3.1 Nutrition for football in extreme temperatures

Football is a high-intensity, intermittent sport played over 90 minutes, consisting of two 45-minute halves, with a 15-minute interval. During a match the player's physical performance may be characterised by total distance covered in a game, total sprint distance and execution of technical skills (pass, shot or cross success). The physical demands of football are therefore dependent on the synchronisation of cardiovascular and muscular systems to support the required energy demands of football specific activities.

These demands are independent from the time, location, temperature or the altitude at which the football training or matches is completed. Football is a global game, and as such, players can be exposed to diverse environmental conditions when playing in countries around the world.

Even within Europe, elite clubs playing in the Union of European Football Associations (UEFA) Champions and Europa leagues play at diverse altitudes and temperatures over the duration of a competitive season. It is important to recognise that playing in environmental extremes, such as extreme heat or cold, or playing at altitude (>580 m above sea level) may negatively impact player performance. Due to fixture congestion and the ease of team travel, through aviation, the exposure to different playing conditions is often transient. Players are typically not afforded the time for appropriate acclimation protocols. It is under these circumstances, nutrition takes on even greater importance in supporting player performance.

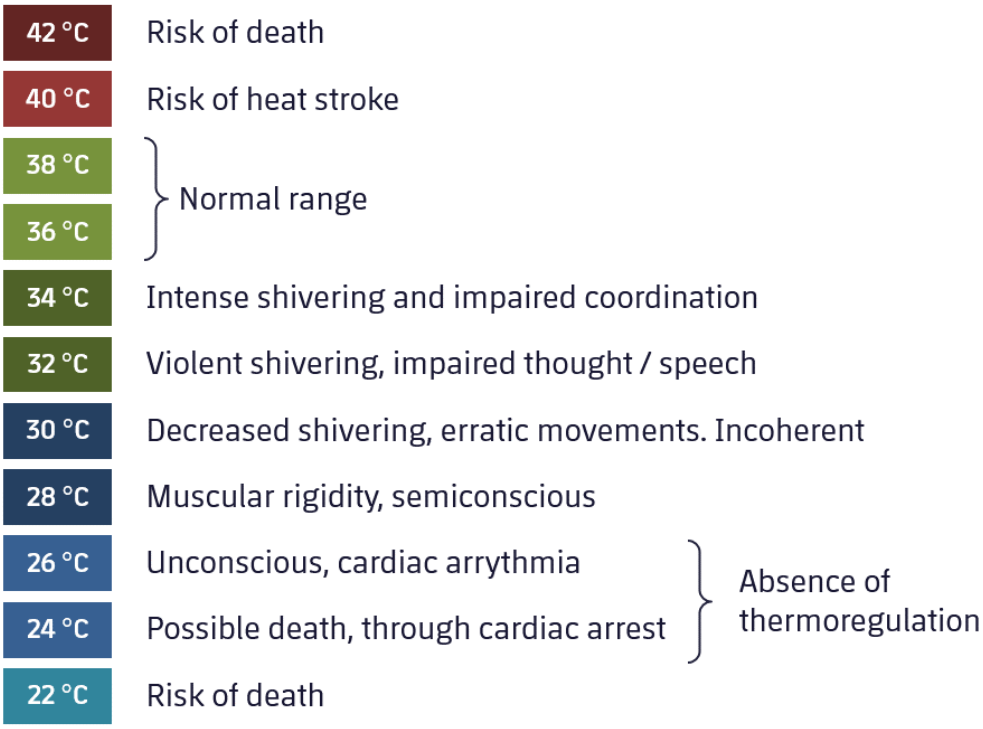
The purpose of this module is to understand the potential nutritional interventions to prevent any negative influences of playing in environment extremes. Unit 1 will discuss the physiological challenges and nutrition interventions relevant to playing football in hot environments. Unit 2 will discuss the physiological challenges and nutrition interventions relevant to playing football at altitude, as well as discuss potential nutrition strategies to support travel.

Extreme temperature

Playing football in the heat

The energy demands of football result in large amounts of metabolic energy being released from the exercising muscles as heat. This heat must be carried to the skin surface before being dissipated to the environment which the player is exercising, to avoid rapid, and potentially dangerous, rises in core body temperature (Figure 1).

