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IMPACT OF ALTITUDE AND HEAT ON FOOTBALL PERFORMANCE

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KEY POINTS

- Football is played in diverse environmental conditions including extremes of heat and hypoxia.
- Both hypoxia and hot environmental conditions are associated with reductions in high-speed running and specifically sprint distances, both of which are likely to directly influence the match result.
- The negative effects of hypoxia can be counteracted in part by a period of altitude acclimatisation that is dependent on the altitude that match-play will be at. Nutritional preparation may include dietary nitrates as well as iron.
- Specific strategies may alleviate some of the heat-mediated decrements in football performance, with recommendations including specific heat acclimation protocols, mixed methods of cooling (pre-match and at halftime) and maintenance of hydration status prior to and within a game.
- Further research is required to modify and optimise interventions to meet football-specific match demands in the environmental extremes of heat and altitude.

INTRODUCTION

Football is universally participated in countries across the world. It is a high-intensity, intermittent sport, normally played over 90 min, consisting of two 45-min halves, with a 15-min interval. During match-play a player's physical performance is typically 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, in turn, dependent on the complex interaction of the cardiovascular and muscular system in supporting both aerobic and anaerobic energy provision for these football-specific activities (Bangsbo, 2014; Mohr et al., 2005). Game-defining events are often correlated to successful integration of high-intensity running and technical capacities. For example, a straight sprint is most often seen prior to a goal being scored. Thus, the sprint is reliant on transient repeated sprint ability and the successful completion of the shoot, being the technical skill (Mohr et al., 2012; Faude et al., 2012).

Within both competitive and non-competitive football matches, research has reported a reduction in total distances players achieved at high-intensity (2.6-57%) in hot (Mohr et al., 2003; Mohr et al., 2004; Grantham et al., 2010; Mohr et al., 2012; Mohr & Krustrup, 2013) and hypoxic (McSharry, 2007; Garvican et al., 2013; Nassis, 2013) environments (3.1-20%). Average heart rate and blood lactate accumulation have been reported to be unchanged within hot environments, despite the aforementioned alterations in total distances covered and high-intensity running (Mohr et al., 2012). During exercise in hypoxic environments greater perturbations in metabolic processes are observed (Billaut & Aughey, 2013) in tandem with reduced running capacity (McSharry, 2007; Garvican et al., 2013; Nassis, 2013).

The quantification of environmentally mediated decrements in football performance is important for governing bodies, medical officers and coaches (Mohr et al., 2012; Nassis, 2013). Elite clubs playing in the Union of European Football Associations (UEFA) Champions and Europa leagues could play in altitudes as high as 1,000 m above sea level. However, "low altitudes" classified as 500 m – 2,000 m are sufficient to produce minor impairments in aerobic performance, due to a reduction in partial pressure of oxygen (Gore et al., 2013; Bartsch et al., 2008). A reduction in maximum oxygen uptake will inhibit recovery from repeated sprint activity and inhibit total distances covered within a game. Aside from hypoxia, the same elite clubs may play in temperatures of >30°C during early and later stages of the season. Furthermore, two of the next three International Federation of Association Football (FIFA) World Cups (Brazil: 2014; Qatar: 2022) will be played in extreme heat of approximately 30°C and may possibly exceed >40°C, respectively. Exertional heat stress (EHS) elicits substantial decrements upon football-specific performance, due to increasing body temperatures amongst other multi-factorial mechanisms accelerating fatigue (Mohr et al., 2010; Mohr et al., 2012; Mohr & Krustrup, 2013).

