The Application of Heat Stress to Team Sports: Football/Soccer, Australian Football and Rugby

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9.1 Introduction

Training and competing for team sports in the heat places the body under an increased thermal load, influencing performance capacity and potentially leading to heat-related illness in extreme conditions. While football/soccer, Australian football (AF) and rugby are usually played in the cooler winter months, there are occasions where matches and major competitions are held in thermally challenging conditions [1, 2]. For example, of the 64 matches played in the 2014 FIFA World Cup in Brazil, 16 were played under high environmental heat stress [wet-bulb globe temperature (WBGT) 28–33 °C] [1]. The professional football league in Australia (A-League) is held over the summer months. Similarly, during the Australian domestic AF season, the temperature and humidity can reach levels that place the players at a high to extreme risk of heat illness [2]. Players also train for the upcoming season in warmer temperatures and compete in pre-season competitions under hot and/or humid conditions [3, 4]. It is therefore important to prepare players to tolerate exercise in the heat from both a performance and health perspective. This can be achieved through both adaptive mechanisms (i.e. heat acclimatisation) and by utilising acute strategies to reduce heat strain such as pre-cooling and ensuring adequate hydration. The development and implementation of heat policies are also needed to protect players from severe environmental conditions.

Team sports performance is the product of a complex interplay between tactical (interaction with other individuals), technical (individual skills), physical (physiological capacity) and psychological constructs [5, 6]. Each moment of the match involves a tactical decision and the execution of a technical skill that requires a specific physical movement. The effectiveness of this process is dependent on an

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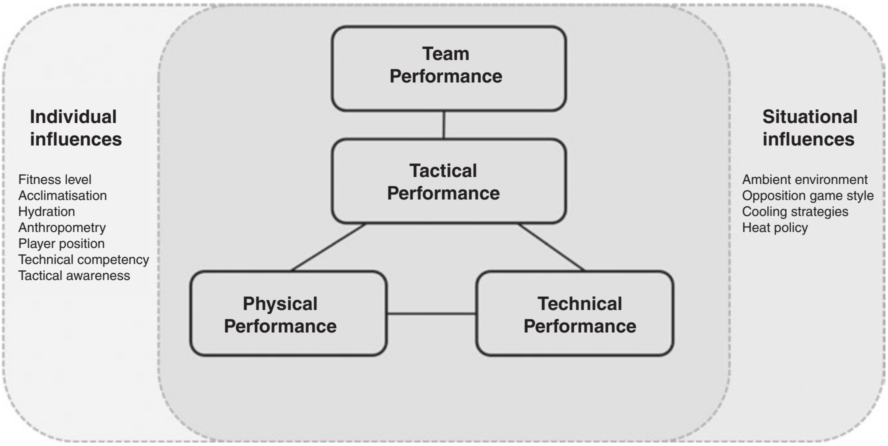

Fig. 9.1 Influences of heat stress on team sport performance. Adapted from Henderson et al. [7]

individual player's readiness to perform (i.e. psychological state, fitness level, health and technical competency) within the context of the match. These constructs are then layered upon situational factors such as the opposition strength, win/loss margin and environmental conditions that combine to influence the outcome of the match. As presented in the conceptual model (Fig. 9.1), any change in an individual construct or situational factor can influence the overall team performance. Moreover, when these changes occur, a whole system adjustment must be made between the tactical, technical and physical performance aspects. This chapter examines how an added heat stress can affect each construct and provides insight into how players adapt their game style or utilise strategies to cope with the thermal load.

9.2 Influence of Heat on Performance and Health

Competitive success in team sports is dependent on a combination of tactical, technical, physical and psychological factors, all of which have been shown to be affected by the heat. In team sport, work demands are stochastic, consisting of explosive multidirectional movement patterns, sport-specific technical skills, running and collisions with varying and unpredictable recovery periods. Due to the self-paced nature, fatigue is characterised by a progressive reduction in work rate throughout the match. It is commonplace for the total distance covered in the second half of football, AF and rugby to be lower than the first [2, 8]. Players may also experience transient fatigue following intense periods of play [9]. As few studies have investigated the impact of heat stress on team sport in an ecological setting, it is difficult to have a complete understanding of how it affects match performance. Below is a summary based on research to date on how hot and/or humid conditions can influence tactical, technical, physical and psychological performance.