Figure 1: Range in core temperatures (°C)



Source: Prepared by author.

The core temperature of the player will be elevated relative to the intensity of exercise. However, greater rises in core temperature will be event in environments of non-compensable heat stress. Heatstroke (sun stroke) is an illness associated with severe heat that typically occurs at a core body temperature greater than 38°C

DID YOU KNOW?

Core temperature refers to the temperature of the inner organs of the players body.

Conditions of "non-compensable" heat stress means that the players body will be unable to thermoregulate as heat cannot be dissipated to the environment due to either extreme temperatures/humidity.

Principles of player heat balance and body heat storage

The fundamental principle that determines the excess heat stored by the player's body when exposed to heat or during exercise is as follows:

Heat stored = Heat energy produced – Heat energy lost from skin surface

Heat is produced by the player's body as a bi-product of metabolism. The amount of metabolic heat produced is determined by the player's absolute rate of oxygen consumption, i.e. the intensity of exercise. The major site of heat loss from the body is the surface of the skin. In summary, heat exchange occurs through four pathways 1) conduction, 2) convection, 3) radiation, and 4) evaporation. Of which, the evaporation of sweat is the most important avenue of heat loss during exercise in the heat. Specifically, 2,427 J of heat energy may be lost from the body following the evaporation of every 1 g of sweat (Parsons 2003). The capacity for evaporative heat loss is determined by the absolute humidity between the skin surface and surrounding environment, as well as the rate of airflow across the skin (Jay & Morris 2018).

Thus, the amount of heat stored by the player's body will be determined by the cumulative difference between the metabolic heat production and net heat dissipation from skin (Parsons 2003). If a player were to complete the same football exercise at the same intensity, the amount of sweating required to limit the storage of heat will increase progressively as the environmental temperature rises.

When playing football in warm environments, the greatest physiological burden for the player is to support high skin blood flow for heat dissipation. A player's skin temperature will increase relative to the ambient air temperature and humidity. Hot-warm skin is easily identified on players. Skin typically will be "flushed/redder" in colour and sweat can be seen either accumulating or dripping from the skin surface. The greater flow of blood to the skin increases the cardiovascular strain. This is because there is no increase in blood volume, yet blood is being redistributed to the skin to thermoregulate the body. The player's heart must pump faster to maintain blood pressure, thermoregulatory

requirements and the demands of the exercising muscle. In general, the warmer the environmental conditions, the greater the skin blood flow responses and the greater the cardiovascular strain. Thus, when playing football there is a duel problem of reduced plasma volume from dehydration, while skin blood flow requirements are elevated. In addition, if thermoregulation is compromised there will be large increases in body core temperature. It is likely that these factors are key physiological prerequisites which would impair the aerobic performance of the player (Morris et al., 2005).

Heat and football performance

In comparison to other detrimental environments (Unit 2), it is common to play competitive football in hot environments. Two examples include the FIFA World Cups (Brazil 2014 and Qatar 2022) which were and are likely to be played in extreme temperatures (30-45˚C). These temperatures will present a great challenge for all the players to maintain the physical demands required for elite match performance. To highlight the challenge it is known that total distance covered during a game is reduced when environmental temperature is increased from 20˚C to 30˚C (Ekblom 1986). Greater relative increases of environmental temperatures (i.e., ~21˚C to ~43˚C) have been reported to reduce total distance covered by 7% (Mohr et al., 2012).

When environmental conditions and muscle metabolic heat production promote the heat gain, core temperature is increased and a players endurance capacity reduced (Nybo et al., 2014). Correspondingly, higher muscle temperatures within the quadriceps and elevated core temperatures occur when playing football in the heat, compared to temperate environments (Mohr et al., 2012). Male professional football players have been shown to reduce distance covered at high-speed by 26% when playing in very hot conditions (~43˚C) compared to a game within temperate environment (~21°C) (Mohr et al., 2012).

