Hydration and thermal strain during tennis in the heat

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Accepted 28 January 2014

To cite: Bergeron MF. *Br J Sports Med* 2014;**48**: i12–i17.

ABSTRACT

Competitive tennis in the heat can prompt substantial sweat losses and extensive consequent body water and electrolyte deficits, as well as a level of thermal strain that considerably challenges a player's physiology, perception of effort, and on-court well-being and performance. Adequate hydration and optimal performance can be notably difficult to maintain when multiple same-day matches are played on successive days in hot weather. Despite the recognised effects of the heat, much more research needs to be carried out to better appreciate the broader scope and full extent of the physiological demands and hydration and thermal strain challenges facing junior and adult players in various environments, venues and competition scenarios. However, certain recommendations of best practices should be emphasised to minimise exertional heat illness risk and improve player safety, well-being and on-court performance.

INTRODUCTION

Playing competitive tennis effectively and safely in the heat is challenging—even for the fittest of players. This is visibly evident in tournament competition where the intensity of match-play is very high and repeated exposure to the demanding environmental conditions increasingly takes its toll as players advance through the draw. Substantial sweat losses and extensive related body water and electrolyte deficits are not uncommon,[1–5] as is a level of thermal strain that considerably challenges a player's physiology, perception of effort and on-court well-being and performance. The challenge is particularly notable and difficult in events where players have to compete in multiple same-day matches. With the duration of each match often extending to several hours or more, the daily cumulative physical activity and concomitant heat exposure can be remarkable.

Unlike with continuous exercise, on-court thermal and cardiovascular strain and perception of effort during tennis can be notably exacerbated by the repeated complex, intermittent activity patterns with varying, frequently demanding workloads and short recovery periods that are characteristic of intense tennis training and competitive match-play.[6 7] Strong and constant sun exposure and reflective solar energy off the court surface can contribute further to the accumulating heat storage and physiological strain. However, body core temperature, until now, has been shown to remain fairly constant during play (and not notably threatening to a player's safety—ie, generally below 40°C on average), following an initial rapid increase from preplay levels.[5 8 9] Self-determined and self-controlled pacing to avoid dangerous levels of physiological strain, by slowing down and/or modifying the style of play to end selected points more quickly, most likely plays an integral role in minimising on-court thermal strain and extending the opportunity to continue play in a range of challenging environmental conditions.[10 11] As with many other sports, however, there are minimal tennis-specific data available regarding the array of on-court and recovery physiological responses and profiles related to hydration status and thermal strain under realistic practice and competition scenarios in natural hot outdoor settings, with an additional prominent deficiency of such findings and profiles in youth.

This brief review provides an overview of the important practical relevant knowledge until now in tennis, with recommendations for further research, advancing the field and improving player well-being, performance and safety in the heat.

- First, the key reported findings featuring hydration-related measures and thermal strain during high-level tennis training and competition in the heat are highlighted. A description of sweat losses and hydration status in junior and adult tennis is presented, followed by representative thermal strain responses in these same distinct populations. Notably, the specific studies examining sweat losses, hydration status and thermal load during tennis highlighted here are limited to selected, published on-court and post-play/training responses in elite-level junior and adult players.
- Scheduling challenges are emphasised next, with an emphasis on same-day repeated bouts of match-play and the potential for 'carry-over' effects from previous competition-related physical activity and heat stress on subsequent physiological strain and performance.
- Selected clinical conditions and medications that can potentially affect a player's thermoregulation, exercise-heat tolerance or exertional heat illness risk during tennis competition or practice in the heat are featured, along with the purported similar effects of caffeine.
- Overall practical implications are then noted, with an emphasis on the hydration challenges associated with tennis in the heat and lowering thermal strain for all players by focusing on readily modifiable and individualised risk factors and reinforcement by close monitoring.
- Recognising the gaps in the literature, the question "Where do we go from here?" is candidly addressed. The appropriate answer to this important question prompts a recognised challenge, as it is typically very difficult to obtain the necessary access and consent to closely assess players during high-level competition; however, clinicians, scientists and tennis governing bodies need to approach this perceived barrier with innovation and creative solutions,

if tennis research is going to advance beyond simply profiling physiological characteristics of tennis training and match-play in more convenient populations and scenarios.

