ORIGINAL ARTICLE

Core body temperature during competition in the heat: national boys' 14s junior tennis championships

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Objective: To examine on-court core body temperature (T_C) and sweat loss, as well as pre- and post-play hydration status, in elite adolescent tennis players during a national championships event in a hot climate.
Methods: Eight healthy, fit, young male tennis players (mean (SD) age 13.9 (0.9) years; mass 56.0 (10.7) kg; height 169.2 (14.7) cm) were evaluated during first-round singles competition at the National Boys' 14s Junior Championships in the heat (wet-bulb globe temperature (WBGT) 29.6 (0.4) ˚C). Five of those same players were also evaluated during a same-day doubles match (WBGT 31.3 (0.5) ˚C).
Results: During doubles (4.37 (0.35) h after singles), pre-play urine specific gravity (USG) (1.025 (0.002); $p = 0.06$) and total sweat loss (1.9 (0.2) litres; $p = 0.10$) tended to be higher before and during doubles, respectively, compared to singles. However, percentage change in body mass (−0.5 (0.3) %) tended to be comparatively less ($p = 0.08$), even though the doubles matches were generally longer (106.6 (11.2) vs 78.8 (10.9) min; $p = 0.09$) and the degree minutes total was greater ($p = 0.04$). T_C increased ($p < 0.001$) during singles and remained elevated, even after 10 min following the end of play. Notably, pre-play (singles) USG was strongly associated ($p = 0.005$) with the players' final T_C (38.7 (0.3) ˚C) recorded at the end of singles play.
Conclusion: Junior tennis players who begin a match not well hydrated could have progressively increasing thermal strain and a greater risk for exertional heat illness as the match advances.

Most junior tennis tournaments are played outdoors in warm to hot climates. Even as the level of play and depth of competition continue to improve, the toughest opponent these young players often face is the heat. The consequent effects on a child's health, safety and performance are well recognised.[1–8] To date, only one study has examined core body temperature (T_C) responses on-court in junior tennis players.[9] Notably, however, there have been no assessments of T_C during actual competition, where the levels of stress and effort are likely to have a comparatively greater effect on behaviour and physiological responses.

In this study, we examined T_C in adolescent tennis players during a national championships event in a very hot climate. Hydration status and sweat loss were also examined. We were not only interested in assessing the degree of heat strain incurred on the court; we also wanted to particularly determine the associations between pre- and post-match hydration status and T_C. Recently, the relationship between level of hydration and T_C as observed in laboratory studies, respective to its relevance in field settings, has been a contentious issue in the literature.[10–12] We hypothesised that hydration status before and after play would be related to the degree of thermal strain at least during singles play. We also wanted to examine on-court T_C responses during a second (doubles) match on the same day, given that doubles is often perceived as not as likely to elicit an appreciable thermal challenge.

These findings provide unique insight to T_C responses in elite adolescent tennis players during actual competition. The combination of heat stress and scheduling of multiple same-day matches in junior tennis can measurably impact performance[13] and often prompts incidents of heat illness (M F Bergeron, unpublished observations). Our goal is that, as more research such as this is conducted, there will be enough information and insight to establish more specific and effective guidelines for enhancing the safety and performance of junior tennis players during tournaments through more appropriate scheduling of matches and events, as well as match preparation and recovery strategies.

METHODS

Subjects

Eight young, healthy, fit male tennis players (mean (SD) age 13.9 (0.9) years; mass 56.0 (10.7) kg; height 169.2 (14.7) cm) participated in this study. All subjects were highly skilled junior tennis players and currently ranked nationally high enough to qualify and be selected (from the national selection/standing or sectional endorsement lists) for this national championships event. To reduce potential bias, limited explanations were provided to the subjects prior to or during the study, regarding fluid intake behaviour (on- or off-court) and the anticipated outcomes related to hydration or thermal strain. The subjects were informed of all procedures; however, the explanation of overall study intent was limited to our primary interest in monitoring body temperature. Moreover, the subjects were not given any protocol for standardising their hydration status prior to each test session. This permitted an assessment of typical variation in pre-play hydration status as it related to the outcome measures. The study was reviewed and approved by the Human Assurance Committee of the Medical College of Georgia, and all subjects (and parents) gave their voluntary, written informed consent to participate in this investigation.

