cooler blood will then be transferred back to the core reducing an increase in core temperature observed during exercise (Charkoudian 2010).

When there is a decrease in core body temperature and skin temperature, the sympathetic noradrenergic vasoconstrictor system causing vasoconstriction is activated. Therefore there is a decrease in skin blood flow (Kellogg 2006). Vasoconstriction is effective in reducing heat loss by constricting blood vessels and shunting the warm blood into the core (Armstrong 2000). In order to prevent heat dissipation, vasoconstriction has to be maximal (Armstrong 2000). If only mild, there is an increased demand for heat production via shivering. Shivering is involuntary skeletal muscular contractions as a result of bursts of activity in the alpha-motorneurons that innervate skeletal muscle fibres (Nakamura and Morrison 2008). Signals to produce shivering are sent from the posterior hypothalamus to the forebrain bundle. Shivering is a last resort response and its threshold is a degree less than vasoconstriction as it is very inefficient (Sessler 2009), however constant muscle contractions can increase metabolic heat production from 70 Wm^{-2} to 200 Wm^{-2} (Parsons 2003).

If shivering does not produce enough heat, hormones such as epinephrine, norepinephrine, cortisol and corticosterone, are released into the blood (Armstrong 2000). All these hormones maintain blood pressure by increasing the action of vasoconstrictors (Marieb and Hoehn 2007).

Thermoregulation during exercise

During exercise, metabolic heat production can increase drastically but only 30% of the heat is converted and used as energy. The other 70% has to leave the body and dissipate to the environment (Lim et al. 2008). If this does not happen, heat will accumulate in the body and increase core temperature (Lim et al. 2008). During exercise, sweating is the primary means for heat loss as over 80% of heat is dissipated in this way (Lim et al. 2008). Sweating can also limit the rise in body core temperature to no more than 2-3ºC (Maughan 2010). Due to sweating, the body may become dehydrated (Parsons 2003). This is where there is a reduction in normal body water content (euhydration) to a water deficit (Parsons 2003). When the body is euhydrated, the water provides the transportation of minerals and allows biochemical reactions to occur (Parsons 2003). Consequently, if the body is dehydrated none of these essential activities will occur. It has been found that dehydration causes a reduction in aerobic performance, increases body temperature and heart rate (Barr 1999). Thus, during exercise it is essential that the body is euhydrated. Dehydration causes the body to lose water in excess of sodium causing the osmolarity of extracellular fluid (ECF) to increase (Piantadosi 2003). The body responds to this by conserving water via decreasing urine output in proportion to the amount of water lost from the body (Piantadosi 2003). The kidneys control the concentration of urine by decreasing water and sodium excreted. Therefore urine that is more concentrated than plasma is excreted (Piantadosi 2003).

In order to detect dehydration, urine osmolality can be used. A urine osmolality value of ≤ 700 mOsm/kg is an index of euhydration (Sawka and Noakes 2007). Another way to detect dehydration is via body mass. Body mass is assessed in the morning and if there is a fall of 1.5-2%, this may be an indication of dehydration and therefore may amplify thermal and cardiovascular strain, reducing exercise performance (Grantham, Cheung et al. 2010).

Sweat evaporation is related to the amount of water vapour in the air, if humidity is high, evaporation is inhibited (Lim et al, 2008). When exercising in a hot and humid environment, the body will lose fluid via sweat but will not lose heat (Lim et al, 2008). The bodies response to exercising under heat stress will be explained further in *section 2.5.*

As explained above, vasodilation occurs when body temperature rises above resting level (>37ºC). During exercise, there is a high demand for the sympathetic vasodilator system due to body temperature increasing above resting level. This then leads to an increased blood flow and volume, therefore heat transfer via evaporation, needs to happen. Due to this increased demand for vasodilation, there will be an increased NO production and regulation of nitric oxide synthase (NOS;(Di Francescomarino, Sciartilli et al. 2009). This increased NO production will allow greater vasodilation and an increase in heat transfer, allowing exercise to continue. This therefore means that there is no need for the sympathetic noradrenergic vasoconstrictor system to be activated as the body does not want to preserve heat during exercise. If enough heat is not transferred from the body, temperature will increase and heat illnesses such as heat stroke may set in (Marieb and Hoehn 2007). Exercise in extreme hot and cold environments add extra stress to the thermoregulatory system.

Intermittent sprint exercise whilst under heat stress and effects on cognition

Competitive matches of football are played in some parts of the world where temperatures exceed 30ºC and relative humidity reaches 50-70% (Morris, Nevill et al. 1998). Intermittent sprint exercise in hot environmental conditions, place extra strain on the thermoregulatory system which may result in reduced exercise performance (Duffield, Coutts et al. 2009). With a combination of thermoregulatory stress and dehydration, fatigue will set in and may lead to heat illnesses such as heat stroke

(Özgünen, Kurdak et al. 2010). The combined effects of fatigue and an increased body core temperature, decreases the amount of high intensity activity and the distance covered during the second half of football matches (Mohr, Krustrup et al. 2003).

Morris et al. (1998) studied the effects of a hot environment on performance of prolonged, intermittent, high intensity running. The protocol used was based on a prolonged, intermittent, high intensity shuttle run rest (Nicholas, Williams et al. 1995). It included various intensities and durations of movements in moderate (~20ºC, 71%) and hot (~30º, 66%) environments. When completed, there was a rest period of 3 minutes, which was followed by a 60 s run at 99% of predicted VO_{2max}. Subjects rested for 60 s and performed the 60 s run/rest pattern until exhaustion. The main finding of this study was that performance to exhaustion was less in the hot environment compared to the moderate environment. Morris et al. (1998) believe there was a decrement in performance due to a rise of 2.1ºC above resting level in core temperature during the hot condition. These findings have been supported by Özgünen et al. (2010). They studied the effects of hot environmental conditions on physical activity patterns and temperature response of football players. Core temperature increased in the hot condition (36ºC, 61%) compared to moderate heat (34ºC, 38%). Also, total distance covered in the second half of the match decreased. They believe this to be due to the players choosing their own pace to keep thermal strain within tolerable limits

Other team sports that include intermittent sprint exercise, show similar responses to those found by Morris et al. (1998) and Özgünen et al. (2010) when exercising in the heat. The Loughborough Intermittent Shuttle Test (LIST;(Nicholas, Nuttall et al. 2000)) was used on field hockey players (Sunderland and Nevill 2005). Hockey skill tests were performed before and after the second and fourth sets of LIST. It was found that hockey skill performance decreased following the LIST in the hot environment compared with the moderate environment. This decrement and an increase in core temperature are consistent with previous research (Morris, Nevill et al. 1998). Sunderland and Nevill (2005) assume that a thermoregulatory strain and increased heart rate, help to explain the poor performance.

As stated previously in *section 2.4.1*, around 70% of metabolic heat produced during exercise must be lost from the body. During exercise under heat stress, environmental temperature will exceed the bodies skin temperature, causing heat gain in addition to the metabolic heat produced (Maughan 2010). Thus, in order to dissipate this heat, the rate at which evaporation of sweat occurs increases.

Due to this increase in sweat evaporation, the body is likely to become dehydrated (Parsons 2003). It has been reported that soccer players suffered significant dehydration (fluid loss of more than 2%) when performing under heat stress and that fatigue was directly correlated to dehydration (Mohr, Mujika et al. 2010). This offers support for Grantham et al's. (2010) statement that dehydration reduces exercise performance. Hydration and sweating responses in football in hot environments were studied and results showed that significant sweat and electrolyte loss does occur during a match (Kurdak, Shirreffs et al. 2010). Previous research reported estimated sweat loss to be 2193 ± 365 mL (Shirreffs, Aragon-Vargas et al. 2005). Kurdak et al. (2010) also report that 16 of 22 players developed hypohydration as they lost >2% of their starting body mass. These results place extra physiological stress on players and therefore may offer support for the previous statement that dehydration plays a part in reducing exercise performance (Grantham, Cheung et al. 2010).

During exercise under heat stress, there is added tension placed upon the cardiovascular system. The primary challenge is to increase cardiac output so it can support high skin blood flow to ensure heat dissipation and high muscle blood flow for metabolism (Tipton 2006). If blood flow to muscle is compromised due to redirection to the skin, there may be changes in muscle metabolism that could inhibit muscle function. However in Morris et al's. (1998) study there was no difference in blood lactate, blood glucose and free fatty acids suggesting muscle blood flow was not compromised.

High body temperatures may have detrimental effects on exercise through cardiac output and blood pressure (Morris, Nevill et al. 1998). Morris et al. (1998) believe that cardiac output was unable to meet the demand of blood flow, causing the reduced performance of exercise.

Factors such as elevated body core temperature and hydration status may have effects on the central nervous system, which in turn may have an effect on aspects of brain function, such as decision making, that are important in match situations (Bandelow, Maughan et al. 2010). According to Bandelow et al. (2010), heat stress and exercise were found to have a negative effect on cognitive tests such as visual sensitivity and finger tapping tests. An increased core temperature was one of the physiological changes that was driving the negative effect. Due to a higher core temperature, there were significant decreases in finger tapping speed and visual sensitivity, therefore providing evidence that a higher core temperature does have a slowing effect on aspects of brain function (Bandelow, Maughan et al. 2010). Gaoua (2010) also point out that changes in core temperature can impair cognition as a rising temperature will have detrimental effects.

As Bandelow et al. (2010) pointed out previously, hydration status may have an effect on cognition, however their results state otherwise. They found that dehydration did not effect cognition which is similar to other findings (Serwah and Marino 2006). However Gaoua (2010) mention that dehydration of more than 2% of body mass impaired complex tasks but has little effect on simple tasks, whereas exercise induced dehydration of 3-5% of body mass impairs both complex and simple tasks. Hence, there are conflicting results when interested in hydration status and cognition. There is little work on cognitive performance and exercise under heat stress, therefore the effects are still relatively unknown.

In summary intermittent sprint exercise performance declines under heat stress. All investigations suggest that high core temperatures are responsible for the decline in performance. Many also suggest that a higher sweat rate leading to dehydration also contributes to the decrement in performance. A wide variety of cognitive tests are used to assess cognitive function, making it difficult to compare studies. However, recent investigations have reported that a higher core temperature associated with exercising under heat stress, have detrimental effects on cognition. Hydration status has also been found to impair cognitive function but also to have no effect. The effects of exercise under heat stress on cognition are therefore contradictory and still relatively unknown, making this area of interest in this study.

Intermittent sprint exercise whilst under cold stress and effects on cognition

There are some football competitions that take place in cold climates such as Moscow where temperatures can fall to -9°C (MetOffice 2011). There are some cold weather scenarios such as low temperature and wind chill, where thermal balance cannot be maintained and therefore decrease exercise performance (Castellani, Young et al. 2006).

Exercising in a cold environment can cause fluid loss and are advised to remain hydrated to sustain performance (Cheuvront, Carter et al. 2005). As stated previously, >2% loss of body mass indicates that the body is dehydrated and impairs performance in the heat (Grantham, Cheung et al. 2010). There is evidence that the cause of decrement in performance under heat stress due to dehydration is blunted and has less impact under cold stress (Cheuvront, Carter et al. 2005). For Cheuvront et al's. (2005) study, in the morning, subjects sat in a hot room (45ºC, 50% RH) for 3 hours either euhydrated or hypohydrated. In the afternoon, subjects sat in a cold room (2ºC, 50% RH) or a temperate room (20ºC, 50% RH) for 1 hour. Following this they performed 30 minutes on a bike at 50% VO_{2peak} and immediately, after a 30 minute time trial. Cheuvront et al. (2005) reported that hypohydration impaired cycle time trial performance in a temperate, but not cold environment. They also reported that in the cold environment, performance was not affected. However, a previous study found that time to fatigue reduced at 4ºC compared with 11ºC (Galloway and Maughan 1997). Both of these concentrate on cycling, therefore comparing to intermittent sprint running is made difficult.

As there is little research available on the effects of intermittent sprint exercise under cold stress, the full physiological response and cognitive function are still relatively unknown.

Goal Line Officials- Thermoregulation and Decision Making

The recent introduction of goal line officials to UEFA competitions presents an interesting research topic in which to investigate. Goal line officials move very little during a 90 minute football match, at most, making small lateral movements which is unusual for an athlete involved in any sporting context. Goal line officials are tasked with making extremely important decisions during fixtures, such as, penalty decisions and whether the ball has crossed the goal line, all of which can decide the out come of a game. The nature of the ‘exercise’ carried out by goal line officials means they are exposed to interesting thermoregulatory demands, such as keeping warm in extreme cold (for example Moscow, -5 ^{o}C) and keeping cool in hot conditions (Madrid, 30 ^{o}C), at the same time as maintaining cognitive integrity. Little research exists into the effects of extreme hot and cold on the decision making performance of humans at rest, so the findings of the present study will be novel. It is important to elucidate the effects of these environmental extremes on decision making ability as it may aid in improving goal line official performance, noteably through the identification of intervention needs should they suffer cognitive decrement in either the hot or cold.

Described below are the mechanisms of metabolic rate, experienced by goal line officials during match performance, the thermoregulatory responses to hot and cold at rest, as well as key factors in the decision making process and all physiological knowledge to date on the effects of hot and cold on cognitive performance.

Resting Metabolic Rate

Metabolic rate is a broad term that encompasses numerous levels of energy turnover and heat production. As goal line officials move very little throughout a 90 minute match consideration of the metabolic heat produced is require especially during exposure to cold conditions. If metabolic heat production isn't significant endogenous temperatures will reduce having an adverse effect on the decision making performance of goal line officials.

The well understood term ***standard metabolic rate***, also known as resting metabolic rate is what is generally referred to as metabolic rate. To achieve standard metabolic rate one must be; awake, resting and not digesting (Rolfe and Brown 1997). Moreover, to attain a steady standard metabolic rate, one must not be exposed to adverse environmental conditions, thus thermoregulatory response is not activated.

Resting (standard) metabolic rate is a direct measure of the expenditure of survival (Clarke 2004). Metabolic rate; both basal and resting have received intense focus throughout the last century. Previous literature has worked towards elucidating on the temperature dependence of metabolism (Clarke 2004; Clarke and Fraser 2004). Metabolism and temperature form a symbiant circle, with one directly affecting the other. Various theories have been proposed to try and explain this interdependence, which will be explained later in the chapter.

Optimal resting metabolism has been developed over millions of years and is a product of evolution (Harper, Antoniou et al. 2002). Resting metabolism augments protein synthesis and ion/proton control, amongst other processes such as gluconeogenesis (Clarke and Fraser 2004).

Proton leak contributes to resting metabolic rate through its relationship with uncoupling proteins (Rolfe and Brown 1997; Rolfe and Brand 1997; Porter, Joyce et al. 1999). During oxidative phosphorylation an electrochemical gradient is created by the electron transport chain, this gradient allows the passage of protons and ions (namely hydrogen) from within the mitochondrial matrix to the inner mitochondrial membrane space (Stuart, Cadenas et al. 2001; Harper, Antoniou et al. 2002). The electrochemical gradient is used into one of two ways; firstly, ***phosphorylation***, this process is well understood and explains the production of adenosine triphosphate (ATP), via the ATP synthase complex. Clearly, the production of ATP is vital as it allows the function and regulation of a living being, but this process is under constant challenge for the electro chemical gradient available(Stuart, Cadenas et al. 2001). Competition for the use of the electro chemical gradient comes from ***proton leak***. Proton leak is the process of hydrogen leakage from the inner mitochondrial membrane space to the mitochondrial matrix (Rolfe and Brown 1997). The passage of protons (hydrogen) into matrix dissipates the electrochemical gradients potential as heat. Recent literature (Virtanen, Lidell et al. 2009; Virtanen and Nuutila 2011) has uncovered the existence of, ***uncoupling proteins.*** Uncoupling protein 1 (UCP 1) has received the most focus, and is also referred to as thermogenin. UCP 1 is located on the inner mitochondrial membrane and allows the passage of hydrogen into the mitochondrial matrix. UCP 1 detaches hydrogen from the oxidative phosphorylation process allowing it to re-enter the matrix to produce heat, a key component in resting metabolism (van Marken Lichtenbelt, Vanhommerig et al. 2009).

Protein turnover, also contributes significantly to metabolic rate. Proteins conduct numerous roles within the body, including; cell signalling, contractile potential, and are responsible for activation of cellular cascades (Waterlow 1984). Protein turnover explains both protein synthesis and protein breakdown. (Waterlow 1984; Rolfe and Brown 1997) explains that the synthesis of one peptide bond requires 4 ATP, and can contribute to metabolic rate by as much as 22% (REF). Protein degradation offers an equally significant contribution to metabolic rate. Contributions as high as 15% have been reported in mammalian samples (Rolfe and Brown 1997).

