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Review

Living, training and playing in the heat: challenges to the football player and strategies for coping with environmental extremes

R. J. Maughan[1], S. M. Shirreffs[1], K. T. Ozgünen[2], S. S. Kurdak[2], G. Ersöz[3], M. S. Binnet[4], J. Dvorak[5]

[1]School of Sport and Health Exercise Sciences, Loughborough University, Loughborough, UK, [2]Department of Physiology, Division of Sports Physiology, Faculty of Medicine, Çukurova University, Balcali, Adana, Turkey, [3]College of Physical Education and Sports, Ankara University, Ankara, Turkey, [4]Ibn-i Sina Hospital, Ankara University School of Medicine, Ankara, Turkey, [5]Schulthess Clinic, F-MARC, Zürich, Switzerland

Corresponding author: R. J. Maughan, School of Sport and Health Exercise Sciences, Loughborough University, Loughborough LE11 3TU, UK. Tel: +44 1509 226329, E-mail: r.maughan@lboro.ac.uk

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Dehydration and hyperthermia both, if sufficiently severe, will impair exercise performance. Dehydration can also impair performance of tasks requiring cognition and skill. Body temperature may exceed 40 °C in competitive games played in hot weather, but limited data are available. Football played in the heat, therefore, poses a challenge, and effects on some aspects of performance become apparent as environmental temperature increases above about 12–15 °C. Prior acclimatization will reduce the impact of high environmental temperatures but provides limited protection when humidity is also high. Ingestion of fluids is effective in limiting the detrimental effects on performance: drinks with added carbohydrate and electrolytes are generally more effective than plain water and drinks may be more effective if taken cold than if taken at ambient temperature. Pre-exercise lowering of body temperature may aid some aspects of performance, but the efficacy has not been demonstrated in football.

Major sporting events are often held in unfavorable environmental conditions. Exercise at altitude or in large cities with high levels of air pollution, as well as at extremes of heat and cold, provides additional challenges for the athlete and for those responsible for their medical care. Across the whole spectrum of sporting events, however, no threat to the health and performance of the athlete is greater than that posed by prolonged hard exercise in a hot and humid environment. In sports where performance can be quantified, as in track and field athletics or marathon running, performance is almost invariably impaired in these conditions (McCann & Adams, 1997; Montain et al., 2007). There is also a serious threat to health, and the history of major endurance events held in hot weather provides many examples of serious, although rarely fatal, heat illness.

The implications of environmental extremes for the health and performance of football players have received less attention, but the modern game began as a winter season sport in Northern Europe, where cold is more often a problem than heat. Today, football is a global game with more than 250 million players in every continent. The challenges of playing in summer heat were well illustrated during the final match of the 2008 Beijing Olympic Games, where air temperatures on the field reached 42 °C (FIFA, 2009). Although reports of serious heat illness are rare and deaths are extremely uncommon, they do occur. In American football, heat-related fatalities are less uncommon, and are a recognized problem affecting players at all levels of competition (Bergeron et al., 2005).

All athletes will be affected by the environmental conditions, but players who are accustomed to living, training and competing in temperate climates are placed at a particular disadvantage when a game must be played in hot humid regions against a local team accustomed to those conditions. Strategies must be devised to minimize this disadvantage, but the options are limited, in part by the rules of the game, which limit access to fluid during playing time. A range of interventions is available to the player who must play in a hot climate, however, and these include prior acclimation, a rehydration strategy and also possible cooling interventions.

Exercise in the heat

Only about 20–25% of the energy released by muscle metabolism during exercise is used to do work, with the remaining 75–80% appearing as heat that must be lost from the body surface (Nadel, 1988).

However, when the environmental temperature exceeds skin temperature, heat is inevitably gained by these avenues in addition to the metabolic heat production. Heat loss by evaporation is effective in dissipating large amounts of heat and will generally limit the rise in core temperature during exercise to no >2–3 °C in all but the most extreme conditions. Sweating leads to a loss of body water, but electrolytes, especially sodium, are also lost in variable amounts depending on the sweating rate and the sweat composition. Small losses are well tolerated, but at some point dehydration may lead to performance impairment and an increased risk of heat illness, and large sodium losses may increase the risk of muscle cramps (Shirreffs et al., 2006).