- Lastly, this synopsis on hydration and thermal strain during tennis in the heat concludes importantly with specific recommendations of best practices to minimise exertional heat illness risk and improve well-being and on-court performance for all players.

SWEAT LOSSES AND REHYDRATION

Junior tennis

Sweating rates in excess of 1 L/h have been reported with young adolescent players during tennis practice[4] and tournament competition[8] in the heat, including during doubles play. This, of course, varies with on-court environmental heat stress (air temperature, humidity and solar radiation) and intensity and duration of play, as the need for evaporative cooling and thus sweating fluctuate proportionately. With older adolescents, the sweating rate during intense practice and competitive play in challenging environmental conditions can often reach 2.5 L/h or more.[1 2] Across this entire range of sweat loss rates, however, junior tennis players are not always effective at appropriately minimising body water deficits during practice or play or recovering with sufficient fluid intake between matches.

In contrast to earlier findings with non-tennis youth,[12 13] unflavoured water has recently been shown to be equally effective as a carbohydrate-electrolyte sports drink (CHO-E) in encouraging voluntary fluid intake in physically active young girls during intermittent exercise in the heat,[14] adolescent boys during basketball[15] and notably with high-level, fit junior tennis players during intense on-court training in very warm conditions outdoors.[4] Effective rehydration, however, during and after play, often involves more than simply ample fluid intake. On-court sweat sodium losses can be substantial, even for a young tennis player who is well acclimatised to the heat.[1 2] Accordingly, sweat electrolyte losses (particularly sodium and chloride) incurred during play must be replaced as well, in order to fully rehydrate and optimise body water retention and distribution in all fluid compartments.[16–20]

Adult tennis

On-court sweating rates and related sodium losses in adult tennis players are generally comparable to those in older adolescents (though they are often much greater for some adults) during intense practice and competitive play.[2 3 5 9 21]

Hornery *et al*[9] examined 14 male professional tennis players (21.4 (2.6) years) during international tournament competition on hard courts in the heat (32.0 (4.5)°C) and clay courts in somewhat less stressful environmental conditions (25.4 (3.8)°C). Postmatch body mass deficits were significantly greater during hard court competition (1.05 (0.49)%) compared to only 0.32 (0.56)% following the clay court matches. Tippet *et al*[5] assessed seven professional women players during outdoor tournament play on hard courts in similar hot environmental conditions (30.36 (2.36)°C). Although the on-court sweating rate was extensive with 2.0 (0.5) L/h, postplay body weight deficits were only modest (1.2 (1.0)%).

Bergeron *et al*[3] evaluated 20 (12 male and 8 female) tennis players from two Division I university tennis teams during three successive days of competitive round-robin play (ie, 2 singles tennis matches followed by 1 doubles match per day) in a hot environment (32.2 (1.5)°C and 53.9 (2.4)% relative humidity at 1200 h). During singles play, percentage changes in body weight were minimal and similar for all players (men: –1.3 (0.8)%, women: –0.7 (0.8)%), and estimated losses (mmol/day) of sweat sodium (men: 158.7; women: 86.5) were generally met by daily dietary intake. However, as with many older adolescent players, on-court and consequent daily accumulated body water and sodium losses and deficits can be much greater from extensive sweating and often need to be more deliberately replaced to adequately rehydrate and maintain more optimal body water retention and distribution, especially with successive days of training or tournament play.[1 2 16 22]

Table 1 provides three representative examples of sweat loss (water and sodium) rates (group mean and selecting the lowest and highest sweat rates) from a group of 17 players evaluated on court during hard-court singles tennis in hot environments.[2] With the respective rates of observed fluid intake (water only), the table demonstrates how these water and sodium losses from sweating would play out in match-play—contrasting the consequent postplay body water and sodium deficits incurred after 1.5 and 4 h of singles match-play (which could be from a single very long match or cumulatively from two closely scheduled same-day matches, recognising that part of the water and sodium deficits would be recovered in between matches in the latter scenario). Such resultant match-play deficits are often in *addition* to the already existing preplay deficits incurred from previous matches or practice/warm-up sessions that were never fully restored. This is frequently the case in tournament play when multiple same-day matches are contested on successive days.

