Module 3. Nutrition for football in extreme environments

Unit 3.1 Nutrition for football in extreme environments

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 (Taylor and Rollo, 2014).

These demands are independent from the time, location, temperature or the altitude at which the football training or matches are 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. For the sports nutritionist, 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, sports nutrition takes on even greater importance in player performance and recovery.

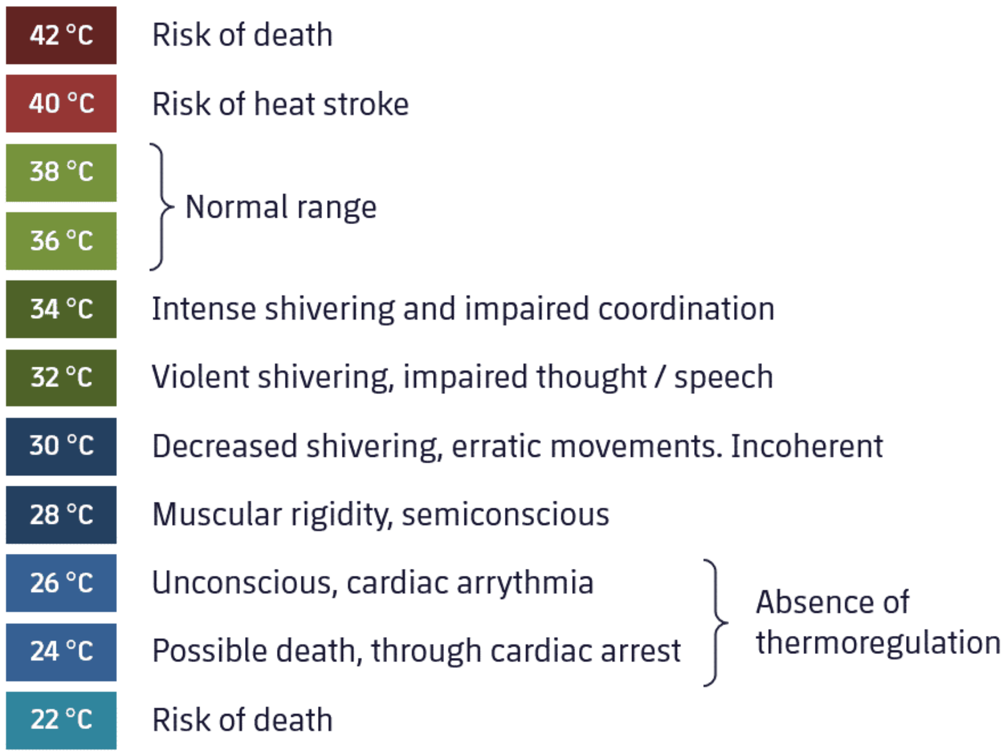
The purpose of this module is to understand the potential nutritional interventions to prevent any negative influences of playing in environment extremes. Unit 1 will discuss the physiological challenges and nutrition interventions relevant to playing football in hot environments. Unit 2 will discuss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

3.1.1 Extreme temperature

Playing football in the heat

Football can be played in thermally oppressive conditions (Wardenaar et al., 2024). 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: own elaboration.

The core temperature of the player will be elevated relative to the intensity of exercise. However, greater rises in core temperature will occur 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 player's body.

Conditions of "non-compensable" heat stress means that the player's 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. 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 and 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 looks "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 reduction in plasma volume with hypohydration, while skin blood flow requirements are elevated. Consequently, 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 physical and technical 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 played in extreme temperatures (25-40 °C). These temperatures 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, cited in Taylor and Rollo, 2014). 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, cited in Taylor and Rollo, 2014).

When environmental conditions and muscle metabolic heat production promote the heat gain, core temperature is increased and a player's endurance capacity reduced (Nybo et al., 2014, cited in Taylor and Rollo, 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, cited in Taylor and Rollo, 2014). 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 environments (~21 °C) (Mohr et al., 2012, cited in Taylor and Rollo, 2014).

"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)" (Taylor and Rollo, 2014, https://lc.cx/cM48bw). 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, cited in Taylor and Rollo, 2014). "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, with a concomitant increase of time in possession of the ball (Mohr et al., 2012)" (Taylor and Rollo, 2014, https://lc.cx/cM48bw). As such, there is less pressure on the ball 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, on average, more proficient during football matches played 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 mechanisms by which exercise-heat stress reduces football performance are likely to be multifactorial. 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, cited in Taylor and Rollo, 2014). This is due to training and acclimation status of individual players, which are influenced by genetic/phenotypic variations of favorable traits associated with innate thermal tolerance and its acquirement (Taylor and Rollo, 2014).

Fatigue in football is complex and well-controlled research in elite male football players suggests that other complementary multifactorial mechanisms, besides muscle, core and skin temperature should be considered when explaining football related fatigue within a hot environment (Mohr et al., 2012, cited in Taylor and Rollo, 2014). If we consider the physiological demands of football performance covered in previous 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 the cardiovascular system's ability 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 thermoregulatory cooling is gradual dehydration of the player's body. If fluid losses are not replaced, then hypohydration (>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 (Course Macronutrients and Fluid for Football):

- 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 sunlight, which also accounts 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 protocols (Taylor, 2014). Heat acclimation protocols range from 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. This method allows 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. 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).

Preferable heat acclimation adaptations to support football training and match performance:

- Earlier onset 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 sports nutritionist, it is important to recognise the early symptoms of heatstroke and the players most at risk. Heatstroke 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 the following.

- 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 heat stroke 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, shade or cooling during breaks in play. A heatstroke is a medical emergency. Therefore, it will require emergency treatment. In the event of suspected heatstroke, the club's doctor 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. It is advised for the sports nutritionist to work with the medical team to develop appropriate response protocols to heat stroke.

