Training and playing football in hot and/or humid environments

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Chapter

TRAINING AND PLAYING FOOTBALL IN HOT AND/OR HUMID ENVIRONMENTS

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ABSTRACT

Football (soccer) is played in various environments and, in some parts of the world, domestic and international matches are performed in challenging environmental conditions where the ambient temperature may exceed 30°C with a high relative humidity (>60%). The extra burden of thermal stress that is added to the physical demand associated with match play compromises the footballers' fatigue resistance. Many factors, such

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as thermoregulatory, cardiovascular and/or metabolic stress, may contribute to the reductions in match performance capacity (i.e., shorter distance covered in the second vs. first half and toward match-end with decrements in high-intensity running activities in the last 15-min period) and match-related fitness (i.e., post-match jump height and repeated-sprint ability) in the heat. Although heat stroke is unusual in football, the consequences of hyperthermia (i.e., core temperature >39°C) are serious, possibly participating in the development of health issues.

Heat acclimatization/acclimation appears as the primary strategy to minimize the thermal stress and the physiological risks of heat-related illnesses when playing football in hot conditions. This can be partly achieved after 6-10 days of training in the heat, with a targeted minimal core temperature of 38.5°C for at least 60 min in each training session, associated to elevated skin temperature and profuse sweating. Another strategy is to ensure that footballers are well hydrated at all times, while enough fluid should be provided before, during, and after matches. Manipulating warm-up and/or implementing cooling interventions (e.g., cold-water immersion, cooling garments) before each match or training or during half-time could be beneficial to optimize physiological readiness for football competition in the heat.

Hence, the aims of this chapter are to present (i) the football match- and training-induced responses when performed in hot and/or humid conditions and (ii) the strategies employed to better cope with such challenging environments.

1. Introduction

Football is played woldwide in various climatic conditions, with the temperature increase affecting match outcome. For instance, in the Gulf Region, the sun can rapidly increase the ambient temperature >40°C where the evening relative humidity (RH) can further augment the severity of the environment. In these conditions, the likelihood of winning for a visiting non-acclimatized football team decreases by 3% for every 1°C rise in ambient temperature compared to home heat-acclimatized opponents (Brocherie et al., 2015a).

Compared to temperate to cool (15-25°C) environments, playing in warm to hot (25-45°C) conditions poses severe thermoregulatory, cardiovascular and perceptual challenges (Galloway and Maughan, 1997; González-Alonso, 2012; Nybo et al., 2014), hindering prolonged football performance in response to the development of hyperthermia (i.e., core temperature >39°C and quadriceps muscle temperature >40°C) (Mohr et al., 2010, 2012; Nybo et al., 2014). With the rate of evaporative heat loss further compromised in conditions of low wind speed and/or high RH, the footballers' physiological responses may be aggravated. In such hot and humid climates, the main risk would be to suffer from mild (i.e., heat rash, syncope and cramps) to serious (i.e., heat exhaustion, injury and stroke) exertional heat illnesses (Brocherie et al., 2015b). While the prevalence of heat illnesses in football is unclear, diverse heat-related incidents have been reported in various football codes (Mueller, 2008). In the best case scenario, this may result in aborting a football session or withdrawing from a match/tournament, whereas in the worst case scenario, it may lead to collapse during or soon after activity (Armstrong et al., 2007). It is noteworthy that there are large inter-individual differences in heat tolerance; whereas some individuals can tolerate core temperature >40°C without any significant loss of physical performance and health consequences (Byrne et al., 2006), others may be prone to collapse from exhaustion in the heat (i.e., those who are not acclimatized, use certain medications, are dehydrated or have recently been ill) (Armstrong et al., 2007; Robert, 2006).

Given the global warming around the world and the growing incidence of football events in hot-dry and/or hot-humid environments (e.g., 2014 FIFA World Cup and 2016 Olympic Games in Brazil), this chapter focuses on (i) the football match- and training-induced responses when performed in hot and/or humid conditions and (ii) the strategies employed to better cope with such challenging environments.