Thus, high environmental temperatures and reductions in partial pressure of oxygen (as seen at high altitudes; hypoxia) can influence the completion of football-specific activities (Garvican et al., 2013; Mohr & Krustrup, 2013), recovery from high-intensity efforts (Mohr et al., 2003; Garvican et al., 2013) as well as the execution of skills (Banderet & Lieberman, 1989; Mohr et al., 2012; Nassis, 2013). Therefore, of interest are the potential interventions to negate any negative influences of environmental extremes, which may have a significant impact on the outcome of a match. To this end, it is important for coaches, performance analysts and sport scientists to

accurately quantify and understand the differences and intricacies of a player's activity profile, within environmental extremes and without, to optimise and rationalise interventions and practical recommendations (Di Salvo et al., 2006; Di Salvo et al., 2007).

HYPOXIA AND FOOTBALL

The misconception when exercising at altitude is that the composition of the atmospheric air is altered. However, this is untrue, as oxygen remains at 20.93% when at sea level or at moderate (2,000 m- 3,000 m) to high (3,000 m- 5,000 m) altitudes (Bartsch et al., 2008, Table 1). It is actually the reduction in partial pressure of oxygen (and other ambient gasses which decrease the higher you ascend) reducing the total number of oxygen molecules inspired with each breath. Although metabolic and physiologic adjustments are seen when performing intensity-matched exercise within low-oxygen environments, compared to sea-level environments, they are not sufficient to offset the reduced partial pressure of oxygen. Compromised oxygen supply, specifically the total number of oxygen molecules inspired per breath, reduces maximum oxygen delivery to the skeletal muscle compromising aerobic capacity (Billaut & Aughey, 2013) and elongating recovery from high-intensity intermittent activity (Garvican et al., 2013). Specifically, this arterial hypoxaemia (defined as a 3% reduction in arterial blood oxygen saturation compared to pre-exercise or in this case sea-level values) hinders the ability to work at a high-intensity and perform consecutive accelerations (Billaut & Aughey, 2013). These movements are central to game-defining moments within football match-play (Gregson et al., 2010; Faude et al., 2012).

Elite players native to sea level suffer a performance decrement (ability to complete and recover from high-intensity runs) when playing football in excess of 1,200 m (Nassis, 2013). During the FIFA World Cup 2010 (South Africa), games were played at a variety of "low" altitudes (0 m -1,400 m and 1,401 m-1,753 m) (Bartsch et al., 2008). It was evident during the tournament that an altitude in excess of 1,200 m reduced the total distance players covered by ~3.1% (p < 0.05) compared to sea level (0 m) (Nassis, 2013). Importantly, the ability to run at a high-intensity, i.e., sprinting, is reduced approximately 150% fold at 1,600 m compared to near sea level controls, in elite youth football players (Garvican et al., 2013). Interestingly, despite decrements in the ability to run at high speeds within elite players between 1,200 m – 1,750 m, this is not accompanied by a reduction in technical skill execution success (Nassis, 2013). Games played at high altitude 3,600 m (Table 1) also reduce the overall distance covered by elite youth football players during a match (Aughey et al., 2013). In this study, players native to sea level (Australia) and altitude (Bolivia) played two friendly matches at 430 m and three friendly matches at 3,600 m. The total distance covered per min and high velocity running per min reduced at altitude in both sets of players, when compared to matches played at sea level. Furthermore, the matches at altitude were played over 13 d i.e., days 1, 6 and 13. As such, it was found that 13 d of high altitude acclimatisation was not sufficient to restore performances to those observed at sea level

(Aughey et al., 2013).

Preceding May 2007, FIFA prohibited international football matches in excess of 2,500 m on three separate occasions (Gore et al., 2013). The last of these vetoes (May 2007) was reversed shortly after its announcement (Gore et al., 2013). The series of announcements and retractions were made despite football-specific research detailing the decline in physical performance during games played at low, moderate and high altitudes (Gore et al., 2013). Attempts have been made to provide empirical data from match-play data regarding football performance at altitude paradigm, with the International Study on Football at Altitude 3,600 m completed in 2012 (ISA3600 [Gore et al., 2013]). However, despite the novelty and well-organised approach of ISA3600, 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 match-specific factors (tactics, opposition) and environmental conditions (Bangsbo, 2014; Bloomfield et al., 2005; Gregson et al., 2010). Therefore, inferences regarding the aforementioned environmentally mediated decrements on football performance, derived from football match-play, are problematic. For example, a key performance indicator such as sprinting has been reported to show poor game-to-game reliability (coefficient of variation ~36%) (Gregson et al., 2010) rendering inferences from environmentally (heat, cold, hypoxia, etc.) mediated decrements in performance, and potential interventions/practical recommendations to minimise such reductions, difficult to ascertain from match-play data.