Universal Temperature Dependence of Metabolism

Metabolism is reliant on temperature. Biochemical reactions required to sustain life are temperature dependant. Metabolic rate can be explained using a simple, elegant equation:

$$B = E_i R_i$$

B represents metabolic rate. Ei is activation energy; energy potential required to begin a chemical reaction. Ri represents the energy output produced by the biochemical reactions that constitute metabolism. The rate of energy production (output) is dependant on 3 factors: ***concentration of reactant***; ***fluxes of reactants***; ***kinetic energy of the system*** (Gillooly, Brown et al. 2001).

Concentration of reactant and fluxes of reactant are reliant on ones body mass and substrate availability (Clarke, Rothery et al. 2010). In the absence of vital reactants the necessary reactions cannot be actioned, thus metabolism becomes inefficient, and is suppressed. An example of this is starvation; starvation explains a lack of energy intake, reducing reactant availability, slowing metabolism. The substrate dependence of *concentration of reactant* and *fluxes of reactant* means that they are body mass dependant (Gillooly, Brown et al. 2001).

However, *kinetic energy of system,* unlike the previous factors is not body mass dependant but temperature dependant. Temperature dependence of a reaction is governed by the Boltzmann Factor (Gillooly, Brown et al. 2001)

$$e^{-E\text{i}/kT}$$

Where Ei is the activation energy, the energy potential required to begin a chemical reaction. K is Boltzmann's constant; this explains that the potential energy within a molecule is directly linked to the absolute temperature. So, an increase in temperature increases energy potential. Finally T represents temperature. Collectively Boltzmanns factor explains the temperature dependence of any chemical reaction (Gillooly, Brown et al. 2001).

The above mentioned equation, $B=E_iR_{I,,}$ although simple and appears to explain the facets involved in metabolic rate it fails to account for the variance in body mass and temperature requirements of a specific species. As previously mention R_i relies on substrate availability and is temperature dependant.

Thermoregulatory Responses to the Hot and Cold

POA (preoptic anterior hypothalamus) Neuron Response

When changes to the body's core temperature occur, whether its due to endogenous hot/cold or variation in metabolic heat production, neurons in the POA are responsible for maintaining homeostasis (Romanovsky 2007). It was previously hypothesised that warm & cold sensitive neurons (of the POA) had the same activation pathway, for example; as the warm sensitive neurons are activated, the cold sensitive neurons are deactivated and vice versa (Bligh 2006; Romanovsky 2007). (Chen, Hosono et al. 1998)proposed an alternative hypothesis; homeostatic responses to both the hot and cold are governed by warm sensitive neurons. Activation of the warm sensitive neurons results in a protective response to heat, while deactivation of warm sensitive neurons causes a cold protective response (Romanovsky 2007).

TRP CHANNELS

The POA pathway is responsible for detecting changes in core body temperature, whereas the peripheral sensors monitor the temperature of the skin (Romanovsky 2007). Transient receptor potential (TRP's) are ion channels, more specifically ThermoTRP's are responsible for the monitoring and detection of temperature changes to the periphery (Voets, Talavera et al. 2005). In addition aid in the monitoring of core temperature also (Romanovsky 2007).

In total 30 TRP channels exist, but not all of these channels are thermosensitive(Dhaka, Viswanath et al. 2006). Of these 30 the following are thermosensitive:

Table 1. Thermal TRP channels.

TRP Channel	TRPA 1	TRPM 8	TRPM 4	TRPM 5	TRPV 4	TRPM 2	TRPV 3	TRPV 1	TRPV 2
Activation Temperature Range (^{o}C)	0-10	10-20	20-30	20-30	30-40	35-40	35-50	42-50	50+

Consists of the adapted works (Voets, Talavera et al. 2005; Romanovsky 2007), displayed are the temperatures at which specific TRP channels are activated. TRPA1 & TRPM8 are cold sensitive channels, with the remaining TRP's warm sensitive. Although the temperature ranges appear specific and not to overlap, there is some overlap between the varying channels. Each TRP has an optimal temperature which is not situated within the upper and lower bounds of its respective activation range thus, activation of two or more TRP's simultaneously is beneficial (Voets, Talavera et al. 2005).

When a hot/cold stressor to any particular TRP (either a hot/warm/cool/cold sensitive TRP) is detected the respective TRP depolarises the cell, this allows the influx of ca^{2}+. Elevated levels of ca^{2}+ catalyses the correct physiological response (activation of sensory nerves) (Talavera, Nilius et al. 2008).

The sensory nerve then sends a pain signal which is transmitted via either; C-type fibres (unmyelinated), located within the peripheral nerves, or; ADelta-fibres (Ad-fibres) which are covered with a myelin sheath (unlike the C-type fibres), this allows for faster signal conduction (Talavera, Nilius et al. 2008). Signals are sent to the hypothalamus, the centre for thermal homeostasis, and the required physiological responses (e.g. skin vasodliation/vasoconstriction) is actioned (Sessler 2009).

Thermoregulatory responses to cold

Skin blood flow

Vasoconstriction is a thermoregulatory response to cold exposure. Vasoconstriction occurs during both local cooling of the skin and whole body cooling (Charkoudian 2010). Vasoconstriction is induced by more than one pathway:

Nitric Oxide:

The availability of nitric oxide (NO) affects both vasodilation and vasoconstriction. If NO is readily available then it aids in the process of vasodilation, an important mechanism in the thermoregulatory homeostasis of heat exposure. Conversely, the inhibition of NO allows vasoconstriction to ensue. Previous work (Kellogg 2006; Kellogg, Zhao et al. 2009; Johnson and Kellogg 2010) demonstrate that vasoconstriction is not possible in the presence of NO, with (Kellogg 2006) reporting successful vasoconstriction when NO is artificially inhibited with N^{G}-nitro-$_{\text{L}}$-arginine ($_{\text{L}}$-NAME), without cooling. (Kellogg 2006) then compared skin blood flow at two separate sites: one site treated with $_{\text{L}}$-NAME, and no treatment at the other site; both sites were exposed to local cooling. $_{\text{L}}$-NAME induced vasoconstriction immediately after prescription, with a slower vasoconstrictory response at the cooling-only site. Importantly at the end of the local cooling protocol both conditions displayed similar, minimal skin blood flow. Although the substance response for NO inhibition in vivo is unknown (Kellogg, Zhao et al. 2009).

Rho Kinase:

Rho kinase, a GTPase, aids in the vasoconstriction of smooth muscle cells (blood vessels), via two pathways (Somlyo and Somlyo 2000). Myosin phosphatase inhibits cellular contraction by dephosphorylating myosin light chains, which phosphorylates myosin of the cross-bridge cycle, reducing contractile potential (Wettschureck and Offermanns 2002). During bouts of myosin phosphate regulation smooth muscle cells are in a relaxed state, when contraction is required Rho kinase is activated. Rho Kinase acts upon the myosin sub unit (a sub unit of myosin phosphatase. The myosin sub unit is phosphorylated by Rho kinase, thus inhibiting myosin phosphatase (Wettschureck and Offermanns 2002). The inhibition of myosin phosphatase allows the phosphorylation of myosin light chains, leading vasoconstriction through smooth muscle contraction (Wettschureck and Offermanns 2002).

Brown Adipose Tissue: Mechanism of Action

On a reduction in body temperature brown adipocytes receive signals via the sympathetic nervous system (CANNON and NEDERGAARD 2004). This signal transmission initiates the release of norepinephrine (NE), which activates the thermogenic action of brown adipose tissue (BAT) (CANNON and NEDERGAARD 2004). The activeation of BAT begins with NE binding to a B3 adrenergic receptor, this initiates a signalling cascade(CANNON and NEDERGAARD 2004), as described in figure 1.

B3 Adrenergic Receptor

↓

Stimulatory G Protein

↓

Adenylyl Cyclase

↓

cAMP

↓

Protein Kinase A

Figure 1. The cascade begins with signal transduction from B3 adrenergic receptor to stimulatory G protein (G3). G3 is response for initiating the production of cyclic adenosine monophosphate (cAMP) via adenylyl cyclase (Lowell and Spiegelman 2000; CANNON and NEDERGAARD 2004). cAMP is a secondary messenger, which in the present pathway activates protein kinase A (PKA).

PKA has a duel role within the present pathway, to explain both roles it is beneficial to elucidate on what happens beyond the next cascade stage (refer to Figure 2.).

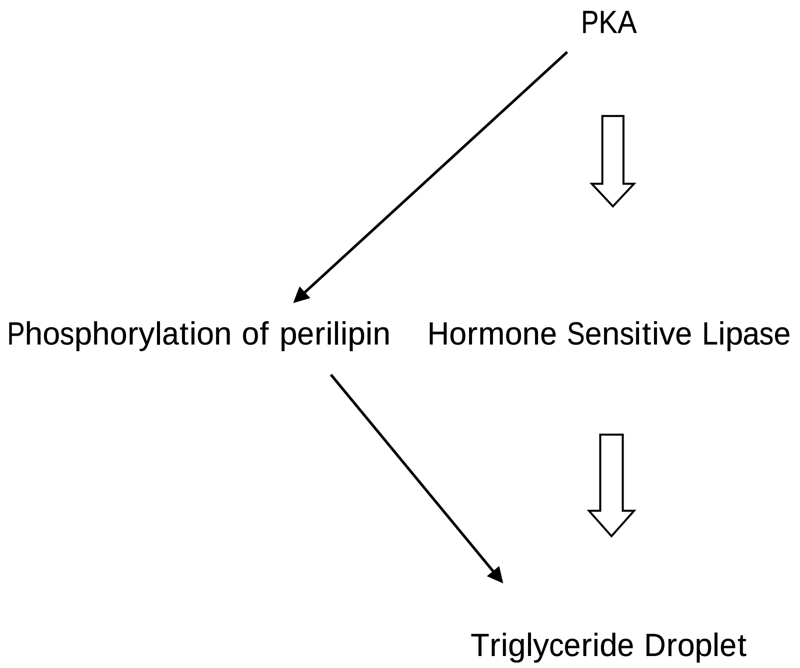

Figure 2. Describes the lipolysis activation stage. In which hormone sensitive lipase (HSL) is activated via PKA (Lowell and Spiegelman 2000; CANNON and NEDERGAARD 2004). HSL is necessary for the breakdown of triglycerides (TG) into free fatty acids (FFA). Yet, PKA must first act upon TG before HSL can begin activate lipolysis (CANNON and NEDERGAARD 2004). Triglyceride contains perilipin, perilipin protects TG against HSL's ability to catabolise lipids . Thus, PKA seperates perilipin from TG via phosphorylation, allowing HSL to begin lipolysis.

HSL has now hydrolysed TG into FFA. FFA cannot permeate the inner mitochondrial membrane, and so they are converted to acyl-CoA via acyl-CoA synthase (Lowell and Spiegelman 2000). Acyl-CoA is the converted to acyl-carnitine via carnitine palmitoyltransferase (Lowell and Spiegelman 2000). A carnitine catalyst then transports acyl-carnitine across the inner mitochondrial membrane to commence beta-oxidation (CANNON and NEDERGAARD 2004).

Beta oxidation results in NADH and FADH production (with further contribution from the cyclic acid cycle). NADH and FADH are them sent to the electron transport chain (ETC), where they undergo oxidisation. The resulting product of the ETC is hydrogen which is released from the mitochondria via the ETC's complex's I, III, & IV (Lowell and Spiegelman 2000).

The shifting of hydrogen from within the mitochondria creates an electrochemical potential gradient. Hydrogen may then re-enter the mitochondria through 1 of 2 pathways: Firstly, via the F_0/F_1ATPase, in which ATP is produced using hydrogen, ADP & Pi (Lowell and Spiegelman 2000)(see Figure 3.). Alternatively hydrogen can re-enter the mitochondria via uncoupling protein 1 (UPC1) (Lowell and Spiegelman 2000) (See figure 3.). This allows hydrogen to pass the mitochondrial membrane in the absence of F_0/F_1ATPase, this process creates energy but is released as heat and not ATP(Lowell and Spiegelman 2000; CANNON and NEDERGAARD 2004). UCP1 makes the transfer of hydrogen across the mitochondrial membrane possible by dissipating the difference between the inner and outer mitochondrial gradient (CANNON and NEDERGAARD 2004).

It is important to note that UPC1 is not activated when FFA are not present.

The production of heat aids in the maintenance of endogenous heat, retaining physiological integrity.

Shivering

Perhaps the most easily visible response to ambient cold exposure is shivering. Shivering aims to increase metabolic heat production via the energy inefficiency of the cross bridge cycle (Haman 2006; Nakamura and Morrison 2011). Shivering is a 'last resort' mechanism not activated until endogenous temperatures are a degree (^{o}C) lower than that required to activate vasoconstriction (Sessler 2009). The signalling pathway which transfers thermo-sensory information from the skins thermo-receptors to brain and a resultant thermoregulatory has only recently been elucidated (Sessler 2009) in a number of recent papers (Nakamura and Morrison 2007; Morrison, Nakamura et al. 2008; Nakamura and Morrison 2008; Nakamura and Morrison 2011). Although it is important to note much of this work is carried out on rodents and not humans.

The signalling pathway is complex and involves many stages, the first of which involves the sensing of environmental cold through a reduction in skin temperature (Nakamura and Morrison 2011). External cold is sensed by the skin thermo-sensors, with the informative signal sent to the dorsal horn which is located on the dorsal (back) of the spinal cord (grey matter section) (Nakamura and Morrison 2008). The signal is then projected to the lateral parabrachial nucleus, which is located within the Pons area of the brain (Morrison, Nakamura et al. 2008; Nakamura and Morrison 2008). The signal is then relayed to the median preoptic subregion of the preoptic area (MnPO) via glutamate neurotransmitters, where the signal is received by glutamate receptors (Nakamura and Morrison 2008; Nakamura and Morrison 2011). On receiving the thermo-sensory signal the MnPO releases GABAergic interneurons, these are inhibitory neurons (Nakamura and Morrison 2008; Nakamura and Morrison 2011). The GABAergic interneurons inhibit the GABAergic neurons of the medial preoptic area (MPO) (Nakamura and Morrison 2008; Nakamura and Morrison 2011). During normothermic conditions the GABAergic neurons of the MPO enforce an inhibitory effect upon the excitatory pathway which is responsible for thermoregulatory response (Nakamura and Morrison 2008; Nakamura and Morrison 2011). During cold exposure the MPO's GABAergic neurons are inhibited (by the MnPO's GABAergic interneurons) and so thermoregulatory response is disinhibited (Nakamura and Morrison 2008; Nakamura and Morrison 2011). The dorsomedial hypothalamus is now free to activate neurons which exist within the rostral raphe pallidus nucleus (rRPa) (Nakamura and Morrison 2008; Nakamura and Morrison 2011). Neurons from the rRPa act upon the ventral horn of the spinal cord (anterior, grey matter section) (Nakamura and Morrison 2011). The ventral horn is responsible from muscle excitation, via the instigation of neuronal motor recruitment. The ventral horn signals to the muscle to rapidly contract, causing shivering (Nakamura and Morrison 2011).

Thermoregulation in the Heat

Convection, Conduction, Radiation, Evaporation

Conduction

Conduction is the process of heat migrating from one surface to another during contact. Similarly to diffusion heat is transferred from a surface of high temperature to a surface of a lower temperature. During exposure to heat conduction provides the smallest contribution to endogenous heat loss, approximately 3% (Kenny Gp Fau - Journeay and Journeay).

Convection

Convection relies on cool air passing over the surface of the skin as a means of heat removal. Convection contributes approximately 15% to total heat dissipation. Convection is most effective when one is outside exposed to the wind, but convection can be artificially employed using fans (Charkoudian 2003).

Radiation

Radiation is the largest contributor to endogenous heat dissipation, providing 60% of ones heat loss. Radiation describes the transfer of heat from the body to the environment via infra red rays. Its worth noting endogenous infra red ray expulsion is in constant competition with external infra red ray absorption from the environment, compromising the efficiency of radiation heat loss (Charkoudian 2003).

Evaporation

Evaporation describes the dissipation of heat through sweating and ventilation. Ambient humidity plays a crucial role in evaporation, environments in which the humidity is high will be reduce evaporation capacity, unlike areas of low humidity in which evaporation more efficient. At rest in comfortable conditions evaporation contributes 20% to heat dissipation, but during exercise and exposure to hot conditions evaporation’s contribution can rise to as much as 80% (Charkoudian 2003).

