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ORIGINAL ARTICLE

Alterations in core temperature during World Rugby Sevens Series tournaments in temperate and warm environments[†]

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Abstract
Purpose: To characterize player core temperature (Tc) across two separate World Rugby Sevens Series (WRSS) tournaments in temperate and warm environments. Methods: Tc was collected in seventeen playing members of one men's team competing at the Singapore ($n = 12$) and London ($n = 11$) WRSS tournaments. Exertional heat illness (EHI) symptoms, cooling strategy use, playing minutes and wet blub globe temperature (WBGT) were also collected. Linear mixed models and magnitude-based inferences assessed differences in Tc between all periods within-and between tournaments and were also used to assess the effect of WBGT and playing minutes on Tc. Results: Several players experienced Tc in excess of 38°C during warm-ups and 39°C during games. The highest mean Tc values were observed in the final game on all days and in Singapore Day Two, there were substantial game-on-game increases in mean Tc. These Tc responses were associated with playing minutes (effect size; ±90% CL = 0.38; ±0.20), although the effect of WBGT was trivial and unclear. Further, there were no differences in Tc between the two tournaments in the different environments. Despite high individual peak Tc values (Singapore 39.9°C; London 39.6°C); no signs/symptoms of EHI were reported, voluntary post-game cooling usage was minimal, and pre- and mid-cooling strategies were not implemented. Conclusions: During WRSS matches, peak Tc values approached thresholds associated with EHI (>40°C) and exceeded those demonstrated to reduce repeated sprint performance (>39°C). Practitioners may consider the use of compatible cooling and heat acclimation strategies to minimize Tc increase and maximize player preparedness and recovery.

Keywords: *Heat, elite, telemetric, hyperthermia*

Highlights

- Despite the very short game duration, several players experienced high peak core temperature (Tc) values approaching thresholds associated with exertional heat illnesses and exceeding thresholds associated with hindered repeated sprint performance.
- The highest Tc values were observed in the final game on all days, highlighting the importance of Tc recovery across a tournament day.
- Playing minutes modified the increase in Tc, but considering this is difficult to manage across a World Rugby Sevens Series (WRSS) tournament, practitioners are recommended to implement cooling strategies (piloting outside of competition required) and heat acclimatization/acclimation where possible.
- Technology is available to monitor Tc during WRSS competition and to provide individualized recommendations for players.

Introduction

The men's World Rugby Sevens Series (WRSS) involves 10 international tournaments played across a 6 to 8 month period. Tournaments are played over 2 to 3 days with up to three matches per day and ~3 h between each match. Tournaments are

[†]Research Conducted: Led by affiliation one, with data collection at relevant stadium in Singapore and London.

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scheduled in pairs separated by 5 days (i.e. consecutive weekends), with ~4 weeks between each tournament pair. Games consist of 7-minute halves separated by a 2-minute half-time interval and are played under modified rugby union rules on a standard 15-player rugby union field. WRSS game actions (e.g. rucking, mauling, etc.) and match-play requirements include relative running demands of ~113–120 m min^{-1}, often at high (~19% ≥ 5 m s^{-1}) or very high (~11% ≥ 6 m s^{-1}) speeds (Fowler, Lumley, Farooq, Murrary, & Taylor, 2017; Ross, Gill, & Cronin, 2014). Ultimately, Rugby Sevens match-play is played at a higher relative intensity than 15-player Rugby Union (Ross et al., 2014).

Across a season WRSS teams experience a variety of stadiums, changing rooms/facilities and climatic conditions (on- and off-pitch), including extremes of heat and humidity. Thermally undesirable match-day conditions and the potentially rapid increase in body temperatures during team sports (Aldous et al., 2016; Aughey, Goodman, & McKenna, 2014; Duffield, Coutts, & Quinn, 2009), challenge players to express repeated short-to-medium length muscular efforts with restricted recovery time (Aldous et al., 2018; Gabbett, 2008; Girard et al., 2017; Girard, Brocherie, & Bishop, 2015); which are central during Rugby Sevens match-play (Ross et al., 2014; Schuster et al., 2018). Indeed, other team sports demonstrate that in as little as 20 min of match-play, core temperature (Tc) values of ~39.5°C and approaching 40°C can be seen (Aldous et al., 2016; Aughey et al., 2014; Duffield et al., 2009); in excess of thresholds (>39°C) known to negatively influence intermittent sprint performance/capacity (Girard et al., 2015). Such performance decrements stem mechanistically from increased body temperatures driving: (i) reductions in arterial oxygen delivery to the working muscles, (ii) greater reliance on anaerobic energy provision and (iii) accelerated accumulation of H^+ (Girard et al., 2015). The WRSS demands, particularly in tournaments within hot and/or humid environments, challenge the WRSS practitioner to modulate player body temperatures relative to physical performance agendas. WRSS practitioners require evidence (e.g. Tc during WRSS competition) to inform their practice including relevant intervention prescription within tournament days. Utilization of a telemetric capsule system would provide a wireless and relatively non-invasive WRSS compatible tool, to acquire this practice orientated data (Bongers, Daanen, Bogerd, Hopman, & Eijsvogels, 2018). Given Rugby Sevens is an Olympic sport (2016 and 2020), such measurements would respond directly to the request from the International Olympic Committee to characterize the specific thermal strain profiles (e.g. Tc) of elite international-level athletes competing in the heat (Bergeron et al., 2012). Particularly relevant, given the 2020 Olympic Games in Tokyo (Japan) will see daytime temperatures approaching 30°C, with relative humidity in excess of 75% (Kakamu, Wada, Smith, Endo, & Fukushima, 2017; Kashimura, Minami, & Hoshi, 2016).