The heat mediated reductions in distances covered and at a high intensity during a match directly impacts match-play characteristics —i.e., possession, interceptions, technical skill execution, etc.— when compared to play within a temperate environment (Mohr et al., 2010; Mohr et al., 2012; Mohr & Krustrup 2013). In fact, compared to temperate match-play environments, the completion of football skills, passing (8%) and crossing (9%), are actually improved when playing in the heat (Mohr et al., 2012). The increase in technical skill proficiency is likely to be an consequence of the associated changes in the characteristics of match play. For example, hot compared to temperate conditions are associated with a decrease in player duels and turnovers of possession. This is mirrored with a concomitant increase of time in possession of the ball (Mohr et al., 2012). As such, there is less pressure on the ball before a before a skill is attempted/completed by a player —i.e., closing-down is less prevalent and space afforded to players is increased, allowing

greater attentional focus to the technical skill to be performed. It is for these reasons that skill execution is more successful during football matches in the heat.

Studies have shown that the mobilisation of glucose from liver stores and glycogen use is greater during fixed intensity exercise in the heat (40°C) compared to temperature conditions (20°C). The increased reliance of carbohydrate as a fuel in the heat is due to an elevated adrenaline response during exercise (Hargreaves et al., 1996). Thus, reduced running performance in the heat may be a consequence of earlier muscle glycogen depletion. Morris et al. (2005) reported that prolonged, high-intensity, intermittent shuttle running in the heat (33°C, 28% RH) resulted in earlier onset of exhaustion in comparison to exercise in a moderate environment (17°C, 63% RH) (Morris et al., 2005).

However, in this study, earlier exhaustion experienced in the heat was not a consequence of carbohydrate availability in the muscle. Instead, hyperthermia was associated with the onset of exhaustion. In support of these findings, distance covered and sprint distances were significantly reduced when participants completed an intermittent treadmill running protocol (to simulate match demands) at 30˚C in comparison to 18˚C (Aldous et al., 2014). Blood glucose concentrations were well maintained. The reduction in sprint distance in hot conditions was associated with higher heart rate (cardiovascular strain) and an elevated core temperature (hyperthermia) (~+0.4˚C) (Aldous et al., 2014).

DID YOU KNOW?

Hyperthermia is an increase in core body temperature.

Mechanisms

The precise mechanisms by which exercise-heat stress reduces football performance are not clear. One possible explanation is a critically limiting, though individually variable, core body temperature of ~38.6˚C. Interestingly the critical core temperature has been reported to be higher (39.2˚C and 40.3˚C) in well-trained individuals, which coincides with prolonged time to exhaustion during constant paced exercise. Thus, importantly the magnitude of exercise-heat stress “fatigue/response” will vary highly among players (Nybo et al., 2014). This is due to training and acclimation status of individual players, which are influenced by genetic/phenotypic variations of favourable traits associated with innate thermal tolerance and its acquirement (Horowitz 2014; Taylor 2014).

Fatigue in football is complex and recent well-controlled research in elite male football players suggests that other complementary multi-factorial

mechanisms, besides muscle, core and skin temperature should be considered when explaining football related fatigue within a hot environment (Mohr et al., 2012). If we consider the physiological demands of football performance covered in later courses, it is reasonable to suggest that a number of variables associated with fatigue at both submaximal and maximal intensities interact to increase cardiovascular/metabolic strain and reduce physical performance.

Maximal intensity exercise is limited by cardiovascular limitations attempting to simultaneously facilitate oxygen delivery to active skeletal muscle whilst maintaining skin blood flow (Nybo et al., 2014). However, sub-maximal fixed intensity efforts will be limited by central fatigue (impaired ability to sustain maximal muscle activation during sustained contractions). The degree of central fatigue will also be mediated by elevated body temperature (skin, core and muscle) as well as metabolic perturbations within skeletal muscle (Nybo et al., 2014).

A consequence of sweating for evaporative heat loss is gradual dehydration of the body. If fluid losses are not replaced, then hypohydration ($\geq$2% pre-exercise body mass) will further increase the cardiovascular strain and the cardiac output required to support the aerobic component of football performance. Hypohydration will also impact multiple physiological responses, independent from heat exposure alone, that may impact player performance in the heat (Sawka et al., 2015):

- Reduction in skeletal muscle blood flow —influencing the delivery of oxygen and nutrient to the muscle and reducing the removal of waste products of metabolism.
- Restriction of cerebral blood flow (but likely not cerebral oxygen uptake) —may impair decision making and cognitive skill.
- Elevation of core temperature —greater rise in core temperature, increased physiological demand.
- Increase in the use of skeletal muscle glycogen —increased risk of fatigue.
- Impairment of skeletal muscle motor-unit recruitment —poor execution of skills i.e. weight and accuracy of pass.