Skin Blood Flow

Vasodilation plays a key role in the homeostasis of endogenous temperatures, especially during exposure to the heat. Many vasodilation activators have been proposed previously, with on going research still attempting to elucidate further on the substance accountable for vasodilation. Here a short review of the possible activators is provided:

Nitric oxide

The synthesis of nitric oxide (NO) begins in the endothelial cells, which are located on the inner lining of blood vessels. Other cells and tissues contribute to NO production although endothelial synthesis is dominant (Lowenstein, Dinerman et al. 1994; Joyner and Dietz 1997).

The signalling pathway for the production of NO begins with acetylcholine. Acetylcholine binds with its transmembrane receptor located next to the lumen (Joyner and Dietz 1997). This binding exponentially increases levels of calcium within the cell, which bind to calmodulin. Calmodulin is a messenger protein, responsible for the transduction of calcium's signal to the next receptor(Lowenstein, Dinerman et al. 1994; Joyner and Dietz 1997). The transduction activates NO synthase, an enzyme responsible for the synthesis of NO. NO synthase is then coupled with arginine and oxygen to produce NO (Lowenstein, Dinerman et al. 1994).

NO then migrates from the endothelial cell to a nearby smooth muscle cell, where it binds to iron and guanylate cyclise (GC). On binding to GC, GC's dephosphorylatng potential is activated, converting guanosine triphosphate into cyclic guanosine monophosphate (cGMP) (Lowenstein, Dinerman et al. 1994).

There are various mechanisms suggested as to how cGMP causes vasodilation, they include; a reduction in calcium migration into smooth muscle cells, reducing contractile potential. cGMP may also reduce a cells membrane potential by activating ion channels, leading to hyperpolarization. Finally it is suggested cGMP may aid in the in the activation of myosin light sub units, reduce the phosphyorlation of myosin II by dephosphorlyating myosin light chains (Lowenstein, Dinerman et al. 1994).

Vasoactive intenstinal petitde (VIP)

Similarly to nitric oxide, vasoactive intestinal petitide (VIP) activates cGMP as a means of relaxing smooth muscle cells (Petkov, Mosgoeller et al. 2003). VIP has the ability to bind to two receptors: vasoactive intestinal polypeptide 1 (VPAC-1) and vasoactive intestinal polypeptide 2 (VPAC-2), both are located on the subintima of peripheral blood vessels. On activation of these receptors the cGMP system is activated and follows the same pathway following activation via NO (Petkov, Mosgoeller et al. 2003).

Other substances such substance P and histamine have been shown to contribute to the vasodilation of blood vessels but to a lesser extent than that of VIP and most notably NO.

Cognitive Function at Rest

Cognitive function is a broad term explaining various facets some of which the majority of living organisms are capable of executing, and some that only higher primates and humans have the ability to process(Savitz, Solms et al. 2006). Animals living in the wild possess the ability to respond to basic cognitive stimuli, such as eluding predators or pursuing prey. Due to evolutionary development higher primates are able to process very complex cognitive tasks; this can be observed through the complex social relationships displayed by higher primates (Savitz, Solms et al. 2006). Humans have become the largest beneficiaries of the evolutionary advancement in cognitive processing ability. The capabilities of the human brain to perform complex tasks not achievable by any other species is referred as, executive functioning. Executive functioning describes the ability to execute such functions as; working memory, response inhibition, planning, concentration, attention, perceptual organisation, judgement, decision making, and self-monitoring (Savitz, Solms et al. 2006). Humans possess larger cortices than other primates as well as advanced cortical folding, which enhances the surface area of the cortices, increasing the volume of neurons available for cognitive processing (Cohen, Braver et al. 2002; Briand, Gritton et al. 2007).

Dopamine

Dopamine (DA), a catecholamine neurotransmitter, plays a key role in the activation of executive functioning which is processed in the prefrontal cortex (Cropley, Fujita et al. 2006; Savitz, Solms et al. 2006; Briand, Gritton et al. 2007). Decision making, attention and concentration fall under the catch-all term of executive functioning and thus are directly effected by the availability of DA, making DA a key component in the cognitive performance of GLO (Savitz, Solms et al. 2006). The following section will focus upon the synthesis and projection of DA, and its activation of prefrontal cortex neurons.

Synthesis

The dopaminergic pathway crosses the synapse and thus takes place in both the pre-synaptic element; where DA is synthesised, and the post-synaptic neuron; where DA acts upon its receptors (D1 and D2) (Cropley, Fujita et al. 2006).

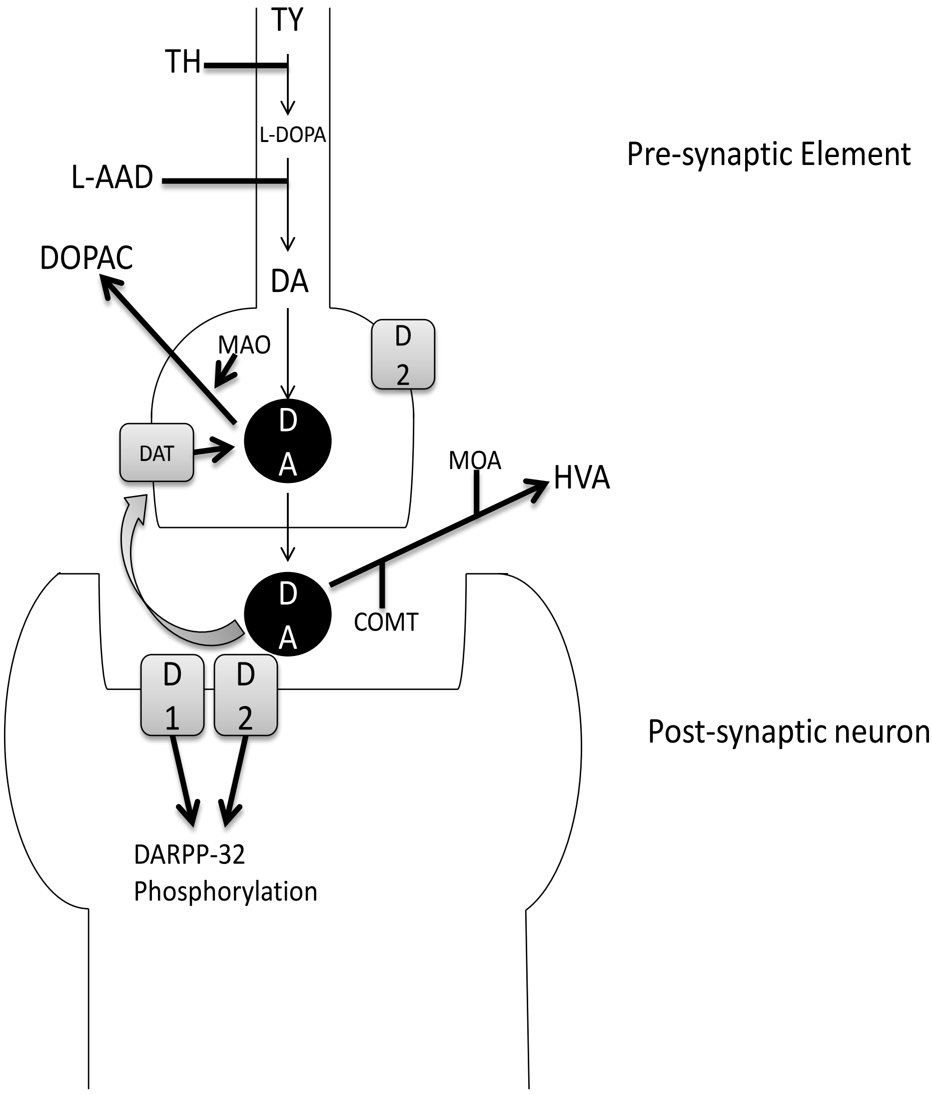

Figure 3. The Dopaminergic pathway: displayed are both the pre-synaptic element; the conversion cascade of tyrosine to dopamine, and the post-synpatic neuron; the activation of dopamine's receptors (D1 & D2) (Cropley, Fujita et al. 2006; Cools 2008).

The synthesis of dopamine begins with the transfer of tyrosine from brain capillaries to the pre-synaptic element. The transfer of tyrosine to the pre-synaptic element does not go unchallenged. Applying the revolving door theory (RDT) tyrosine is constantly in competition with *large neutral amino acid* transporter (*LNAA) (See figure 3.)* (Cools 2008).

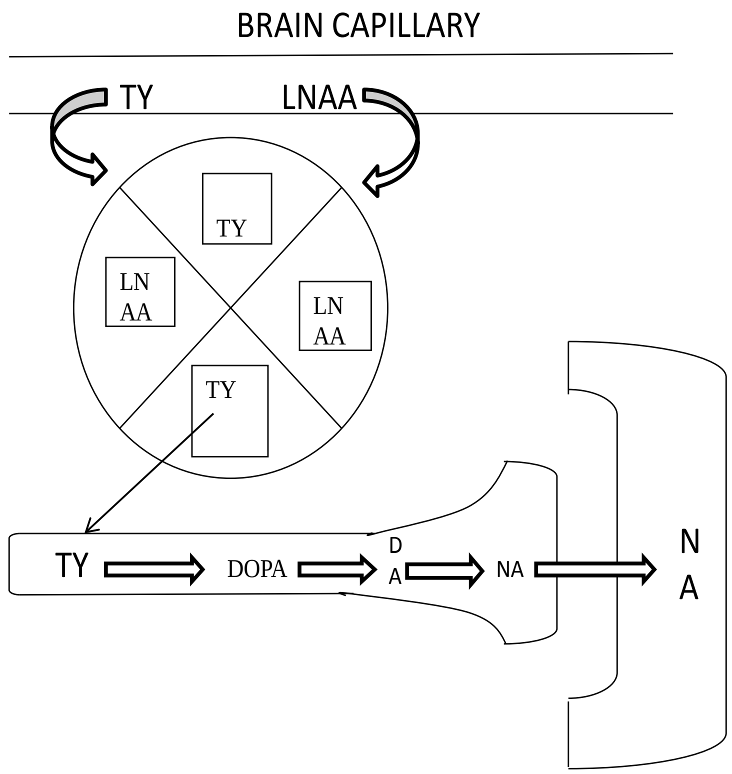

Figure 4. The revolving door theory; competition between tyrosine and LNAA's for transfer into the pre-synaptic element.

The RDT explains that a finite number of ‘carrier positions’ are available to transfer amino acids from brain capillaries to the awaiting neurons, and the amino acid with a higher molecular affinity within the brain capillaries will be transferred to the pre-synaptic element more frequently. On reaching the pre-synaptic element tyrosine is converted to L-3,4-dihydroxyphenylalanine (L-DOPA) by tyrosine hydroxylase (TH) an oxygenase, meaning it converts tyrosine to L-DOPA using molecular oxygen (Cropley, Fujita et al. 2006). L-DOPA is then converted to dopamine (DA) via the catalyst L-aromatic amino acid decarboxylase (L-AAD) (Cools 2008).

Receptors

Dopamine receptors (namely D_1 and D_2) are located on the post synaptic neuron and are activated by the binding of dopamine after it has crossed the inter-synaptic space. Another receptor exist that belongs to the D2 receptor family; D_2SH, and is located pre-synaptically (Cohen, Braver et al. 2002).

Dopamine Receptor 1 (D_1)

Dopamine receptor 1, situated on the post synaptic neuron, is a G protein of the Gs alpha subunit class (G_{as}). G protein G_{as} is responsible for initiating the cAMP cascade, which terminates in the activation of cognitive control processes (e.g. the reward system) via the mesolimbic and mescortical projections (Cropley, Fujita et al. 2006; Savitz, Solms et al. 2006).

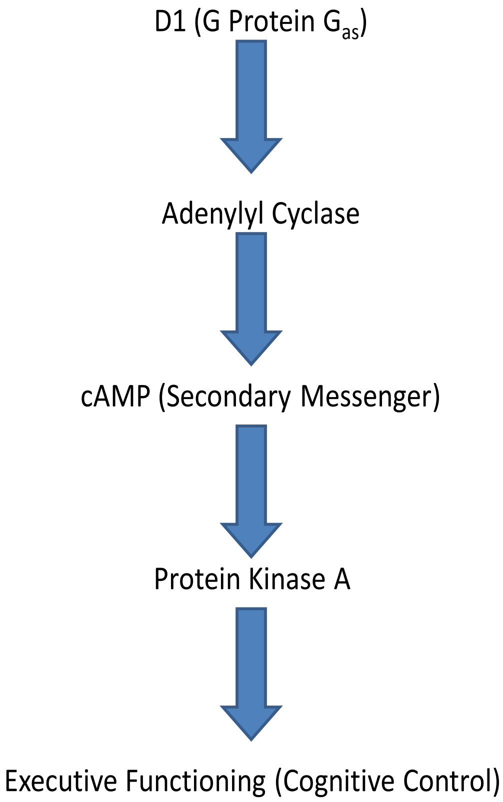

Figure 5. Cyclic adenosine monophosphate (cAMP) cascade.

Dopamine receptor 1 activates adenylyl cyclase a rate limiting factor for the production of cAMP a secondary messenger responsible for signal transduction. The passage of the neural signal via cAMP initiates the formation of protein kinase A, which is responsible for the activation of cognitive control systems within the prefrontal cortex and striatum (Cohen, Braver et al. 2002; Cropley, Fujita et al. 2006).

Neural information- The purpose of the D1 receptor and cAMP cascade is to relay a neural signal to an area of the brain in which it can be processed. Dopamine receptor 1 is a regulatory receptor. It is referred to as a ‘gating receptor’, that is, it sets the level of significance to which information must adhere in order to be processed by D1 and the cAMP cascade (Savitz, Solms et al. 2006). This gating system is an elegant solution in dealing with unnecessary stimuli, significantly reducing the amount of information sent to the prefrontal cortex for processing. In streamlining the amount of information forwarded to the prefrontal cortex the information processing system works more efficiently.

Dopamine Receptor 2 (D_2LH)

Dopamine receptor 2, situated on the post synaptic neuron, is a G protein of the Gi alpha subunit class (G protein G_{ai}). Dopamine receptor 2 can be either excitatory or inhibitory. If inhibitory it works by suppressing the synthesis of cAMP, a signal transductor (Cropley, Fujita et al. 2006).

cAMP suppression- Dopamine receptor 2 initiates the activation of phosphodiesterase, which diminishes the phosphodiester bond of second messenger cAMP, negating its signal carrier potential (Cools 2008).

Neural Information- When dopamine receptor 2 is required to carry out an excitatory function it is tasked with processing new, important information. Activation of an excitatory dopamine receptor 2 causes the prefrontal cortex to update its working memory system, to deal with the new stimuli presented (Savitz, Solms et al. 2006).

Dopamine Receptor 2 ($D2^{sh}$)

Dopamine receptor 2 ($D2^{sh}$) is situated on the pre-synaptic element and similar to the afore mentioned receptors is a G protein, of the Gi alpha subunit class (G protein G_{ai}) (Cools 2008). This receptor is tasked with regulating the release of dopamine into the inter-synaptic space for post synaptic reception. It monitors the levels of dopamine within the inter-synaptic space; using a feedback loop it either enhances the release of dopamine or suppresses it, relative to the levels encountered inter-synaptically (Briand, Gritton et al. 2007).

In respect to goal line officials both dopamine receptor 1 and dopamine receptor 2 work in tandem to cope with the numerous stimuli presented at any one time (see figure 6).