9.2.1 Physical Performance

Physical performance during football, AF and rugby matches is highly variable and influenced by situational match-related variables, including the environmental conditions [6, 10–13]. To date, few studies have investigated how an added heat stress affects the physical characteristics of team sport matches [1–3, 14, 15], and changes in activity profiles are still to be determined in rugby league and union. Based on the findings from comparisons between matches played in the heat versus temperate conditions in football and AF, evidence suggests that when in a hot environment, players modify their physical activity patterns to enable the maintenance of key physiological parameters that are critical to match performance [1, 3]. For example, in football total distance covered in a match played at 43 °C was 7% less than a match played at 21 °C [14]. Yet, sprint frequency and sprint distance covered in both matches was similar and in the heat, a more consistent pacing of high-intensity running was observed throughout the entire match. A similar result was found when a match was played in moderately hot (34 °C, 38%RH) compared to hot conditions (36 °C, 61%RH) [15], where no difference in sprinting or high-speed running was found between the matches. To achieve this, players reduced the amount of time spent jogging and increased their time spent walking in the hotter environment. Likewise, AF players competing in the heat have been reported to reduce the total distance covered but sustain high-intensity running performance and increase the number of accelerations [2]. Further evidence of players modifying physical performance in the heat has been reported during the 2014 FIFA World Cup in Brazil [1]. During the competition, players were exposed to a range of environmental conditions. When the physical activity responses to low, moderate and high levels of heat stress were compared, there was no difference in playing time, or total distance covered. Notably however, there was a reduction in high-intensity running distance associated with matches played in the heat. Collectively, these results suggest that team sport athletes modify physical activity patterns to ensure that they are able to perform high-intensity efforts when required. However, this conclusion is based on observational data from a small sample group of matches. Further well-controlled research is needed to establish whether these initial findings are consistent across football codes and different levels of participation.

9.2.2 Physiological Response

When players train and compete in hot and humid conditions, the metabolic heat created by the contracting muscle combined with the greater thermal load from the environment puts a considerable stress on the body's thermoregulatory system. Heat stress can negatively affect many aspects of team sport performance including a player's aerobic capacity [14, 16], cognitive ability [17], perception of effort [3], muscle force generation capacity and ability to perform repeat sprints [18, 19]. As players complete intensive physical training in hot conditions, coaches and support staff should be aware of the effect of heat exposure on the ability to perform high-intensity intermittent exercise. Changes observed in the physiological response of team sport players when training and competing in the heat are summarised in the following sections.

9.2.2.1 Core Temperature

High-intensity intermittent running creates a large thermal load and can rapidly increase core temperature [20]. However, there can be little difference in the core temperature reached when matches are played in temperate or hot environments [2, 3]. For instance, even in cooler conditions, core temperatures above 39 °C have been reported in professional AF players [2]. There is evidence of players altering physical activity patterns or applying pacing strategies to preserve physical capacity during pre-season AF matches in the heat [3]. Where after an initial rise in the first quarter, core temperature plateaued for the remainder of the match. Similarly, in semi-professional football players, core temperature peaked at the end of the first half and did not reach the same level again in the second half when matches were played in hot conditions [15]. Due to this lack of relationship between core and ambient temperature, it has been proposed that the amount of physical activity completed is more closely linked to rises in core temperature during matches than the environmental conditions [2, 3, 14, 21].

However, in extreme conditions body temperature can be significantly higher during team sport matches. When elite players completed a football match in very hot (~43 °C) conditions, both core and muscle temperature were significantly elevated compared to a match in a temperate environment (~21 °C) [14]. As increases in whole-body temperature can lead to severe heat illness and injury (see Chap. 5), precautionary measures should be applied (i.e. additional drink breaks or schedule training for earlier in the day) to minimise the thermal load when training and competing in a hot and/or humid environment.

9.2.2.2 Heart Rate

Changes in heart rate can provide insight into the cardiovascular response to a thermal load. During steady-state exercise at a fixed workload in the heat, heart rate increases to counteract the reduction in stroke volume and to meet the higher demands on cardiac output [22]. This is also evident when high-intensity shuttle runs are completed at a standardised workload [20, 23]. Under heat stress, the heart rate response is higher than the equivalent work undertaken in temperate conditions. However, in team sport matches, where the players can self-regulate their physical activity, the resultant heart rate response in the heat is similar to matches that are played in a cool climate [14, 15]. Despite a ~22 °C difference in playing conditions, a very similar average and maximal heart rate was observed in professional football players [14]. Average heart rate during a match played at ~43 °C (hot) was 158 ± 2 bpm, compared to 160 ± 2 bpm when the temperature was ~21 °C (temperate). Although, total distance (hot: −7%) and the amount of high-intensity running (hot: 883 ± 45 m, temperate: 978 ± 97 m) completed in the heat was significantly reduced. Similar results were shown during a high-intensity intermittent running protocol where university-level football players continued to exercise regardless of whether their prescribed velocities were met [16]. Whether the protocol was completed in a hot (30 °C, 50% relative humidity [RH]) or temperate (18 °C, 50%RH) environment, only a ~2 bpm difference was observed in average heart rate. Like the findings in actual football matches, total distance covered and high-speed distance were reduced by ~4% and ~8%, respectively, in the hotter conditions. Collectively, these findings suggest that rather than continuing to exercise at an unsustainable intensity under hot conditions, players adjust their workload to maintain a similar relative exercise intensity. This is in line with the observation that core temperatures of team sport athletes during matches are often alike, irrespective of the environmental conditions [2, 3].