3.1.2 Practical nutrition recommendations for football in the heat

Two main nutrition interventions to consider in combating potential heat-induced decrements in football performance are the following.

Habitual euhydration

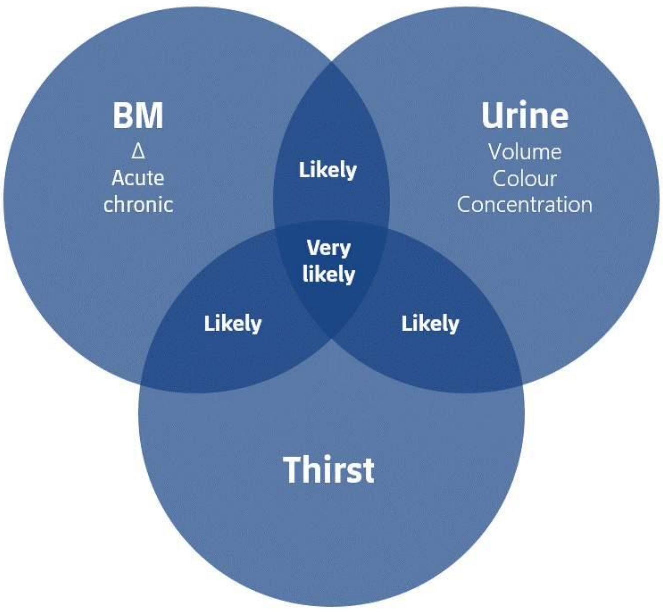
In the heat, player's sweat rates can reach in excess of 1-2 L per hour of exercise –most players will drink less than they sweat. Maintaining a euhydration status before players engage in training or matches and limiting the degree of hypohydration during exercise would be beneficial when preparing 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 and 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 in 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 personalized for each player. Optimal considerations of fluid replacement for football were covered in Course Macronutrients and Fluid for Football.

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: own elaboration based on Armstrong et al., 2014.

Players should have access to water during meals. During training, sports nutritionists should ensure that players have easy access to fluids. For example, the players' drinks should be placed nearby for easy 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 and Lee, 2015). The ingestion of a cold beverage is effective as it provides an additional avenue for heat transfer, in addition to the four mechanisms 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.

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 and Morris, 2018). As with all nutritional strategies, the player should practice and refine ice slurry strategies in training first before adopting them in matches.

Ice slurry/cold water ingestion before exercise has been reported to reduce core temperature by ~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. Playing with a lower core temperature may also improve the players' perceived exertion and subjective rating of fatigue during the match.

During training and matches, 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 Brazil world cup (2016), FIFA introduced designated "cooling breaks" during competitive matches. The "cooling breaks" are three minutes in duration, and applied by the referee 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 changing 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 and Morris, 2018). Chilled beverages are also likely to appeal to the player's taste and perceptual preference, facilitating re-hydration/recovery strategies.

Combining cooling strategies

Complementary 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. Thus the ingestion of a cold fluid/ice slurry is an effective cooling approach which can easily be incorporated into the players pre-match routine. Importantly, carbohydrate ingestion recommendations can also be effectively delivered via ice slurry (Naito et al., 2022). Although ice slurry can be delivered before the match and at half time, the pre-match ingestion appears most important for augmenting performance during the first half of a simulated football running protocol (Aldous et al., 2019).

Interesting, there are no governing body restrictions on using cooling aids before a match or at half-time. 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).

Nutritional considerations to counteract gastrointestinal permeability during exertional heat stress

The success of sports nutrition interventions is dependent on the functionality of the intestines to process the incoming nutrients. However, when playing in the heat a player's intestinal barrier integrity and function can be compromised. This can potentially lead to a range from symptoms from minor gastrointestinal disturbances to fatal outcomes in exertional heat stroke or septic shock (King et al., 2021). Importantly, there are nutrition interventions which can have protective effects on the intestinal barrier.

Exercise-induced hypohydration compromises gastrointestinal integrity independent of heat stress. This is generally attributed to reduced blood flow to the intestines, resulting in hypoxia and an increase in reactive oxygen species production (King et al., 2021). Thus, maintaining an adequate hydration status as well as providing carbohydrate (Course Macronutrients and Fluid for Football) during exercise can help maintain blood flow to the intestine maintaining integrity and function (Lambert et al., 2008).

Amino acids have a dual purpose in the intestine, serving as substrates for energy and maintaining the structure of the intestinal barrier (King et al., 2021). The amino acid glutamine serves as a fuel for the intestinal cells. Should players be deficient in glutamine in their diet, supplementation (0.25, 0.5, and 0.9 g/kg fat free mass) 2 h before a match may be effective in supporting gut function prior to training or matches in the heat (Pugh et al., 2017).

The ingestion of sufficient probiotic and prebiotic foods in the diet are also relevant to supporting intestinal function when playing in the heat. Although, this gastrointestinal health will be covered in detail in course 4, probiotic and prebiotic may be associated with improved microbiota diversity and stability as well as an increased abundance of butyrate-producing bacteria. Butyrate is a short chain fatty acid, which is an important energy source for intestinal cells and may inhibit production of pro-inflammatory compounds (King et al., 2021). Therefore, it is reasonable to suggest that an improved gut function will benefit the player when exposed to the additional demands of playing in the heat.

Practical note: clothing/kit

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.

Unit 3.2 Playing at altitude and considerations for travel

This unit will discuss the physiological challenges and nutrition interventions relevant to playing football at altitude. In addition, traveling away from "home" for pre-season training, during the season and for international tournaments is now common practice for most professional football players. Significant nutrition challenges are encountered by players when traveling. Therefore, it is important for you to recognise those challenges and introduce specific strategies to minimize the disruption to the player's schedule.