2. Football Match- and Training-Induced Responses to Hot and/or Humid Environments

Training and performing football competition in hot and/or humid environments is not an isolated phenomenon. Indeed, football FIFA World Cup tournaments are generally scheduled during the hottest months of the northen hemisphere (i.e., June-July; >30°C) often with high RH (>60% RH). In such conditions, core, muscle and skin temperatures can reach significantly elevated values (Aughey et al., 2014; Mohr et al., 2004, 2010, 2012; Nybo et al., 2013), potentially impairing football physical performance (Mohr et al., 2012). For instance, compared to thermoneutral condition (21°C), the total distance and the high-intensity running decreased respectively by 7% and 26% in elite footballers playing in the heat (43°C) (Mohr et al., 2012). Furthermore, less total distance is covered in the second half of matches played at 41°C *vs*. 35°C (Özgünen et al., 2010). This is accompanied by transient fatigue development and post-match decreases in jumping (-8.2%) and repeated-sprint (-2.6%) performances (Mohr et al., 2010). Similarly, during the last 2014 FIFA World Cup, high-intensity running activity decreased in matches performed under elevated heat stress (Nassis et al., 2015). It has been suggested that such reduction may allow footballers to preserve their sprinting ability (Link and Weber, 2017) and/or to maintain successful technical skills (Nassis et al., 2015). Interestingly, Mohr et al., (2012) also reported an improvement in peak sprinting (+4%) during a football match performed in hot condition. In the face of severe climatic conditions, footballers may maintain their capacity to perform the more intense and decisive actions (e.g., sprinting, accelerations) in matches by modulating the amount of low-intensity activity undertaken to ensure control of their internal heat load (Aughey et al., 2014; Duffield et al., 2009). However, it remains unclear if the decrease in high-intensity distance is the result of a pacing strategy or is corresponding to the maintenance of a given relative intensity as previously observed in endurance sports (Periard and Racinais, 2015).

An increase in muscle temperature may improve contractile function and nerve conduction velocity (Allen et al., 2008; Racinais and Oksa, 2010), potentially enhancing explosive skeletal muscle performance (e.g., sprinting) (Girard et al., 2015; Mohr et al., 2012). The precise biochemical and contractile mechanisms by which temperature elevations may improve single-sprint performance have not been fully outlined. Possible explanations may relate to: (i) a faster rate of phosphocreatine utilization (i.e., mainly in fibers expressing predominantly myosin heavy chain IIA isoform) (Gray et al., 2006); (ii) a greater anaerobic adenosine triphosphate turnover (i.e., activity of glycolytic enzymes: glycogen phosphorylase, phosphofructokinase, and lactate dehydrogenase) and adenine nucleotide degradation at high muscle temperature (Febbraio et al., 1996; Steinen et al., 1996); and (iii) an accelerated muscle fiber conduction velocity, as individual sarcomeres become more rapidly activated at higher muscle temperatures (Farina et al., 2005; Gray et al., 2006).

However, an increase in core temperature is associated with increased fatigue development during sustained maximal voluntary isometric contractions (Racinais et al., 2008) and impairs repeated-sprint ability (i.e., decrements in propulsive power, step frequency and vertical stiffness) (Drust et al., 2005; Girard et al., 2016, 2017). Reportedly, mean power output was impaired during repeated-sprint exercise (5 × 15 s sprints – 15 s of recovery) when both core (~39.5°C) and muscle (~40.2°C at a depth of 3 cm) temperatures were elevated (Drust et al., 2005). Hence, the high core temperature as well as the thermal gradient between the skin and the environment seem the primary factors limiting repeated-sprint performance in the heat, which also negate the beneficial effect of a higher muscle temperature.

Finally, the rise in core and muscle temperatures that occurs during football match and/or training in the heat, along with the narrowing of the thermal gradient between the skin and the environment, increases the cutaneous circulatory requirements necessary for the maintenance of thermal homeostasis. Thus, as football practice is maintained, cardiovascular strain develops as greater blood flow is directed towards the peripheral circulation (Sawka et al., 2011). This heat-related circulatory adjustment decreases the central blood volume and is associated with reductions in prolonged football performance. As previously mentioned, the combined effect of an increase in core, muscle and skin temperatures, cardiovascular strain, and central and peripheral fatigue results in a decrement of high-intensity running, and lower distance covered toward match-end (Mohr et al., 2012; Nassis et al., 2015). However, heat-acclimatized and well-hydrated footballers can commonly compete in the heat while achieving high core temperature without experiencing other symptoms than exercise-associated fatigue. Different strategies can therefore help footballers to cope with the heat stress.

