ADJUSTMENTS IN FOOTBALL PERFORMANCE UNDER HEAT STRESS

– *Written by Julien Périard and Sébastien Racinais, Qatar*

Football is truly a global game. It is estimated that over 250 million people in over 200 countries participate in the sport. As such, it is played in varied climatic conditions to which professionals and recreational players alike must adapt. In Europe, league play is held throughout the year in conditions that range from warm and humid to cold and damp. In the Middle East, the scorching summer sun can rapidly increase ambient temperature above 40°C and the evening humidity can further enhance the harshness of the environment. Over the last decades not only have the physiological, metabolic and nutritional demands of the game been described, but so have the thermoregulatory requirements associated with playing in a range of environmental conditions. This has led to a better understanding of how match-play may be altered in the heat. It has also led to the development of strategies to enhance performance in such conditions. This brief review will address the influence of heat stress on football performance and describe the adaptations that occur during a match in response to the development of hyperthermia. Heat acclimatisation will also be examined as a strategy to enhance performance and insight into how it impacts match-play characteristics will be discussed.

FOOTBALL MATCH-PLAY CHARACTERISTICS

Football is an intermittent activity. It is a game interspersed by high intensity sprints and jumps, and low intensity running and walking. Typically, elite level football players cover distances ranging from 10 to 13 km during matches[1]. At this level, players perform 150 to 250 brief intense actions such as tackles, jumps and short accelerations. Peak running velocity during such accelerations can reach 32 km/hour[2]. However, position and playing style have a significant influence on the activity pattern of a player during a match, with mid-fielders usually covering greater distances. Although most of this distance is covered at a walking or low-intensity running pace, mean heart rate for an entire match rarely falls below 65% of maximum. This is mostly related to the high intensity efforts that occur during play, which increase heart rate upwards of 90% of maximum. Consequently, mean oxygen uptake during a match generally hovers around 70% of maximal aerobic capacity. Given this level of exertion and the demand on aerobic and anaerobic metabolism over a protracted period, core temperature can exceed 39°C during matches played in temperate conditions.

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Research regarding the development of fatigue during a football match has flourished with the advent of new technologies. The use of global positioning systems (GPS) and semi-automated match analysis systems (e.g. Prozone™) has given researchers the ability to follow specific players and analyse their movements on a continual basis. As a result, several studies have determined that the capacity to perform high intensity efforts is reduced in both elite and recreational players towards the end of a match[3]. More specifically, in the last 15 minutes of a match the distance covered during high-intensity running decreases by ~40%. Total distance covered is also significantly reduced during this period (Figure 1). Comparisons of pre- and post-match jumping, sprinting and intermittent exercise capacities have further shown that performance is progressively reduced following match-play. Interestingly, fatigue also appears to develop temporarily during a match following periods of high-intensity efforts, irrespective of player position. Indeed, the amount of high-intensity efforts is briefly reduced to levels below match average following a 5-minute period of particularly intense exercise at any point in a match[1]. The mechanisms modulating progressive and temporary fatigue remain unclear. However, the depletion of muscle glycogen stores and peripheral muscle fatigue have been suggested as potential sources.

HEAT STRESS AND PERFORMANCE

It is well established that prolonged exercise performance is impaired when undertaken in hot climatic conditions. The rise in core temperature that occurs during such sustained efforts in the heat, along with the narrowing of the thermal gradient between the skin and the environment, increase the cutaneous circulatory requirements necessary for the maintenance of thermal homeostasis. As a result, cardiovascular strain develops as greater blood flow is directed towards the peripheral circulation[5]. This heat-related circulatory adjustment decreases central blood volume and is associated with reductions in aerobic exercise capacity. Consequently, relative exercise intensity and the perception of effort increase. When fluid needs are not met during these prolonged efforts, dehydration progressively develops. In football players, fluid loss via sweating can amount to 3 L during matches played in temperate conditions, and up to 5 L in hot and humid conditions. Such losses exacerbate the rise in body core temperature, which contributes to reduce performance all the more. Interestingly, it is suggested that aerobic exercise performance is degraded proportionally to the level of dehydration. However, the magnitude of performance decrement is also specific to the exercise task or sport, and related to the prevailing environmental conditions.