3.2.1 Altitude

A common misconception when playing at altitude is that there is an alteration in the composition of atmospheric air. This is not true. The composition of air remains the same, i.e. oxygen content of air remains at 20.93 %, be it at sea level or 4,000 m. Instead, it is the reduction in the partial pressure of oxygen and other ambient gasses, which decrease the higher the ascent. A reduction in partial pressure results in a reduction in the total number of oxygen molecules inspired with each breath. The low oxygen pressure of ambient air is known as hypoxia, which is induced by a reduction in barometric pressure. Barometric pressure is a measure of the pressure exerted by the weight of the air above us. There is an inverse relationship between barometric pressure and altitude, i.e. the higher the altitude, the lower the barometric pressure.

Did you know?

Hypoxia refers to a low oxygen pressure in the ambient air, caused by a reduction in barometric pressure. Hypoxaemia generally refers to a decrease in the oxygen content of air.

Table 1. Altitude classification, implications and potential action

Altitude (m above sea level)	Classification	Implication	Action
0-500 m	Near sea level		
> 500 – 2,000 m	Low altitude	Minor impairment in aerobic performance	3-5 d acclimation Dietary Nitrate
> 2,000 – 3,000 m	Moderate altitude	Mountain sickness begins to occur and acclimation gets increasingly important.	1-2 weeks acclimation Dietary Nitrate
> 3,000 – 5,500 m	High altitude	Performance considerably impaired, acclimation becomes clinically relevant.	>2 Weeks acclimation Dietary Nitrate
> 5,500 m	Extreme alltitude	Prolonged exposure results in progressive deterioration.	

Source: own elaboration.

Hypoxia and football

Although less extreme in Europe, players may still be required to play at various altitudes. For example, figure 3 shows the altitude of club stadiums in the Spanish first division "La Liga". The player's body will make both physiological and metabolic adjustments when playing in low oxygen environments. However, depending on the degree of altitude, these compensatory changes are usually not enough to off-set the negative influence of a reduction in the partial pressure of oxygen.

A reduced oxygen supply (lower total number of oxygen molecules inspired per breath) compromises the player's aerobic capacity by reducing the maximum oxygen delivery to the skeletal muscle (Billaut and Aughey, 2013). The arterial hypoxaemia (3 % reduction in arterial blood oxygen saturation compared to pre-exercise or sea level values) impairs the players' ability to run at high intensity and complete repeated high intensity efforts (Billaut and Aughey, 2013; Garvican et al., 2013). As covered in previous courses, these attributes are key for player performance and match defining moments.

Elite players who live at sea level may experience a performance decrement (ability to complete and recover from high intensity runs) when asked to play football at low altitude (table 1) (Nassis, 2013). Data on player physical performance was captured throughout the FIFA World Cup 2010 (South Africa), where matches were played at a variety of altitudes (0 m-1,753 m). During the tournament it was reported that an altitude in excess of 1,200 m significantly reduced the total distance covered by players during a match (-~3.1 %), in comparison to sea level (0 m) (Nassis, 2013). Furthermore, the players capacity to complete high speed runs, i.e. repeated sprinting, is reduced approximately 150 % fold at 1,600 m compared to near sea levels controls, in elite youth football players (Garvican et al., 2013). It is important to note that decrements in high speed running capacity observed when playing at 1,200 m – 1,750 m were not accompanied by reductions in technical skill proficiency (Nassis, 2013).

Figure 3. Altitude of club stadiums participating in the Spanish first division "La Liga" (2018-2019)

Source: own elaboration.

On three separate occasions, FIFA has banned international football matches that were proposed to be played at altitudes in excess of 2,500 m (Gore et al., 2013). One of these vetoes (May 2007) was reversed shortly after its announcement. Unfortunately, this sequence of announcements as well as retractions were made without consideration of the football-specific research on player match performance at low, moderate and high altitudes (Gore et al., 2013). Subsequently, there was a scientific approach and data gathered during matches played at altitude, completed by a project named the International Study on Football at Altitude 3,600 m, in 2012 (ISA3600) (Gore et al., 2013).

However, despite the novel and well organised approach of the ISA3600 research, poor reliability and high variability have been reported for key outcome measures (i.e. total distance covered and distance at high speed running) during football match-play due to other match-specific factors independent of altitude (tactics, opposition). Therefore, it is difficult to draw clear conclusions regarding the impact of altitude on football specific performance, derived from football match-play data.

On pitch or laboratory based football simulations, which mirror the physical match demands of football, have provided valuable insights on the impact of altitude. This is because the physiological and performance response of the player can be assessed without confounding match factors such as tactics, formation and opposition. For example, to investigate the impact of hypoxia (1,000 m) on player running performance, researchers have validated a intermittent soccer performance test (iSPT) (Aldous et al., 2015). Data using this exercise model suggests that total distance covered, and distance covered at high speed, are significantly reduced in hypoxic conditions in comparison to sea level (control). Interestingly, the final 15 minutes of iSPT, saw the greatest reductions in high-speed running compared to all other 15-min blocks of the protocol.

It is likely that the time-dependent decline in high-speed running at altitude could influence the outcome of a match. This is because data from the FIFA World Cups (1998, 2002) has shown that most goals are scored in the second half of the match (Armatas et al., 2007). With respect to the influence of altitude, compared to all other 15-min time phases, more goals were scored/conceded within the final 15 minutes of a match (76-90 min). This phenomenon in goals scored is likely due to the factors of fatigue discussed in previous courses. However, these decrements in performance appear to be exacerbated within hypoxic environments (Garvican et al., 2013; Taylor et al., 2014).