DID YOU KNOW?

To acclimate is to become accustomed to a new environment. Environmental conditions can be classified as follows:

Cool: WBGT = ←15°C.

Temperate: WBGT = 16-26°C.

Hot: WBGT →27°C (Armstrong et al., 2007).

WBGT is an abbreviation for wet blub globe temperature. The WBGT is a measure of heat stress in direct sun light, which, also considers for humidity, wind speed, and solar radiation.

Heat acclimation protocols

Prior to discussing nutrition strategies, it is important for sports nutritionists to be aware of the other strategies to optimise performance in the heat. The most potent being a heat acclimation protocol (Taylor 2014). Heat acclimation protocols take 4–14 days to elicit a partially (4 d) or fully heat acclimated (14 day plus) response (Gibson et al., 2014; Taylor 2014).

There will be considerable variation between players in the acclimation response. Changes in blood (haematological) adaptation such as plasma volume expansion can be used to determine an individual player's response. For example, players who exhibit greatest plasma volume expansion, adapt best to the heat acclimation intervention. Interestingly, these same (semi-professional) football players were also shown to be best able to replicate a "temperate-like" (normal) match running activity profile when playing in the heat (Racinais et al., 2012).

Another method to consider is artificially induced heat acclimation. This method allows specifically controlled hyperthermia to produce heat acclimation. For example, artificial heat acclimation can be achieved by exercising in heat chambers in preparation for travel to and competition in the heat.

In general, increasing the frequency (number of days) of heat acclimation sessions and/or exposing the players to higher temperatures will provide a greater adaptive stimulus (Taylor 2014).

This method does allow a greater degree of control with regard to the exercise-heat stress stimulus, allowing the protocols to be adopted to suit fixture schedules in preparation for travel or specific competition.

Preferable heat acclimation adaptations to support football training and performance:

- Earlier on-set of sweating
- Increased sweat rate
- Increase in plasma volume
- Lower heart rate at relative exercise intensity
- Lowered subjective/perceptual response to exercise
- Lower rise in core temperature during exercise

Heatstroke

Heatstroke —also known as sunstroke— is an illness that is caused by the body overheating. As a nutritionist, it is important to recognise the early symptoms of heatstroke and the players most at risk. Heat stoke is most common during training or matches in hot environments, i.e. in the summer months. It is caused by prolonged exercise in the hot environment and the player's body "overheating". Often a thermometer to measure core temperature will not be available. In this case, visual symptoms/assessments include:

- An alteration in the player's mental state, including slurred speech, agitation and confusion.
- An alteration in the player's physical state with un-coordinated movements.
- The player may feel nauseous and begin to vomit.
- Players may complain of a headache.
- The player's breathing may be rapid and shallow, and their pulse may be racing when at rest.

Players at most risk of experiencing heatstroke are often the "hardest workers" in a team. Other players at high risk are those with low fitness (high body fat percentage) who are "determined" to "prove" themselves during training. Other significant risk factors include uneducated coaches that persist in training in extreme environments and limit player's access to fluids. A heatstroke is a medical emergency. Therefore, it will require emergency treatment. In the event of suspected heatstroke, the club's doctor and/or local emergency services should be immediately notified. In a situation of waiting for medical assistance, the priority is to lower core body temperature, which can be achieved by submerging the player in cool water.

Practical nutrition recommendations for football in the heat

There are two main nutritional interventions to consider in combatting potential heat-induced decrements in football performance.