The response to exercise in the heat is determined in part by the intensity of the exercise and in part by the degree of heat stress. The sweating response is influenced more by the relative intensity of exercise, expressed as a fraction of individual aerobic capacity, than by the absolute exercise intensity (Greenhaff & Clough, 1989). Other factors, such as the type and amount of clothing worn and the physiological characteristics of the individual, will also play a role. Soccer is a game of intermittent work where players generally perform low-intensity activities for $>70\%$ of the game, but heart rate and body temperature measurements suggest that the total energy demand is high (Bangsbo et al., 2006). The high energy demand is largely accounted for by the repeated high-intensity efforts that players are called upon to perform. A top class player performs about 150–250 brief intense actions during a game. The total distance run by a player during a game depends on many different factors, including the level of competition, the player's position and the playing style and fitness level of the individual. The playing pattern of the opponent may also have a considerable influence. At the elite level, male outfield players typically cover a total distance of about 10–13 km, making football an endurance sport. In elite players in the Spanish Premier League and in the Champions League, the mean ($\pm$ SD) distance covered by 300 outfield players was 11.4 ± 1.0 km, with a range from 5.7 to 13.7 km (Di Salvo et al., 2007). This indicates that not all players will cover large distances in all games.

Even when the total distance covered is not high, the physical demands of football are greatly increased by the fact that >600 m are typically covered at sprinting speed and about 2.4 km at high intensity. Over the whole duration of the game, heart rate will typically average about 85% of maximum and the oxygen demand is about 70% of the maximum oxygen uptake (VO_{2max}). It should be noted, although, that these values refer to measurements made in temperate or cool conditions. At the same power output, exercise in the heat results in a higher heart rate and a higher cardiac output, as well as higher core and skin temperatures, compared with exercise in a cooler environment (Rowell, 1983). These cardiovascular and metabolic alterations are accompanied by a greater subjective sensation of effort in the heat, and these various factors combine to cause a reduction in exercise capacity in a way that is as yet unknown. There are also some metabolic differences: exercise in the heat is usually accompanied by a higher blood lactate concentration and there is some evidence of a faster rate of depletion of muscle glycogen (Jentjens et al., 2002). The glycogen content of the exercising muscles is lower at the point of fatigue in cold or temperate environments than it is in the heat, however, suggesting that substrate depletion is not the primary cause of fatigue during exercise in the heat (Parkin et al., 1999). Some aspects of cognitive function may also be adversely affected by both hyperthermia (Racinais et al., 2008) and hypohydration (Lieberman, 2007) with implications for decision making and the execution of skilled movements during match play, but there is very little information that is directly relevant to football match play (McGregor et al., 1999; Edwards et al., 2007).

Performance in endurance events – which can be defined as those lasting longer than about 20–30 min – is reduced under conditions of heat stress, and there seems to be no way of avoiding some impairment of performance. The factors responsible for this early fatigue are not well understood, but seem to be different from those that cause fatigue in cool weather (Maughan et al., 2007b). In a study carried out under laboratory conditions, endurance time on a cycle ergometer at a power output that could be sustained for 94 min at a temperature of 10 °C was reduced to 81 min when the temperature was increased to 20 °C and to 52 min when the temperature was increased to 30 °C (Galloway & Maughan, 1997). This suggests that the effects of increasing environmental temperature on performance may be apparent at much lower temperatures than most people suppose to be the case. Performance was also lower at 4 °C that at 10 °C, suggesting that there may be an optimum temperature, although this will vary with exercise intensity, clothing worn and other factors. In the conditions prevailing at many competitive events, the reduction in exercise capacity would likely be substantial. It is usually recommended that hard exercise should not be undertaken when temperature and humidity are high, but major sporting events are seldom or never cancelled even when conditions are extreme. If the athlete is dehydrated before exercise begins, the reductions in performance, which are observed in the heat, are greatly magnified (Sawka, 1992).