To get a better understanding of the effects of different environmental conditions on football performance, more controlled conditions are necessary. Laboratory- or field-based football simulations, which replicate the match demands of football players, without the aforementioned confounding game factors (tactics, opposition, environmental condition) can provide such insights. Fixed distance, constant speed and motorised treadmill-based protocols have limited ecological validity to football and therefore field and variable distance protocols have been developed to increase the validity of measurements. The intermittent football performance test (iSPT) is one such individualised protocol which has been used to investigate the impact of hypoxia (1,000 m; 18.4 % oxygen) on player running performance (Taylor et al., 2014a; Aldous et al., 2013). Pilot data has shown that total distance covered (Figure 1b) and distance covered at high speed (Figure 2b) were significantly greater in control compared to hypoxic conditions. Furthermore, the greatest reduction in high-speed running was observed in the final 15 min of iSPT compared to all other 15-min blocks of the protocol. It is reasonable to suggest that such time-dependent differences in high-speed running at altitude would be pivotal to match outcome. For example, in the 1998 and 2002 FIFA World Cups most goals were scored in the second half (p <0.05) (Armatas et al., 2007). Furthermore, more goals were scored/ conceded within the final 15 min of game play (76-90 min) compared to all other 15-min time phases. This phenomenon in goals scored is likely due to the inability to maintain repeated sprint ability or discrete

episodes of non-fatigued maximal sprint performance capacity, within the final 15 min of game play (Rollo, 2014; Aldous et al., 2013). These decrements in performance appear to be exacerbated within hypoxic environments (Garvican et al., 2013; Taylor et al., 2014a).
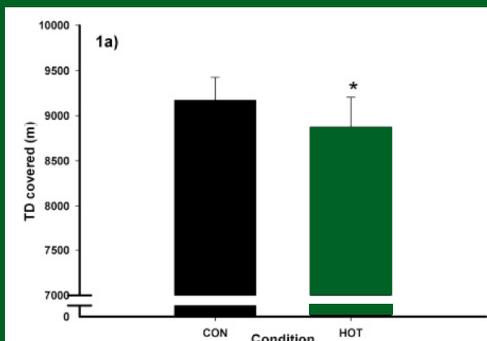
Figure 1

1a)

Figure 1a: Total distance (TD) covered was significantly reduced (P<0.05;↓3.23%) in the hot condition (HOT) (8876.2±328.95m) compared with temperate control (CON) (9172.67±253.91m). 1b: TD covered was significantly reduced (P<0.05; ↓1.27%) in HYP (9420±543m) compared with CON (9542±353m).
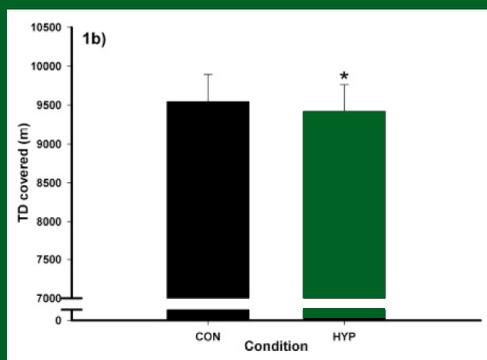

1b)

Figure 1b: Distance covered at high speed (HSD): control (CON): 9542±353 m; hypoxia (HYP): 9420±543 m; p < 0.001;↓1.27%).