During brief explosive efforts such as single jumps and sprints, an increase in core and particularly muscle temperature is beneficial to the production of maximal force and power. The benefit is related to an enhancement in muscle contractility, which stems from an improvement in neuromuscular function at the mechanical, biochemical and neural level. Conversely, when brief explosive tasks are repeated under heat stress, performance deteriorates more rapidly. However, alterations in performance are largely dependent on the rest interval taken between repetitions, as well as the level of hyperthermia attained. For example, repeated cycling sprint ability in hot ambient conditions is unaffected when less than 10 efforts are interspersed by >60 seconds and only a modest increase in core temperature (≤38°C) occurs[6]. On the other hand, performance during repeated cycling sprints decreases when core temperature exceeds 39°C and the rest interval is brief (15 seconds)[7]. Thus, there appears to be a dose-response relationship between hyperthermia and performance that considers both local (i.e. muscle) and central (i.e. core) temperature.

HEAT STRESS AND FOOTBALL PERFORMANCE

When football is played in the heat, both core and muscle temperature can reach significantly elevated values (Figure 2). In well-trained football players, it has been shown that fatigue profiles are more pronounced at the end of matches played in the heat than in those played in cool conditions. Under heat stress, less total distance is covered in the second half of matches[8]. Accordingly, the amount of high-intensity running is lower (57%) during the final 15 minutes of a match compared with the first 15 minutes. Repeated sprint and jump performance are also significantly reduced post-relative to pre-match (2.6 and 8.2% respectively)[9]. This increased level of fatigue is suggested to be associated with fitness levels and the level of hyperthermia or dehydration attained.

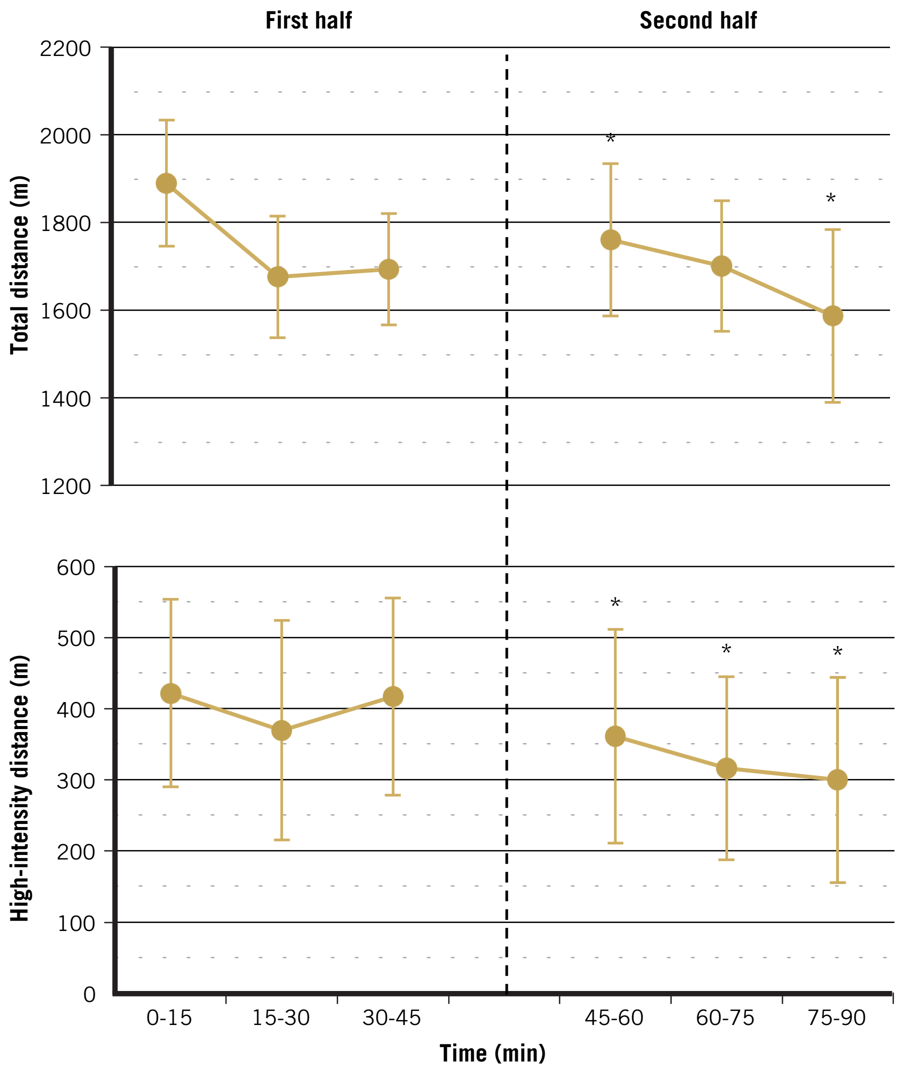

Figure 1: Total and high-intensity distance (>14 km/hour) covered in 15-minute segments during the first and second halves of a simulated football match in cool conditions (17.4°C and 55% RH). *Significantly different from equivalent time period in the first half (P <0.05). Adapted with permission from Mohr et al[4].