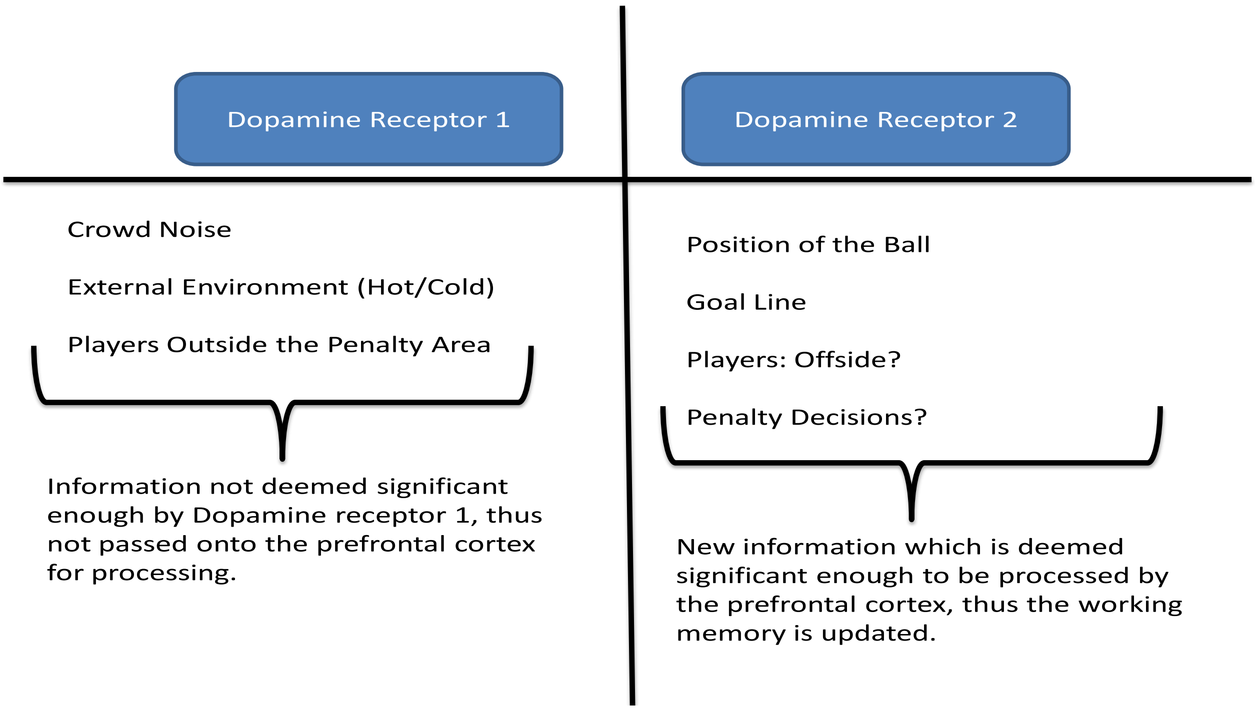

Figure 6. Dopamine receptors and coping with external stimuli.

Dopaminergic Projections

Dopamine synthesis originates in two main regions on the brain: the ventral tegmental area and the substania nigra. Both regions produce dopamine that is projected to various areas of the brain, allowing the activation of numerous cognitive process, namely the 'executive functions' (Savitz, Solms et al. 2006).

Substania Nigra

The substania nigra is responsible for dopaminergic projections to the different areas of the striatum, namely; the caudate nucleus and the putamen. The striatum plays an important role in the cognition process as it is allows for 'cognitive flexibility' (Savitz, Solms et al. 2006; Cools 2008). Cognitive flexibility explains the process by which 'cerebral energy' is applied to more than one category. For example, it may delegate cerebral energy to various processes such as; attention, tracking and working memory simultaneously (Savitz, Solms et al. 2006).

The Prefrontal Cortex

The mesocortical dopamine projection from the ventral tegmental area is key in allowing the activation and successful processing of executive functioning (Savitz, Solms et al. 2006). The prefrontal cortices offer 'stability' to the execution of higher cognitive functions, unlike the striatum which allows flexibility. Cognitive stability refers to the blockade of extraneous stimuli that are unwanted and may cause distraction from the stimuli under scrutiny (Savitz, Solms et al. 2006).

The Dopamine Trade-Off

As both the striatum and prefrontal cortex require dopaminergic projections in order to function there must be a trade-off in terms of dopamine prioritisation. Thus, if one brain region is prioritised and receives the desired dosage of dopamine it will work to optimal capacity, leaving the opposing region to suffer performance decrement; this will lead to a cognitive decrement; this will be explained in a later section.

The dopamine trade-off (Cools 2008):

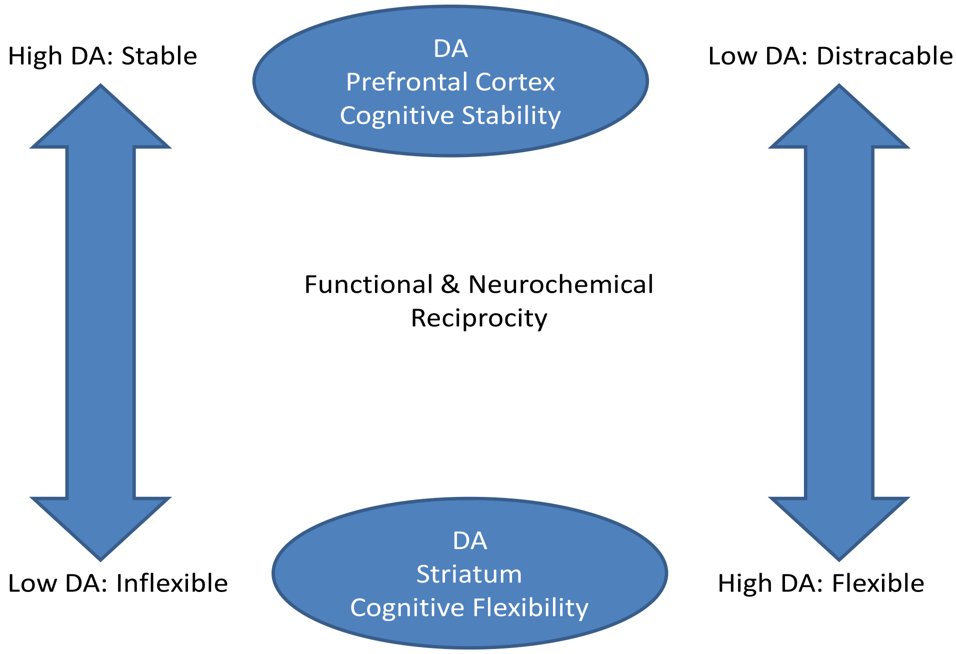

Figure 7. The dopamine trade off: Sufficient dopaminergic projections to the striatum allow for cognitive flexibility, but cognitive stability is sacrificed, causing the subject to become susceptible to distraction and attentional deficits. Conversely, sufficient levels of dopamine in the prefrontal cortex activates cognitive stability,

reducing the susceptibility to distractions, but reduces cognitive flexibility resulting in a reducing is cognitive process variability.

Cognition in the Cold

Previous literature (Mäkinen, Gavhed et al. 2001; Makinen, Palinkas et al. 2006) reports reductions in numerous cognitive processes during exposure to cold environmental conditions when at rest. Goal line officials make only small lateral movements during a 90 minute football match, essentially in a state of rest. Thus, it seems rational to hypothecate that the cognitive performance of goal line officials during exposure to the cold may suffer decrement. The mechanism by which the cognitive decrement may occur can be explained by disturbances to the dopaminergic pathway, key to the cognitive process.

The Effect of Cold Exposure to the Dopamingeric Pathway

During exposure to environmental stressors such as cold conditions the synthesis of central neurotransmitter catecholamines such as dopamine or norepinephrine is reduced (O'Brien, Mahoney et al. 2007). Reductions in these neurotransmitters may be due to a reduction in the availability of dopaminergic rate limiting factors such as tyrosine, which begins to process of dopamine synthesis (Yeghiayan, Luo et al. 2001). Regardless of causation a reduction in dopamine production will have a detrimental effect on the processing of the prefrontal cortex, which is responsible for cognitive control and the processing of executive functions (Cools 2008).

Effects on the Dopamine Receptors

Reductions in the synthesis of dopamine can lead to an unbalancing of the dopamine ratio delivered to the dopamine receptors (D1 & D2) (Savitz, Solms et al. 2006). Interference in the dopaminegric deliveries to the dopamine recpectors notably dopamine receptor 1 can lead to either a hypo-dopminergic state or a hyper-dopaminergic state. **Hypo-domingeric state:** A reduction in dopamine transport to dopamine receptor 1; suppressed activation of dopamine receptor 1 (an excitatory receptor) will reduce the dopaminergic projections to the prefrontal cortex(Savitz, Solms et al. 2006). The prefrontal cortex plays a stabilising role in the processing of stimuli and execution of responsive behaviours, thus a reduction in prefrontal activation will theoretically reduce the stability of information processing. Instability of the information processing system explains the decay of neural signal transduction, by means of neural signal decay or allowing the passage of unwanted stimuli information to reach the prefrontal cortex (Cools 2008). Unwanted neural signals within the prefrontal cortex increase the signal to noise ratio, making it more difficult for one to differentiate background (unwanted stimuli) from target (important stimuli) (Cropley, Fujita et al. 2006). A poor signal to noise ratio may lead to distractive behaviour, a loss of attention and a reduction in working memory capacity. **Hyper-dopminergic state:** Disturbances in dopamine release to the dopamine receptors can manifest in a reduction of dopamine delivery to dopamine receptor 2 (Savitz, Solms et al. 2006). Abnormally low dopamine delivery to dopamine receptor 2 can result in excessive dopamine delivery to dopamine receptor 1. Over stimulation of dopamine receptor 1 causes disproportionate dopaminergic projections to the prefrontal cortex, causing the striatum to suffer (Savitz, Solms et al. 2006). Under-stimulation of the striatum may cause a reduction in cognitive flexibility; reducing cognitive performance in tasks that require more than one cognitive process (Cools 2008) e.g. a goal line official judging whether the ball has crossed the line requires both tracking, to follow the trajectory of the ball, and attentional processes to allow focus upon the footballers important to that particular passage of play; signal-to-noise activation.

A lack of literature explaining the effect of cold exposure on cognitive processes and decision making performance in regard to physiological response and adaptation currently exists. Most research to date simply attributes cognitive decrement in the cold to distraction, failing to explain the physiological cause of distraction. The effect of reduced dopamine delivery to dopamine receptors as described above is the hypothecated mechanism to which distraction occurs in the cold although empirical evidence does not yet exist to elucidate this further.

Cognition in the Heat

Goal line officials move very little during a 90 minute football match, essentially they are at rest. Exercise increases metabolic heat production, which increases endogenous temperatures beneficial in the cold but detrimental in the heat (Johnson and Kellogg 2010). Because goal line officials create very little metabolic heat they do not suffer from extreme endogenous temperatures during exposure to the heat. Previous works explain a reduction in neurotransmitter synthesis and expression during exercise in the heat, leading to suppression of brain and central nervous system function, reducing cognitive performance (O'Brien, Mahoney et al. 2007).

Again, because goal line officials exert no physical strain during a football match they do not experience fatigue, thus neurotransmitter catecholamine expression should remain optimal maintaining cognitive performance and desirable thermoregulatory response. It is then hypothecated that the cognitive performance of goal line officials will remain similar to that of cognitive performance in comfortable conditions (18 ^{o}C).

Hypotheses and Research Questions

Research Questions

1. Do extreme environmental conditions reduce the decision making ability of active referees?
2. Do extreme environmental conditions reduce the decision making ability of goal line officials?

Hypotheses

1. Exposure to hot conditions will reduce the decision making ability of active referees.
2. Exposure to cold conditions will reduce the decision making ability of goal line officials.

Methodology

Health and Safety

All procedures were approved by the University of Bedfordshire ethics committee. Two experimenters were present during all testing sessions, with first aiders on hand if required. All apparatus used was clean and sterile eg. mouthpieces used for VO_2max. These are all cleaned using 1% Virkon solution (Antec Int. Suffolk, UK) and rinsed with tap water. Heart rate monitors and skin thermistors were washed in clean water and wiped using an alcohol swab after every experiment. Rectal thermometers were one time use only and kept in a sterile and sealed bag. The experimenter and participant could only handle the thermometer if they were wearing surgical gloves. All non-reusable equipment was disposed of in a clinical waste bin.

Criteria for the termination of testing:

- If the subject requested that testing be stopped
- If the experimenter felt it necessary: if the subject was displaying symptoms of heat/cold illness, for example, significant changes to core temperature, lack of lucidity, heat exhaustion, severe discomfort.
- Significant changes in core temperature include: a drop of >1.5 ^oC from resting baseline value. Or, an increase in core temperature of more than 2.0 ^oC or greater than 39.7 ^oC which ever was observed first. If either of these criteria are met testing will be immediately terminated according to the guidelines set out by the University of Bedfordshire ethics committee.

Subjects

Subjects included both undergraduate and post graduate students from the University of Bedfordshire, and qualified referees registered to the Bedfordshire Football League.

Beds FA recruitment

Before subjects agreed to take part they were instructed to thoroughly read through all information sheets, to ensure they were given the best opportunity to make a fully informed decision on whether to take part. Participants who decided to take part were required to fill out an informed consent form and health questionnaire. The health questionnaire was necessary as it ensures participants are healthy and in the correct condition for exercise. Subjects were made explicitly aware they were free to withdraw from participation at any time.

Diet & Lifestyle Standardisation

Pre-experimental diet and life style requirements were explained in full to all participants before they agreed to take part in the study. All subjects were required to adhere to these requirements in order to maintain the integrity of the study and its findings. Table (2) describes the diet and lifestyle expectations prior to testing.

Table 2. Lifestyle requirements subjects must adhere to prior to and during testing.

Control Measures	Duration	Reasons
No intense exercise (e.g. no more intense than a light jog)	24hours prior to testing	May induce premature fatigue
No Alcohol	24hours prior to testing	May effect cognitive performance
No caffeine	12hours prior to testing	May effect cognitive performance
No acclimation to extreme cold or hot environmental conditions	1 month prior to testing	May effect cognitive and physiological response to extreme hot/cold

Subjects were questioned on their adherence to the agreed diet and lifestyle standardisation prior to each session of testing. If subjects have not adhered to the lifestyle standardisation experimental testing was postponed until the standardisation criteria was successfully completed.

Experimental Design

Participants made a preliminary visit to the Sport and Exercise Science Laboratories at the University of Bedfordshire for a tour of the facilities that were used throughout testing. The following 2 visits were familiarisation sessions. Participants then made a further 5-6 visits during which the experimental conditions were completed. The 5-6 visits allocated for experimental testing encompass all environmental conditions employed, these include; cold; 5^{o}C, 40% relative humidity; temperate; 18 ^{o}C, 40% relative humidity; hot; 30 ^{o}C, 40% relative humidity. These various conditions were employed to mimic the differing environmental conditions experienced throughout European cup competitions (Europa League, UEFA Champions League).

The protocol employed during both the familiarisation sessions and experimental conditions was designed to mimic the match day performance of a goal line officials and active referees. It consisted of 45 minutes activity followed by a 15 minute half time break, then a final 45 minutes activity. The activity completed in the two studies (goal line official and active referee) was representative of the respective activity completed by the different officials on a match day. This was interspersed with 4 computer based cognitive tests designed to measure vigilance, visual tracking and attentional ability.

The relevant temperatures and humidity were attained using the University of Bedfordshire’s environmental chamber. The chamber was examined prior to experimental testing for validity and reliability.

Figure 8. Temperature monitor outside of the chamber to control the temperature and humidity within the chamber.

Familiarisation to Experimental Protocol

As some of the subjects were unfamiliar with the process of scientific testing and the equipment being used familiarisation was split into two sessions to reduce the strain on subjects.

Visit 1: The protocol

During visit 1 anthropometric measurements were taken for each subject. They included; height, measured using a stadiometer (Harpenden stadiometer, Holtain Ltd, Crosswell, UK) measured to the closest 0.1cm, subjects were required to stand upright and inhale maximally, the stadiometer was then lowered to the top of the subjects head, the measurement was then recorded. Body mass was attained using electronic scales (Tanita BC-418MA, Tanita UK Ltd, Middlesex, UK) measured to the closest 0.1kg. Body composition was assessed using air displacement plethysmography (BodPod 2000A, Cranlea, Birmingham, UK), body fat was measured to the nearest 1%. Maximal oxygen uptake (VO_2max) was used to measure the participant's aerobic fitness as this was required to ensure subjects were fit enough to complete the active referee study. When establishing maximal oxygen uptake the following criteria (Bird and Davidson, 1997) should be considered:

- a final heart rate within 10 bpm of age related-maximum (220-age)
- post exercise blood lactate of ≥8 $mmol.l^{-1}$
- a plateau in oxygen uptake/exercise intensity relationship
- a respiratory exchange ratio of ≥1.15
- rating of perceived exertion of 19-20 on the Borg scale.

Each stage of the incremental VO2max test lasted for 1 minute and the treadmill was set to a gradient of 1% (Jones, 2007, p. 147). Running speed started at 8 $km.h^{-1}$ and increased by 1 $km.h^{-1}$ after every stage until volutional exhaustion. Expired air was analysed continuously using a metalyser (Online gas analyser, Cortex, Metalyser 3B, Cranlea, UK) which had been calibrated before every use. Heart rate and RPE were recorded every 15 seconds.