Whether players are native to altitude (for example, Bolivian) or sea level (for example, Australian) appears not to influence total distance covered in either environment. For example, total distance covered was reduced similarly in both groups across three matches played at 3,600 m, compared to performance close to sea level (Aughey et al., 2013). This reduction was not positively influenced by 14 days altitude acclimation by sea level natives, nor lifelong residency at altitude within the high landers group (Aughey et al., 2013).

Table 2. Examples of stadiums and the associated teams who play at moderate to high altitude

Stadium	Team/Club	Altitude (M)	Country
Estadio Daniel Alcides Carrión	Unión Minas (3 Ra division of Peruvian league)	4380	Peru
Estadio Víctor Agustín Ugarte	Club Bamin Real Potosí (Bolivian 1st division)	3960	Bolivia
Lhasa Recreational and Sports Centre	Lhasa Chengtou (China league two)	3658	China
Estadio Hernando Siles	Bolivia national team	3637	Bolivia
Estadio Garcilaso	Real Garcilaso (Peru 1st division)	3360	Peru
Estadio Olímpico Atahualpa	Ecuador national team	2782	Ecuador

Source: own elaboration.

3.2.2 Altitude: practical recommendations

Hypoxic environments, induced by altitude (>1,200 m, match-play) (Garvican et al., 2013; Nassis, 2013); or simulated laboratory studies (>1,000 m) (Taylor et al., 2014) limit football-specific physical performance. Current advice recommends that players acclimatise for several days and include 1-2 weeks training at or near the competition venue when located at moderate/high altitude (Gore et al., 2008). This strategy is aimed to promote adaptation to altitude, i.e. to increase the oxygen carrying capacity of the blood. This is achieved by an increase in red blood cells and an increase in haemoglobin mass. However, the nutritional status of the player may influence how they respond to altitude driven adaptation. Furthermore, when a period of acclimation is not realistic/possible due to the transient nature of a football team's fixture schedule, acute nutrition strategies may be considered.

To this end, in addition to the "core" sports nutrition recommendations of "fuelling and hydration," specific nutrition interventions should be considered when preparing for and playing at altitude.

Sports nutrition preparation

Nutritional recommendations for supporting performance at altitude would include ensuring players have an adequate iron status (table 3). Iron is the functional component of myoglobin, haemoglobin and is also an essential constituent of mitochondrial enzymes. Iron is also required for the proliferation of red blood cells in response to altitude. Therefore, the player's iron deficiency will benefit from increasing their intake of dietary iron, prior to (several weeks before) and during periods of acclimation at altitude.

Current recommendations are to assess the player's iron status 4-6 weeks prior to going to altitude. A typical routine involves the ingestion of 100-200 mg of elemental iron per day (Hall et al., 2018). Vitamin C (200 mg/d) should be co-ingested with iron to enhance absorption, whilst foods or fluids that impair iron absorption such as tea and coffee should be avoided around player meal times (Armstrong, 2006; Gore et al., 2008).

Table 3. **Haematological assessments of iron deficiency and iron anaemia**

	Normal	Deficiency
Serum ferritin (μg/L)	>110 (M) >35 (F)	<35
Haemoglobin (g/L)	135-175 (M) 120-155 (F)	125-134 (M) 115-119 (F)

Source: own elaboration based on Peeling et al., 2008.

Values will vary for male (M) and female (F) players (Peeling et al., 2008).

If an iron deficiency has been clinically diagnosed, a supplementation period may be considered at levels above the recommended daily allowance, following consultation with a qualified medical practitioner/ club doctor. If specific iron supplementation is recommended, then guidelines surrounding dietary supplementation should be followed (Module 2).

Performance

Dietary nitrate ingestion may be a potent acute sports nutrition strategy when preparing for exercise at altitude (Shannon et al., 2017).The ingestion of dietary nitrate has been shown to result in several positive physiological responses, which may positively impact on player performance at altitude. Specifically, dietary nitrate ingestion has been reported to:

- improve muscle oxygenation during submaximal and maximal exercise in acute severe hypoxia (Masschelein et al., 2012),
- reduce negative muscle metabolic perturbation during high-intensity exercise within hypoxia (Vanhatalo et al., 2011),
- improve intense intermittent exercise performance at sea level (Wylie et al., 2013).

Practical recommendations to optimise nitrate dietary supplementation (dose, nitrate source, acute or chronic supplementation) were covered in the previous module (Vanhatalo et al., 2014). Based on the available literature, players would be advised to ingest inorganic nitrate delivered by ingesting approximately 140 ml, nitrate-rich vegetable products (such as beetroot juice) daily on the 3-4 days prior to competing at altitude. In addition, players may also benefit from the ingestion of 140 ml (providing ~8.4 mmol Nitrate) of inorganic nitrate with the pre-match meal (i.e. ~3 h before exercise). Although there is potential for performance improvements with a single pre-exercise dose, chronic supplementation of at least several days may increase the likelihood of exercise performance benefits being observed (Hoon et al., 2013). During nitrate supplementation, the player's urine may turn a "pinkish" colour. Players should be warned about this side effect. There is no harm in the urine changing colour, but self-monitoring of hydration status at altitude, via urine colour, may be compromised. Therefore, hydration monitoring using objective markers such as urine specific gravity would be recommended.

3.2.3 Travel

For a professional football player, domestic and international travel is common. Players may travel to weekly matches and routinely to different countries during the season for

European or International commitments. In addition, players are required to participate in pre-season training camps or organised tours that also require significant international travel. It is essential that strategies are put in place to minimize the impact of travel on a football player's food intake. Regardless of whether the player is embarking on a long bus trip or overseas, the key to successful eating while on the move is planning and preparation.