Recently, a study was conducted to examine the effects of heat-acclimatisation on football performance and match-play characteristics. To evaluate the influence of heat-acclimatisation, a first match was played in temperate conditions (~21°C) and followed 1 week later with a match played in the heat (~43°C). This match was conducted after the week's training was undertaken in the same hot ambient conditions. Core and muscle temperature were noted to be ~1°C higher during the game played in the heat[4]. It was also shown that while average heart rate, plasma lactate concentration and body mass losses were similar between matches, total distance covered decreased by 700 m in the hot condition (Figure 3). Moreover, the distance covered at high intensity (>14 km/hour) decreased from 2.2 km in temperate to 1.7 km in hot conditions. However, there appeared to be vast individual variations in the distances covered between players during matches in temperate versus hot conditions. These variations were not related to core or muscle temperature, end-game blood lactate or heart rate. Rather, they appeared to correspond with changes in haematocrit level, a potential marker of heat acclimatisation[10]. Interestingly, sprint performance was improved in the hot environment as a 4% higher peak sprint speed was observed. However, there were no differences in the quantity or length of maximal sprints >24 km/hour between conditions. In addition, the success rate for passes and crosses was improved by 8 and 9%, respectively, in hot compared with temperate conditions[4].

The ability of a player to perform during tournaments held in hot ambient conditions is a function of their ability to acclimatise and recover between games. Following a competitive football match muscle glycogen stores can remain depressed for more than 48 hours, irrespective of having played in a temperate or hot environment[11]. Match-play has also been shown to induce a three-fold increase in serum myoglobin, a marker of muscle damage. However, the increase is not dependent on ambient conditions and values return to baseline within 24 hours. Creatine kinase, another marker of muscle

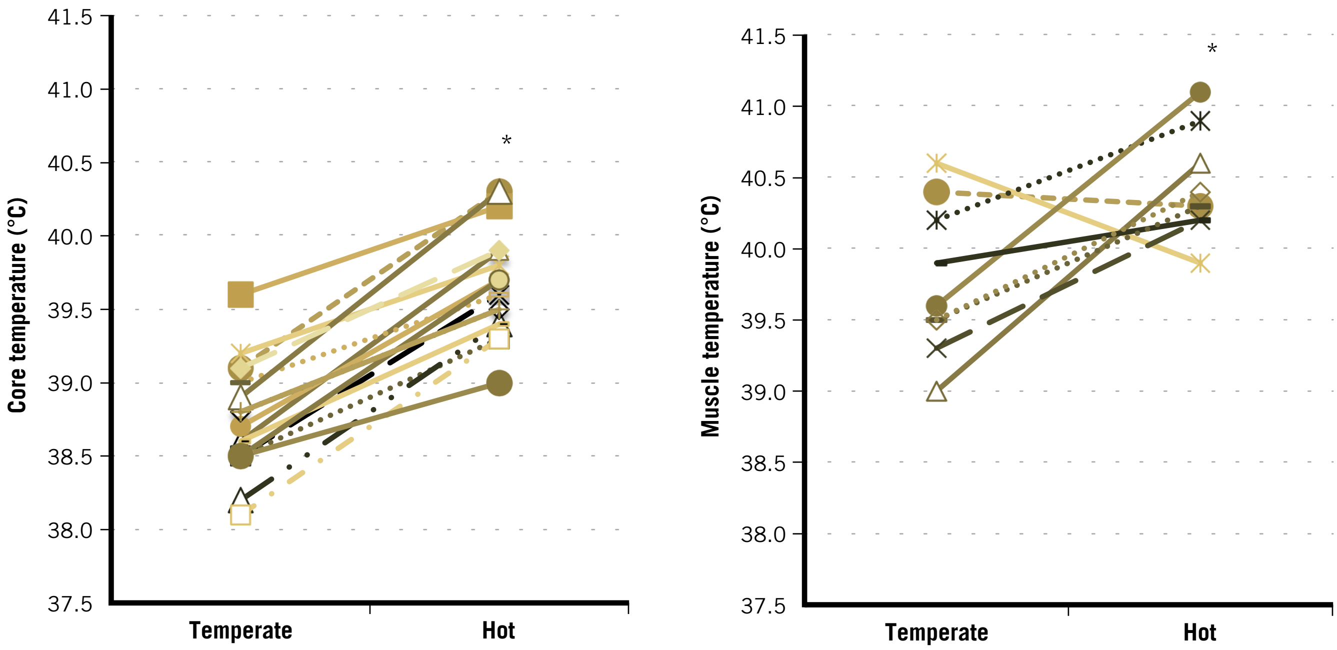

Figure 2: Individual peak core and muscle temperatures reached during football matches played in temperate (21°C) and hot (43°C) conditions. *Significant difference between environmental conditions ($P < 0.05$). Adapted with permission from Mohr et al[4].