THERMAL STRAIN

Junior tennis

Especially during a hard practice session or an intense competitive match in the heat, a young player's metabolic heat production, heat storage and thus body core temperature can be expected to progressively increase. While visible indications of thermal strain in young players are routinely witnessed during hot-weather competition, the full extent and prevalence of excessive body core temperature and exertional heat illness incurred on court, as well as the consequent contributing role of thermal strain in performance outcome, are largely unknown in junior tennis.

Bergeron *et al*[4] examined differences in ad libitum fluid intake, comparing a 6% CHO-E and water, and thermal strain in highly skilled, fit junior tennis players (15.1 (1.4) years) during intense on-court training in a very warm environment (wet-bulb-globe temperature (WBGT) ~26.4°C). With a randomised, cross-over design (two 2 h test training sessions on separate days, separated by 1 day), the players experienced the same environment, workload, intensity, drill sequence, break times and activity/rest intervals, to maintain consistency (as much as possible) in the metabolic rate and load between trials. Moreover, players assigned to the CHO-E condition hit with those using water, to further equalise workload and metabolic rate between groups. Accordingly, the average total sweat loss in each group was the same (just over 2.2 L), as was the fluid intake (just over 1.8 L). While a number of players began the monitored training sessions not well-hydrated, prepractice urine-specific gravity (also the same between trials) was not statistically associated with body core temperature responses (which approached or reached 39°C for some players) during the 2 h practice sessions, and no players had any visible indications of excessive thermal strain. However, in examining the main effect for trial (water vs CHO-E), a significantly ($p<0.001$) lower mean body temperature was observed during the CHO-E trial than during the water trial (37.97 (0.24)°C vs 38.20 (0.31)°C, respectively). Although such a small difference in the observed thermal strain is not likely to be clinically relevant or provide a

Bergeron MF. *Br J Sports Med* 2014;**48**:i12–i17. doi:10.1136/bjsports-2013-093256

Table 1 Representative examples from Bergeron[2] of sweat loss, fluid intake (water only) and consequent postplay body water and sodium (Na^+) deficits incurred from 1.5 and 4 h of singles match-play

				1.5 h of play		4 h of play	
	Sweating rate (L/h)	Sweat [Na^+] (mmol/L)	Fluid intake rate (L/h)	Body water deficit (L)	Total-body Na^+ deficit (mg)	Body water deficit (L)	Total-body Na^+ deficit (mg)
Player 1	2.0	40.0	1.1	1.4	2759	3.6	7357
Group mean	2.6	44.5	1.6	1.5	3990	4.0	10 640
Player 2	3.4	60.8	2.3	1.7	7129	4.4	19 010

noticeable performance advantage, it speaks to an apparently measurable effect of drink content (Na^+) on potentially enhancing body water distribution and thermoregulation.[17–19 23]