3. Strategies to Counteract Heat Stress

3.1. Heat Acclimatization/Acclimation

Heat acclimatization (i.e., training in a naturally hot ambient condition) or acclimation (i.e., training in an artificially hot indoor environment) appears as the primary strategy to minimize the thermal stress and the physiological risks of heat-related illnesses when football competition is organized in hot-dry or hot-humid conditions. Although regular exercise in temperate condition elicits partial heat acclimatization (Armstrong et al., 1988), it cannot replace the benefits induced by consecutive days of training in the heat (Gisolfi and Robinson, 1969;, Nadel et al., 1974). Consequently, before any match or tournament in hot-dry or hot-humid environments, footballers should train in the heat in order to benefit from cardiovascular (e.g., plasma volume expansion, reduced heart rate response), thermoregulatory (e.g., decreased core temperature, increased skin blood flow, decreased core temperature threshold for the onset of sweating, fluid-electrolyte balance), metabolic (e.g., attenuated carbohydrate metabolism), and perceptual (e.g., enhanced thermal comfort) adaptations (Périard et al., 2015; Sawka et al., 2011; Taylor, 2014). These changes have been reported to enhance endurance (i.e., cycling) performance both in the laboratory (Nielsen et al., 1993) and in the field (Racinais et al., 2015a). Noteworthy that such adjustments progress more quickly in highly-trained athletes (up to half the time) compared to untrained individuals (Armstrong et al., 1988; Pandolf et al., 1977).

Most of these adaptations occur within the first week of heat acclimatization and develop more slowly in the following 2 weeks (Flouris et al., 2014; Ladell, 1951; Robinson et al., 1943). That said, while sudomotor and cardiovascular adaptations were reported after only a few days of training in the heat (Karlsen et al., 2015), a miminum of 5-6 days (ideally prolonged to 2 weeks) heat acclimatization period is recommended for optimal football performance (Buchheit et al., 2011; Grantham et al., 2010). Heat acclimatization/acclimation sessions should last at least 60 min per day to induce sufficient increase in core, skin and muscle temperatures, and stimulate profuse sweating. Its implementation during 5-7 days permits to offset some of the heat-induced aerobic performance decrement in trained athletes (Chalmers et al., 2014; Racinais et al., 2012). Of note, heat acclimatization in hot-dry environment improves exercise in hot-humid condition (Fox et al., 1967) and vice-versa (Eichna et al., 1945). While it is generally recommended to predominantly acclimatize to the environment in which competition will be compete (Racinais et al., 2015b), it might also be beneficial for footballers to train in hot-humid environments at the end of their heat acclimatization process to further stress the cardiovascular and thermoregulatory systems (Racinais et al., 2015b).

In reference to football, repeated heat exposures increases performance of high-intensity, but not maximal, intermittent running in the heat (Sunderland et al., 2008; Racinais et al., 2012). Meanwhile, a 10-day acclimation period resulted in a 2% increase in peak power output during a 40-min intermittent-sprint protocol in the heat (Castle et al., 2011). The ability of a footballer to perform during tournaments held in hot ambient condition is a function of his ability to acclimatize and recover between games. Nybo et al., (2013) demonstrated that the heat stress does not aggravate the recovery response from football-related intermittent exercise associated with elevated muscle temperature and markers of muscle damage, delayed resynthesis of muscle glycogen, and impaired post-match performance. Interestingly, creatine kinase – a marker of muscle damage – recovered more rapidly in the 24- to 48-h period following football performance in hot *vs*. thermoneutral conditions (Nybo et al., 2013). This may indicate that the recovery of match-related fitness alterations relates to exercise- rather than heat-induced factors.