9.2.2.3 Sweat Rate

Evaporation of sweat is a primary thermoregulatory mechanism to dissipate heat and is dependent on the thermal gradient between the environment (i.e. temperature, humidity and wind speed) and the skin [24]. For team sport players, sweat losses can be considerable due to the high metabolic load of intense exercise, uniform requirements and their typically larger body mass [25]. Even in temperate conditions, team sport athletes lose a significant amount of body water during exercise [26, 27]. This loss of fluid results in a reduction in plasma volume, placing greater strain on the cardiovascular system and can lead to accelerated increases in core temperature [16]. The sweat response can vary greatly between individuals. For instance, sweat rates have been reported to range from 0.3 L/h to 2.5 L/h in football players, 0.4 L/h to 2.0 L/h in rugby players and from 0.9 L/h to 2.1 L/h in AF players in a range of environmental conditions [25]. This variability in sweat loss during training and competition is explained in part by the intensity of exercise [21], fitness level [28] and acclimatisation status of the player [29].

Interestingly, while sweat rates for team sport athletes are higher in a hot environment [14, 20], body mass changes are similar to games or training conducted in temperate conditions when fluid is available [2, 14, 20]. This suggests that players are able to increase their fluid intake accordingly when playing in the heat. For example, when an intermittent running shuttle test designed to replicate the physical demands of a team sport match was completed in a hot (~30 °C) and temperate (~20 °C) environment, the change in body mass was almost identical (hot: 0.56 ± 0.20 kg, temperate: 0.59 ± 0.24 kg) as the players drank almost twice the amount of fluid in the hot trial (hot: 1.18 ± 0.12 L/h, temperate: 0.63 ± 0.07 L/h) [20]. It is important to note that even with restricted access to fluid during game conditions, football players were able to minimise body mass changes while playing in the heat [14, 30]. These findings suggest that players are able to adequately hydrate during training and competition in hot and/or humid conditions.

9.2.2.4 Metabolic Response

Team sports are metabolically demanding, requiring a high rate of energy turnover to complete the multiple intense efforts, maximal sprints and accelerations required for success [31–33]. For players, an additional heat stress may place a greater reliance on anaerobic pathways for ATP regeneration [34]. Indeed, a greater carbohydrate utilisation and higher rate of glycogenolysis have been associated with exercise in the heat which can accelerate the accumulation of metabolic by-products and lead to an earlier onset of peripheral muscle fatigue when exercising at a given workload [35]. However, in a practical setting, studies have not found a relationship between markers of metabolic fatigue and a reduction in team sport running capacity in a hot environment. While an indirect measure of anaerobic metabolism, no difference in the post-exercise blood lactate values have been found following either high-intensity intermittent shuttle runs [16, 20, 23, 36], repeat sprint efforts [18] or during match play [14] in hot compared to temperate conditions. These findings are in line with changes observed at a muscular level during repeated cycling sprints performed under heat stress [9] where an elevated core temperature (39.5 ± 0.2 °C) and reduced power output, accompanied by a lower extracellular potassium, muscle hydrogen ion concentration and lactate accumulation, were observed following 5 × 15-s maximal sprints at 40 °C compared to 20 °C. Likewise, a link between an altered substrate use and high-intensity exercise in the heat has not been found. When prolonged high-intensity exercise was completed in both hot (~30 °C) and temperate conditions (~20 °C), similar levels of plasma ammonia, plasma free fatty acids and blood glucose were measured [20]. In support of this finding, no difference in the amount of muscle glycogen depletion was observed between a football match played at 43 °C or 21 °C [37]. Combined, these results suggest that an added environmental thermal load does not substantially affect the metabolic response to team sports matches as the effect of an increased temperature is negated by a reduced overall physical performance.