Ensuring a quick adjustment to the "new" environment takes on greater importance if the player must perform soon after arrival. This is because jetlag, unaccustomed environmental conditions, illness or inappropriate dietary intake have the potential to negatively affect player performance (Halson et al., 2019). The sports nutritionist can oversee specific strategies to ensure appropriate hygiene and manage travel fatigue and jet lag. Some objectives may be achieved indirectly by player education, but others require the direct involvement of the nutritionist, for example, directly ensuring adequate health and safety standards are met by the catering staff/facilities of kitchen/restaurant environments.

It is the nutritionists responsibility to check the ability to travel with any dietary supplements provided at the club, as well as check the safety of sports products in the destination country. We are lucky to work in a supportive sports nutrition community. In my experience you can contact the local football teams sports medical departments or sports nutritionist for advice and local knowledge. The nutritionist should work with the team sport manager and kit person, to ensure adequate space in travel containers for sports nutrition specific items such as drink coolers, drinks cradles, bottles and any dietary supplementation.

Travel hygiene

During travel to destinations with greater than a five-hour time difference, the incidence of illness (i.e. upper respiratory tract infection and gastrointestinal tract and infectious illness) is increased two to three-fold (Schwellnus et al., 2012). This is of importance for those nutritionists who work with players who frequently travel long distances "home", i.e. Europe to Asia or Latin America and vice versa.

When traveling, the player is frequently exposed to situations where they are in contact with many people and often in a confined space. In addition, players are often demanded/expected by fans to shake hands, "high-5", meet sponsors/hosts and pose for photographs. These factors theoretically expose the player to new and more pathogens in comparison to a "non-player".

Did you know?

A pathogen is anything that can produce illness or disease.

If players experience illness when traveling, it can create numerous problems for the individual player as well as the support staff and teammates. Beyond the inability to train and play matches, illness may require the player to be isolated to reduce the risk of passing the illness to staff and teammates.

An example of a common illness associated with frequent or long-distance travel is traveler's diarrhea. Traveler's diarrhea may be defined as three or more unformed bowel movements within 24 hours. This illness is associated with nausea, cramps, blood in stools and vomiting. It is typically caused by contamination from fecal matter containing microbes such as salmonella, virus and pathogens and food or water contamination by E. Coli. The duration of symptoms of traveler's diarrhea is usually 3-4 days. In some cases, it may be more severe resulting in bowel complaints affecting the player's ability to train and compete in the weeks following the initial incident (Reilly et al., 2007).

Gastrointestinal distress and illness related to travel in some countries may be associated with poor hygiene practices such as hand washing. It is important to emphasise that picking up illness can occur in both developing countries and destinations considered 'safe'. Thus, adopting good personal hygiene and food safety practices for all travel will help to decrease the risk of infection and illness over the duration of a season. In all situations, players should avoid sharing cups or utensils as infections and illness may spread this way. During training and matches, ensure players have their own designated drinks bottle. Below are key points to consider for the travelling player.

- Wash hands regularly and before all meals.
- Wash hands following contact with many people, meeting fans, hosts, etc.
- Drink bottled water or beverages from sealed containers.
- Avoid (non-drinking water) ice in beverages.
- Clean teeth with bottled water.
- Eat fruits only if they can be peeled.
- Aim to eat only from reputable hotels or franchises.
- Avoid markets and street stalls.
- Only consume food that is prepared properly, i.e. steaming hot.

In the event of a player experiencing an illness, it should be immediately reported to the medical team/club doctor. The aim will be to ensure the player receives the appropriate medical care but also to avoid contaminating the other members of the team and finally identifying the root cause of the illness. As a general guide, the sports nutritionist is advised to be prepared with specific rehydration sachets, which may be used in the treatment of players with gastrointestinal illnesses.

Figure 4. Sports nutrition to prepare for travel

Sports Nutrition items to consider when travelling:

Empty drinks bottles for each player (member of staff)
can be taken through the airport and filled in the terminal

Chewing gum
helps to avoid eating due to boredom and also avoids getting a dry mouth

Rehydration sachets
in case of dehydration or gastrointestinal illness

Hand sanitiser
to maintain good hygiene: however not a substitute for hand washing.

Snacks for coach/train/plane
as travel rarely goes to plan, best to be prepared for potential delays.

*Liaise with local hotel on menus before trip
Understand safety of drinking water

Source: own elaboration.

Jet lag

Jet lag (circadian desynchronisation) occurs due to a mismatch between the player body's circadian rhythm(s) and the external 24-hour light-dark cycle. Jet lag results from rapid travel across multiple time zones. Jet lag is influenced by the number of time zones crossed as well as the direction of travel. There are numerous negative consequences of jet lag that could impact on a player's performance, including:

- disturbed sleep,
- fatigue,
- insomnia,
- decreased alertness,
- headaches,
- mood disturbance,
- decreased motivation.

As a guide, one day should be allowed for each hour of time difference, for players to fully adjust. Light is the most powerful cue to synchronise the player's internal body clock. The aim is to realign the player's circadian systems as quickly as possible. This is vital if there is a short period of time for transition prior to competition. One key symptom of jet lag includes appetite loss. Thus, the nutritionist should plan meals carefully to ensure players are meeting energy requirements. In addition, certain nutrition strategies may be considered to help speed the player's body clock synchronisation.

Did you know?

The circadian rhythm is also known as the “body clock". The player's circadian rhythm informs the player's body behaviour, for example, when to sleep, wake and eat.

Nutrition planning

Prior to travel, the nutritionist should develop a general plan which details where, when and what the players are going to eat on each day. It is important to research the destination and investigate the catering options as thoroughly as possible. A common problem when dining in a “new” venue is that it results in a change in the availability, type and quality of food as a result of differences in the local food supply and catering capabilities.