Overall protocol

The eight subjects were tested in San Antonio, Texas, USA during first-round play of the United States Tennis Association (USTA) National Boys' 14s Junior Championships during the first week of August. San Antonio has a history of consistently warm summers. During the period 1999–2005, wet-bulb globe temperature (WBGT) was measured continuously in the same

Abbreviations: ANOVA, analysis of variance; USG, urine specific gravity; WBGT, wet-bulb globe temperature

tournament location. For the nearly 580 h of environmental monitoring during the hours of championship play, average WBGT was 30.3 (2.5) ˚C, which indicates a consistent ''extreme or hazardous'' level of risk.[13 14]

Each subject was evaluated during a singles match and some (n = 5) were evaluated during doubles as well. For those players who were evaluated during singles and doubles, both of their evaluated matches were on the same day. Each match was played outdoors on hard surface tennis courts in accordance with standard USTA national tournament rules, regulations and format for play (best of three tiebreak sets).[15] New tennis balls were used for each match, and players retrieved their own balls during play. Environmental conditions (WBGT) were monitored and recorded continuously with a thermal environment monitor (QUESTemp°34, QUEST Technologies, Oconomowoc, Wisconsin, USA) that was set up at 07:30 each day (at least 30 min prior to the start of any match) in a central unobstructed location as near as possible to the playing area (~1 m above the court surface) of the stadium court. All participants were free to follow their own individually selected diets, sleep and eating schedules, pre-match warm-up routines, and fluid intake amount and beverage type(s) on- and off-court (ad libitum). The players were encouraged during the tournament orientation session (and via the materials included in the pre-tournament package) to consume sufficient fluid during the event. However, all players were responsible for bringing their own fluids (and containers) to their matches and warm-up sessions. Players typically left the tournament site between matches and were responsible for their own meals. T_C was monitored during each evaluated match, using an ingested temperature-monitoring sensor that transmitted continuous readings of T_C (see below).

Following their own pre-match warm-up routine (on- and off-court hitting and exercises), on arrival to the tennis clubhouse locker room (07:45–15:45, depending on when the match was scheduled to begin), each subject emptied his bladder and provided a urine sample. The urine samples were used to immediately assess pre-exercise hydration status, as indicated by urine specific gravity (USG), using a handheld clinical refractometer (Spartan Refractometer, Model A 300 CL; Spartan, Tokyo, Japan). Each subject was subsequently weighed nude (within 50.0 g), using a precision scale (A&D Model UC-300, A&D Engineering, Milpitas, California, USA). After being weighed, the T_C for each subject was recorded and then each subject dressed for tennis. Self-selected clothing typically consisted of light-coloured or white shorts, a collared tennis shirt and sometimes a hat, along with socks and tennis shoes. The filled on-court beverage containers for each subject were weighed (within 50.0 g). Each subject then proceeded to the tournament desk to then be assigned a court. Once weighed, subjects were allowed to only drink from their own pre-weighed beverage container(s) until after the post-match body mass measurement.

During the match, players had opportunities to consume fluid (ad libitum) after the 5 min warm-up and during each break on odd-game changeovers. As needed, players could have their beverage container(s) weighed, refilled, and weighed again by the investigators during the matches. No food consumption was permitted during each entire match. At convenient similar time points during each match, T_C was recorded (without the subject's knowledge of the reading) just prior to the subject sitting on a changeover. While on court, the players were completely exposed to direct sunlight throughout the matches; that is, there was no shade provided by trees, buildings, or other structures. Moreover, on all courts, the area (courtside benches) for players during changeovers was uncovered (no shade).

On completion of each match, each subject immediately turned in his beverage container(s) for weighing and refrained from consuming any further fluid or emptying the bladder until after a second body mass measurement was completed. Following the post-match body mass measurement (nude), each subject was free to depart the locker room. The same procedures (described above) were followed for the monitored doubles matches.