9.2.2.5 Neuromuscular Response

Peak speeds and sprint running distances during team sport matches are often maintained [2, 15], or even improved [1, 14] in hot conditions. This may be a physiological effect as increases in muscle temperature accelerate fibre conduction velocity, increase ATP turnover and cross bridge cycling rate to enhance sprint performance [38]. Improved sprint performance in the heat has been shown in isolated bouts of explosive and high-intensity exercise. For example, when rugby union [39] and rugby league players [40] wore passive heat maintenance jackets to maintain core temperature following a warm-up, peak power output in a counter-movement jump and repeat sprint ability (6 × 40 -m shuttle sprints, 20-s passive recovery) were both improved compared to the control condition. Alternatively, as players typically reduce the amount of low-moderate intensity activity when competing in the heat [1, 2], the capacity to perform maximal efforts at crucial time points throughout a match may be preserved. In support, neuromuscular testing prior to and following team sport matches in thermally challenging environments has shown that muscle function is unaffected by the conditions [3, 14, 37, 41, 42]. Players are able to maintain power output in single maximal efforts such as a vertical jump [3], counter-movement jump [41], 30-m sprint [14] or a maximal voluntary contraction torque of the plantar flexors [37] when tested following a match in the heat. Moreover, if reductions in neuromuscular capacity occur, they appear to be no different to the expected decrease after a match played in a temperate environment. For instance, a similar decrease in repeat sprint performance (~2%), reduction in voluntary activation (~1.4%) and lower peak twitch torque of the plantar flexors was observed following football matches played in either 43 °C or 21 °C [37]. These results are contrary to investigations that have assessed the neuromuscular response of team sport athletes during field-based tests of physical performance. Where during prolonged high-intensity shuttle running, a significant heat-induced reduction in sprint performance has been reported [16, 23]. This observation is in line with the reductions in central nervous system drive, impaired neural recruitment and decreased muscle activation that are associated with hyperthermia-induced fatigue during sustained voluntary maximal isometric contractions [22]. These differing findings highlight the importance of assessing any changes in the neuromuscular response associated with the heat within the tactical and technical context of a match.

9.2.3 Tactical and Technical Performance

Skill level, decision-making ability and tactical awareness are key differentiators for success in team sport [43, 44]. While the physical characteristics of a player allow them to perform these actions, matches are not necessarily won by the fittest or fastest team. When competing in hot and/or humid conditions, technical performance parameters appear to be unaffected by the environment [1, 14]. For example, in football matches played under high heat stress, there was a higher success rate for all passes [1, 14] and a similar total number and length of passes and crosses [14]. This may be the result of slower game play, as in these matches a reduction in physical activity was also observed, either by reducing total distance [14] or the amount of high-intensity running completed [1]. In addition, the number of goals scored, actual playing time and the total number of penalty cards given were similar, suggesting that these aspects of game play were unaffected by the environmental conditions [1]. This is in line with observations during professional football matches in temperate conditions where technical actions and ball involvement are maintained despite declines in physical performance throughout the match [45]. However, these findings are based on highly skilful professional players who did not exhibit any hyperthermia-induced signs of fatigue. If hyperthermia-induced fatigue was present during a team sport match, it is possible that skill execution, cognitive function and decision-making ability could be impaired [46].

9.2.4 Cognitive Function

Tactical performance is closely linked to cognitive function as during matches players are continually processing task-specific information, evaluating movement patterns within the context of the match and making behavioural adjustments accordingly [47]. Increases in core temperature during football matches played at

~34 °C and 64% RH have been associated with reductions in cognitive function [17]. Collectively, the results from a range of tests for viso-motor reaction time, fine motor speed and working memory revealed a slower, yet more accurate response after the match. Thermally challenging environments can also exacerbate mental fatigue and lead to further impairments of technical and tactical performance [46]. For example, when mental fatigue levels are high, speed and accuracy during football-specific decision-making skill [48], offensive and defensive technical performance in small-sided games [49] and passing accuracy in a football-specific skill test [48] are all negatively impacted. While these findings provide examples of how an added heat stress can affect technical and tactical performance in football, they may not translate to other competitions, players or team sports. Moreover, a match outcome will only be impacted if one team's technical and tactical capacity is affected more than their opponent. Nonetheless, they do show that increases in body temperature can compromise motor skill performance and cognitive functioning and suggest that players reduce physical workload to preserve technical and tactical parameters in hot conditions.

9.2.5 Health

When team sport training and competition are completed in thermally challenging environments, there is a potential increased risk of heat illness and injury [50, 51]. However, from the available published data, it appears that football, AF and rugby players are able to cope with hot and humid conditions without any adverse effects [1, 3, 14, 52, 53]. Despite players reaching core temperatures of above 40 °C, no signs or symptoms of heat illness were reported during AF matches in hot and/or humid conditions [2, 3]. Similarly, no heat-related illness or injuries were reported during major competitions including the 2003 Rugby World Cup [53] or the 2014 FIFA World Cup [1], which were held in hot environments. These examples are from professional competitions however, where medical staff are well-prepared and educated on prevention strategies to reduce the likelihood of heat illness and injury. At a participation level, the early signs of heat stress may more easily be missed. Without immediate cooling interventions, players can then rapidly progress along the continuum of heat illness and injury to the more severe and potentially fatal, exertional heat stroke. It is also important to note that heat-related illness and injury can occur in cool climates as the environmental heat stress is only one of several predisposing factors [50]. When players are unfit, unacclimatised, hypohydrated, have an infective illness, are wearing non-breathable clothing or have taken stimulants, they are more susceptible to heat illness and injury, regardless of the ambient conditions [50, 54]. It is therefore necessary to have an understanding of a player's health status prior to training and competition. Additionally, all staff, officials and players should be educated on the early warning signs of heat strain such as dizziness, nausea or a headache [54]. Countermeasures such as acclimatisation, hydration and cooling can also help reduce the likelihood of heat illness and injury.