Figure 2

2a)
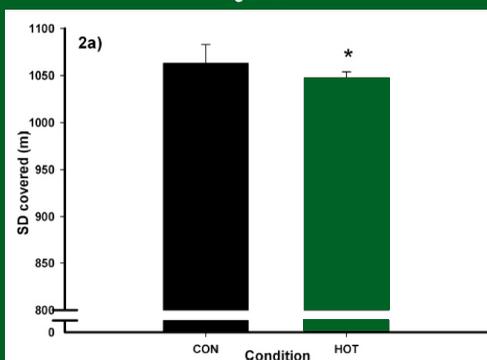
Figure 2a: Sprint Distance (SD) covered was significantly reduced (P<0.05;↓1.51%) in the hot condition (HOT) (8876.2±328.95m) with temperate control (CON) (1063±19.94m).

2b)
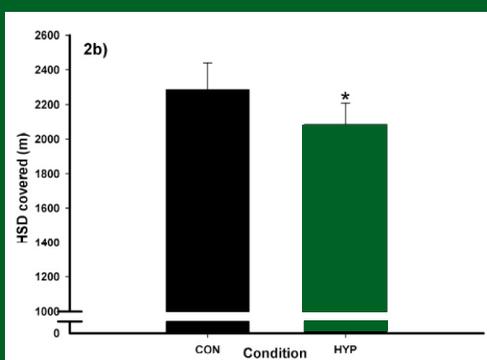
Figure 2b: High-speed distance (HSD) covered was significantly reduced (P<0.05; ↓ 12.65%) in HYP (2084±124m) compared with CON (2386±154m).

HYPOXIA: PRACTICAL RECOMMENDATIONS

Specific recommendations to prepare for exercise at altitude depend on the degree of ascent. Bartsch et al. (2008) provided a consensus statement recommending a 3-5 d acclimatisation period when players ascend from sea level to low altitude (1,500 m). However, an acclimatisation period of one to two weeks is recommended when playing at moderate altitudes. Finally, a minimum of two weeks' acclimation at the match location is advised when playing at high altitude (Table 1). Research suggests that an altitude-acclimatised football player (or altitude native) will have greater endurance capacity (more distance covered at high running speeds if the game requires it), more effective pacing, better recovery between multiple games and potentially improved ball control with low air density (Aughey et al., 2013).

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

Table 1. Altitude definition: The impact of altitude on performance and health is highly individualised. Therefore, it should be noted that the above definitions of altitude zones can vary significantly between players and by some hundreds of meters (Table modified from: Bartsch et al., 2008).

It is important to note that the majority of papers which informed the consensus by Bartsch et al. (2008) regarding altitude and performance were related to individual athletes in specific sports, which are not immediately applicable to team sports such as football. Thus, guidelines are not exclusively based on the systematic research and investigation into football players. Furthermore, the high individual variability in the adaptation process to the different altitudes adds further challenges when generalising recommendations to an entire football team (Bartsch et al., 2008). In fact, the most recent consensus statement regarding "altitude training for team sports" stated there is no single recommendation that will be suitable for all players in a team. In theory, when preparing for a period of acclimation at altitude or trying to gain an ergogenic advantage by

training at altitude, not all players of a team should be exposed to the same hypoxic conditions. Instead, an optimal dose/time/type should be established for each player (Girard et al., 2013).

Specific nutrition interventions may be of significance in hypoxic environments. Dietary nitrate has been shown to improve muscle oxygenation during sub-maximal 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) and improve intense intermittent exercise performance at sea level (Wylie et al., 2013). Practical recommendations to optimise nitrate supplementation (dose, nitrate source, acute or chronic supplementation) specific to soccer within hypoxia are difficult. This is because of the high variability in supplementation strategy seen across studies which have demonstrated worthwhile effects of supplementation on exercise and the lack of nitrate and exercise based studies within hypoxia (Vanhatalo et al., 2011; Masschelein et al., 2012; Hoon et al., 2013). Nevertheless, an acute dose of inorganic nitrate (300 mg to 600 mg, delivered by ingesting nitrate-rich vegetable products such as beetroot juice) 75-150 min before exercise (whether preceding chronic supplementation has occurred or not) appears to improve exercise performance and/or efficiency – though chronic supplementation of at least several days increases the likelihood of exercise performance benefits being observed (Hoon et al., 2013; Jones, 2013).