The magnitude of adaptation depends on the intensity, duration, frequency and number of heat exposures (Périard et al., 2015). Other confounding factors including training characteristics (e.g., athletes type and level, exercise mode, duration and intensity), body composition, clothing and/or weather variables (Brocherie et al., 2014, 2015b; Racinais et al., 2015b) would influence, alone or in combination, the magnitude of heat-related effects on exercise performance. Another point to bear in mind is that as acclimatization develops, a progressive lower training stimulus (i.e., decrease in relative exercise intensity) may occur and may limit the amount of adaptation (Taylor, 2014). It is therefore important to increase the duration and/or intensity of the heat-exercise training sessions. In this view, it has been proposed to use isothermic protocols (i.e., controlled hyperthermia to a core temperature of at least 38.5°C) to boost the adaptations (Garrett et al., 2009; Patterson et al., 2004). However, such protocols are laboratory-based and may not allow football-specific training. Consequently, it has also been proposed to use heart rate readings to control training intensity as acclimation develops (Periard et al., 2015). Altogether, this suggests that a careful individual monitoring is necessary to optimize footballers' heat adaptive response.

The rate of decay of heat acclimatization is generally slower than its induction, allowing maintenance of the majority of the physiological benefits for 2-4 weeks (Daanen et al., 2011, 2018; Flouris et al., 2014; Weller et al., 2007). Specifically, while the decay in core temperature is ~2.5% per day, it seems that the longer the heat acclimatization/acclimation is, the lower the decay is. Moreover, during this period, individuals re-acclimatize faster than during the first acclimatization period (Daanen et al., 2018; Weller et al., 2007). However, as with its induction, heat acclimatization decay also varies between individuals (Robinson et al., 1943) and differs between parameters (i.e., core temperature and sweat rate) (Daanen et al., 2018). It is therefore recommended to undergo an acclimatization/acclimation procedure in the months preceding an important event in the heat to determine the individual rate of adaptation and decay (Bergeron et al., 2012; Racinais et al., 2012).

While the ergogenic effect of heat acclimatization/acclimation on well-trained endurance athletes' performance in temperate condition is still debated (Minson and Cotter, 2015), this approach is of particular interest to speed up the footballers' adaptations (Buchheit et al., 2011; Racinais et al.,

2014) with possible transfer to football-specific game behavior (Brocherie et al. 2015a).

3.2. Hydration

Footballers are generally less concerned about the effects of hypohydration (i.e., a body water deficit) (Shirreffs, 2010) than endurance athletes (Sawka et al., 2011). That said, securing *ad libitum* hydration prior to, during and in the recovery periods is integral to physical performance and safety during football training and competition in the heat (Bergeron et al., 2012, Racinais et al., 2015b). A particular attention should be given to the limited opportunity to drink during matches (re-hydration breaks are rarely implemented despite the recommendations made by the FIFA) to minimize dehydration (i.e., <2% percent body weight deficit) (Maughan et al., 2010; Mohr et al., 2010, 2012; Sawka et al., 2007). During a sporting activity, not only hydration depends on fluid availability, but also on gut absorption rate. As such, it is primordial to initiate any football-related activity euhydrated rather than simply trying to adjust hydration during the activity. In this view, it is advisable to prescribe fluid intake of 5-6 ml of water per kg of body mass, at a frequency of every 2-3 h, as well as 2-3 h prior to either training or competing in the heat (Racinais et al., 2015b).

Post-activity rehydration should be implemented within 1 h following cessation of exercise (Racinais et al., 2015b). Because sweat rates and sweat composition depend on the ambient temperature, humidity, exercise intensity, and vary greatly among individuals (Shirreffs et al., 2006), fluid loss via sweating can amount up to 5 L in hot-humid conditions (*vs*. 3 L in temperate conditions). An increase in sodium intake (e.g., 3.0 g of salt added to 0.5 L of a carbohydrate-electrolyte drink) may also be recommended for heavy sweaters (Racinais et al., 2015b). Furthermore, given that exercising in the heat increases the carbohydrate metabolism (González-Alonso et al., 1999b), recovery rehydration regimens should include sodium, carbohydrates and protein as this latter will also support fluid retention as well as better restoration of fluid balance (James et al., 2013). Yet, the impact of carbohydrate-electrolyte solution remains anecdotal regarding prolonged football-related intermittent high-intensity running performance in the heat (Morris et al., 2003).