damage, also increases following a football match and remains elevated for 24 hours. Interestingly, creatine kinase levels appear to recover more rapidly in the 24 to 48 hour period following play in hot compared with temperate conditions. Taken together, these observations suggest that environmental heat stress does not influence recovery responses from a football match following 1 week of training in the heat. This is further confirmed by the fact that, irrespective of the ambient temperature during the match (i.e. hot vs temperate), performance tests such as sprinting and intermittent endurance capacity (estimated by a Yo-Yo IR1 test) are fully recovered within 48 hours.

COUNTERMEASURES TO IMPROVE PERFORMANCE

Hydration

International sports organisations acknowledge that sufficient hydration prior to, during and in the recovery period is integral to athlete performance and safety during training and competition in the heat[12]. Although it is difficult to provide general recommendations due to large inter-individual variations, simple tools such as pre- to post-exercise changes in body mass, as well as urine colour and volume, can be used to estimate hydration status. Simple recommendations could be to undertake a match in a euhydrated state with light-coloured urine and avoid a percentage decrement in body mass above 2%.

Clothing

The choice of clothing during sporting activities is largely dependent on the regulations and safety requirements within each sport. Several products have been developed during the last decades claiming to improve performance. However, it is important to understand these claims and make informed decisions about clothing choices when exercising in the heat. Indeed, it is important to wear garments that maximise the evaporation of sweat, while balancing the protection of the skin from solar radiation. In activities such as American football, where the protective clothing induce an evaporative resistance, several hyperthermia cases have been reported when playing in hot ambient conditions. Given that evaporation is the main source of heat dissipation in humans, evaporative heat loss should be maximised by minimising the barriers between the skin and the environment.

Warming-up

The warm-up is a general practice in athletes. It is typically performed at a moderate intensity and followed by a few minutes of recovery before an event. However, while an increase in muscle temperature can be beneficial to performance, a significant increase in core temperature during warm-up may limit heat-storage capacity when exercising in the heat. Indeed, laboratory experiments have shown that aerobic performance is reduced by pre-warming. However, these and similar observations are generally done in laboratory environments during continuous exercise tasks. On the field, individual players have the ability to tailor their effort based on experience and coach's instructions. As such, the warm-up may be modified to suit the ambient conditions in order to receive both temperature-dependent (e.g. physiological preparation) and non-temperature-dependent (e.g. psychological preparation) benefits.

> *Under heat stress less total distance is covered in the second half of matches*