Goal line officials

During visit 1 subjects completed the 90 minute protocol, including all 4 cognitive tests, as described in figure 1. No physiological data was recorded during visit 1. The 90 minute protocol was completed in temperate conditions (18 ^{o}C, 40% RH).

Active referees

During visit 1 subjects completed a five minute warm up, jogging on the treadmill at a speed of 10 km.h^{-1} with no gradient. Following this, participants completed one half (45 minutes) of the intermittent sprint exercise protocol to experience the changes of intensities during the protocol. No physiological data was recorded during visit 1. The 45 minute protocol was completed in temperate conditions (18 ^{o}C, 40% RH).

Visit 2: Physiological Measurements

Similar to visit 1 subjects completed the 90 minute protocol for the goal line official study. The active referee study also employed the full 90 minute protocol during visit 2. Physiological data was recorded during this visit these include; core temperature; measured using a rectal thermistor, a small, flexible, plastic thermometer inserted 10 centimetres past the rectal sphincter (Henleys, 400H and 4491H, Henleys, Herts, UK). Skin temperature thermistors were applied located at four sites; the posterior belly of the gastrocnemius, the anterior belly of the vastus intermedius, the anterior belly of the pectoralis major, and the posterior belly of the triceps brachii (Ramanthan, 1964)(Grant, EUS-U-VS5-0, Wessex Power, Dorset, UK). Heart rate was measured using a heart rate monitor (Polar Electro Oy, Professorintie 5, FIN-90440, Finland). Rating of perceived exertion; this subjective measure indicates how hard a subject feels they are working. The Borg scale a numerical scale starting at 6 (very light workload) increasing to 20 (maximal workload) was used to measure ratings of perceived exertion (Borg, 1970). Thermal sensation was also measured, this is also a subjective measure used to indicate how hot or cold a subject is feeling. An 8 point scale was used to measured thermal sensation which starts at 4 (neutral/comfortable) and increases to 8 (unbearably hot) or reduces to 0 (unbearably cold) as described by Toner et al, 1986).

Experimental Procedures

The 90 minute Protocol- Goal line official study

A specific 90 minute protocol was devised to replicate the movements and cognitive demands placed upon a goal line official (GLO) during a football match. A protocol timeline is described in figure 9.

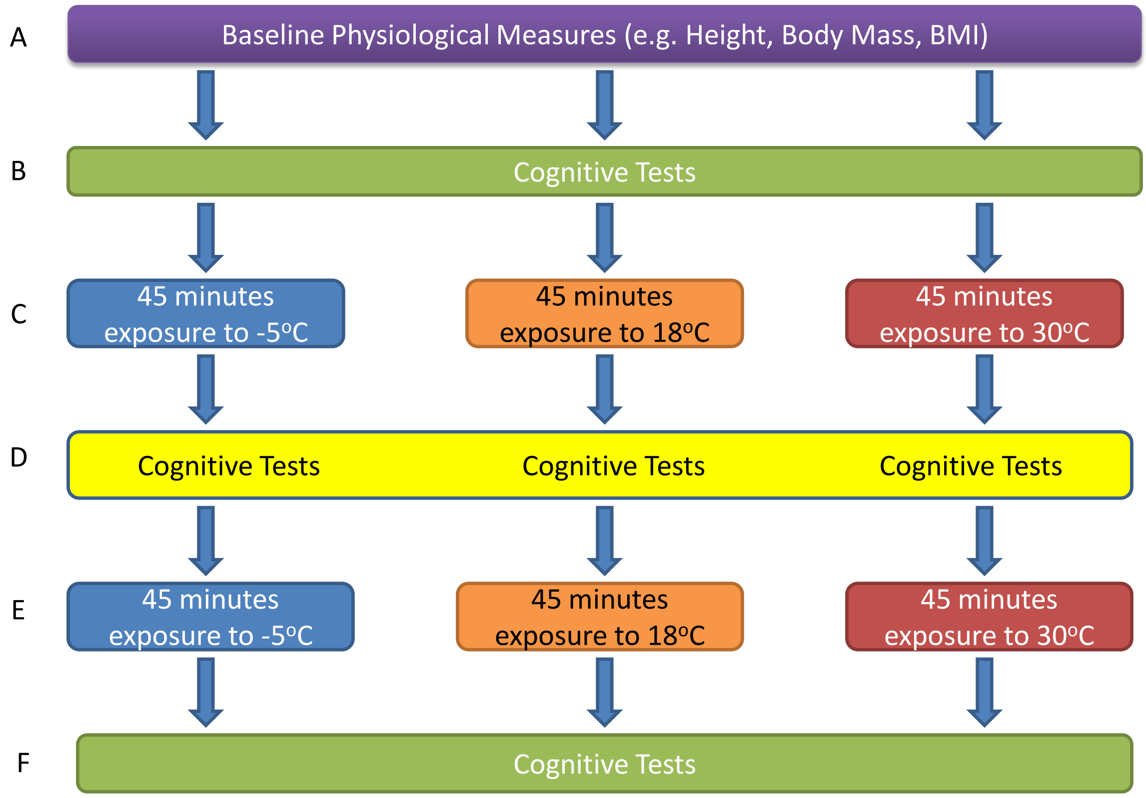

Figure 9: Chronological layout of the 90 minute experimental procedure.

During the two 45 minute exposure phases (Stage C & E) subjects performed small lateral movements; side-stepping inside a small box (2 X 1 metres) marked out on the floor of the environmental chamber. During lateral movement subjects kept their arms at their side and head facing forward. Small lateral movements were selected as the method of exercise as it mimics the minimal movement produced by GLO during a football match. Subjects were given some freedom as to how much they moved as long as they were not static for the entire phase, and stayed within the box marked out on the floor. The box was marked out on the floor to offer some standardisation for the lateral movements. Subjects watched a football match on a large television through a window in the environmental chamber during both 45 minute exposures. The same football match was used for all experimental trials.

The 90 minute Protocol- Active referees

A specific 90 minute protocol was devised to replicate the movements and cognitive demands placed upon active referees during a football match. The active referee protocol followed the same chronological procedure as the goal line official study as described in figure 9. The 90 minutes of exercise consisted of 5 different movements that are observed during a match. These are shown in the table below.

Table 3. Speed and durations of the 5 different movements during the 90 minute intermittent sprint exercise protocol.

Movements	**Speed ($km.h^{-1}$)**	**Duration (s)**
Stand	0	60
Walk	6	120
Jog	12	57
Run	15	33
Sprint	20	6

The movements described in the table above mimic the speed and duration of the movement patterns completed by professional referees during a match (Drust et al, 2000). The varying speeds were randomly assigned to different time points of the 90 minute protocol. The protocol was performed on a motorised treadmill (Woodway, PPS55 Med-i, Cranlea, Germany; figure 10) and participants were familiarised with the treadmill before testing began.

Figure 10. Woodway motorized treadmill used for the active referee study.

Cognitive tests were performed at 4 stages throughout the 90 minute protocol. The first was completed prior to any exposure to the various environmental conditions (Fig.9, Stage B). The second was completed immediately after the first 45 minutes of exposure (Stage D). The third cognitive stage was carried out on the completion of the 15 minute half time break (Stage D), immediately before the second stage of exposure. The final cognitive test was completed immediately on completion of the second exposure phase (Stage F). All cognitive tests were completed in the environmental chamber (Fig. 11).

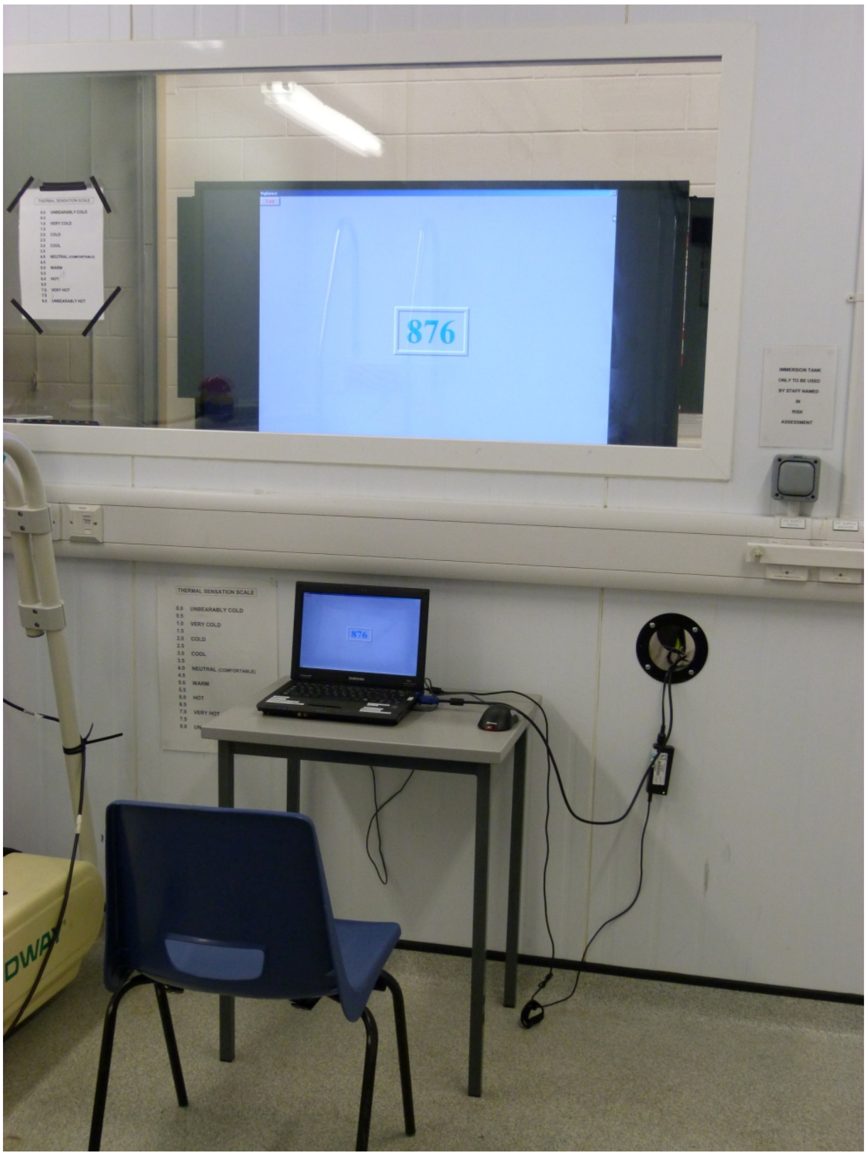

Figure 11. Psyche set up within the environmental chamber.

Equipment and Apparatus

Physiological Measures

Rectal temperature was the chosen method used for the measurement of core temperature; it has been employed in numerous other published works. General medical tape was applied to a rectal thermistor (Henleys, 400H and 4491H, Henleys, Herts, UK) to form a bunge was constructed to indicate the 10cm insertion depth. Rectal temperature was recorded at 5 minute intervals. Similarly, skin temperature (Grant, EUS-U-VS5-0, Wessex Power, Dorset, UK) was also recorded at 5 minute intervals throughout the protocol. Four skin thermistors were used, placed on the gastrocnemius, rectus intermedius, pectoralis major, and the tricep brachii. Skin thermistors were held in place using general medical tape. Heart rate was recorded using a heart rate monitor (Polar Electro Oy, Professorintie 5, FIN-90440, Finland), and data was recorded at 5 minute intervals. Urine samples were taken pre and post protocol to test for hydration status, urine was analysed using urine refractometer (Atago, I Pocket PAL-OSMO, Japan). A desirable level of hydration reads between 200 - 600 on the urine refractometer. A reading of >600 indicates dehydration, if this occurred subjects were given 500 millilitres of water to drink, and testing was resumed half an hour after fluid ingestion. If a reading of >1000 was observed testing was rescheduled as this suggests subjects were severely dehydrated.

Subjective Measures

Rating of perceived exertion (RPE) (Borg, 1970) and thermal sensation (TSS) (Toner et al, 1986) were taken during the two exposure phases only; recordings were taken at 5 minute intervals. RPE exertion is a scale which indicates the level of physical strain a subject is experiencing. RPE begins at 6 (very, very light) and increases to 20 (very, very hard). TSS indicates the thermal comfort of a subject, starting at 0.0 (unbearably cold) through to 8.0.

The environmental chamber (Custom made, T.I.S.S., Hampshire, UK) was tested for reliability prior to any experimental testing, and was stable to within 1 ^{o}C of the desired temperature. Similarly relative humidity was stable to within 1% of the desired humidity.

Figure 12. Interior view of the environmental chamber, showing a subject completing an experimental trial of the goal line official study.

Figure 13. Interior view of the environmental chamber, showing a subject completing an experimental trial of the active referee study.

Cognitive Tests

Cognitive performance testing of vigilance, tracking and attentional ability was carried out using the Psyche software package (Hope et al; 1998). Biological variance testing was completed to ensure that the cognitive tests were valid and reliable. This required 10 subjects to complete all cognitive tests on five occasions, prior to any experimental testing, to ensure that similar scores were attained on each occasion. Results were then analysed for to ensure homogeneity. None of the subjects involved in biological variance testing took part in any experimental trials. The program was run on the same computer for every session of testing. Subjects completed 4 cognitive tests during each visit, as described in figure 9.

The numerical vigilance test measured subjects' vigilance performance. The test consists of 3 digit numbers flashing on screen (100 per minute), there is an 8% duplication rate and subjects were required to identify when a 3 digit number is duplicated on screen (Hope et al; 1998).

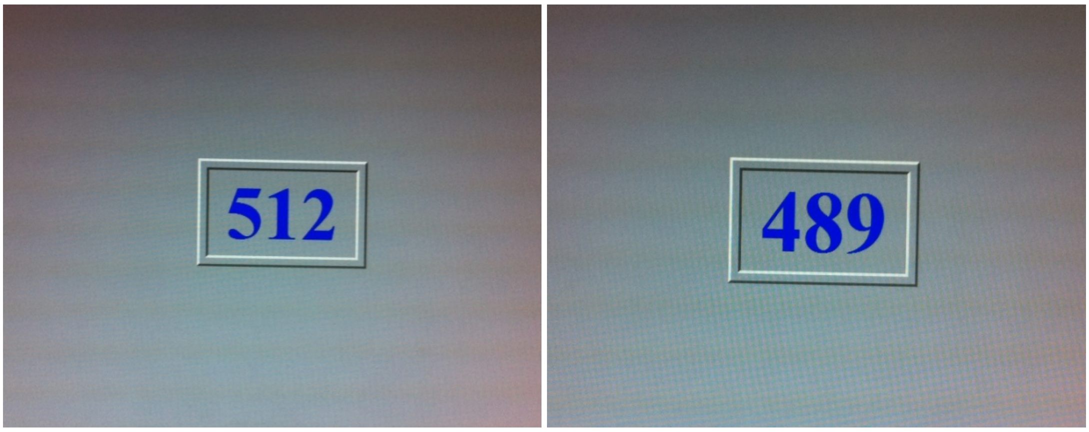

Figure 14. Screen shots of the vigilance task (Psyche).

The dual task measures two facets of cognitive performance simultaneously. Tracking, this required subjects to keep the cursor within a circle, the circle constantly moves around the screen during a 3 minute period. The second aspect of the test measures visual reaction time. While subjects are tracking the circle on screen an icon will randomly appear subjects must hit the space bar on seeing the icon, the register acknowledgment. Measuring these two facets of cognitive function together assesses ones attentional capacity.

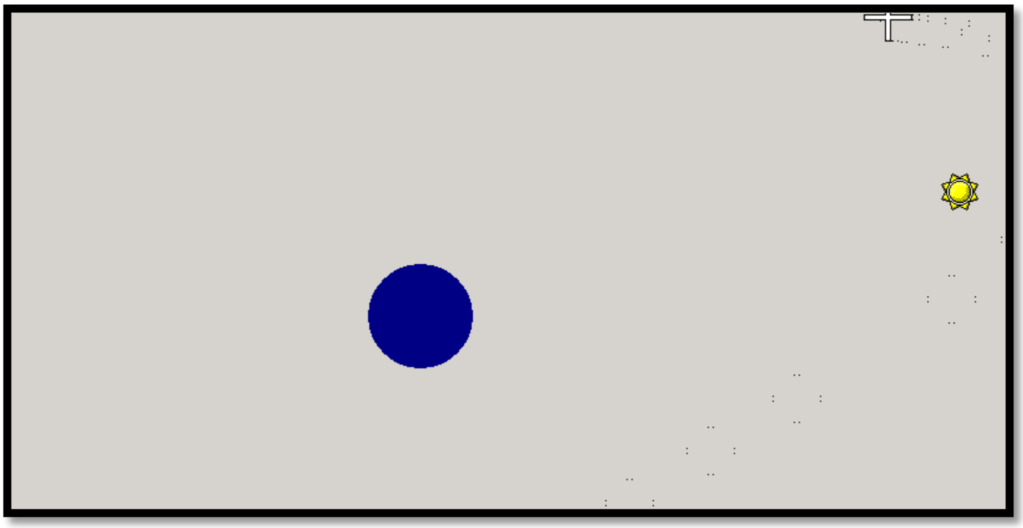

Figure 15. Screen shot the Dual Task test (Psyche).