Some degree of exposure to heat even without exercise is inevitable when living in a hot climate, and this may result in a variety of symptoms, including headache, nausea, dizziness and a sensation of fatigue (Wenger, 1988). Even in the absence of heat exposure or exercise, mild dehydration resulting from restriction of fluid intake may produce unwanted symptoms of fatigue, lethargy and headache in <24 h (Shirreffs et al., 2004). Some exposure to the local conditions is inevitable when championship events played over several days take place in hot countries. In the hours when competitors are exposed to the local climatic conditions, they are likely to become dehydrated, with the potential for negative effects on subsequent exercise performance. In one laboratory study, where sauna exposure was used to induce dehydration equivalent to 2.5% of body weight before exercise, a 30% reduction in power output occurred in a test (which was carried out in cool conditions) lasting about 7 min (Nielsen et al., 1982). Another carefully controlled experiment, carried out under race conditions, showed that running speed in simulated races at distances of 1500–10 000 m was 3–6% slower when diuretic administration was used to dehydrate runners by 1.5–2% before the start of the races (Armstrong et al., 1985).

Thermoregulation and fluid balance in football

Many studies have investigated the effects of football training and match play on body core temperature and on fluid and electrolyte balance in different environmental conditions, and several reviews of these studies have been published (Maughan & Leiper, 1994; Shirreffs et al., 2006). Evaporation of sweat secreted onto the skin helps to limit the rise in core temperature, but the core temperature during match play typically reaches 39–40 °C (Shirreffs et al., 2006). Severe heat stress seems to be less common in soccer than in some other team games, but in a single youth soccer tournament played in hot conditions in the United States, a total of 34 players were treated for heat exhaustion (Kirkendall, 1993). Post-match rectal temperatures in excess of 39 °C are common, and perhaps even normal, in warm weather competitive games: in an unpublished report of a Swedish first division match quoted by Bangsbo (1993), all players had a rectal temperature in excess of 39 °C at the end of the game. Individual values in excess of 40 °C have been reported in the published literature (Ekblom, 1986; Smodlaka, 1978), and such high values raise concerns for the well-being of the players involved. Because measurements in these studies were made only at the end of games, it is not known whether higher values may have occurred earlier in the game.

Several recent studies have reported data on the sweat losses of elite players during training and match play in a range of different environmental conditions. The mean sweat losses of squads performing similar training sessions of about 90 min duration are, unsurprisingly, generally higher in hot (32 °C: 2.2 L; Shirreffs et al., 2005) and temperate (26 °C: 2.0 L; Maughan et al., 2004) environments than in cool environments (5 °C: 1.7 L; Maughan et al., 2005). More striking, however, is the large inter-individual variability in sweating responses, even when all measures are made in a single training session where all players are performing the same training and environmental conditions are the same. Drinking behavior in these studies also varied greatly between individuals, with some players drinking very little while others, with the same access to fluids, consumed close to 2 L during a single training session. Because of the logistical difficulties in making measurements in a competitive environment, only a limited amount of information is available on the mass (sweat) loss of soccer players during match play. Ekblom (1986) reported a mass loss of 1–2.5 kg during games played in temperate climates, with the loss being greater in international-level games and less in players performing at a lower standard. A body mass loss of 1.0 kg (1.4% of the pre-exercise body mass) was reported by Leatt (1996) in a study where players consumed 1 L of fluid during the game, indicating a total sweat loss of close to 2 L. Maughan et al. (2007c) reported values from two teams engaged in a competitive match played at an about 6–8 °C: mean ± SD sweat loss of players amounted to 1.68 ± 0.40 L, and mean fluid intake was 0.84 ± 0.47 L ($n = 20$), with no difference between teams. Much larger losses were reported by Mustafa and Mahmoud (1979) to occur in some international level players playing in hot conditions. In games played in the heat, sweat losses of almost 4 L were observed in some individual players, although the mean loss was 2.0–2.5 L: when players performed in cooler (13 °C) conditions, a much smaller mean sweat loss of 0.85 L was reported. Sweat losses of up to 3.5 L in some individuals were also reported by Bangsbo (1993). Aragón-Vargas et al. (2009) have recently reported mean sweat losses of 4.4 L in professional players in a match played at a WBGT of 31.9 °C with individual values as high as 6.2 L: it should be noted, however, that the measurement period began approximately 1 h before kick-off and that the final measurement was made about 15 min after conclusion of the game. Nevertheless, these are very high rates of fluid loss. It is likely that such losses would seriously impair both physical and cognitive performance if fluid was not ingested to limit the hypohydration incurred.