9.3 Countermeasures to Optimise Performance and Health

9.3.1 Heat Acclimation

Football, AF and rugby players can naturally acclimatise by travelling earlier to a hot location before the match or acclimate by completing a block of training in an artificially heated environment [51]. To ensure the best outcome from the training block, players need sufficient exposure to the heat without compromising training quality or causing excessive fatigue. This can be achieved through carefully structuring the training program. Generally, it is recommended that acclimation protocols replicate the demands of team sport performance [55]. This allows players to experience heat in a situation that reflects their competitive environment and has the additional benefit of more easily integrating the heat stimulus into an existing training schedule [51]. One approach is to use natural heat exposure during skills-based training, then complete resistance and high-intensity conditioning sessions in a cool environment [56]. Another is to use alternating days of heat training sessions (i.e. intermittent exposure) to better fit into a player's overall training load [57]. Other example strategies of how heat acclimatisation can be applied in team sport are outlined in Table 9.1. Forms of passive exposure, including saunas [59] or hot-water immersion [65], can also be used to further promote physiological adaptations to the heat.

Both short-term [61, 63, 66] and medium-term (8–14 days) [56, 67] heat acclimation protocols can improve physical performance parameters in team sport athletes. A 7-day training camp in a hot environment (~39.8 °C, 27% RH) has been shown to induce thermoregulatory adaptions including plasma volume expansion, increased sweat rate and reduced sweat sodium concentration in semi-professional football players [51]. Similar signs of heat adaptation were observed in professional AF players living and training in a hot environment (~32 °C and ~39% RH) for 14 days [56, 68]. However, travelling in advance to prepare for a competition is not always a practical option for teams. Short-term acclimation protocols (≤7 days) can provide a time- and cost-efficient alternative [66]. While the thermoregulatory adaptations are not as pronounced after a shorter exposure period, players have been shown to have an improved thermal tolerance following as little as four sessions in the heat [63].

9.3.1.1 Player Monitoring During Heat Acclimation

Heat places an additional stress on the body. Like any training stressor, how a player tolerates and adapts to the heat should be monitored, from both the perspective of assessing the thermoregulatory response and the management of a player's well-being. Table 9.2 provides a summary of common measures used in team sport players.

Changes in exercise heart rate during standardised heat exposure provide valuable insight into how a player is responding to the increased thermal load. However, it can be difficult to distinguish between an adaptive or maladaptive state based on heart rate alone [69]. When assessing heat acclimatisation, it is important to

Table 9.1 Practical application of heat acclimation strategies in football, AF and rugby

Training phase	Objective	Protocol length	Distribution of exposures	Type of heat stress	Ambient temperature	Relative humidity	Total duration of heat exposure (min)	Training prescription	Training sessions	Reference
Early preparatory	Initial preparatory camp to evaluate individual responses to the heat to optimise re-acclimation during future heat protocols	10–14-day	Consecutive	Natural or artificial	30–35 °C	40–60%	600–840	Constant rate	Low-moderate intensity cycling	Castle et al. [58] Racinais et al. [56]
	Promote thermoregulatory adaptions associated with improved aerobic performance.	10-day	Consecutive	Sauna	87 °C	11%	300	Passive	Post-training	Stanley et al. [59]
Late preparatory	Preparation for a major tournament	8–14 days	Consecutive	Natural	Same as competition		600–1200	Self-regulated	Routine training	Buchheit et al. [60] Racinais et al. [61] Racinais et al. [56]
In-season	Preparation for a mid-season one-off match in hot conditions	4–5 sessions	Intermittent	Artificial	30–35 °C	40–60%	150–200	Constant rate or self-regulated	High-intensity intermittent running	Brade et al. [62] Kelly et al. [57] Sunderland et al.[63]
Injury management and rehabilitation	Reduce mechanical workload for an equivalent metabolic response	As required	Intermittent	Artificial	30–35 °C	40–60%	150–200/week	Controlled hyperthermia	Low-moderate intensity cycling	Philp et al. [64]

Table 9.2 Implementation of tools used in team sport to monitor training and adaptive responses to the heat