Further practical recommendations for performance at altitude recently published (Armstrong, 2006; Gore et al., 2008), would include increasing dietary iron intake typically via 100-300 mg/d oral inorganic iron supplementation co-ingested with approximately 1000 mg/d Vitamin C, for several weeks prior to altitude sojourn. It is recommended that this dosing regimen should be initiated and overseen by a physician, who themselves should be guided by Serum Ferritin levels (Armstrong, 2006; Gore et al., 2008). Caution must be taken as such iron dosing as described above can cause constipation and mild gastrointestinal discomfort (Gore et al., 2008). Additionally, adequate dietary carbohydrate and carbohydrate ingestion during a game appear a prudent strategy at altitude (Gore et al., 2008).

Finally, cognitive function is of great importance during a match, as it will influence a player's decision-making, anticipation of a pass, timing of a run and tracking the ball or defender. Preliminary research suggests that tyrosine supplementation may offer some benefit to cognitive function within hypoxic environments (Banderet & Lieberman, 1989). Acute dosages of Tyrosine at 150 mg/kg BM have been reported to be well tolerated when ingested 5 h and 1 h prior to completion of the iSPT, with positives effects (Taylor et al., 2014b), although further research is needed before tyrosine is recommended with confidence within a football match paradigm at altitude (O'Brien et al., 2007; Baker, 2013).

HEAT AND FOOTBALL

Competitive football is more commonly played within hot environments, compared to other detrimental environments such as hypoxia. Two of the next three FIFA World Cups (Brazil 2014 and Qatar 2022) are likely to be played in extreme temperatures (30-45°C) that will pose a great challenge for the world's best players to complete the physical demands associated with elite match performance. For example, total distance covered during a game is compromised when environmental temperature is increased from 20°C to 30°C (Ekblom, 1986), with greater relative increases of environmental temperatures (i.e., ~21°C to ~43°C) reducing total distance covered by 7% (Mohr et al., 2012).

Exercise capacity is reduced within hot environments with core body temperature raised by the environmental conditions and metabolic heat production (active skeletal muscle), disrupting the heat gain (exercise and the environment) and loss (evaporative, convective and radiative) equation in favour of heat gain (Nybo et al., 2014). The precise mechanism by which exercise-heat stress reduces exercise performance is not clear, with intricate interplay between peripheral (feedback) and central factors (feed forward) known to occur dependent on exercise modality, intensity and duration (Nybo et al., 2014). For example, early studies suggested that there was a critical core body temperature (~38.6°C) which coincided with exhaustion. This concept has now been abandoned although it is clear that core temperature can play a crucial role in the development of fatigue, but muscle temperature, skin temperature and several other factors play important roles as well. Interestingly, well-trained individuals seem to tolerate higher core temperatures (39.2°C and 40.3°C) than less trained individuals, and this coincides with prolonged time to exhaustion during constant paced exercise (Cheung, 2010). Higher muscle temperatures within the quadriceps and elevated core temperatures have been reported when playing football in the heat, compared to temperate environments (Mohr et al., 2012). It is clear that fatigue in football is multifactorial and several complementary multi-factorial mechanisms, besides muscle, core and skin temperature (Sawka et al., 2011; Sawka et al., 2012) should be considered when explaining football-related fatigue within a hot environment (Mohr et al., 2012).