All cognitive tests were carried out on a laptop computer, tests lasted for 3 minutes; the accuracy of the test duration was validated during pilot work.

Statistical Analysis

Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS version 17.0) and a computer. Data from the main experimental trials were analysed using a two way repeated measures ANOVA. This allowed for the comparison of data (physiological and subjective) from various environmental conditions (cold, temperate and hot) to be compared against one another at various given time points. It also allowed a comparison of cognitive scores between conditions at various time points.

Results

Active Referee Study

Core Body Temperature

There was little difference in core temperature between the 3 conditions (cold, temperate and hot) throughout the 90 minute protocol. No statistically significant (>0.05) overall difference was observed between any of the conditions.

Although there was some variance in core temperatures at particular time points. Core temperature during the hot condition was significantly higher than that of the core temperature recorded during the temperate condition after 15 & 20 minutes intermittent sprint exercise of the first half (P<0.05). No other differences in core temperature were observed at any other time point (P>0.05).

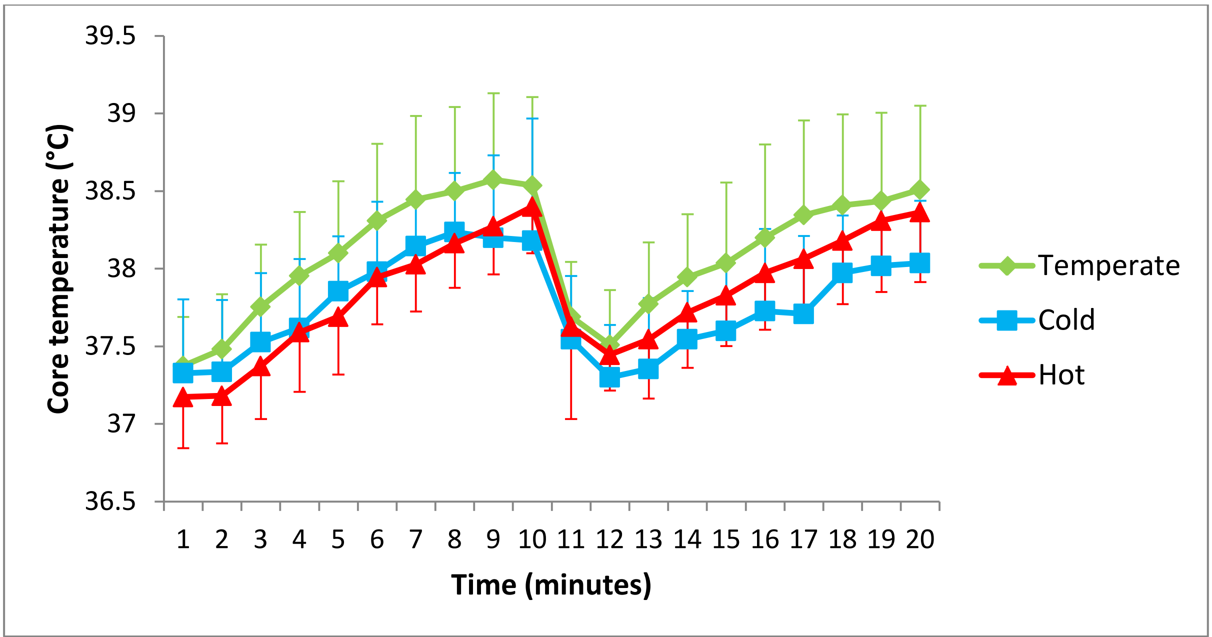

Figure 16. Core temperature for all three conditions of the active referee study. Displayed is mean core temperature with standard deviations.

Skin Temperature

There was a considerable difference observed in mean body skin temperature between all 3 conditions. A statistically significant difference was recorded when comparing all conditions: cold and temperate, cold and hot, temperate and hot ($P<0.05$).

Significant differences in mean body skin temperature were recorded at nearly all time points also. Mean body skin temperature was significantly different after 5, 10, 15, 20, 25, 30, 35, 40, 45, 45 (immediately after half time), 50, 55, 60, 65, 70, 75, 80, 85, and 90 minutes. Differences at these time points were observed between all conditions (cold and temperate, cold and hot, temperate and hot) ($P<0.05$).

The only time points in which mean body skin temperature was not significantly different were 0 minutes and 15 minutes, between the cold and temperate condition ($P>0.05$).

Mean body skin temperature was significantly higher during the hot condition when compared to both the temperate and cold conditions. Mean body skin temperature was significantly higher in the temperate condition than the cold condition.

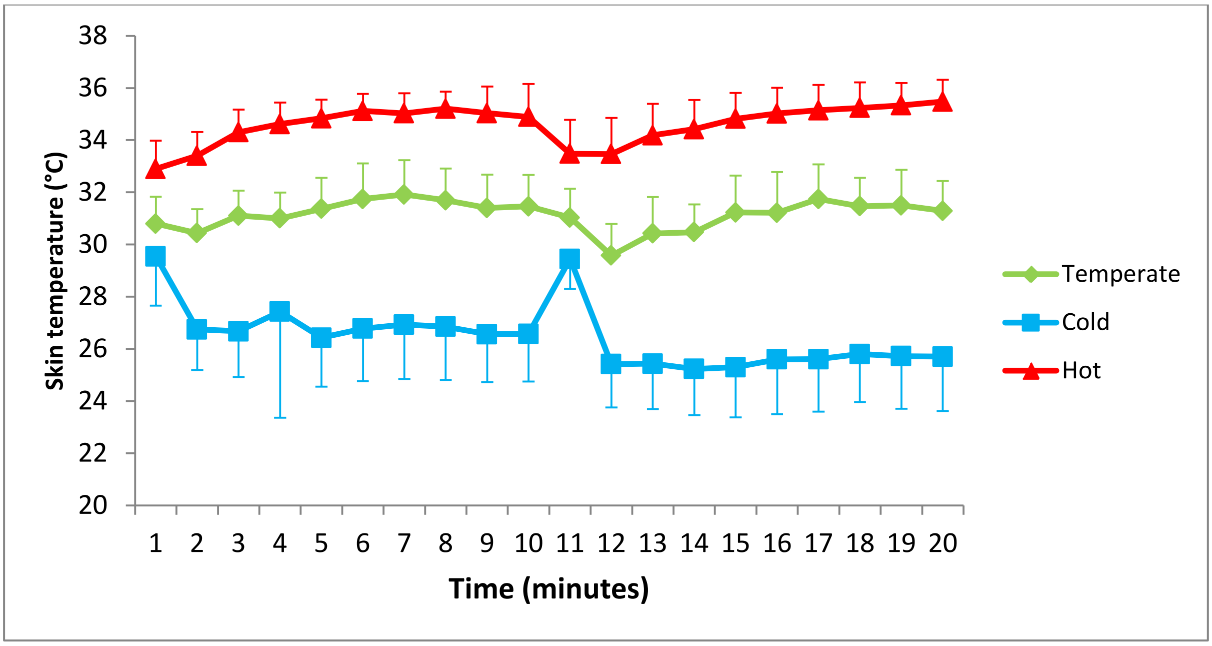

Figure 17. Mean body skin temperature for all three conditions of the active referee study. Displayed is mean body skin temperature with standard deviations.

Heart Rate

Heart rate produced much more inter-condition variation than core temperature, with overall statistically significant differences between the cold and hot conditions ($P<0.05$). No overall significant difference were observed between temperate and hot or cold and temperate ($P>0.05$).

There was considerable variation observed in heart rates recorded between different conditions at numerous time points.

Significant differences in heart rate were observed after 5 and 35 minutes when comparing temperate and hot conditions. Heart rate during the temperate condition was significantly higher than that of heart rate in the hot condition after 5 minutes of exercise ($P<0.05$). Conversely heart rate was significantly higher in the hot condition than the temperate condition after 35 minutes of exercise ($P<0.05$).

Significant differences in heart rate were observed after 10, 15, 30, 35, 55, 60, 80, 85, and 90 minutes of exercise when comparing the cold and hot condition. Heart rate in the hot condition was significantly higher than that of the cold condition at all time points (10, 15, 30, 35, 55, 60, 80, 85, 90).

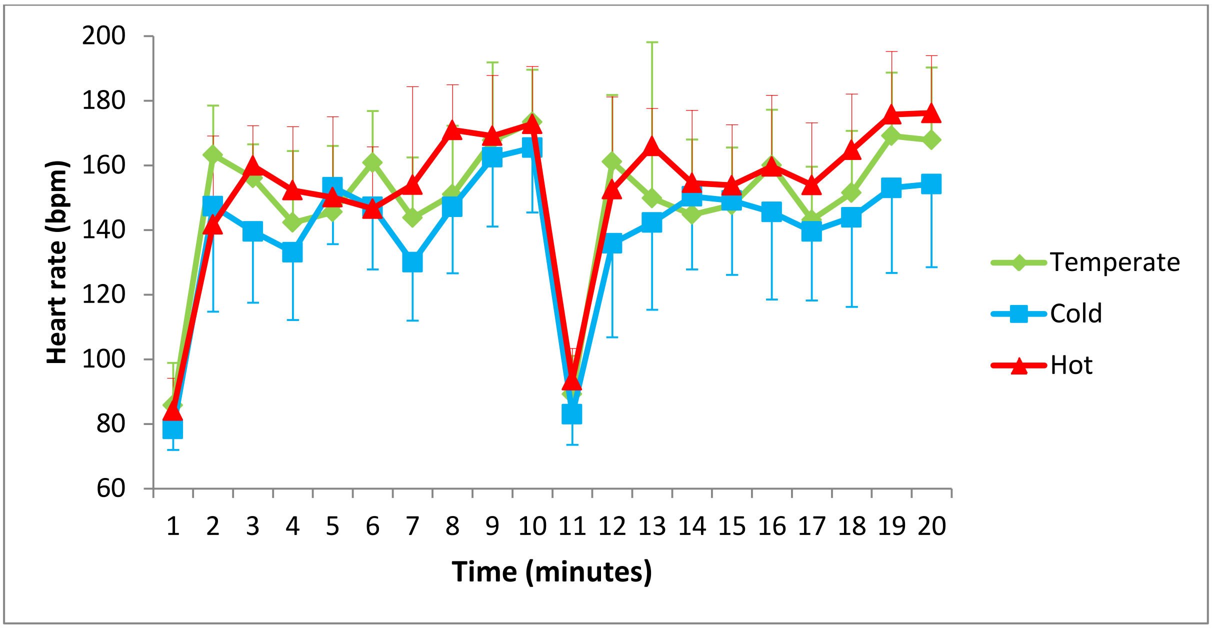

Figure 18. Heart rate for all three conditions of the active referee study. Displayed is mean heart rate with standard deviations.

Ratings of Perceived Exertion (RPE)

There was an overall significant statistical observed in ratings of perceived exertion between the temperate and hot conditions as well as the cold and hot conditions respectively (P<0.05).

Similar to heart rate, ratings of perceived exertion produced numerous significant differences between various conditions at various time points.

Significant differences in ratings of perceived exertion were observed after 15, 60, 80, 85, and 90 minutes of exercise when comparing the temperate and hot conditions. Ratings of perceived exertion were significantly higher in the hot condition when compared to the temperate condition after 15, 60, 80, 85 and 90 minutes (P<0.05).

Significant differences in ratings of perceived exertion were observed after 10, 15, 25, 30, 55, 60, 65, 80, 85, 90 minutes of exercise when comparing the cold condition to the hot condition. The hot condition displayed ratings of perceived exertion that were significantly higher than that of the cold condition at all time points (10, 15, 25, 30, 55, 60, 65, 80, 85, 90) (P<0.05).

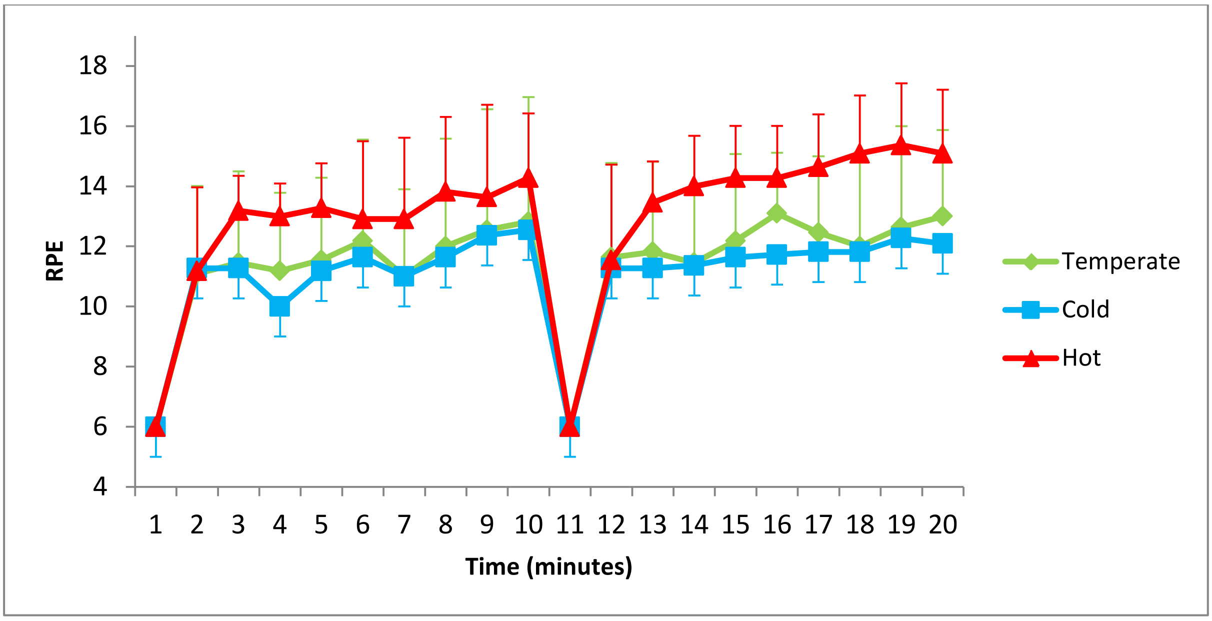

Figure 19. Ratings of perceived exertion for all three conditions of the active referee study. Displayed is mean ratings of perceived with standard deviations.

Thermal Sensation

There was an overall statistically significant difference in thermal sensation scores recorded between the temperate and cold condition, as well as the cold and hot condition respectively (P<0.05).

Significant differences in thermal sensation scores were recorded at most time points between the afore mentioned conditions. A comparison of the differences in thermal sensation scores between the temperate and cold condition produce variations after 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 85, and 90 minutes, with the temperate condition displaying the significantly higher (hotter) thermal sensation scores (P<0.05). When comparing the cold and hot condition thermal sensation scores variance was observed after 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, and 90 minutes, with the hot condition displaying the significantly higher (hotter) thermal sensation scores (P<0.05).