Habitual euhydration

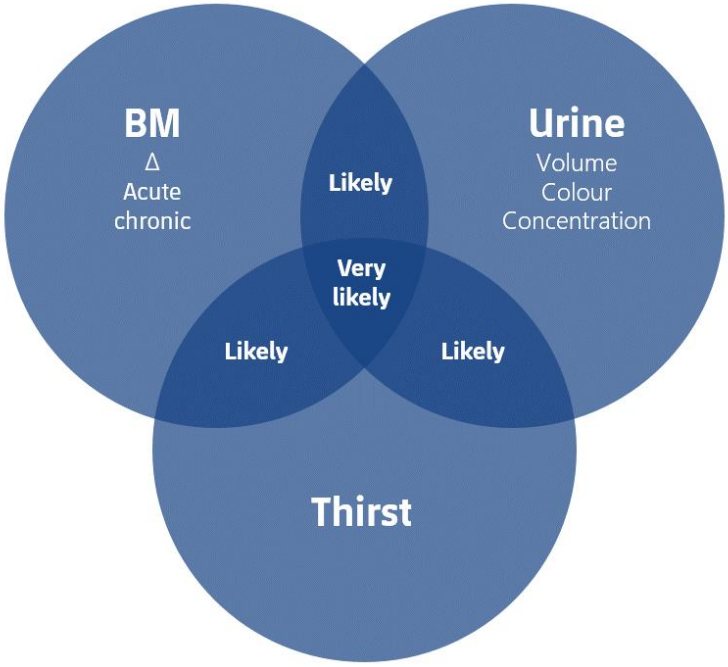
In the heat, player's sweat rates can reach in excess of 1-2 L per hour of exercise –most players will drink less than they sweat. Maintaining a euhydration status before players engage in training or matches and limiting the degree of hypohydration during exercise would be beneficial when preparing players to complete in the heat (Sawka et al., 2007). Hypohydration greater than 2% of pre exercise body mass has been reported to reduce maximal aerobic power in hot environments (Craig & Cummings 1966) and impair sub-maximal aerobic performance in temperate, warm and hot environments (Sawka et al., 2012).

Compared to a euhydrated state, hypohydration during football exercise in the heat will result in further increases skin, core and muscle temperatures (Sawka et al., 2012). Despite increased temperatures not being solely accountable for exercise-heat stress fatigue (Nybo et al., 2014), it would seem logical advice to aim to prevent any further increases in body temperatures or cardiovascular strain during match play than what is necessary.

Of note, there will be a large individual player variation in the response to dehydration and its influence on exercise performance. Therefore, fluid ingestion guidelines may be personalised individualised for each player. Optimal considerations of fluid for football were covered in later courses.

In summary, to achieve the hydration recommendation, education efforts are encouraged. Players should be educated to assess their own hydration status by monitoring their own urine colour, acute changes in body mass, and also sensations of thirst (Figure 2).

Figure 2: Likelihood of hypohydration



Source: Adapted from (Armstrong et al., 2014), pp.138-144

Players should have access to water during meals. During training, nutritionists should ensure that players have easy access to water. For example, the players' drinks should be in close proximity to the players so that they have access to beverages when required. If possible, beverages should be kept chilled to improve the flavour profile of the drink and promote an increase in voluntary fluid intake. The coaches should be aware of the challenging environmental conditions and allow routine breaks for drinks, ideally in a shaded area. During matches, players should be encouraged to drink during breaks in play. Stoppages in the match —such as corners, injuries, substitutions— offer the opportunity to drink fluid (as well as ingest carbohydrate if required). The sports nutritionist may facilitate this by placing drinks bottles at strategic locations around the pitch, such as corner flags, behind the goals and side lines. Physiotherapists and trainers may assist in carrying drinks bottles in the medical bags should they need to enter the field of play to attend to an injured player. Following exercise, fluid intake can be encouraged by offering a variety of beverages to the players' preference. Ice lollies and fruit platters also serve as excellent methods to assist in replacing fluid losses incurred during a match. Combining the fluid with salty foods will help the retention and distribution of the fluid in the player's body.

Cold water/ ice slurry ingestion

The available evidence suggests that the ingestion of ice slurry or cold (< 10°C) water may be beneficial for enhancing aerobic performance in the heat (Tan & Lee 2015).

The ingestion of a cold beverage may work, as it provides an additional avenue for heat transfer, i.e. an internal avenue in addition to the four avenues of heat transfer at the skin. Thus, the player may theoretically stay cooler —even if the skin surface heat loss remains unchanged— following cold fluid or ice slurry ingestion. The practical recommendations when considering cold water or ice slurry ingestion as a cooling strategy for reducing body heat storage, before exercise, during exercise and after exercise are discussed below. In general, the temperatures of beverages used in research studies have ranged from ≤ 10°C to 0°C (ice) provided in volumes ranging 700-1500 ml (Jay & Morris 2018). As with all nutritional strategies, the player should practice and refine any ice slurry strategies in training first before adopting them for matches.