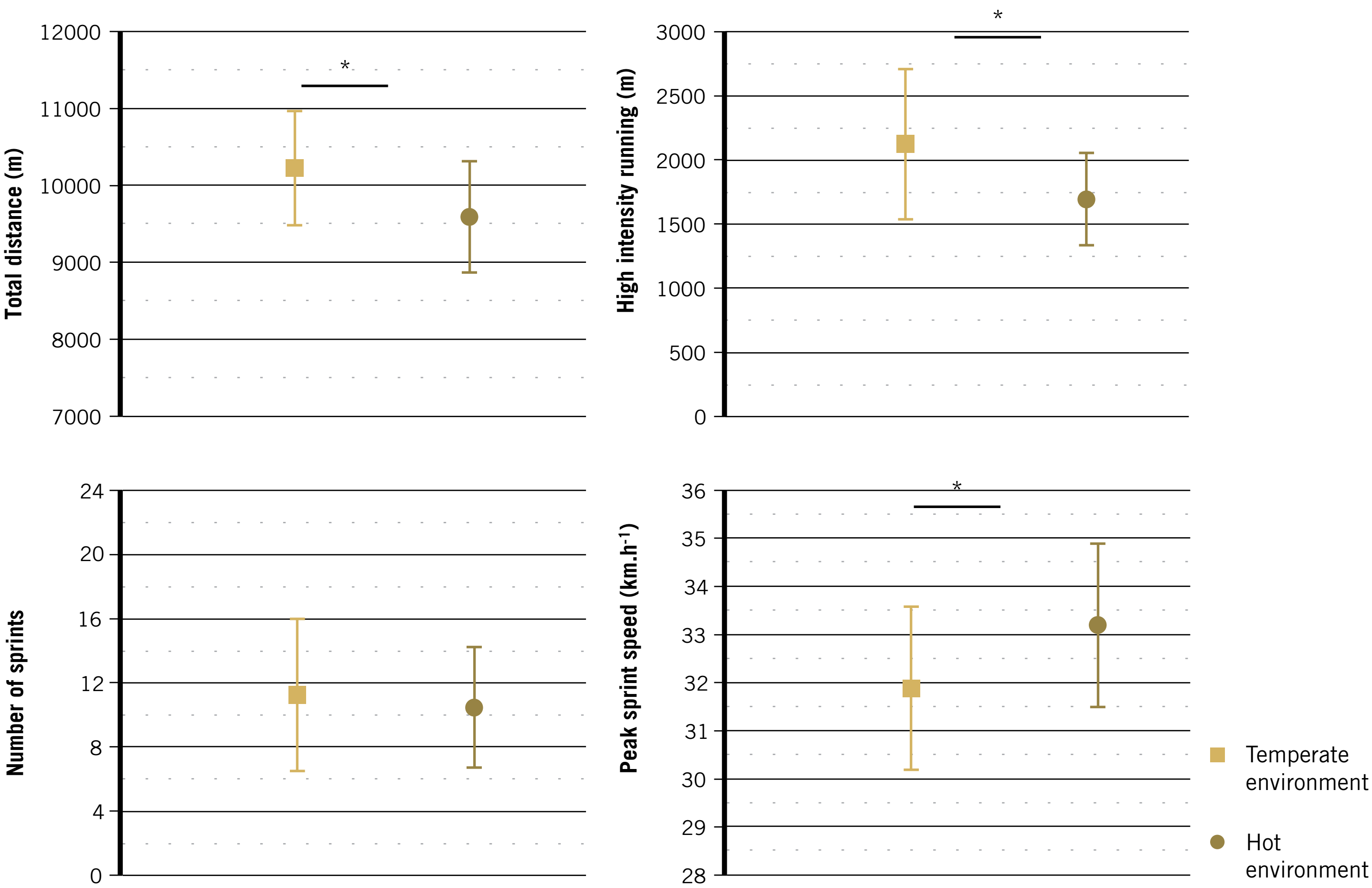

Figure 3: Total distance covered, high-intensity distance (>14 km/hour) covered, number of sprints and peak sprint speed during football matches played in temperate and hot environments. *Significant difference between environmental conditions ($P < 0.05$). Adapted with permission from Mohr et al[4].

Acclimatisation

Heat-acclimatisation can be referred to as a general adaptation process allowing to better cope with heat stress. It includes an increase in sweat rate, as well as decreases in sweat sodium concentration, core temperature and heart rate at given exercise intensities. Changes in sweat sodium concentration and sweat rate can be observed in football players after no more than a week of training in the heat. Therefore, a minimum of 1 week and an optimum of 2 weeks of acclimatisation are generally advised. However, acclimatisation responses are highly individualised and it is recommended for coaches and team doctors to determine the acclimatisation response of each player by recording, for example, the changes in haematocrit concentration after a heat-response test[10]. This index is of particular interest for coaches as it has been related to the ability of the players to cope with heat stress during a match in hot ambient conditions. Heat-acclimatisation is therefore a major factor in determining the ability of a player to cope with the heat and their relative physical performance when competing in hot ambient conditions. Moreover, recent findings suggest that training in hot ambient conditions might improve physical performance when competing in both hot and temperate climates[13], as well as reduce the risk of exertional heat illness.

> **Heat-acclimatisation is a major factor in determining a player's physical performance when competing in hot conditions**

SUMMARY

It is clear that football performance is altered in hot ambient conditions. These alterations may be manifested differently in various players based on fitness level, position, hydration status and the level of hyperthermia attained. As such, it is important to develop strategies to identify the potential impact of heat stress on each individual player's performance, and their ability to tolerate heat. Elite football players participating in events such as the FIFA World Cup to be held in Qatar will be partly acclimatised as a result of their physical training in temperate environmental conditions. However, these adaptations are different, or incomplete, and do not substitute for heat-acclimatisation per se. Therefore, football players preparing for a tournament to be held in hot ambient conditions should, as is current practise, include training-camps in the heat as part of their preparation. However, to ensure that all players are benefiting from these camps, regular monitoring and testing should occur to identify potential responders and non-responders to heat-acclimatisation.

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Julien D. Périard Ph.D.

Sébastien Racinais Ph.D.

Research Scientists

Aspetar – Qatar Orthopaedic and Sports Medicine Hospital

Doha, Qatar

Contact: julien.periard@aspetar.com