In these circumstances, players may avoid foods creating challenges to achieving their specific nutrition goals. The quality of the food and food availability can be critical to the success of the trip, especially during prolonged pre-season camps. Ideally, menus can be shared with the hotel chefs in advance and followed up with a telephone conversation prior to arrival. Ideally, this is completed in partnership with the team's performance chef (Course 4) who may also travel with the team. This process will allow you to discover which foods are available and if menus need to be modified. Researching the travel destination will allow you to determine the hygiene and food safety risks, but also potential culinary opportunities. It is important not to forget that travel provides the opportunity for the sports nutritionist, players and staff to learn about new foods, recipes and cultural etiquettes.

Travel tip

When traveling regularly, delays are guaranteed, both on the roads and at the airports. As the nutritionist, plan for these eventualities by packing enough food to cater for the players “just in case”. For example, cereal bars and bottles of water can be easily stored on the team coach and used if needed.

The teams travel schedule will determine the opportunities for players to eat. Even short-haul travel may result in poor eating practices. Preparing food for the team bus reduces the need for unscheduled stops, which may result in the selection of less appropriate "convenience" options. Food should be stored appropriately, i.e. in chilled containers when traveling.

When planning for a flight, knowledge of the duration is the priority. Two meals are typically provided during long haul flights. The first is provided following departure and the second usually two hours before arrival. In my experience, it is very difficult to influence the meals provided on long haul flights.

Nonetheless, appropriate snacks can be purchased at the airport such as fresh and dried fruit, nuts, and milk. These supplies may need to be purchased once customs is cleared. These snacks should be easily accessible; however, eating out of "boredom" should be discouraged.

Changes in bowel habits of players are common with travel. This may be due to a change in the common foods in the player's diet (reducing fibre intake) and also hypohydration due to a change in the type/volume of food and fluid ingested. In addition, insensible fluid losses may be increased by cabin pressure and air dryness (Leatherwood and Dragoo, 2013).

Nutritionists traveling with the team should ensure that the players have easy access to fluids and may remind cabin staff to routinely provide drinks. To encourage voluntary fluid intake, one strategy is simply to place a water bottle on each of the player's seats before they board the airplane (or coach). This forces the player to move the bottle and reminds them to drink.

On arrival at the destination, the ingestion of caffeine is a common means of alleviating daytime fatigue experienced as a consequence of jet lag (Halson et al., 2019). For example, 300 mg of caffeine ingested at 08:00 (destination time) for 5 days resulted in a more rapid resynchronization rate compared to placebo (Pierard et al., 2001). Caffeine ingestion (300 mg) has also been reported to decrease sleepiness in comparison to placebo but resulted in more objective and subjective sleep complaints (Beaumont et al., 2004). As the half life of caffeine is ~5 hours, you can count back the planned sleep time of players as to when to ingest the caffeine, without it negatively impacting the players sleep.

Did you know?

A "Zeitgeber" is the term given to a rhythmic cue in the environment that helps synchronize the internal body clock to the external environment (Choy and Salbu, 2011).

Summary

- Football may be played at extremes of altitude.
- An immediate solution to the demands of hypoxic match play is challenging, though dietary nitrate supplementation alongside items of "best practice" are recommended.
- Frequent travel is common in football; player education surrounding hygiene may reduce the risk of infection.
- Dedicated planning by the nutritionist is essential for all travel.

References

Aldous, J. W., Chrismas, B. C., Akubat, I., Beel, L., Dascombe, B., and Taylor, L. (2014). Hot Environment Mediated Decrements In Soccer-Specific Capacity Utilising A Non-Motorised Treadmill Soccer-Specific Simulation (iSPT). 4th World Conference on Science and Soccer (WCSS), Portland, USA.

Aldous, J. W., Chrismas, B. C., Akubat, I., Dascombe, B., Abt, G. and Taylor, **L.** (2015). Hot and Hypoxic Environments Inhibit Simulated Soccer Performance and Exacerbate Performance Decrements When Combined. *Front Physiol.,* 6, 421.

Aldous, J.W.F., Chrismas, B.C.R., Akubat, I., Stringer, C. A., Abt, G., and Taylor, L. (2019) Mixed-methods pre-match cooling improves simulated soccer performance in the heat. *Eur. J. Sport Sci.,* 19(2), 156-165.

Armatas, V., Yiannakos, A. and Sileloglou, P. (2007). Relationship between time and goal scoring in soccer games: Analysis of three World Cups. *International Journal of Performance Analysis in Sport*, 7(2), 48-58.

Armstrong, L. E. (2006). Nutritional strategies for football: Counteracting heat, cold, high altitude, and jet lag. *Journal of Sports Sciences,* 24(7), 723-740.

Armstrong, L. E., Casa, D. J., Millard-Stafford, M., Moran, D. S., Pyne, S. W. and Roberts, W. O. (2007). American College of Sports Medicine position stand. Exertional heat illness during training and competition. *Med. Sci. Sports Exerc.,* 39(3), 556-572.

Armstrong, L. E., M. S. Ganio, J. F. Klau, E. C. Johnson, D. J. Casa and C. M. Maresh (2014). Novel hydration assessment techniques employing thirst and a water intake challenge in healthy men. *Appl. Physiol. Nutr. Metab.,* 39(2), 138-144.

Aughey, R. J., K. Hammond, M. C. Varley, W. F. Schmidt, P. C. Bourdon, M. Buchheit, B. Simpson, L. A. Garvican-Lewis, M. Kley, R. Soria, C. Sargent, G. D. Roach, J. C. J. Claros, N. Wachsmuth and C. J. Gore (2013). Soccer activity profile of altitude versus sea-level natives during acclimatisation to 3600 m (ISA3600). *British Journal of Sports Medicine,* 47(1), i107-i113.