Core body temperature (T_C) monitoring

We used an ingestible temperature sensor telemetry system (CorTemp™ 2000, HQ Inc., Palmetto, Florida, USA) in this study, which has been shown and noted to provide a valid (acceptable level of agreement compared to oesophageal and rectal temperature) and feasible measure of T_C during rest and exercise,[16–19] and has been safely and comfortably used in other research studies with children conducted at the Medical College of Georgia, including monitoring adolescent tennis players on court.[9 20] Prior to distributing a sensor to a subject's parent on the day before the player's first match, the temperature sensor was temporarily activated and verified to be indicating ambient temperature. Each subject ingested his designated sensor approximately 8–12 h before the beginning of the desired monitoring period (ie, the scheduled first match starting time), in order to minimise any effects of fluid intake and enhance the validity of the sensor signal during match play. On arrival to the locker room just before each player dressed for his match (singles and doubles), a temperature reading was made to verify that the sensor was not already excreted and was indicating a normal T_C. After being weighed, the player's pre-play T_C was recorded. During the monitored matches, T_C was recorded from each player at two convenient time points (during changeovers, prior to the player sitting) and at the end of (within 1 min after) the match. The sensor was excreted (usually within 24 h of ingestion), as indicated by a lack of a transmitted signal, and did not have to be retrieved. No subject indicated any discomfort or particular difficulties with the use of the temperature sensor.

Calculated measures

A change in body mass for each evaluated match was calculated from the difference between body mass measurements recorded before and after play. Accordingly, percentage change in body mass (% ΔBM) was based on initial body mass measured just before each match. The amount of sweat loss during each match was estimated from the difference in body mass measurements before and after play and the difference in that player's beverage container(s) weight before and after play, which indicated the subject's total fluid intake for the match. That is, the amount of sweat loss was estimated to be equal to the combined total of a difference in body mass and fluid consumed (assuming 1 kg = 1 litre). Total degree minutes for each match is the product of the average WBGT (˚C) and the length of the match (including warm-up) in min.

Statistical analysis

Descriptive statistics were calculated for all subject characteristics and variables within singles and doubles and, if appropriate, at each measurement time. In examining differences between singles and doubles, paired t tests were used to compare sweat loss, % ΔBM, length of match, pre-play USG and total degree minutes. A repeated-measures analysis of variance (ANOVA) was performed for evaluating the multiple measures of T_C during singles and doubles. Finally, correlations between pre-play USG (and % ΔBM) and T_C at selected time points were calculated for singles and doubles. All statistical analyses were performed using GraphPad PRISM® (Graphpad Software, San

Diego, California, USA) and statistical significance was assessed at $\alpha = 0.05$. Results are presented as the mean (SD) when describing the characteristics of the player sample (ie, age, mass and height) and mean (SEM) for all other results.

RESULTS

Table 1 includes the descriptive statistics for selected outcome measures for the singles and doubles matches for all players. Two players had particularly high pre-play USG measurements (1.027 and 1.029) just before their singles matches; and the latter player presented with a pre-play USG of 1.032 for his doubles match, while another had a value of 1.030. For the five players who were evaluated during doubles match play (4.37 (0.35) h later) on the same day as their singles first round match, pre-play USG (singles: 1.019 (0.004), doubles: 1.025 (0.002); $p = 0.06$) and total sweat loss (singles: 1.5 (0.3) litres, doubles: 1.9 (0.2) litres; $p = 0.10$) tended to be somewhat higher before and during doubles, respectively, compared to singles. However, % ΔBM tended to be comparatively less (singles: −1.1 (0.3) %, doubles: −0.5 (0.3) %; $p = 0.08$), even though the doubles matches were generally longer (singles: 78.8 (10.9) min, doubles: 106.6 (11.2) min; $p = 0.09$), the degree minutes total was greater (singles: 2512 (307), doubles: 3908 (461); $p = 0.04$), and accordingly their total sweat loss was more. Pre-play body mass for those same five players was similar ($p>0.05$) for singles (51.8 (5.1) kg) and doubles (51.9 (5.2) kg). Notably, for all players ($n = 8$), pre-play (singles) USG was strongly associated ($r = 0.87$; $p = 0.005$) with the players' final T_C recorded at the end of singles play (table 1). Pre-play USG was also statistically associated ($r = 0.74$; $p = 0.035$) with the first measure of T_C during singles play, but not significantly associated with the pre-play ($r = 0.66$; $p = 0.077$) or second measure ($r = 0.78$; $p = 0.069$) of T_C. Despite the higher pre-play USG before playing doubles, there were no statistical associations with any of the T_C measures before, during, or at the end of play. The % ΔBM incurred during singles or doubles was not statistically associated with T_C recorded at the end of play.