Monitoring tool	Use	Interpretation / sign of heat acclimation	When to measure	Reference
Health and well-being				
Psychometric questionnaires i.e. rating of perceived fatigue, sleep, mood, soreness and stress scored on a 5-point scale (1 = poor, 5 = very good)	Measure the perceived state of well-being	High ratings of wellness variables: Player is tolerating overall training stress Low ratings of wellness variables: Player is not tolerating the overall training stress	Daily or prior to each key training session. The questionnaire should be completed before, during and after the heat acclimation period	Buchheit et al. [68] Buchheit et al. [67]
Urine-specific gravity	Assess level of hydration	A high concentration of solutes in the urine indicates dehydration	Daily or at regular intervals, upon waking Pre- and post-match or heat-response test	Aughey et al. [2] Kelly et al. [57] Kurdak et al. [30]
Body mass	Assess fluid balance over consecutive days	Large daily fluctuations in body mass can indicate a player has not adequately re-hydrated following the previous session	Daily, upon waking	Racinais et al. [56] Racinais et al. [51]
Sub-maximal running test 5′-5′ test: 5-min run at a fixed speed, followed by 5-min of seated recovery	Provides insight into changes in fitness and fatigue	Fatigue measure: Increased RPE Fitness measure: Improved heart rate recovery	Complete as part of warm-up. 2–3/week, or 3 consecutive days at beginning and 3 consecutive days at the end of protocol	Buchheit et al. [60] Buchheit et al. [68]
Thermoregulatory adaptations				
Heat-response test i.e. 24–30-min walking at 5 km/h, 24–30-min seated rest at 44 °C, 44% RH or standardised prolonged repeated sprint protocol	Lab-based test to directly measure thermoregulatory responses to rest and exercise	Reduced core and skin temperature, lower sub-maximal heart rate at the fixed work rate, higher sweat rate, reduced sodium concentration and reduced haematocrit percentage	Pre- and post-heat acclimation period. Can also re-test 1–2 weeks following to assess decay of adaptations	Brade et al. [62] Kelly et al. [57] Racinais et al. [61] Racinais et al. [56]

(continued)

Table 9.2 (continued)

Monitoring tool	Use	Interpretation / sign of heat acclimation	When to measure	Reference
CO re-breathing test	Indirect measure of plasma volume	Plasma volume expansion	Pre and post-heat acclimation period. Can also re-test 1–2 weeks following to assess decay of adaptations	Buchheit et al. [68] Racinais et al. [56]
Haemoglobin and haematocrit	Relative change in plasma volume	Decreased haemoglobin concentration and haematocrit percentage	Pre- and post-heat acclimation period. Can also re-test 1–2 weeks following to assess decay of adaptations Daily measures at rest Pre- and post-heat-response test	Buchheit et al. [60] Philp et al. [64] Racinais et al. [56]
Sub-maximal running test i.e. 5′-5′ test: 5-min run at a fixed speed, followed by 5-min of seated recovery	Field-based test to estimate heat adaptation	Reduced sub-maximal heart rate and increased heart rate variability	Complete as part of warm-up. 2–3/weeks, or 3 consecutive days at beginning and 3 consecutive days at the end of protocol	Buchheit et al. [60] Buchheit et al. [68] Buchheit et al. [67]
Body mass pre- and post-exercise and account for fluid intake during the session	Estimate sweat loss and sweat rate	A greater amount of body mass loss suggests an increased sweat rate	Pre- and post-heat acclimation period. Can be assessed more regularly to prescribe fluid intake for rehydration.	Aughey et al. [2] Brade et al. [62] Buchheit et al. [67] Kelly et al. [57] Philp et al. [64] Racinais et al. [56]
Performance measures/fitness testing				
YoYo intermittent recovery test	Assess high-intensity intermittent running performance	Increased distance covered during the test	Pre- and post-heat acclimation period	Buchheit et al. [60] Racinais et al. [56]

Table 9.2 (continued)

Monitoring tool	Use	Interpretation / sign of heat acclimation	When to measure	Reference
30–15 intermittent fitness test	Assess high-intensity intermittent running performance	Improved peak velocity (V_{IFT})	Pre- and post-heat acclimation period	Philp et al. [64]
Match analysis	Assess match-running performance	Similar physical activity profile to matches played in temperate conditions	Pre- and post-heat acclimation period	Racinais et al. [61]
Standardised training drills	Assess sport-specific running performance	Increased total distance and greater amount of high-intensity running	Pre-, during and post-heat acclimation period	Racinais et al. [56]
Repeated sprint efforts i.e. 4 × 60-m runs with 30-s passive recovery	Assess neuromuscular efficiency	Improved neuromuscular efficiency index (accelerometer-derived ratio between velocity load and force load)	Pre-, during and post-heat acclimation period	Buchheit et al. [67]
Session monitoring				
Record environmental conditions	Quantify thermal load		Heat training sessions	Buchheit et al. [60] Racinais et al. [61]
Thermal comfort	Assess perceptual response to the ambient environment	Improved thermal comfort	Heat training sessions	Kelly et al. [57]
Thermal sensation	Assess perceptual response to the ambient environment	Reduced heat sensation	Heat training sessions	Brade et al. [62] Philp et al. [64] Racinais et al. [56]
Heart rate	Internal training load measure	Average heart rate or prescribed heart rate for a constant rate training session	Field-based training and conditioning sessions	Buchheit et al. [60] Racinais et al. [61]
Running volume and intensity	External training load measure	Total distance and high-intensity running	Field-based training sessions and running conditioning	Racinais et al. [56]
RPE:min	Contextualise internal training load to external load	Increased ratio suggests increased level of heat strain	Field-based training sessions and running conditioning	Buchheit et al. [67]