Prophylactic interventions

To minimize the adverse impact of hot humid conditions, several issues need to be addressed. These include the development and implementation of a rehydration strategy, an acclimatization strategy, the use of cooling interventions before and during exercise, modifications to the usual warming up routines, the clothing worn and the lifestyle issues associated with living, training and playing in a challenging environment.

Acclimatization strategies

Regular exposure to hot humid conditions results in a number of physiological adaptations, which together reduce the negative effects of these conditions on exercise performance and reduce the risk of heat injury (Wenger, 1988). The magnitude of the adaptation to heat that occurs is closely related to the degree of heat strain to which the individual is exposed. The two primary determining factors for adaptation to hot humid conditions are the rise in body temperature that occurs and the sweating response that is induced.

Adaptation therefore depends largely on the intensity and duration of exercise and on the environmental conditions, and there is clearly an optimum set of conditions for the most effective acclimatization. Some adaptation is seen within the first few days of exposure to exercise in the heat, and even a few sessions of exercise in the heat are beneficial (Lind & Bass, 1963). Full acclimatization is most effectively achieved when the duration of exercise in the heat is about 100 min, and that there is no advantage in spending longer periods than this exposed to heat (Lind & Bass, 1963). Exercise at higher intensities for shorter periods of time may be equally effective in bringing about beneficial adaptations: even 30 min/day at an intensity equal to about 75% of maximum oxygen uptake (VO_{2max}) was as effective as 60 min at 50% of VO_{2max} (Houmard et al., 1990). Exercising in the heat every third day for 30 days resulted in the same degree of acclimatization as exercising every day for 10 days (Fein et al., 1975). This is because it takes time to reverse the adaptations to heat; for subjects who are completely acclimatized, some of the improved responses are still present after as long as 21 days in a cool climate (Pichan et al., 1985). Adaptation is more or less complete for most individuals within about 7–14 days, and hence there may be no advantage to living for prolonged periods in a hot climate (Montain et al., 1996). It is equally clear that regular endurance training in temperate conditions confers some protection (Piwonka et al., 1965): endurance-trained subjects are already partially adapted, and it has to be admitted that we do not know how complete this process is for highly trained Olympic athletes. The endurance athlete who trains wearing extra clothing to induce sweating even in a cool climate will also show some degree of heat acclimation, but this can be further enhanced by a period of training in the heat (Dawson, 1994). There can be no doubt that a period of acclimatization is necessary for all athletes if they are to achieve optimum performance in hot humid conditions, but this must be set against the demands of other competitions. Acclimatization probably becomes even more important when repeated rounds or events have to be completed as in a major tournament.

In some sports, athletes may choose to spend some days or even weeks in a hot environment before a major competition. Such an option is seldom open to the professional football player except at a very few competitions such as the World Cup. More often, players living in cold climates must be prepared to travel to thermally challenging locations with little time to prepare, thus limiting the opportunities for acclimation. This places a greater emphasis on other coping strategies.

Active cooling strategies

Strategies that can reduce body temperature before exercise have long been recognized to have the potential to improve endurance capacity (Veghte & Webb, 1961). The rationale for this intervention is that a reduced pre-exercise body heat content would result in an increased margin for metabolic heat production, leading to an extension of the exercise time before the attainment of a critical temperature that would cause exercise to be terminated (Marino, 2002). Gonzalez-Alonso et al. (1999) showed that lowering initial esophageal temperature by water immersion for 30 min before exercise and attenuating the rise in esophageal temperature by wearing a water-perfused jacket during exercise have separate beneficial effects in extending cycling time to exhaustion in the heat. Pre-cooling maneuvers such as exposure to cold air (Lee & Haymes, 1995) or water immersion (Booth et al., 1997; Gonzalez-Alonso et al., 1999) are generally impractical in the athletic, occupational and military fields because of problems regarding the time required to achieve sufficient body cooling to improve exercise performance (Marino, 2002). Likewise, wearing a cold vest (Cotter et al., 2001) may reduce the core temperature but is restrictive and increases the weight that has to be carried. Cooling vests are also of limited use in promoting cooling of hyperthermic athletes (Lopez et al., 2008). Finally, these strategies can also cause significant discomfort due to excessive cooling of the skin.