In a hot environment, maximal intensity exercise is limited by cardiovascular limitations in synergistically facilitating oxygen delivery to active skeletal muscle whilst maintaining adequate thermoregulatory outputs (Nybo et al., 2014). However, sub-maximal fixed intensity is limited by central fatigue (impaired ability to sustain maximal muscle activation during sustained contractions), with this central fatigue mediated by dopaminergic neurotransmitter activity, elevated body temperatures (skin, core and muscle) and metabolic perturbation within skeletal muscle (Nybo et al., 2014). When playing football within hot temperatures, a player's total distance and high-intensity activity will decrease markedly, though accompanying elevations in average heart rate and blood lactate are not always seen, when compared to performance within a temperate

environment (Mohr et al., 2012).

Considering the physiological demands of football performance (Bangsbo, 2014) it is rational to assume that a combination of factors associated with maximal and submaximal exercise fatigue interplay to reduce distances covered and increase cardiovascular/metabolic perturbations. These effects would be evident across a whole game, transiently within game and in hot compared to temperate environments (Mohr et al., 2003; Mohr et al., 2004; Mohr et al., 2005; Mohr et al., 2010; Mohr et al., 2012; Mohr & Krustrup, 2013).

The magnitude of exercise-heat stress "fatigue/response" has high inter-individual variation (Nybo et al., 2014), due to training and acclimation status of players, which are influenced by genetic/phenotypic variations of favourable traits associated with innate thermal tolerance and its acquirement (Horowitz, 2014; Taylor, 2014b). Readers are directed to recent excellent reviews on hyperthermia-induced exercise fatigue (Nybo et al., 2014) and human heat adaptation (Horowitz, 2014; Taylor, 2014).

Although reductions in total distance will alter game play characteristics, they are not always central to match outcomes as previously discussed, for example high-speed running. In particular, to reiterate, sprint activity is more central to match outcome than total distance covered (Gregson et al., 2010; Bradley et al., 2011; Faude et al., 2012; Bradley & Noakes, 2013). Within very hot conditions (~43°C) male professional football players demonstrated a 26% reduction in distance covered at high speed compared to a game within temperate conditions (~21°C) (Mohr et al., 2012). Therefore, it appears that the match-play in the heat has a greater impact on those variables of performance specifically related to the outcome of the match.

The heat-mediated reductions in distances covered at a high intensity, and total distances within game, directly impact match-play characteristics, i.e., possession, turnovers, technical skill execution, etc., when compared to play within a temperate environment (Mohr et al., 2010; Mohr et al., 2012; Mohr and Krustrup, 2013); though these changes may not predict match outcome. Conversely to hypoxia, technical skills, i.e., passing (8%) and crossing (9%), are improved within hot compared to temperate match-play environments (Mohr et al., 2012). This increase in technical skill is likely to be an artifact of the inherent changes in game-play characteristics. 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). Therefore, prior to a technically challenging skill being attempted within hot compared to temperate conditions, pressure toward the player in possession of the ball is less, i.e., closing down is less aggressive and proximity is increased, allowing greater attentional focus to the technical skill to be performed. This is the likely explanation for an increase in successful skill execution.

As discussed in the hypoxia section, there are advantages of

studying performance-related parameters in more controlled conditions (Gregson et al., 2010). Variation in these parameters may be even greater in match-play in the heat (~43°C) because there may be an altered "pacing strategy" and distribution of absolute exercise intensity across the game (Mohr et al., 2012). Morris et al. (2005) had previously reported that prolonged, intermittent, high-intensity 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). Interestingly, while muscle glycogen utilization was being elevated by heat stress, low whole muscle glycogen concentration was not reported to be the cause of the earlier exhaustion. Instead, the onset of exhaustion was associated with hyperthermia. A recent study utilising the iSPT at 18°C and 30°C revealed total distance covered and sprint distances were significantly reduced when exercise was performed in the hot environment (Aldous et al., 2014). Specifically, the reduction in sprint distance in hot conditions was accompanied with higher heart rate and blood lactate concentrations and an elevated core temperature (~0.4°C) (Aldous et al., 2014).