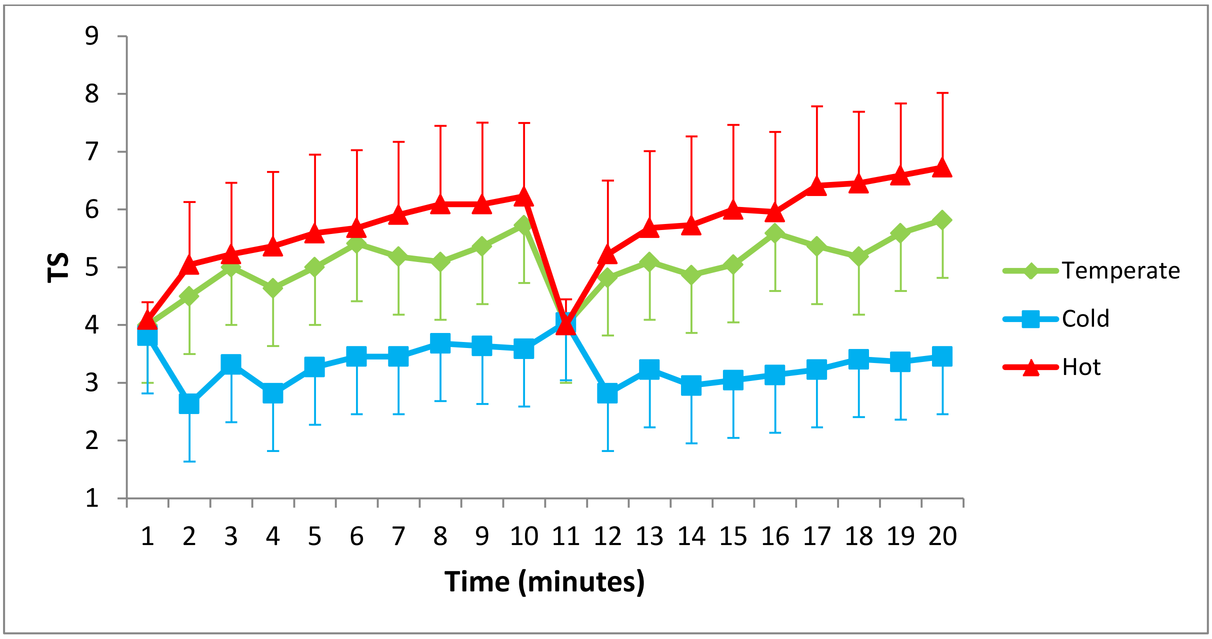

Figure 20. Thermal sensation scores for all three conditions of the active referee study. Displayed is mean thermal sensation scores with standard deviations.

Cognitive Performance

Dual Task- There no were overall statistically significant differences in any of the dual task parameters measured (FALSE Scores, MISSED Scores, TRACKING Scores) ($P>0.05$). There were no significant differences in cognitive performance recorded at any of the various time points between conditions either ($P>0.05$).

Vigilance- Similar to Dual Task performance, there were no overall statistically significant differences reported for any of the parameters measured (FALSE Scores, MISSED Scores, HIT Scores) ($P>0.05$). Again, no significant differences were observed at any of the various time points between conditions ($P>0.05$).

Cognitive Performance- Percentage of Decrement

The nature of the data involved in the output of the cognitive tests may mean that analysis designed to test for statistical difference is void. The data output given by the cognitive test is numerical, but the numbers given are small and there is large inter-subject overlap, reducing the chance of any significant differences being found, even though there may be large differences in mean scores. This considered the percentage (%) of difference in scores has been calculated to give practical significance (clear, useable differences).

Displayed below are the significant differences in cognitive scores (displayed as % of decrement):

Vigilance Task:

1st half:

Hit Scores: No significant cognitive decrement was observed between any conditions.

Miss Scores: No significant cognitive decrement was observed between any conditions.

False Scores: False scores were ***20% higher*** in the hot condition than the temperate condition. False scores were also ***24% higher*** in the hot condition than the cold condition.

2nd Half:

Hit Scores: No significant cognitive decrement was observed between any conditions.

Miss Scores: Miss scores were ***19% lower*** in the hot condition when compared to both the cold and temperate conditions.

False Scores: No significant cognitive decrement was observed between any conditions.

Dual Task:

1st Half:

False Scores: False scores were ***33% higher*** in the hot condition when compared to the temperate condition. False scores were ***42% higher*** in the hot condition when compared to the cold condition.

Miss Scores: Miss scores in the temperate condition were ***15% higher*** when compared to the cold condition.

Tracking Scores: No significant cognitive decrement was observed between any conditions.

2nd Half:

False Scores: False scores were ***17% higher*** in the hot condition when compared to both the temperate and cold conditions.

Miss Scores: Miss scores were ***32% higher*** in the temperate condition when compared to the cold condition. Miss scores were ***21% higher*** in the hot condition when compared to the cold condition.

Tracking Scores: No significant cognitive decrement was observed between any conditions.

Cognitive Test Recap

Hit scores are desirable responses to a stimulus, for example a correct decision made by a match official. Miss scores are when an important stimuli is missed, for example an important incident missed by a match official. False scores are an incorrect response given to a stimulus, for example a match official giving the incorrect decision to an incident. And finally tracking, this is the ability to follow a visual stimulus, for example a match official following the flight of the football.

Goal line official Study

Core Body Temperature

Overall statistically significant differences were observed in core temperature when comparing the temperate to cold condition, and the cold to hot condition respectively ($P<0.05$).

When comparing the temperate and cold condition core temperature was significantly different at nearly all time points (5,10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90) ($P<0.05$). Core temperature was not significantly significant at 0 minutes (immediately after entering the environmental chamber) and at the beginning of the second half (immediately after re-entering the chamber after the half time break). Core temperature was significantly lower in the cold condition at all time points mentioned ($P<0.05$).

Similar to the comparison of the temperate and cold condition, comparison of the cold and hot conditions displayed significant differences in core temperate at all of the same time points (5,10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90) ($P<0.05$). With no difference in core temperature at 0 minutes (immediately after entering the environmental chamber) and at the beginning of the second half (immediately after re-entering the chamber after the half time break). Core temperature was significantly lower in the cold condition at all time points mentioned ($P<0.05$).

There was also a statistically significant difference in core temperature after 80 minutes between the temperate and hot condition.

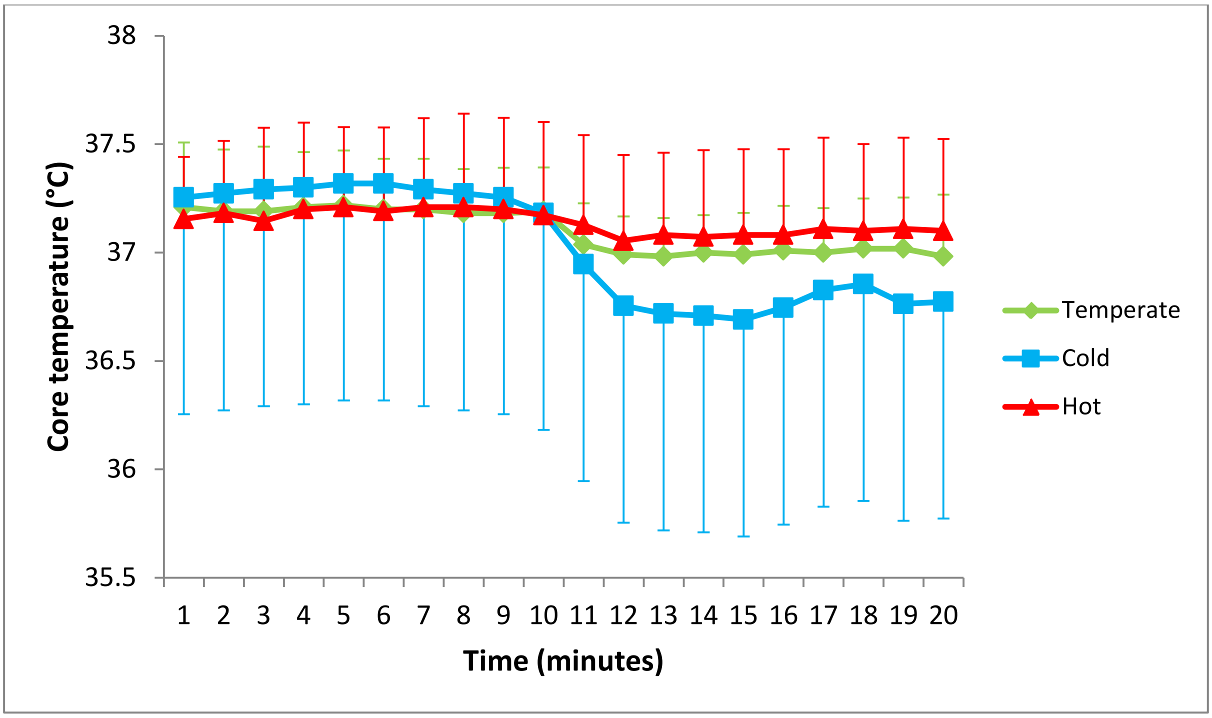

Figure 21. Core temperature for all three conditions of the active referee study. Displayed is mean core temperature with standard deviations.

Mean Body Skin Temperature

An overall statistically significant difference in mean body skin temperature was observed between all 3 conditions: cold and temperate, cold and hot, temperate and hot ($P<0.05$).

Significant differences in mean body skin temperature between all conditions was observed at most time points: 5, 10, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90 minutes (cold and temperate, cold and hot, temperate and hot) ($P<0.05$).

No significant differences were observed at 0 minutes when comparing the temperate to cold and temperate to hot conditions (P>0.05). At 15 minutes no significant difference was observed between the temperate and hot, cold and hot conditions (P>0.05). And finally at 45 minutes (immediately after half time) no significant difference between the temperate and cold, cold and hot conditions (P>0.05).

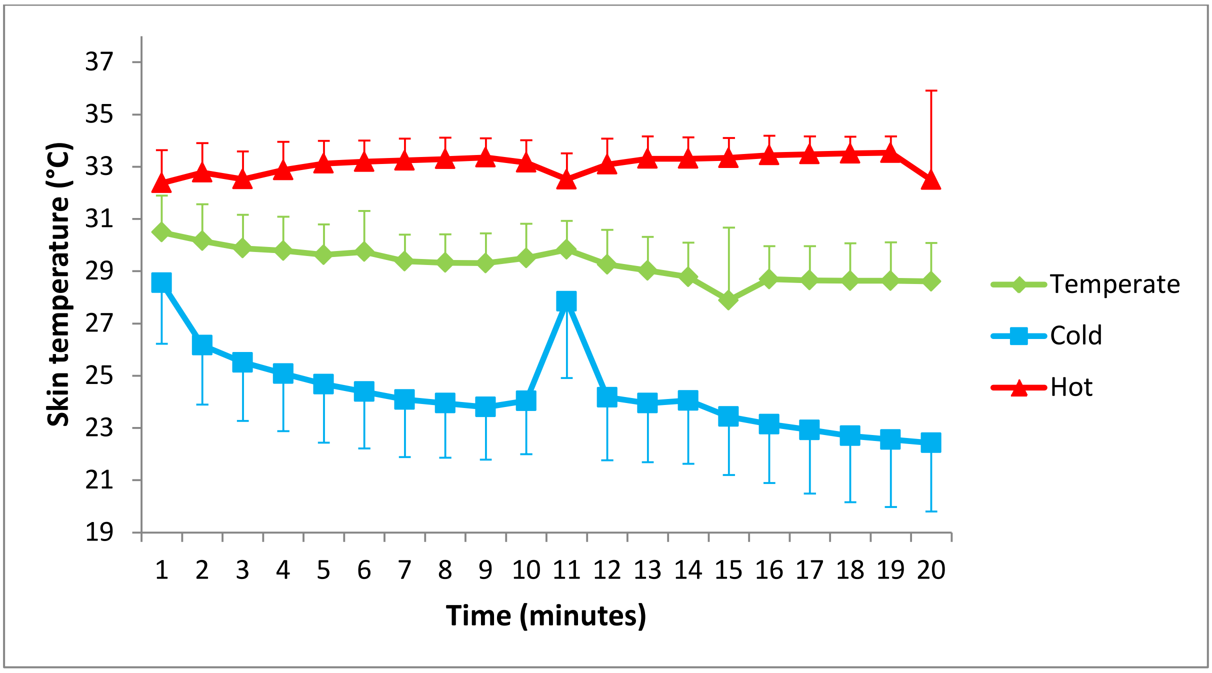

Figure 22. Means body skin temperature for all three conditions of the active referee study. Displayed is mean body skin temperature with standard deviations.

Heart Rate

An overall statistically significant difference in heart rate was observed between the temperate and hot condition, as well as between the cold and hot conditions (P<0.05).

Significant differences in heart rate were observed at numerous time points between the various conditions than displayed significant overall differences. When comparing the temperate and hot conditions a significant difference in heart rate was observed after 0, 15, 30, 35, 50, 55, 60, 65, 70, 75, 80, 85, 90 minutes. Heart rate was significantly higher in the hot condition than that of the temperate condition during all time points mentioned ($P<0.05$).

When comparing the cold condition to the hot condition a significant difference in heart rate was observed after 10, 15, 20, 30, 35, 40, 45 (immediately after half time) minutes. For all the time points mentioned heart rate was significantly higher in the hot condition than that of the cold condition ($P<0.05$).

Significant differences in heart rate were also observed when comparing the temperate to hot condition. Differences were observed after 45 (immediately after half time), 50, 55, 60, 65, and 75 minutes. With a the hot condition displaying a significantly higher heart rate than that of the temperate condition at all time points mentioned ($P<0.05$).

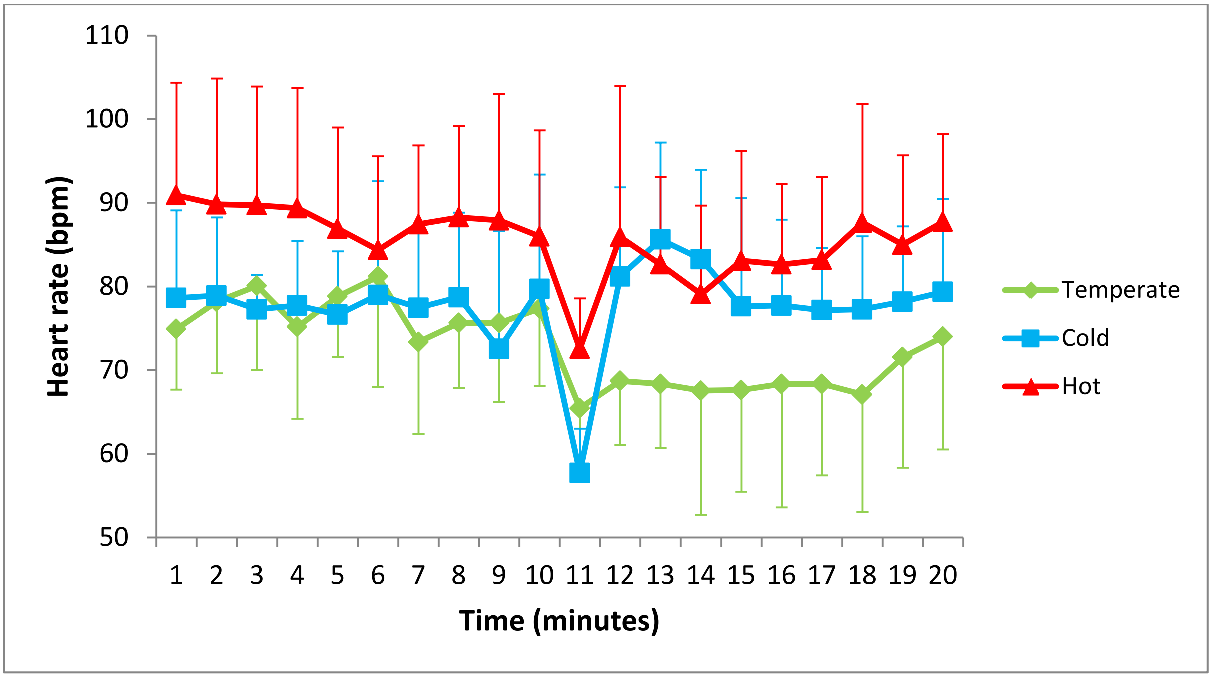

Figure 23. Heart rate for all three conditions of the active referee study. Displayed is mean heart rate with standard deviations.

Ratings of Perceived Exertion

No statistically significant differences were observed in respect to ratings of perceived exertion between any of the conditions (P>0.05). Moreover, no significant differences were observed at any of the various time points between any of the conditions (P>0.05).

Thermal Sensation

An overall statistically significant difference in thermal sensation scores was observed between all conditions: hot and temperate, hot and cold, temperate and cold ($P<0.05$).

No significant differences in thermal sensation scores were observed between any of the conditions after 0 minutes of the protocol ($P>0.05$).

When comparing both the hot and temperate conditions to the cold condition significant differences in thermal sensation scores were observed after 5, 10, 15, 20, 25, 30, 35, 40, 45, 45 (immediately after the half time break), 50, 55, 60, 65, 70, 75, 80, 85, and 90 minutes. With significantly lower (colder) thermal sensation scores recorded in the cold condition compared to both the temperate and hot conditions ($P<0.05$).