Overall, no single recommendation is best for all individuals in every situation, and development of a personalized hydration strategy is essential for the protection of health (e.g., sickle cell trait) (Connes et al., 2008) and preservation of performance in the heat (Maughan & Shirreffs, 2008). Daily assessment of body weight and urin-specific gravity and/or colour and volume, as well as sweat sodium losses measurements (Maughan et al., 2010), can provide useful insights into the hydration state of the footballers.

3.3. Warming Up (and Cooling Down)

The primary purpose of the warm-up is generally to prepare footballers physically and mentally before a match or training. This also participates to injury prevention. Most of active (muscular work) and passive (hot water immersion or radio-diathermy) warm-up procedures are temperature-dependent, with both increased in core and muscle temperatures. This results in improved muscle force and power production, improved muscle blood flow, amplified muscle glycogen and carbohydrate utilization, accelerated oxyhaemoglobin dissociation, increased metabolic rate and enzymatic reactions, and changes in both mechanical efficiency and muscle fiber conduction velocities (Racinais et al., 2017).

However, performing a warm-up in a hot environment would exagerate the increase in core temperature and limit heat-storage capacity, thereby affecting repeated-sprint ability (Bishop and Maxwell, 2009) as well as prolonged exercise performance in the heat (Gregson et al., 2002; Gonzàles-Alonzo et al., 1999a). Consequently, in order to avoid a “heated-up” rather than a “warm-up” state, the active warm-up should be specifically tailored (e.g., modified exercise types and intensity, lower duration) before playing football in hot condition. A specific attention is required regarding the first part of the warm-up which is targeted on the thermoregulatory homeostatic systems (Grantham et al., 2010; Racinais et al., 2017).

There are other countermeasures that can be implemented before, during or after the warm-up, throughout exercise and during half-time breaks. External (e.g., application of iced garments, cooling vest, towels, cold water immersion or fanning) or internal (e.g., ingestion of cold fluids or ice-slurry) cooling techniques would contribute to minimize the increase in core temperature while (in some cases) maintaining optimal muscle temperature (Ross et al., 2013). While such approaches seem uneffective for single sprint (or first repetitions of repeated-sprint exercise) (Castle et al., 2006; Sleivert et al., 2001), repeated-sprinting performance could be enhanced using ice packs to precool the quadriceps (Castle et al., 2006) and/or mixed methods (involving multiple site ice pack/vest application) (Minett et al., 2011, 2012). However, others have not reported beneficial effects of pre-cooling on intermittent or repeated-sprint exercise performance (Brade et al., 2013; Cheung and Robinson, 2004; Duffield et al., 2003). Of note, the combination of different cooling strategies may have a larger impact than individual cooling techniques used independently (Racinais et al., 2015b).

Cooling technique implemented during half-time breaks may help to avoid early onset of fatigue in hot ambient condition. For instance, 5 min of leg cooling during half-time was effective to improve sprint performance in the second half of a football match (Yasumatsu et al., 2008). Although cooling garments induced a lower reduction in core temperature than cold water immersion or mixed methods, they present the practical advantage to be easily used during warm-up or recovery breaks to reduce the skin temperature without impacting muscle temperature.

CONCLUSION

Training or playing football in a hot-dry or hot-humid environment pose severes challenges to the human regulatory systems. Although a rise in muscle temperature enhances single sprinting performance, a rise in core and skin temperatures aggravates (i.e., earlier and larger changes) fatigue development and alters the football-related physical performance throughout a match. These alterations may be manifested differently depending on fitness level, position, hydration status and the level of hyperthermia attained. As such, it is important to mitigate the influence of heat stress on football performance, as well as the risk of heat illnesses. Various strategies – mainly heat acclimatization but also hydration regimen, warm-up and/or cooling interventions – have been proposed. However, because football performance depends directly on match-type scenarios, no single recommendation is best for all footballers in every situation, and development of a personalized approach is essential for the protection of health and preservation of physical performance in the heat. In any case, all strategies/procedures provided to footballers should be a-priori tested to minimize disturbance and evaluate its benefits.

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