Until now, only one study has examined body core temperature in junior tennis players during an actual sanctioned tournament competition. Bergeron *et al*[8] observed eight elite-level young boys (13.9 (0.9) years) during the first round of singles and doubles play in a US Tennis Association national championships event during the first week in August. In contrast to the 2 h practice sessions in somewhat less stressful environmental conditions described above,[4] preplay hydration status (urine-specific gravity) in these tournament players was progressively and ultimately strongly associated (r=0.87; p=0.005) with on-court thermal strain (38.7 (0.3)°C at the end of match-play, while exceeding 39°C for some players) during singles competition. While recognising the difference in environmental stress between the two scenarios, these differing relationships between preactivity hydration status and subsequent on-court thermal strain underscore the distinctive characteristics of individual or team practice sessions, where the emphasis is on completion versus *winning*. That is, players may be able to "get away with" a greater level of dehydration during practice, without that fluid deficit necessarily translating into a significant increase in body core temperature or risk of heat-related complications, because the intensity of activity is typically not sustained at a competitively high level. During elite individual sport competition such as these national championships (or even local and regional contests), however, young athletes will often maintain a strong effort and intensity, despite not feeling 100% or even having the capacity to safely continue. The degree of thermal strain observed in this tournament play study is particularly notable, as the singles matches were relatively short and contested mostly in the morning (WBGT 29.6 (0.4)°C), which also underscores the contrast of metabolic heat production and storage during meaningful competition (vs practice or simulated contests). It is also noteworthy that the preplay to postplay increase in body core temperature from 37.6 (0.2)°C to 38.7 (0.3)°C (p<0.001) during singles remained elevated (38.4 (0.3)°C), even after 10 min following the end of play. As with most dedicated efforts to win, with the later rounds of more competitive play in this event, these elite players characteristically maintained a strong effort and very high intensity, even when facing more challenging environmental heat stress. Unfortunately, the likely greater body core temperature responses were not collected. This study also highlights how even doubles play in junior tournament-level tennis can elicit appreciable thermal strain in hot conditions.

Adult tennis

Hornery *et al*[9] reported moderate thermal strain with similar peak body core temperatures during hard and clay court tournament play (38.9 (0.3)°C vs 38.5 (0.6)°C). With female professional players, Tippet *et al*[5] observed a similar mean body core temperature of 38.65 (0.20)°C throughout match-play and a peak temperature of 39.13 (0.34)°C. The notable aspect of this latter study was a specific examination of the effectiveness of the Women's Tennis Association Extreme Weather Conditions Rule (allowing for a break in play between the second and third sets of a match) in reducing thermal strain. Although body core temperature decreased by 0.25 (0.20)°C after a 10 min break, it remained slightly higher than it was at the start of set two. Subsequently, there was a similar degree of peak thermal strain by the end of play as was observed at the end of the second set. Whether thermal strain at the end of play would have been higher had the players not taken a between-set break is unknown.

REPEATED-BOUT CHALLENGES

It can be a near impossible challenge for a tennis player to maintain adequate hydration, minimise on-court thermal strain, and perform optimally during a hot-weather tournament when multiple singles matches are played on the same day with inappropriately short rest and recovery periods scheduled between contests. This scenario is particularly characteristic of junior tennis tournament play, especially at the regional and local levels. The specific impact of previous practice/training-related or competition-related physical activity and heat exposure on subsequent same-day physiological strain and performance has not been adequately examined in tennis. However, field and laboratory studies on repeated-bout exercise in adults and youth clearly indicate that previous same-day strenuous physical activity and heat exposure can have a negative 'carry-over' impact on physiological strain, perception of effort, and performance during the next bout of activity.[24–29] This is evident, even with ample hydration and body core temperature returning to baseline before starting the second bout of exercise. Accordingly, there would be an expected greater effect in stressful environmental conditions, following a long intense match where there is appreciable incomplete rehydration and body cooling before going on court again. This is not an uncommon occurrence in junior tennis and is, at times, practically unavoidable when sweating has been extensive and between-match time is short. An increase in thermal strain can also be particularly evident during subsequent physical activity in the heat following a bout of muscle-damaging exercise[30]—another cautionary consideration to excessive on-court training or same-day competition loads.

The only reported impact of prior heat exposure incurred during same-day previous play was that examined by Coyle[31] with boys during a 14's national championships event. Match outcome and environmental data were studied over a 7-year period. With the effect of tournament seeding removed, Coyle found that the winner of an afternoon singles match could be effectively predicted from the heat exposure (degree minutes) acquired during the players' earlier matches on the same day. These findings provide an important insight regarding the potential carry-over impact from previous competition-related physical activity and heat stress and should help guide tournament scheduling as levels of heat and humidity increase.