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Table 9.2 (continued)

Monitoring tool	Use	Interpretation / sign of heat acclimation	When to measure	Reference
Session RPE	Quantify overall training load	Training time and associated post-session RPE	Each session	Buchheit et al. [68] Buchheit et al. [67] Philp et al. [64]
HR-based TRIMP	Quantify overall training load	Training time and associated average heart rate	Each session	Buchheit et al. [60] Racinais et al. [61]

contextualise changes in heart rate to the physical work completed or to the perception of effort. For example, standardised sub-maximal running [60, 67, 70] or training drills [56] can be used at regular intervals to track the time course of heat adaptation and ensure that players are adequately coping with the training stress. These field-based monitoring tests are practical to implement, repeatable, relatively non-fatiguing, time efficient and can be completed as part of the warm-up. Heart rate measures and rating of perceived exertion (RPE) during a 5-min run at a fixed speed, followed by 5-min of seated recovery (5′-5′ test) has been used throughout an in-season football [60] and a pre-season AF [70] heat training camp. A trend for average heart rate during the final 30 s of exercise (HRex) to decrease and heart rate variability to increase (HRV; logarithm of the standard deviation of instantaneous beat-to-beat R–R interval variability, log SD1, measured from Poincaré plots during the last 3 -min of recovery) as the camp progressed was associated with heat-induced plasma volume expansion. Heart rate recovery (HRR; absolute difference between HRex the HR recorded after 60-s recovery) and RPE remained stable, indicating a balanced fitness/fatigue status. Similar sub-maximal tests can be used as part of a warm-up before training sessions done in a heat chamber [71]. It is highly recommended to incorporate the test used for monitoring into the training schedule prior to the heat acclimation period. By having a better understanding on how players respond to training in a temperate environment, it will allow for a more meaningful interpretation of the heat-induced changes.

A measure of both internal and external load should be taken to capture the overall training stimulus during heat acclimation. Otherwise, when conditioning sessions, technical practise or competition are completed under hot and/or humid conditions, training stress can be over- or underestimated. For instance, if training load is quantified based on external load parameters alone, such a total distance covered, or time in specific velocity bands, practitioners may conclude that the training stimulus is lower in the heat as a player's running output is reduced. To gain a more accurate understanding, it is also important to consider a measure of internal training stress, such as heart rate, or RPE when quantifying the training response, particularly when players are under a high thermal load. Heat-induced elevations in heart rate for a reduced mechanical workload are indicative of the greater training stress that occurs during exercise in hot compared to cooler environments [64]. Moreover, a reduction in internal training measures as the heat acclimation period progresses can be used as an indicator of thermoregulatory adaptation. For example, the average heart rate of AF players during a standardised training drill was reduced and external load measures (total distance and amount of high-intensity running) improved at the completion of a heat acclimation camp [56]. To a similar effect, RPE has been used to contextualise changes in training volume (m/min) [67]. For the first two sessions of a heat training camp, RPE:m/min ratio of footballers increased substantially, suggesting an increased perceived exertion for a given workload. The RPE:m/min ratio then followed a downward trend and stabilised after 5 days. This coincides with the 5–7 days it typically takes for the initial signs of heat acclimation to appear. These examples show how player monitoring can provide insight into the effectiveness of the heat acclimation period.

9.3.2 Hydration

Adequate hydration can minimise the effects of heat stress during training and competition in football, AF and rugby [17, 50, 51, 72]. It is generally recommended that players drink 5–6 ml of fluid per kg of body mass every 2–3 h prior to training and competition [51]. As sweat rates can vary considerably between each person, it is suggested that hydration practices are individualised [21, 25]. Individualisation of fluid intake can be based on the intensity and duration of the match or training session [21] or by using pre- and post-session changes in body mass to estimate fluid loss (as shown Table 9.1). To ensure that the fluid intake is sufficient, urine specific gravity (<1.020) and fluctuations in body mass (<1%) upon waking are useful measures to track hydration status over a period of days (see Table 9.1) [51]. Alternatively, for youth or players at a participation level, a urine colour chart can be an appropriate tool to assess hydration [73]. The inclusion of additional drink breaks and recommended fluid intakes in heat policies highlights the importance of hydration to reduce the adverse effects of heat exposure [74, 75]. For example, the Australian Football League (AFL) suggests players consume 500–700 ml per quarter [75]. FIFA recommends players replace each kilogram of weight lost during training or matches with 1.2–1.5 L of fluid [74]. Moreover, when replacing sweat losses, replenishment of electrolytes should also be considered [51].