Figure 1 presents the T_C responses for all players before, during, at the end of play, and after the singles and doubles matches. Elapsed time is shown for each measurement and average WBGT is indicated for each period of play leading up to the associated recorded T_C. For all eight subjects, the average WBGT during singles was 29.6 (0.4) °C. For the five players who were evaluated during doubles match play, the average WBGT during singles was 29.1 (0.5) °C compared to 31.3 (0.5) °C. Notably, these five players had a higher ($p = 0.046$) pre-play T_C for doubles (38.07 (0.38) °C) compared to singles (37.67 (0.38) °C). In examining the main effect for time, T_C increased ($p<0.001$) during singles and remained elevated, even after 10 min following the end of play.

DISCUSSION

This study provides novel insight to the hydration status and thermal strain in elite adolescent tennis players during a national championships event. To date, this is the first study to examine T_C responses in juniors during actual tennis competition. Moreover, these findings reveal some of the potential challenges and impact of playing multiple matches in a hot environment.

USG provides a valid indication to hydration status;[21] though, we recognise the potential influence of recent fluid intake and exercise. However, based on our experience with junior tournament tennis, these young players would not likely have just participated in extensive exercise (beyond a short pre-match warm-up) or consumed a large quantity of fluid to an extent that would measurably impact the validity in using USG as an index of pre-play hydration status. As previously shown,[2 9 22] it is not surprising to have some players begin play already significantly dehydrated even for a first match. Notably, pre-play USG was particularly high prior to the same-day doubles matches, indicating the need to drink more especially when recovering from a previous match earlier in the day.

Given the relatively small body mass deficit incurred from singles and the amount of time between these matches (more than 4 h), there was certainly enough time to fully rehydrate. We suspect that the players might not have fully recovered their fluid deficit from singles and/or might not have offset additional fluid losses incurred during the time between singles and doubles (which would include the doubles pre-match warm-up). This could not be supported using pre-play body mass for comparison, because all players observed during afternoon doubles consumed a meal (which might have been fairly substantial for some players knowing that they had to only play doubles in the afternoon) and some might have had faecal loss between the two matches. Junior players at such events need to appreciate that heat stress and significant fluid losses can continue during the time between matches with off-court activities (eg, recreational games or watching other matches), especially in such a hot and dry environment with intense sun exposure. Players, parents and coaches need to consider the impact of these activities and also the additional contributing effects of a pre-match warm-up in the heat on sweat loss, hydration status and thermal strain, as indicated by the players' higher pre-play USG and T_C before doubles began.

During play, the subjects seemed to more effectively keep up with sweat losses incurred on court (ie, maintained hydration status) during doubles, as confirmed by the smaller body mass deficit at the end of play, even though the total sweat loss incurred during doubles was greater, due to the more stressful environment (indicated by a higher average WBGT) in the afternoon and longer duration of play. However, even in singles, incurring a body mass deficit of only 1.0% or a little less by the end of a match is not likely to have a measurable negative effect on overall thermal strain or performance, except for those players who begin play already significantly dehydrated. The impact on thermal strain was underscored here by the stepwise progressively stronger association between pre-play USG and T_C during and at the end of play in singles.