Ice slurry/cold water ingestion before exercise has been reported to reduce core temperature by up to ~0.5°C. Beginning football exercise in the heat with a lower core temperature may extend the time taken to reach a critical absolute core temperature threshold, which will be specific to the individual player. This may result in the player being able to continue exercising in the heat for longer and may have greater relevance for tournament football, if matches enter extra time.

During exercise, ice slurry or cold water ingestion is likely to have the greatest impact when playing football in hot humid conditions where the evaporation of sweat from the skin surface is reduced. The challenge for football players is that the opportunity to drink during breaks in play are limited. Nevertheless, in the recent world cup (Brazil 2016), FIFA introduced designated “cooling breaks” during competitive matches. The “cooling breaks” was three minutes in duration, and were applied by the referee at approximately 30 minutes into both halves of the match (i.e. around the 30th minute and 75th minute respectively).

Under these circumstances, having the ability to provide beverages to players that are ≤ 10°C, may offer a significant performance advantage over the opposition. A common mistake is to leave the beverages exposed on the sideline, where they get heated to the environmental temperature. To this end, the sports nutritionist should be prepared with appropriate drinks carriers and cool boxes to store drinks prior to ingestion.

After training or matches, the relative benefit of drinking ice slurry/cold fluids during post-exercise recovery of core temperature may be greater.

The players sweat rate will be rapidly reduced as metabolic heat production has stopped. In addition, professional players may quickly move to an air-conditioned cooler training room, reducing the environmental stress. Nevertheless, ice slurry or cold-water ingestion will likely reduce the core temperature at a faster rate during the early stages of recovery (Jay & Morris 2018). Chilled beverages are also likely to appeal to the player's taste and perceptual preference, facilitating re-hydration strategies.

Combining cooling strategies

The ingestion of a cold fluid/ice slurry is one of a few potential cooling approaches which have been shown to have ergogenic effects during exercise-heat stress.

Cooling methods include the application of ice packs onto skin surface (core, neck, wrists), cold water immersion, the wearing of ice-cooling garments or a mixture of these approaches (Tyler et al., 2013).

Irrespective of the method, the goal of pre-cooling is to reduce core, skin and muscle temperatures. These methods all aim to increase heat storage capacity of the player's body (Bongers et al., 2014). The effectiveness of these methods is variable. Cooling "ice" vests are likely to have negligible to small effects on performance. Whilst cold water immersion may have moderately positive effects, it is not practical to apply this method before a football match.

Before a match and at half-time, there are no governing body dictated restrictions on using cooling aids. However, a major consideration with regard to the use of pre-cooling (of any type) within professional football is the limited time available during warm-up drills (~30 min), post warm-up prior to kick off (~12 min) and time available during halftime (~2.6 min) (Towlson et al., 2013). To this end, combining "cooling" methods with cold fluid/ice slurry ingestion is likely to be the best practical approach when seeking to benefit exercise capacity in hot environments (Drust et al., 2000; Clarke et al., 2011; Bongers et al., 2014).

Practical note: clothing

When playing in hot environments, ensure players are wearing appropriate clothing. It is common for players to wear "base layers" under training or match shirts. It is recommended that players do not wear these during exercise in hot conditions. This is because it will reduce the surface area of the skin available for sweat evaporation, increase skin temperature and lead to a more rapid rise in core temperature.

Conversely, when players are training in the cold it is common for them to commence training wearing multiple layers. As training intensity

increases, players often forget to remove the layers of clothing. In these situations, skin temperature and sweat rates may be comparable to that of training in warm conditions. Under these circumstances, it is important to ensure that players compensate their drinking during/after the exercise accordingly.

Summary

- Football is played in hot environments.
- Playing football in hot environments increases the strain on the player's cardiovascular system, due to the increased demands of thermoregulation.
- The heat mediated reductions in distances covered at high intensity during a match directly impacts match-play characteristics.
- Ensuring adequate hydration status and preventing significant hypohydration during football exercise can limit performance decrements in the heat.
- Providing beverages chilled (<10°C) before and at half-time may reduce the rate of core temperature rise by providing an additional avenue for heat transfer.