9.3.3 Cooling Strategies

Cooling strategies can be used in football, AF and rugby to improve heat storage capacity (pre-cooling), reduce exercise-induced increases in core temperature (mid-cooling) and accelerate recovery (post-cooling). While the evidence supporting improved performance in a competitive team sport setting has been equivocal, it is prudent to provide access to cooling from a heat-illness prevention perspective, particularly for players who are unacclimatised to hot conditions [58, 62]. To optimise performance, it is also important to balance the effects of pre-cooling and ensuring that players are adequately warmed-up [76], as excessive external cooling may negatively impact muscle function and speed [77]. The summary below outlines examples of cooling interventions that can benefit training and competition in the heat and be incorporated into a player's schedule. More details on cooling are available in Chap. 7.

Pre-cooling: A mixed method approach to cooling with both internal (i.e. ice slurry) and external (i.e. ice vest, cold pack and iced towels) techniques applied for 20–30-min prior to warming up [78, 79]. Provide access to fans, spray bottles, shaded area and/or air conditioning.

Mid-cooling: Drinks should be provided at less than 15 °C to assist with absorption [80]. At half time, reapply ice vest, cold pack and iced towels [78]. Provide access to fans, spray bottles and either a shaded area, a cool room and/or air conditioning [75]. On interchange bench, provide fans, spray bottles and shade [75]. Substitute players should also have access to fluids and ice [80].

Post-cooling: Cold water immersion or cold showers can be used to quickly reduce the core and skin temperature of players [81].

9.4 Heat Policy and Implementation

Players and officials are susceptible to heat illness and injury when training and competing in the heat. By outlining preventative measures in heat policies, the governing bodies of football, AF and rugby aim to reduce this risk. These policies consider both the environmental conditions and each individual player's capacity to tolerate heat stress and then provide strategies to reduce heat exposure, such as the rescheduling of games and countermeasures to minimise the impact of hot and humid environments. For example, the Australian National Rugby League (NRL) employs the Sports Medicine Australia guidelines to determine the appropriate game day intervention [82]. Based on a combination of external factors such as the ambient environment, duration and intensity of the exercise, availability of fluid, playing facilities, access to medical staff or first aid and the individual player characteristics (i.e. age and fitness level), the match may be postponed. Common countermeasures to heat stress across the federations include the provision of additional drink/cooling breaks [74, 80, 82] or other approaches, such as an increased number of on-field water carriers [75] to ensure ample drinking opportunities for players. A strong emphasis on player preparedness and education is also present, where players are encouraged to begin the match or training session well-hydrated, utilise cooling inventions and be aware of, then seek medical help at the first signs of heat distress [74, 75, 80].

Considering the commercial impact of rescheduling or cancelling a professional match, it is important that robust heat policies are in place to protect the welfare of players. World Rugby [80] and the AFL [75] provide the most comprehensive policies that outline the responsibilities of the player, team officials, medical officers and event organisers to manage thermal load during both training and competition. The AFL policy also advocates that clubs should continue to research the effect of heat stress and management strategies for players [75]. In comparison, the FIFA [74] and NRL policies are quite brief and centred on heat management strategies during competition. Another key difference between the policies is how the level of heat risk is assessed. FIFA [74] and the NRL [82] utilise a WBGT of 32 °C and 30 °C, respectively, to consider measures to minimise heat illness and injury. World Rugby uses a heat stress index of 150 to signify when the interventions outlined in the heat policy should be implemented [80]. The AFL does not specify exact criteria that determine when additional heat management strategies are warranted. Instead, it is under the discretion of the event organiser to base the decision on the information provided by the Australian Bureau of Meteorology [75]. It is difficult to comment on the most appropriate approach to assess when the environmental conditions become severe enough to activate a heat policy, as there is little published information on the incidence of heat-related illness and injury during matches. In the future, greater collaboration, surveillance and reporting of all cases of heat illness and injury ranging from mild to severe in these sports will assist in better understanding the potential mechanisms of heat stress. Based on this knowledge, improved prevention and management of strategies can then be developed.

9.5 Conclusion

Football, AF and rugby players can gain a competitive advantage in hot conditions by being able to better tolerate an added heat stress. This can be from the strategic application of cooling interventions or by being well-acclimatised to enable the maintenance of match-running performance in hot environments. Consecutive days of heat exposure during on-field training sessions is an effective acclimation method in team sports. Although, due to the variable nature of these sessions it is important to closely monitor and track individual responses to the increased thermal load. This ensures that players are receiving a sufficient heat stress and adapting appropriately. Moreover, to reduce the likelihood of heat-related illness and injury during both training and competition, players, support staff and coaches should be educated on the early warning signs and have the facilities (i.e. fans, ice, fluids and shaded areas) to quickly cool players if required. In general, it appears that in football, AF and rugby, players can adequately manage heat stress as severe heat illness and injury are rarely reported. This is in line with initial evidence that suggests players reduce their physical activity outputs during matches in hot conditions in response to an increase in thermal strain, which preserves the capacity to execute tactical strategies during key moments of the match. However, further well-controlled, field-based studies are needed to confirm if these findings occur across football codes and in different levels of participation.

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