Although the precise mechanism for decreased sprint activity due to football-specific exercise heat-stress is not clear, it is likely underpinned by the previously discussed interplay of peripheral and central factors (including the observed increase in core, muscle and skin temperature) which govern hyperthermia-induced fatigue during intermittent exercise over 90 min (Mohr et al., 2012; Nybo et al., 2014).

HEAT: PRACTICAL RECOMMENDATIONS
Football performance within hot environments, ~30°C (Ekblom, 1986) to 41°C (Mohr et al., 2012) and 30°C laboratory data (Aldous et al., 2014) reduces high-intensity running and total distances covered, which can influence game outcome (Faude et al., 2012) and match-play characteristics (Mohr et al., 2012), respectively. The coinciding perturbations in body temperatures contribute (note not exclusively) to a multi-factorial model of football specific hyperthermia induced fatigue (Nybo et al., 2014).

Conversely to hypoxia, there are several commonly employed, practically valid and ergogenic interventions to consider, in an attempt to offset some of this heat-induced decrement in football performance. The most prevalent strategy is a heat acclimation protocol (Taylor, 2014). Heat acclimatisation protocols traditionally take between 4 – 14 d to elicit a partially (4 d) or fully heat acclimated (14 d plus) phenotype (Gibson et al., 2014; Taylor, 2014), although it is difficult from a practical point of view to implement such acclimatisation periods with a typical fixture scheduling within national and international football. Six days' naturally induced heat acclimation can be achieved by normal training regimes within a hot environment. In one study, semi-professional footballers had individual-specific positive effects on the ability to maintain match running performance within a hot compared to temperate environment (Racinais et al., 2012). However, there was notable inter-individual variation in this response correlated to haematological adaptation (plasma volume

expansion), i.e., those players who exhibited greatest plasma volume expansion, adapted most to the heat acclimatisation intervention and were best able to maintain a "temperate-like" match running activity profile within the hot, compared to temperate environment (Racinais et al., 2012). Practitioners should explore the use of artificially induced heat acclimation (within any fixture dictated period of time), specifically controlled hyperthermia induced heat acclimation (also known as isothermic heat acclimation). Controlled hyperthermia heat acclimatisation protocols prevent the adaptive stimulus (exercise-heat stress) diminishing due to heat acclimation across time relative to a pre-heat acclimation baseline value (typically core temperature), whilst also reducing total work required (Gibson et al., 2014; Taylor, 2014). Thus, heat acclimation efficacy varies and practicalities for a whole football team involved within typical fixture scheduling is challenging. Specific recommendations are likely to be influenced by external factors such as fixture scheduling and thus generic guidelines are challenging to propose. First, whether "natural" heat acclimatisation, as used by (Racinais et al., 2012) or artificial heat acclimatisation (Taylor, 2014; Sunderland et al., 2008) use must be decided. This should be discussed between technical/tactical coaches and sports scientists to find the best option to achieve the physiological response in context of the training priorities. Second, the number of heat acclimatisation sessions (typically days) required if the protocol is to be implemented must also be taken into consideration. In general, a greater frequency of heat acclimatisation sessions equals more complete adaptation (Taylor, 2014). Third, the temperature which players are exposed to should be at least equivalent to the likely temperature at the proposed competition venue, although higher temperatures will provide a greater adaptive stimulus (Taylor, 2014). Finally, the use of a progressive hyperthermia heat acclimatisation model with an ecologically valid exercise stimulus such as a soccer simulation may increase efficacy and ecological validity respectively (Sunderland et al., 2008).