In a game like football, there may be opportunities for active cooling strategies to be used during the half-time break, but the time available may be too short to bring about a meaningful reduction of body temperature. Selkirk et al. (2004) compared the effects of active and passive cooling during recovery intervals of 30 min duration in firefighters exposed to work-heat stress for periods of 50 min. They found that active cooling – achieved by immersion of the hands and forearms in cold water or by exposure to a water vapor mist – was both effective in reducing the rate of rise of rectal temperature and heart rate and also that both prolonged the total exposure time. Forearm immersion in cool (18 °C) water was more effective than the misting spray, and about 70% of the cooling was achieved during the first 10 min of the cooling session. Armstrong et al. (1996) showed that cooling of hyperthermic casualties in a road race was achieved much more effectively by whole-body immersion in ice water than by application of cold, wet towels to the skin. The former method, although effective, is impractical in the short-time interval available to players at the half-time break. The cooling rate would likely be lower in individuals with a lower core temperature, and it should be noted that the initial core temperature of the group cooled by water immersion was substantially higher (41.7 °C) than that of the group cooled by application of wet towels (40.4 °C). Cooling with wet towels achieved a rate of fall of core (rectal) temperature of 0.11 °C/min. These results suggest that active cooling during even short breaks might assist in the prevention of hyperthermia.

Rehydration

Daily water turnover for sedentary individuals living in a temperate environment is typically about 2–3 L. In hot environments, sweat losses will be increased even without exercise being performed and athletes who move from a temperate region to a tropical or desert region will require an increased fluid intake to match the increased loss. The water requirement will be increased even for resting individuals and will thus affect team support staff as well as players. Sweat losses during training can add 0.5–3 L/h depending on the training intensity, the clothing worn, the climatic conditions and characteristics of the individual. For athletes training intensively in hot climates, fluid needs can reach 10–15 L/day, representing about 25–30% of the total body water content of the average young male. Failure to replace sweat losses – if these are sufficiently large – will impair exercise capacity and will increase the risk of heat illness. Athletes who incur a fluid deficit will also lose the beneficial effects of acclimatization: heat-acclimatized individuals who are hypohydrated respond to heat stress as though they are unacclimatized (Sawka & Pandolf, 1990). There may be some situations in which it is sufficient to advise athletes simply to drink according to the dictates of thirst (Noakes, 2003), but it is not clear that this can always be relied upon when access to fluid is limited by the rules of the sport or where players have learned to ignore normal thirst signals.

Hard exercise may reduce the availability of ingested fluids by slowing the rates of gastric emptying and intestinal absorption (Maughan et al., 1990). More recently, however, Leiper et al. (2001, 2005) have shown that gastric emptying rate is slowed during football match play, but that ingested fluids continue to be emptied into the small intestine where they are available for absorption. Drinking significant amounts of fluid during training is not part of the normal routine for many players from temperate regions, but must be practiced when training in hot climates or when preparing for hot weather competition. From a hydration perspective, the composition of the fluids that players choose to drink is generally less important than the total intake, but there is good evidence that the effects of fluids and carbohydrates in improving exercise performance are independent and additive (Below et al., 1995). Taste is also a key factor in promoting intake and becomes more important when a high fluid intake is required (Passe, 2001). Although drinking plain water does confer advantages, a properly formulated sports drink is likely to be the best option in most situations (Maughan, 2001; Hulston & Jeukendrup, 2009).