Beaumont, M., D. Batejat, C. Pierard, P. Van Beers, J. B. Denis, O. Coste, P. Doireau, F. Chauffard, J. French and D. Lagarde (2004). Caffeine or melatonin effects on sleep and sleepiness after rapid eastward transmeridian travel. *J. Appl. Physiol.* (1985), 96(1), 50-58.

Billaut, F. and Aughey, R. J. (2013). Update in the understanding of altitude-induced limitations to performance in team-sport athletes. *British Journal of Sports Medicine,* 47(1), i22-i25.

Bongers, C. C. W. G., Thijssen, D. H. J., Veltmeijer, M. T. W., Hopman, M. T. E. and Eijsvogels, T. M. H. (2014). Precooling and percooling (cooling during exercise) both improve performance in the heat: a meta-analytical review. *British Journal of Sports Medicine*.

Choy, M. and Salbu, R. L. (2011). Jet lag: current and potential therapies. *P T*, 36(4), 221-231.

Clarke, N. D., Maclaren, D. P., Reilly, T. and Drust, B. (2011). Carbohydrate ingestion and pre-cooling improves exercise capacity following soccer-specific intermittent exercise performed in the heat. *European Journal of Applied Physiology*, 20(11), 1447-1455.

Craig, E. N. and Cummings, E. G. (1966). Dehydration and muscular work. *Journal of Applied Physiology*, 21(2), 670-674.

Drust, B., Cable, N. T. and Reilly, T. (2000). Investigation of the effects of the pre-cooling on the physiological responses to soccer-specific intermittent exercise. *Eur J Appl Physiol Occup Physiol.,* 81(1-2), 11-17.

Garvican, L. A., Hammond, K., Varley, M. C., Gore, C. J., Billaut, F. and Aughey, R. J. (2013). Lower Running Performance and Exacerbated Fatigue in Soccer Played at 1600 m. *International Journal of Sports Physiology and Performance*.

Gibson, O. R., Dennis, A., Parfitt, T., Taylor, L., Watt, P. W. and Maxwell, **N. S.** (2014). Extracellular Hsp72 concentration relates to a minimum endogenous criteria during acute exercise-heat exposure. *Cell Stress Chaperones*, 19(3), 389-400.

Gore, C. J., Aughey, R. J., Bourdon, P. C., Garvican-Lewis, L. A., Soria, R., Claros, J. C. J., Sargent, C., Roach, G. D., Buchheit, M., Simpson, B. M., Hammond, K., Kley, M., Wachsmuth, N., Pepper, M., Edwards, A., Cuenca, D., Vidmar, T., Spielvogel, H. and Schmidt, W. F. (2013). Methods of the international study on soccer at altitude 3600 m (ISA3600). *British Journal of Sports Medicine*, 47(1), i80-i85.

Gore, C. J., McSharry, P. E., Hewitt, A. J. and Saunders, P. U. (2008). Preparation for football competition at moderate to high altitude. *Scandinavian Journal of Medicine & Science in Sports*, 18, 85-95.

Hall, R., Peeling, P., Nemeth, E., Bergland, D., McCluskey, W. T. P. and Stellingwerff, T. (2018). Single versus Split Dose of Iron Optimizes Haemoglobin Mass Gains at 2106 m Altitude. *Med. Sci. Sports Exerc*.

Halson, S. L., Burke L. M., and Pearce, J. (2019). Nutrition for Travel: From Jet lag To Catering. *Int. J. Sport Nutr. Exerc. Metab.*, 1-8.

Hargreaves, M., Angus, D., Howlett, K. Conus, N. M and Febbraio, M. (1996). Effect of heat stress on glucose kinetics during exercise. *J. Appl. Physiol. (1985)*, 81(4), 1594-1597.

Hoon, M. W., Johnson, N. A., Chapman, P. G. and Burke, L. M. (2013). The Effect of Nitrate Supplementation on Exercise Performance in Healthy Individuals: A Systematic Review and Meta-Analysis. *International Journal of Sport Nutrition & Exercise Metabolism*, 23(5), 522-532.

Jay, O. and Morris, N. B. (2018). Cold water and ice slurry ingestion for reducing body temperature during exercise in the heat. *Sports Science Exchange*, 29(180), 1-6.

King, M.A., Rollo, I., and Baker, L. B. (2021). Nutritional considerations to counteract gastrointestinal permeability during exertional heat stress. *J. Appl. Physiol*., 130(6), 1754-1765.

Lambert, G.P., Lang, J., Bull, A., Pfeifer, P.C., Eckerson, J., Moore, G., Lanspa, S., and O'Brien, J. (2008) Fluid restriction during running increases GI permeability. *Int. J. Sports Med.,* 29, 194–198.

Leatherwood, W. E. and Dragoo, J. L. (2013). Effect of airline travel on performance: a review of the literature. *Br. J. Sports Med.,* 47(9), 561-567.

Masschelein, E., Van Thienen, R., Wang, X., Van Schepdael, A., Thomis, M. and Hespel, P. (2012). Dietary nitrate improves muscle but not cerebral oxygenation status during exercise in hypoxia. *J. Appl. Physiol.* (1985), 113(5), 736-745.

Morris, J. G., Nevill, M. E., Boobis, L. H., Macdonald, I. A. and Williams, C. (2005). Muscle metabolism, temperature, and function during prolonged, intermittent, high-intensity running in air temperatures of 33 degrees and 17 degrees C. *Int. J. Sports Med.,* 26(10), 805-814.

Nassis, G. P. (2013). Effect of altitude on football performance: Analysis of the 2010 FIFA World Cup data. *Journal of Strength & Conditioning Research*, 27(3), 703-707.

Naito, T., Saito, T., Morito, A., Yamada, S., Shimomasuda, M., and Nakamura, M. (2022) Pre-cooling with ingesting a high-carbohydrate ice slurry on thermoregulatory responses and subcutaneous interstitial fluid glucose during heat exposure. *J. Physiol. Anthropol*., 41(1), 34.