Another strategy is pre- and during-game "cooling" (commonly termed pre-cooling), which has been shown to have ergogenic effects during exercise-heat stress, though there is substantial variation in effect size and practicality for these approaches (Tyler et al., 2013). The most commonly employed cooling methods include cold water immersion, ingestion of a cold fluid/ice slurry, application of ice packs onto skin, the wearing of ice-cooling garments or a combination (mixed methods) of these approaches (Tyler et al., 2013). Irrespective of the method, the goal of pre-cooling is to reduce core, skin and muscle temperatures, increasing heat storage capacity with this increased capacity ergogenic to work rates and exercise time to exhaustion (Bongers et al., 2014). Efficacy of these afore-mentioned methods is variable with cooling vests having negligible to small effects on performance, whilst cold water immersion has moderate positive effects but lacks practicality. Mixed methods and cold fluid/ice slurry ingestion have been shown to be both practical and ergogenic to exercise capacity during exercise-heat stress (Bongers et al., 2014). Football-specific pre-cooling literature is limited to two studies (Drust et al., 2000; Clarke et al., 2011). Repeated sprint

activity within hot environments has been enhanced by ice pack pre-cooling to the quadriceps (Castle et al., 2006) and mixed method approaches (involving multiple site ice pack/vest application; (Minett et al., 2011; Minett et al., 2012a). To positively influence exercise-heat stress, specifically physiological and perceptual responses, pre-cooling must be of a sufficient duration (Minett et al., 2012a) and volume (Minett et al., 2011). Specific to football, adoption of a mixed method pre-cooling approach (Minett et al., 2011; Minett et al., 2012a; Minett et al., 2012b) which maximises ergogenic effect, both prior to and during (halftime) football performance may be beneficial. However, a major constraint to implementation of pre-cooling (of any type) within professional football is the limited time available during warm-up procedures (~30 min), post warm-up prior to kick off (~12 min) and realistically available during halftime (~2.6 min) (Towlson et al., 2013). Further pre-cooling football-specific research must develop an effective and practical solution (Minett et al., 2011; Minett et al., 2012a; Tyler et al., 2013), especially regarding the limited time available to implement such interventions (Towlson et al., 2013). Practical recommendations would include the use of mixed method pre-cooling (focused on maximising volume of area cooled without hindering practicality) when possible within match-day preparations and at halftime. Currently there are no governing body dictated restrictions on the use of cooling prior to a match and at halftime.

Habitual euhydration and maintenance of this status prior to and within game would be advantageous when preparing to complete exercise in the heat (Laitano et al., 2014; Sawka et al., 2007). Dehydration of greater than 2% of pre-exercise BM has been reported to reduce maximal aerobic power in hot environments (Craig & Cummings, 1966) and impair sub-maximal aerobic performance in temperate, warm and hot environments (Sawka et al., 2012). Dehydration during exercise in the heat increases skin, core and muscle hyperthermia relative to euhydrated states (Sawka et al., 2012). Although such temperatures are not solely responsible for exercise-heat stress fatigue (Nybo et al., 2014) it is prudent to prevent such increases in body temperatures and exasperated cardiovascular strain during soccer match-play (Sawka et al., 1992; Sawka et al., 2011; Sawka et al., 2012; Nybo et al., 2014). It should be noted that there is large individual variation in response to dehydration and its influence on exercise performance. Therefore, hydration recommendations must be individualised to each player – readers are encouraged to view Laitano et al. (2014) for guidance on this matter.

SUMMARY

Environmental extremes of hypoxia and/or heat are commonly encountered during FIFA-endorsed football match-play. Specific to match-play, hypoxia and hot environmental conditions are associated with reductions in high-speed running and specifically sprint distances, both of which are likely to directly influence the game outcome. The negative effects of hypoxia can be counteracted in part by a period of altitude acclimation that is dependent on the altitude that match-play will be at. Nutritional preparation may include dietary nitrates as well as iron. More specific strategies may alleviate

some of the heat-mediated decrements in football performance, with recommendations including specific heat acclimation and mixed methods of cooling (pre-match and at halftime) and routine euhydration. Further research is required to modify and optimise these interventions to meet football-specific match demands.

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