The relationship between level of hydration and T_C as observed in laboratory settings has been challenged recently as being invalid for field situations, suggesting that greater levels of dehydration on the practice field or in actual competition are not associated with increased thermal strain and a greater risk for exertional heat illness.[11 12 23] It has been argued,[10 11] however, that unless exercise intensity is maintained over sufficient duration

Table 1 Selected characteristics of the singles and doubles matches

	Pre-play USG	Degree minutes	USG vs end T_C (r)	Sweat loss (litres)	Fluid Intake (litres)	% ΔBM
Singles (n = 8)	1.017 (0.003)	2502 (191)	0.87 (p = 0.005)	1.5 (0.2)	1.1 (0.2)	−0.9 (0.2)
Doubles (n = 5)	1.025 (0.002)	3908 (461)	0.14 (p = 0.82)	1.9 (0.2)	1.7 (0.1)	−0.5 (0.3)

USG, urine specific gravity; degree minutes, mean WBGT (°C) x length of match (including warm-up) in min; end T_C, core body temperature at end of play; r, Pearson correlation between USG and end T_C; % ΔBM, percentage change in body mass (compared to pre-play body mass).

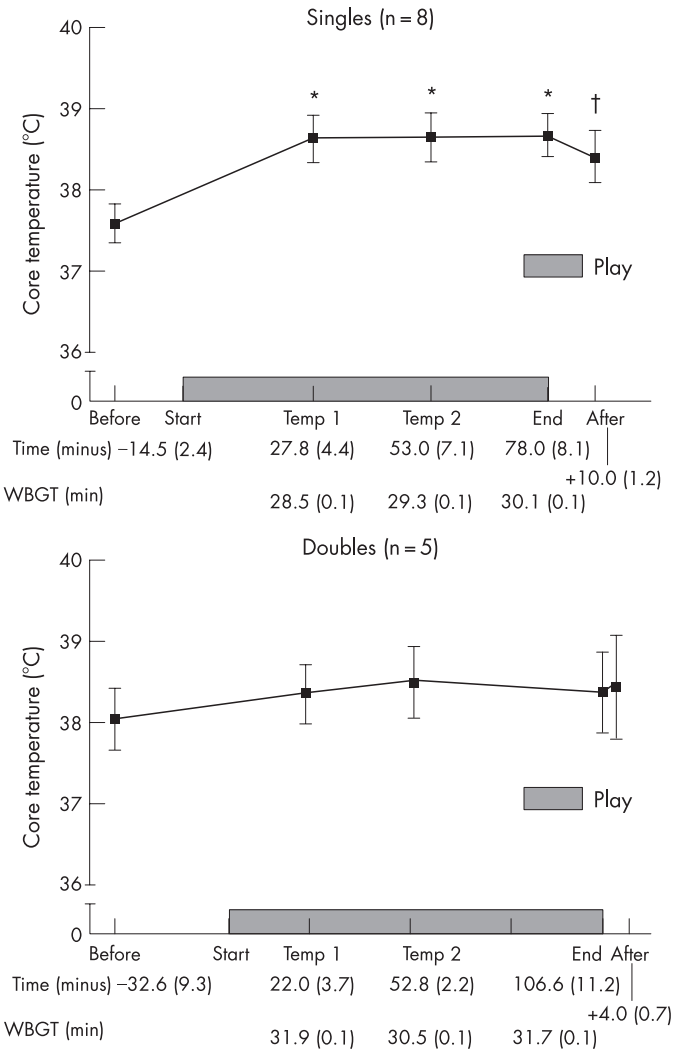

Figure 1 Core body temperature (T_C) recorded at similar time points before (Before), during (Temp 1, Temp 2), at the end of play (End), and after (After) the singles and doubles matches. Match play (including the pre-match warm-up period) is indicated by the shaded bars. Elapsed time (Time) in min is indicated relative to the beginning of play (Before–End) and from the end of the match (After). WBGT (°C) values represent the average WBGT for the period of time defined by the first minute immediately following the preceding T_C measurement to (and including) the elapsed time minute of the associated T_C time point. *Significantly greater ($p<0.01$) T_C compared to the pre-play (Before) measurement. †Significantly greater ($p<0.05$) T_C than pre-play (Before). Data are presented as the mean (SEM).

the established relationship between progressive dehydration and increasing T_C is not likely to be observed. During team practice sessions or competitions where the emphasis is on completion versus winning, athletes might be able to ''get away with'' a greater level of dehydration, without the fluid deficit necessarily translating into a significant increase in body temperature or risk of heat-related complications, because the athletes have the option of reducing exercise intensity. However, during a high-level individual sport competition such as these national championships, young athletes will often maintain a strong effort and metabolic rate, despite not feeling 100% or even having the capacity to safely continue.