Nybo, L., Rasmussen, P. and Sawka, M. N. (2014). Performance in the Heat—Physiological Factors of Importance for Hyperthermia-Induced Fatigue. *Comprehensive Physiology*, 4, 657-689.

Parsons, K. (2003). *Human Thermal Environments* (Second Ed.). Taylor & Francis Inc.

Peeling, P., Dawson, B., Goodman, C., Landers, G. and Trinder, D. (2008). Athletic induced iron deficiency: new insights into the role of inflammation, cytokines and hormones. *Eur. J. Appl. Physiol.,* 103(4), 381-391.

Pierard, C., M. Beaumont, M. Enslen, F. Chauffard, D. X. Tan, R. J. Reiter, A. Fontan, J. French, O. Coste and D. Lagarde (2001). Resynchronization of hormonal rhythms after an eastbound flight in humans: effects of slow-release caffeine and melatonin. *Eur. J. Appl. Physiol.,* 85(1-2), 144-150.

Pugh, J.N., Sage, S., Hutson, M., Doran, D.A., Fleming, S.C., Highton, J., Morton, J.P., Close, G.L. (2017). Glutamine supplementation reduces markers of intestinal permeability during running in the heat in a dose-dependent manner. *Eur. J. Appl. Physiol.,* 117, 2569–2577.

Racinais, S., Mohr, M., Buchheit, M., Voss, S. C., Gaoua, N., Grantham, J. and Nybo, L. (2012). Individual responses to short-term heat acclimatisation as predictors of football performance in a hot, dry environment. *British Journal of Sports Medicine,* 46(11), 810-815.

Reilly, T., J. Waterhouse, L. M. Burke, J. M. Alonso and F. International Association of Athletics (2007). Nutrition for travel. *J Sports Sci.,* 25(1), S125-134.

Sawka, M. N., Burke, L. M., Eichner, E. R., Maughan, R. J., Montain, S. J. and Stachenfeld, N. S. (2007). Exercise and fluid replacement. *Medicine and Science in Sports and Exercise,* 39(2), 377-390.

Sawka, M. N., Cheuvront, S. N. and Kenefick, R. W. (2012). High skin temperature and hypohydration impair aerobic performance. *Experimental Physiology*, 97(3), 327-332.

Schwellnus, M. P., W. E. Derman, E. Jordaan, T. Page, M. I. Lambert, C. Readhead, C. Roberts, R. Kohler, R. Collins, S. Kara, M. I. Morris, O. Strauss & S. Webb (2012). Elite athletes travelling to international destinations >5 time zone differences from their home country have a 2-3-fold increased risk of illness. *Br J Sports Med.,* 46(11), 816-821.

Shannon, O. M., McGawley, K., Nyback, L., Duckworth, L., Barlow, M. J., Woods, D., Siervo, M. and O'Hara, J. P. (2017). "Beet-ing" the Mountain: A Review of the Physiological and Performance Effects of Dietary Nitrate Supplementation at Simulated and Terrestrial Altitude. *Sports Med*., 47(11), 2155-2169.

Tan, P. M. and Lee, J. K. (2015). The role of fluid temperature and form on endurance performance in the heat. *Scand. J. Med. Sci. Sports*, 25(1), 39-51.

Taylor, L., Chrismas, B.C., Beel, L., Akubat, I., Dascombe, B. and Aldous, J. W. (2014). Hypoxia Mediated Decrements In Soccer-Specific Capacity Utilising A Non-Motorised Treadmill Soccer-Specific Simulation (iSPT). 4th World Conference on Science and Soccer (WCSS), Portland, USA.

Taylor, N., A, S (2014). Human Heat Adaptation. *Comprehensive Physiology,* 4, 325-365.

Taylor, L. and Rollo, I. (2014). Impact of altitude and heat on football performance. *Gatorade Sports Science Institute.* https://www.gssiweb.org/sports-science-exchange/article/sse-131-impact-of-altitude-and-heat-on-football-performance

Towlson, C., Midgley, A. W. and Lovell, R. (2013). Warm-up strategies of professional soccer players: practitioners' perspectives. *Journal of Sports Sciences,* 31(13), 1393-1401.

Tyler, C. J., Sunderland, C. and Cheung, S. S. (2013). The effect of cooling prior to and during exercise on exercise performance and capacity in the heat: a meta-analysis. *British Journal of Sports Medicine*.

Vanhatalo, A., Fulford, J., Bailey, S. J., Blackwell, J. R., Winyard, P. G., and Jones, A. M. (2011). Dietary nitrate reduces muscle metabolic perturbation and improves exercise tolerance in hypoxia. *The Journal of Physiology,* 589(22), 5517-5528.

Vanhatalo, A., Jones, A. M., Blackwell, J. R., Winyard, P. G. and Fulford, J. (2014). Dietary nitrate accelerates postexercise muscle metabolic recovery and O2 delivery in hypoxia*. J. Appl. Physiol. (1985)*, 117(12), 1460-1470.

Wardenaar, F.C., Beaumont, J.S., Boeckman, J., van Geffen, B., and Vanos, J.K. (2024) Analysis of potential hydration opportunities during future football tournaments based on data from the 2018 FIFA World Cup. *Sci Med Footb.*, 8(1), 32-36.

Wylie, L. J., Mohr, M., Krustrup, P., Jackman, S.R., Ermidis, G., Kelly, J., Black, M.I., Bailey, S. J., Vanhatalo, A. and Jones, A. M. (2013). Dietary nitrate supplementation improves team sport-specific intense intermittent exercise performance. *European Journal of Applied Physiology*, 113(7), 1673-1684.