CLINICAL CONDITIONS, MEDICATIONS AND CAFFEINE

Current or recent illness can readily increase the physiological strain and clinical risk associated with tennis competition or practice in the heat, because of the potentially negative residual effects on a player's hydration status and regulation of body temperature. The on-court risk to players is especially significant for illnesses involving gastrointestinal distress (eg, vomiting and diarrhoea) and/or fever. Notably, a history of concussion may increase the risk for exertional heat illness during training and competition, secondary to autonomic nervous system dysfunction,[32 33] although this has not been examined until now in tennis. Sickle cell trait should also be considered a possible contributing clinical risk/complicating factor for vascular dysfunction, exertional rhabdomyolysis and collapse related to red blood cell sickling during strenuous practice or play in the heat[34–36]; although this has not been reported or explored in tennis either. A prior episode of exertional heat stroke, however, generally does not have long-term negative effects on subsequent thermoregulation, exercise-heat tolerance or exertional heat illness risk, especially for those who received prompt cooling therapy.[37] Similarly, prior episodes of heat exhaustion or exertional muscle cramping should not have any long-term residual effects on a player's subsequent on-court well-being or performance, unless the primary contributing factors (eg, poor hydration, inadequate sodium intake or insufficient heat acclimatisation) are not addressed and corrected.[16]

Combined with the reduced intestinal blood flow and high intestinal temperature during exercise-heat stress, commonly used non-steroidal anti-inflammatory drugs (eg, aspirin) can further increase gastrointestinal permeability and intestinal barrier dysfunction, prompting endotoxin leakage.[38 39] A consequent increase in proinflammatory cytokines can exacerbate exertional heat illness risk.[40] Other medications that inherently affect hydration or thermoregulation (eg, a dopamine reuptake inhibitor to treat attention-deficit/hyperactivity disorder or enhance performance or diuretics) can also contribute to lowering the exercise-heat tolerance and increasing the physiological strain and exertional heat illness risk.[41] Accordingly, the use of these medications should be discussed with one's primary healthcare provider, in advance of training or competing in a hot environment, especially if there is a history of excessive thermal strain and exertional heat illness.

Caffeine consumption has been another potential concern for tennis players during hot weather training and competition. However, research refutes any purported measurable effects on thermoregulation, fluid-electrolyte balance and exercise-heat tolerance.[42 43] That is, caffeine intake does not appear to be appreciably thermogenic or interfere with heat dissipation during exercise-heat stress. Therefore, even with large doses, caffeine consumption prior to play is not likely to increase physiological strain to augment exertional heat illness risk or impede or lessen on-court performance.

PRACTICAL IMPLICATIONS

Considering the sweating rates reported here for junior and adult tennis players in the heat, it is easy to appreciate how players can readily incur significant total body water and sodium deficits during such training and competition, especially when participating in multiple same-day practice/training sessions or matches over several days or more in a row. Coaches and tournament directors need to appreciate this and accordingly provide frequent breaks during practice and sufficient opportunities to rehydrate and recover during tournament play, respectively, as conditions warrant. And even when a player drinks regularly or on each changeover during a match, the postpractice/play body water and sodium deficits can be significant, especially following a long session or contest (table 1). Accordingly, a deliberate effort to fully (or to the extent appropriate, given the time provided) and effectively rehydrate between practice/training sessions and matches is essential to prevent or minimise accumulated body water and electrolyte deficits.

Regarding thermal strain in junior tennis, there has been a long-standing perspective that children are less effective than adults in regulating body temperature during exercise in the heat. Consequently, they are less tolerant to and capable of performing well in a hot environment and are at greater risk for incurring heat illness compared to adults. However, more current research does not support this viewpoint, indicating that children (9–12 years) do not have insufficient cardiovascular capacity, less effective thermoregulation or lower exercise-heat tolerance when hydration is amply maintained.[44–47] This perspective is supported as well by the on-court (albeit limited) observations of body core temperature in young players during practice and competition in the heat presented here. Accordingly, appropriate and effective safety and performance guidelines for *all* tennis players training and competing in the heat should initially focus on readily modifiable risk factors such as hydration management, acclimatisation and scheduling of play, with close monitoring and modifications in activity based on individualised clinical risk characteristics. These recommendations are outlined below.