Notably, all but one of the singles matches started in the morning and only one of those was not completed well before 12:00. Therefore, the relatively lower average WBGT for singles could have somewhat attenuated certain players' T_C responses accompanying their poor pre-play hydration status; that is, we might have seen greater and more rapid T_C increases in those beginning play with a high USG, had the singles matches been scheduled even a little later in the day. Moreover, all eight singles matches were fairly easy straight sets wins (two sets only), with only one set going to a tiebreak. Longer, more difficult matches would have also likely prompted higher T_C responses, even in the morning.

With the doubles matches beginning in the afternoon (start times 13:50–16:45), it is not surprising that the doubles T_C profile was similar to that observed during singles matches played earlier, even with less overall on-court movement and relative intensity during doubles play. Moreover, Coyle[13] has shown how cumulative heat stress can affect a second match outcome. In Coyle's study (based on data collected during 1999–2005 from the same event and site of the current study), when the effect of seeding was removed, same-day degree minutes acquired during a morning match could effectively predict the outcome of an afternoon singles match. Such a potential ''carry-over'' effect was demonstrated by Ronsen *et al*[24] in elite endurance athletes who participated in two identical 75 min exercise bouts in a neutral environment (20 °C) on the same day. With 3 h of recovery between bouts, Ronsen *et al* observed augmented metabolic stress (including T_C) during the second exercise bout. Our data support that a second match on the same day, even if it is ''only doubles'', can elicit an appreciable thermal challenge by virtue of the environmental conditions and potentially as precipitated by accumulated heat strain and physiological carry-over effects from a previous match on the same day.

There was a slight increase in T_C when measured in the locker room shortly (about 4 min) after the end of doubles. Notably, even 10 min (following singles) was not enough time to lower T_C appreciably. This has important implications for the effectiveness of the commonly utilised 10 min break when players split sets, in reducing subsequent heat strain risk.

Several important points should be emphasised regarding junior tennis players competing in the heat, based on these findings and other related reports and field observations.[2 3 9 13 25]

- Many players begin play not well hydrated, especially before a subsequent match on the same day.

What is already known on this topic

- Hydration status directly modulates thermal strain during exercise in the heat; though, very little such data are available from youth sports during actual competition in natural outdoors settings.
- Junior tennis players often begin training or play not well hydrated.

What this study adds

- This study provides a novel profile of hydration status, fluid intake, sweat loss, and core temperature responses in elite junior tennis players during actual competition in the heat.
- Players beginning a match not well hydrated might have progressively increasing thermal strain and a greater risk for exertional heat illness.

- The relationship of pre-match hydration status and T_C increases as the match progresses. Those players who begin a match not well hydrated may have a progressively increasing thermal strain and a greater risk for exertional heat illness as the match advances to the later stages.
- Multiple matches on the same day (even doubles) may pose a greater risk for excessive thermal strain and decreased performance, due to insufficient fluid recovery between matches and potential carry-over effects related to exertion and accumulated heat exposure (degree minutes) from previous play. Accordingly, current rules regarding minimum rest between singles matches (1 h in the juniors division)[15] seem particularly inappropriate and potentially unsafe, especially in extreme heat.

This is the first time on-court thermal strain has been examined in elite junior tennis players, during a sanctioned tournament event. These novel findings provide a critical basis for further needed related research specific to monitoring junior tennis players across a range of environments, match durations and scheduling scenarios. Such data will help to improve guidelines for scheduling matches and managing junior tennis tournaments in the heat to enhance player safety and performance.

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