Athletes may be tempted to believe that the need for fluid replacement will decrease as they become adjusted to the heat, but heat acclimatization will actually increase the requirement for fluid replacement because of the enhanced sweating response. Athletes therefore not only have to drink more in the heat, but also have to drink even more as they become acclimatized and begin to sweat more. If dehydration is allowed to occur, the improved ability to tolerate heat, which results from the acclimatization process, will disappear completely (Sawka & Pandolf, 1990). There is no way of adapting to dehydration: any attempt to do so is futile and dangerous. Several studies have shown that some players are dehydrated – at least as assessed by urine parameters such as osmolality or specific gravity – when they report for training (Shirreffs et al., 2006) or for competitive games (Maughan et al., 2007b).

Monitoring of body mass changes before and after training can give some indication of the extent of sweat loss in training: each kilogram of weight loss after correction for the weight of any ingested fluid represents a loss of approximately 1 L of sweat (Maughan et al., 2007a). Athletes should aim to drink sufficient fluid after exercise to replace about 1.5 times the net fluid deficit to allow for ongoing urinary and other losses (Shirreffs et al., 1996). Fluids or food consumed after training must include sufficient electrolytes – especially sodium – to replace the losses in sweat (Shirreffs & Maughan, 1998b). If large volumes of plain water are consumed, urine production is stimulated because of the fall in the plasma osmolality and sodium concentration. As well as preventing a diuresis, adding some sodium can help to maintain the body's thirst mechanism. Where training sessions or games are close together, the recovery from the first session is part of the preparation for the next and the composition and amount of food and fluid ingested will have a strong influence on the recovery of the muscle and liver glycogen stores and on the restoration of water and electrolyte balance.

Athletes are often advised to avoid drinks that contain caffeine or alcohol because of the diuretic action of these agents, but it may not be wise to suggest that such drinks be avoided altogether. Any restriction on the choice of drinks may have the unwanted effect of reducing total fluid intake at a time when athletes are finding it difficult to achieve the necessary intake. Caffeine withdrawal symptoms can be unpleasant for those accustomed to a regular intake, and might disrupt preparation. Although both alcohol and caffeine have undoubted diuretic effects, it is unlikely that a significant diuretic action will result from a modest intake of these agents in an athlete who is already hypohydrated. Strong alcoholic drinks should certainly be avoided, but there does not appear to be sufficient evidence to warrant the prohibition of tea, coffee or cola drinks or of drinks with a low alcohol content (Shirreffs and Maughan, 1997; Shirreffs, 2001).

Daily measurements of body mass – made at the same time of day, wearing the same clothes and under the same conditions – can give some indication of progressive sweat loss, but may be complicated by changes in training load, food intake, bowel habits and other factors related to the new environment when players are away from home. Monitoring of urine parameters, including volume, color, conductivity, specific gravity or osmolality may help identify individuals suffering from dehydration (Shirreffs & Maughan, 1998a) and can provide feedback that athletes find helpful in establishing their fluid requirements. Such measurements are only useful, however, if care is taken to standardize sample collection and analysis.

The temperature of drinks ingested just before or during exercise may be an important factor for two reasons. The palatability of cool drinks is generally perceived as being more acceptable, and this can be important when large volumes of fluid have to be ingested (Passe, 2001). More recently, Lee and Shirreffs (2007) showed that the thermoregulatory responses to endurance exercise are influenced by the temperature of ingested drinks: this effect appears to be due in part to a direct effect of the heat content of the drinks on body heat content and in part to the effects of drink temperature on cutaneous vasodilatation and sweating responses. The same authors have also shown that ingestion of a cold (4 °C) drink before and during exercise resulted in a longer time to fatigue during cycle ergometer exercise in a hot environment compared with ingestion of the same volumes of a warm (37 °C) drink (Lee et al., 2008).

Conclusion

Living, training and competing in hot climates will remain a challenge for the competitive football player. Players can adopt various strategies, including acclimation, hydration and cooling strategies, to minimize the impact of the environment on their playing capabilities and to protect themselves against the possibility of potentially harmful hyperthermia and hypohydration.

Key words: hydration, dehydration, thermoregulation, sweating, fatigue, soccer.

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