WHERE DO WE GO FROM HERE?

With only limited published research and reported on-court hydration and thermal strain responses and profiles in youth and adult tennis, we are far from a full appreciation of the related challenges facing players and being able to confidently prescribe definitive heat safety and optimal performance protocols for all scenarios and environmental conditions. That is, much more research needs to be carried out to better appreciate the broader scope and full extent of the physiological demands and hydration and thermal strain challenges facing junior and adult players in various environments, venues and competition scenarios. This is essential before more specific and all-inclusive evidence-based guidelines for optimally enhancing safety and performance can be established. For example, a more comprehensive and clear perspective of court surface and variation in reflective heat on respective differences in intensity, pace and duration of play and consequent influences on thermal strain would be helpful to players and tournament officials and staff. And while no sex-specific differences in on-court thermal strain were noted in the studies cited here, potential differences and contributing factors should be examined further. Accordingly, it needs to be recognised that currently established general recommendations for maintaining hydration and minimising on-court thermal strain and exertional heat illness risk in youth and adults[37 48–50] have a limited field-supported, sport-specific (tennis) evidence base.

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The findings highlighted in this review could be interpreted as suggesting that there should not be much concern for tennis players training and competing in the heat, as these reported fluid deficits and thermal strain responses appear to be very manageable and non-threatening. This viewpoint is only reinforced by the intermittent, somewhat self-paced nature of tennis competition that additionally includes regular longer periods of inactivity and opportunities to rehydrate, cool down and recover on changeovers. However, the data featured here and other currently available reported findings are collectively limited in scope. There is a critical need to monitor players during longer, more intense 3-set and 5-set competitive matches played in the afternoon in more extreme (which can be, at times, near uncompensable) environments during later rounds of tournaments where potentially there would be greater body water deficits and increasingly greater thermal strain, as well as more prominent carry-over effects from previous rounds of play. Additional studies using non-tennis repeated-bout, intermittent exercise in the heat could provide important supplementary insight as well.[24] Moreover, currently considered and proposed risk reduction protocols such as preplay and on-court cooling, enhanced hydration and effectiveness of between-set cooling and between-match recovery strategies for able-bodied players and those participating in wheelchair tennis also need to be better clarified and validated for effectiveness during actual competition.[51–56] Addressing all of these and other research gaps are critical to providing sufficient information to develop and support more effective and practical evidence-based player preparation and management recommendations and guidelines for playing tennis in the heat.

RESPONSIBILITIES AND RECOMMENDATIONS

The often formidable physical activity and environmental thermogenic-contributing and thermal strain-contributing factors during play are well recognised by players, coaches, on-site healthcare staff and even the spectators. While acknowledging that published studies until now do not indicate appreciable thermal strain in tennis players during competitive play, these data represent a very limited perspective. Until a more inclusive and diverse representation of players competing in more challenging environments and extended and/or repeated same-day play is available, any assertion that tennis players, even when competing in extreme heat, are not at risk for incurring exertional heat illness related to excessive thermal strain should be questioned. Moreover, not fully recognising, appreciating and making appropriate accommodations in advance for reasonably assuring each player's safety and well-being during hot-weather training and tournament events could arguably (though unintentionally) increase the potential clinical risk to participating players.

While the knowledge base, awareness and concern for player safety and well-being have improved, most of the current hot-weather preparation, on-court, recovery and scheduling recommendations and guidelines promoted by tennis governing bodies for effectively managing hydration, reducing thermal strain, optimising performance and minimising exertional heat illness risk on-court are not sufficiently sport specific and evidence based. However, while recognising the lack of sufficient tennis-specific on-court and recovery data to better guide players, parents and coaches, certain recommendations of best practices should still be emphasised to minimise exertional heat illness risk and improve player safety, well-being and on-court performance.