When comparing the temperate to hot condition significant differences in thermal sensation scores were observed at most time points 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, and 90 minutes. The only time point with no difference was immediately after the half time break. Thermal sensation scores were significantly higher (hotter) during the hot condition when compared to temperate ($P<0.05$).

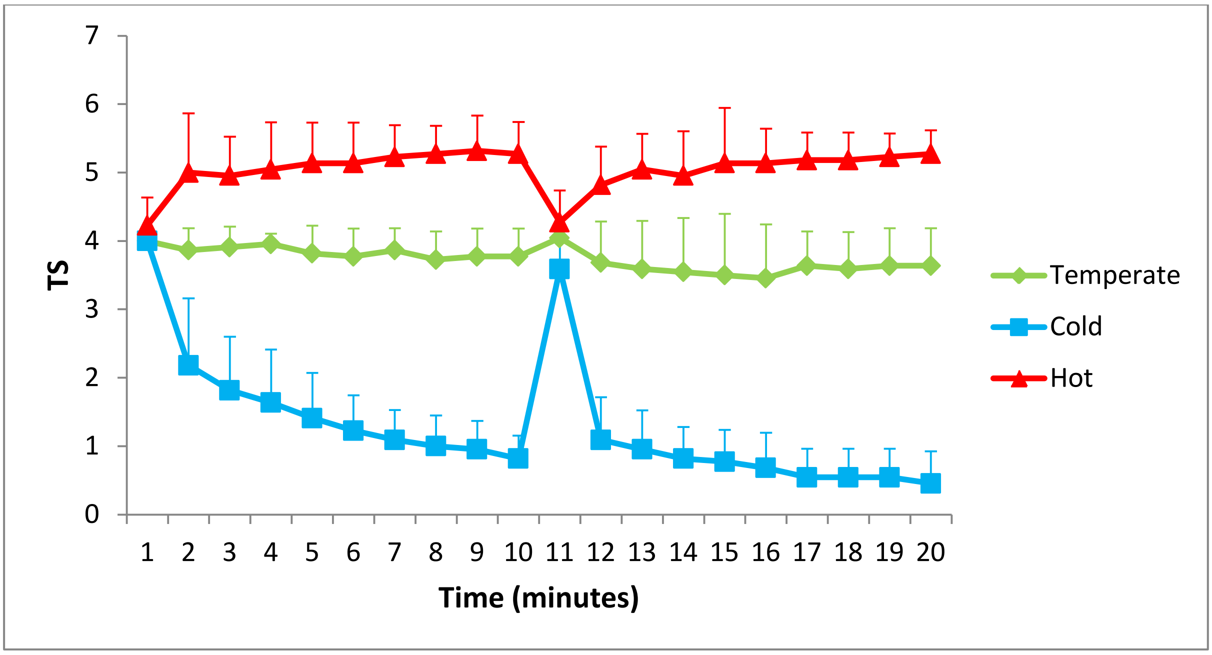

Figure 24. Thermal sensation scores for all three conditions of the active referee study. Displayed is mean thermal sensation scores with standard deviations.

Cognitive Performance

Dual Task- No overall statistically significant differences were observed between conditions for the MISSED Score and FALSE Score parameters of the Dual Task ($P>0.05$). Yet there was an overall statistically significant difference in TRACKING Score was observed between the temperate and cold condition, as well as the cold and hot condition ($P<0.05$).

Significant differences in TRACKING performance between the temperate and cold conditions was observed after 45 minutes, 45 minutes (immediately after the half time break), and 90 minutes.

Vigilance- No overall statistically significant differences were observed between any of the conditions for the False and Hit parameters of the Vigilance task ($P>0.05$). An overall significant difference in Miss scores was observed between the cold and hot conditions ($P>0.05$).

Cognitive Performance- Percentage of Decrement

Similarly to the active referee study the nature of the data output recorded for the cognitive tests of the Goal Line Official Study may not have allowed for statistical differences to be found. Thus, working out the percentage of difference in mean scores recorded may be of benefit and offer clear, useable differences.

Displayed below are the significant differences in cognitive scores (displayed as % of decrement):

<u>Vigilance Task:</u>

1st half:

Hit Scores: Hit scores were ***10% higher*** in the hot condition when compared to the cold condition.

Miss Scores: Miss scores were ***28% higher*** in the cold condition when compared to the hot condition. Miss scores were ***22% higher*** in the temperate condition when compared to the hot condition.

False Scores: False scores were ***86% higher*** in the cold condition when compared to the temperate condition. False scores were ***80% higher*** in the cold condition when compared to the hot condition.

2nd Half:

Hit Scores: Hit scores were ***14% higher*** in the hot and temperate conditions when compared to the cold condition.

Miss Scores: Miss scores were ***27% higher*** in the cold condition when compared to the temperate condition. Miss scores were ***34% higher*** in the cold condition when compared to the hot condition.

False Scores: False scores were ***69% higher*** in the cold condition when compared to the temperate condition. False scores were ***64% higher*** in the cold condition when compared to the hot condition.

Dual Task:

1st Half:

False Scores: False scores were ***94% higher*** in the cold condition when compared to the temperate condition. False scores were ***86% higher*** in the cold condition when compared to the hot condition.

Miss Scores: Miss scores were ***45% higher*** in the temperate condition when compared to the cold condition. Miss scores in the hot condition were ***34% higher*** than that of the cold condition.

Tracking Scores: Tracking scores were ***12% lower*** in the cold condition when compared to the temperate condition. Tracking scores were ***11% lower*** in the cold condition when compared to the hot condition.

2nd Half:

False Scores: False scores were ***90% higher*** in the cold condition when compared to the temperate condition. False scores were ***92% higher*** in the cold condition when compared to the hot condition.

Miss Scores: Miss scores were ***15% higher*** in the temperate condition when compared to the cold condition. Miss scores were ***15% higher*** in the hot condition than the temperate condition. Miss scores were ***28% higher*** in the hot condition when compared to the cold condition.

Tracking Scores: Tracking scores were ***26% lower*** in the cold condition when compared to the temperate condition. Tracking scores were ***24% lower*** in the cold condition when compared to the hot condition.

Cognitive Test Recap

Hit scores are desirable responses to a stimulus, for example a correct decision made by a match official. Miss scores are when an important stimuli is missed, for example an important incident missed by a match official. False scores are an incorrect response given to a stimulus, for example a match official giving the incorrect decision to an incident. And finally tracking, this is the ability to follow a visual stimulus, for example a match official following the flight of the football.

Active referees- Implications and Interventions

The results from this study show there is a significant difference between all conditions in skin temperature. Skin temperature is significantly higher in the hot condition compared to temperate and cold conditions. A higher skin temperature is related to an increase in body core temperature experienced during exercise under heat stress. As core temperature rises, it reaches a threshold of around 37ºC where vasodilation of cutaneous arterioles very close to the skins surface, occurs (Kellogg 2006).With vasodilation, the warmer blood is transferred from the core to the skins surface therefore causing a higher skin temperature. To cool the skin, sweating occurs creating a thermal gradient where heat dissipates from the blood to the skin and into the environment via evaporation of sweat (Charkoudian 2010). Cognitive function changes can be explained by skin temperature and the alliesthesial effect (Cabanac 1971). Thermal stimuli such as high thermal conditions can cause a feeling of displeasure and are considered as a cognitive load placing additional attentional demands on cognitive tasks (Gaoua 2010). The results from the present study support this as results show that in the second half of the intermittent sprint exercise protocol, dual task test miss scores were 21% higher in the hot condition compared with the cold condition.

Heart rate was significantly higher during the hot condition compared to the cold condition. This is due to an increased heart rate to ensure enough blood reaches skin blood vessels (Armstrong 2000). Blood is temporarily diverted away from inner organs such as the liver and kidneys via constriction of the arteries, thus increasing blood flow to the skin causing an increased skin blood volume therefore vasodilation occurs (Armstrong 2000; Charkoudian 2010). A higher heart rate which leads to vasodilation, allows a greater amount of heat dissipation to occur (Armstrong 2000). This higher heart rate and higher skin temperature in the hot condition may be the reason there was no significant difference in core temperature between the three conditions.

As would be expected, thermal sensation and ratings of perceived exertion were significantly higher in the hot condition. This is due to the extreme high temperature coupled with high intensity exercise, placing added stress on the physiological system. From the high TS and RPE scores and the percentage decrements in cognitive performance, it can be seen that not only was there added stress on the physiological system but there was also added stress on the psychological system. Where a referee reports that the exercise is very, very hard and they feel unbearably hot, performing the cognitive tasks may be difficult due to thermal discomfort such as excessive sweating and lack of concentration (Morris, Nevill et al. 1998).

Interventions

Interventions recommended to referees prior to matches in conditions of >30 may include sufficient hydration, pre-cooling and half time cooling. These interventions may help to reduce the onset of a critically high core temperature and skin temperature and also help referee’s to make correct decisions when needed.

60 minutes prior to the match, referees should consume 500 mL of water to prevent dehydration. Urine osmolarity can be used in order to detect dehydration, if there is a value of <700 mOsm/kg, the referee is dehydrated and should therefore consume more water. Gaoua (2010) believe that dehydration can impair decision making ability, therefore hydration status is very important for the referee. If the urine osmolarity value reads ≤700 mOsm/kg then the referee is euhydrated.

Pre-cooling can be achieved by cold water immersion, exposure to cold air or using ice vests. For a referee, the most practical method of pre-cooling would be to use an ice vest/ice packs on the thighs in order to reduce core temperature prior to exercise (Castle, Macdonald et al. 2006). Pre-cooling has been shown to improve thermoregulation, thermal sensation and ratings of perceived exertion when performing in the heat (Castle, Macdonald et al. 2006). It has been found in this study for example, that extreme heat increased the amount of false scores for the dual task test by 42% in the first half of the match. This is due to an increased physiological strain. Pre-cooling has been recommended for any football activity as there were practical reductions in physiological strain (Duffield, Coutts et al. 2011). This would delay the referee’s fatigue, allowing them to remain closer to infringements where optimal decision making is required (Galanti, Pizzi et al. 2008). This would therefore prove beneficial for the referee’s performance and decision making as they will be less fatigued.

However, pre-cooling may not provide advantage for the second half of the match following a rest period of 15 minutes. Therefore, the referee could also use half time cooling. For this, the referee could use the same pre-cooling method (ice vest and ice packs) for 10 minutes during the rest period. Performance times were faster in the second half of exercise following cooling between two bouts of exercise (Yeargin, Casa et al. 2006). Recently, a study used 5 minutes of cold water immersion during a recovery period and found that this half time cooling significantly lowered core temperature and maintained performance during high intensity exercise (Peiffer, Abbiss et al. 2010). This could also prove beneficial as it may improve thermoregulatory responses and decision making in the heat.

Goal Line Officials – Implications and Interventions

In consideration of the results attained during the present study it seems reasonable to suggest that exposure to cold environmental conditions (-5 ^{o}C, 50% relative humidity) causes significant reductions to the cognitive performance and decision making ability of goal line officials.

During exposure to cold conditions participants experienced reductions in core temperature, skin temperature, as well as feeling thermally uncomfortable.

During exposure to cold conditions participants displayed core temperatures significantly lower than those recorded during the temperate and hot conditions. Reduced core body temperature has been shown previously to reduce cognitive performance (Wright, Hull et al. 2002), and may be the cause of the cognitive decrement observed in the present study. A cold induced reduction in core body temperature will initiate physiological stress responses tasked with minimising heat loss and maintaining thermoregulatory homeostasis. Such responses include vasoconstriction of the subcutaneous blood vessels (Kellogg 2006), activation of brown adipose tissue (CANNON and NEDERGAARD 2004) and shivering(Nakamura and Morrison 2008). Vasoconstriction of the subcutaneous blood vessels minimises the flow of blood to the skin, which negates processes such as conduction and radiation which contribute to endogenous heat loss (Johnson and Kellogg 2010). Vasoconstriction is a heat saving mechanism in contrast brown adipose tissue is a heat producing mechanism. Brown adipose tissue which is found in subclavian regions of the trunk (close to the chest and shoulder) actively produces heat by uncoupling hydrogen from the mitochondrial energy producing process (Virtanen and Nuutila 2011). Furthermore involuntary shivering attempts to maintain thermoregulatory homeostasis by producing heat. Shivering works on the basic principal that muscular contraction produces heat as a by-product, which aids in keeping core temperature at a safe leve.

These mechanisms attempt to reduce the effects of ambient cold temperatures, but as shown in the results they only offer damage-limitation as a desirable core temperature core temperature was not maintained. The a-fore mentioned mechanisms also consume valuable resources most notably norepinephrine. As explained in the literature review dopamine is a key component of the cognitive/decision making process as it initiates the entire cascade. Norepinephrine is also important in the cognitive/decision making process similarly to dopamine is a neurotransmitter. Norepinephrine is synthesised from dopamine and so when it is required to initiate thermoregulatory mechanisms such as vasoconstriction, brown adipose tissue and shivering it reduces the levels of dopamine and norepinephrine available to process decision making tasks.

The reduction in cerebral norepinephrine and dopamine following the increase in systemic levels of norepinephrine may reduce cognitive capabilities (Cohen, Braver et al. 2002). Cognitive suppression is further intensified by a reduction in neurotransmitter synthesis during exposure to stressors, such as cold temperatures (O'Brien, Mahoney et al. 2007). The combination reduced neurotransmitter synthesis and increased systemic neurotransmitter projection may lead to negligible levels of dopamine and norepinephrine available for cognition (decision making). This is reiterated in the present study by the reduction in cognitive performance (decision making ability) observed during exposure to cold conditions when compared to more comfortable conditions (18 ^{o}C & 30 ^{o}C) (**SEE RESTULTS SECTION**).

Interventions

Having highlighted the detrimental effects of cold exposure on the decision making ability of goal line officials it's necessary to consider some interventions to aid in alleviating the cold induced decrement.

The effects of cold exposure on levels of cerebral neurotransmitters appears to be considerable (synthesis reduction & increased systemic norepinephrine) it would seem beneficial to attempt to increase levels of dopamine and norepinephrine within the brain. Tyrosine, a branch chain amino acid, is essential in the synthesis of dopamine and norepinephrine. Tyrosine is the primary substance that undergoes a series of chemical changes to eventually becomes dopamine (the dopaminergic pathway), which can be used to augment cognition or can be converted into norepinephrine which can be used in cognition or systemic responses (Mahoney, Castellani et al. 2007). It is then hypothesised that supplementation of tyrosine may elevate the synthesis of dopamine, negating the suppression of dopamine synthesis during exposure to the cold. Increased dopamine synthesis should then lead to enhanced norepinephrine production which will allow for the projection of systemic norepinephrine as well as supplying the prefrontal cortex and striatum with significant amounts of norepinephrine for cognitive processes (executive functioning). The elevation in norepinephrine production may also aid in the thermoregulatory responses which require norepinephrine to function, improving the maintenance of a desirable core temperature, which may also aid in the process of cognitive function.

Much simpler interventions may also be employed. As the reduction in core temperature is the key component in suppressing cognitive function then asking goal line officials to wear additional clothing may be of benefit. Simply adding more layers of clothing, for example, trousers, a jumper, a coat and a hat should minimise heat loss as well as reduce skin contact with the cold environmental air, resulting in the maintenance of core temperature and decision making ability.

Another intervention for consideration is the use of four goal line officials. 1 goal line official behind each goal, but each goal line official only performs in one half on the game. As explained earlier a low core temperature adversely affects the number of neurotransmitters available for cognitive performance (decision making ability). The present study reports a significantly lower core temperature in the second half on the cold condition compared to the first half, which may affect second half decision making performance to more of an extent that the first half. Thus, it is hypothecated that having four separate goal line officials may reduce the second half reduction in core temperature, as the goal line officials who officiate in the second half only will have a higher core temperature at the beginning of the second half when compared to a goal line official who had been exposed to cold conditions during their first half officiating.

Conclusion

In conclusion, both studies have shown that extreme environmental conditions do have detrimental effects on decision making ability in active referees and goal line officials, supporting both hypotheses.

For the active referees, when performing intermittent sprint exercise and cognitive tasks, the hot condition has a greater effect on physiological strain and decision making than temperate and cold conditions. Therefore when refereeing in hot conditions, their decisions may be inaccurate due to fatigue and discomfort, thus having detrimental effects on the final result of the match.

For the goal line officials, the cold condition has a greater effect on thermal comfort and decision making than temperate and hot conditions. The goal line officials are at risk of suffering from hypothermia and due to be going so cold, they are less likely to pay attention to what is happening throughout the match. This will lead to incorrect decisions being made and may affect the final result of the match.

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