Players, parents and coaches

- Progressive acclimatisation—that is, graduated appropriate exposure to a hot and/or humid environment and the intensity and duration of practice/training and competition—is essential to improve performance and minimise the risk of exertional heat illness, especially when travelling to a more stressful (greater heat and/or humidity) environment.[37 57]
- Tennis players often begin competition measurably dehydrated, which can increase on-court cardiovascular and thermal strain. All players have the responsibility to be well hydrated and well nourished prior to playing. Regular appropriate fluid intake during play and a deliberate effort to fully (or as appropriate) rehydrate between on-court sessions should be a priority for all players, especially in the heat.[1–5 58]
- Effective rehydration involves more than simply ample water intake. Sufficient electrolytes (especially sodium) need to be consumed as well to offset often extensive sweat-related electrolyte losses and to better retain and distribute ingested water.[1–3 16 59 60]
- Incomplete between-match rehydration is often impossible to avoid when multiple same-day singles matches are played and sweating has been extensive, with inappropriately short rest and recovery periods scheduled between contests. In these instances, it is imperative to begin the first match of each day well hydrated and well nourished (especially having sufficiently restored carbohydrate and sodium levels) and immediately begin appropriate postplay rehydration and macronutrient intake (carbohydrate and protein) in order to minimise preplay body water and electrolyte deficits and maximise muscle and energy recovery before the next match. Along with water, a cold carbohydrate–protein replacement drink and small, easily digestible salty snack can be more effective and better tolerated in the heat than a large amount of solid food, especially when there is little time between matches. As between-match time increases, proportionately bigger meals and more optimal fluid intake volume can be considered.[58 59]
- In extreme heat conditions, players should take advantage of opportunities to minimise heat exposure (eg, shorten the prematch warm-up, stay out of the heat prior to play as much as possible and stand in the shade between points, if such areas are available) and maximise cooling opportunities—preplay, on-court and immediately after play. While there has been limited tennis-specific research on popular effective methods for precooling and recovery (eg, ice slurries and cold/ice water baths),[55 56 61] players are increasingly recognising their appeal and apparent effectiveness. Ice slurries can also be convenient during match-play changeovers, although their effectiveness, along with that of applying ice bags/towels or ice/cooling vests during these brief periods, in lowering physiological strain, improving safety or providing a performance advantage on-court has not yet been demonstrated empirically.
- Coaches must be prepared to adjust for changing weather conditions, while recognising that tolerance to physical activity decreases and exertional heat illness risk increases, as the heat and/or humidity rise. Accordingly, it is imperative to modify practice and training duration and intensity, and increase the frequency of breaks, to maintain safety and performance.[37 48] The same considerations should apply to prematch warm-ups in hot weather tournaments.
- A player's individual level of fitness and medical status also directly affect on-court performance and exertional heat illness risk, especially in the heat. Thus, individualised appropriate modifications to practice and training are essential.

Importantly, players should avoid or significantly limit practice, training and competition in the heat if they are currently ill or are recovering from illness, especially those illnesses involving gastrointestinal distress (eg, vomiting, diarrhoea) and/or fever.[37 48 62]

- All players should be closely monitored in the heat, and a prompt and appropriate response, including immediately stopping participation and seeking appropriate medical attention and treatment, should be implemented at the earliest signs of developing exertional heat illness.[37 49 62]

Tournament administrators and tennis governing bodies

- Multiple competitive matches on the same day can pose a particular performance challenge and exertional heat illness risk due to insufficient recovery time and rehydration between contests, as well as potential carry-over effects from the previous match.[24 58] Tennis governing bodies and tournament administrators should provide longer rest and recovery periods between same-day matches as environmental heat stress increases, to improve player safety and performance.
- Effective written protocols should be in place and practised and trained personnel with readily available facilities should be on-site for treating all forms of exertional heat illness for tennis tournaments played in warm to hot environmental conditions.

What are the new findings and features highlighted by this review?

- Highlights knowledge acquired until now regarding practice/training and competitive match-play in the heat with on-court and postplay responses in elite-level players.
- Provides specific best practices recommendations to optimally enhance safety and tennis performance in the heat.
- Sets a course for needed new research to better appreciate the physiological demands and hydration and thermal strain challenges facing junior and adult players.

Competing interests None.

Provenance and peer review Not commissioned; externally peer reviewed.

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