Aside from on-pitch physical performance issues, an accumulation of Tc across a tournament day(s) could have further subtle undesirable effects upon players. Indeed, elevated body temperatures and/or exercise in warm/hot environments can transiently decrease energy intake and enhance physical activity induced negative energy balance, in part due to increased anorexigenic hormone levels (Charlot, Faure, & Antoine-Jonville, 2017; Shorten, Wallman, & Guelfi, 2009; Wasse, King, Stensel, & Sunderland, 2013). Hence, the important issue of appropriate refuelling within tournament day(s) (Schuster et al., 2018) may change depending on the Tc achieved. Further, WRSS players often experience sleep and circadian body temperature disruptions, caused by extensive long-haul intercontinental travel demands and associated travel fatigue and jet-lag (Fowler et al., 2017; Schuster et al., 2018). Match-play mediated high Tc values may in some scenarios confound practitioner approaches to manage jet-lag symptomology, if their intervention(s) is/are based on endogenous circadian rhythms including Tc (Reilly et al., 2007).

The experimental aims were therefore to characterize player Tc across relevant match-days of a typically temperate (London, UK; as per Köppen Climate Classification) and warm (Singapore; within a climate-controlled stadium) WRSS tournament. It was hypothesized that (i) an accumulation (i.e. game-to-game increase) in Tc would occur on each tournament day and (ii) some player's peak Tc response would exceed thresholds (>39°C) known to be detrimental to WRSS specific performance indices.

Methods

Subjects

Data were collected from a total of seventeen different playing members (25.5 ± 4.5 yr, 94.2 ± 7.7 kg, 184.6 ± 6.5 cm) of a 2016–17 WRSS men's team across two tournaments [n = 11 Singapore; n = 12 London; n = 6 both], after written informed consent was provided, under ethical approval from the Anti-doping Lab Qatar (ADLQ; F2017000203) and the Southern Cross University Human Research Ethics Committee (SCU HREC; ECN-17-2017) in the spirit of the Helsinki Declaration.

Design

Data were collected at both the Singapore (placed 10th; 6 games played over two days; 15th–16th April 2017) and London tournaments [placed 1st; 6 games played over two days – N.B. – only 5 games data (game 6 missing) were available due to commitments associated with (i) placing first and (ii) final tournament of season; 20th–21st May 2017], the final tournaments of two separate but consecutive competitions. Players arrived at both competition venues 5 days before and had been within the same time zone for at least two weeks prior to the first match (e.g. Day 1 at each competition venue); this ensures that circadian misalignment in Tc (e.g. jet-lag symptomology) was not a confounding factor within the experimental design. When examining several data sets regarding Tc within human males (Baehr, Revelle, & Eastman, 2000; Krauchi & Wirz-Justice, 1994; Refinetti, 2010; Refinetti & Menaker, 1992; Scales, Vander, Brown, & Kluger, 1988), despite well-established circadian Tc oscillation, Tc is relatively unchanged (e.g. a plateau is seen) between approximately 11:00–12:00 and 21:00–22:00. However, a significant increase (by 0.26°C) in Tc has been demonstrated in elite rugby sevens athletes between the times of 10:00 and 17:00 (West, Cook, Beaven, & Kilduff, 2014). Therefore, an influence of circadian variation in Tc (albeit small) is ingrained in the current study design, given that WRSS tournaments involve games scheduled at various times across a day from morning to evening.

Methodology

Players ingested an e-Celsius™ telemetric capsule (BodyCap, Caen, France) upon waking each match day which allowed for a 5-hour time period between ingestion and establishment of the baseline values used within subsequent statistical modelling. This 5-hour time period between ingestion and measurement is within the range used previously (3–13 h), and very close to the 6-hour time period described as optimal (Byrne and Lim, 2007). Tc was sampled at 30 s intervals, with data downloaded at the end of the day (no player passed the capsule during this time) via a wireless data receiver (e-Viewer, BodyCap, Caen, France). Capsules underwent an individual 3-point calibration (Bongers, Hopman, & Eijsvogels, 2018; Travers, Nichols, Farooq, Racinais, & Periard, 2016) at 35°C, 38.5°C and 42°C in a water bath (Apuro, Campbelltown, NSW, Australia), with temperature monitored by a reference standard thermometer (uninsulated digital thermistor; MAC flexible probe, Ellab, Hillerod, Denmark) facilitating manual correction of raw Tc data as per;

$$\text{Corrected Value} = \text{Intercept} + \text{Slope} \times \text{Observed Value}$$

where; the observed value is the raw (i.e. uncorrected) Tc data transmitted by the capsule at any given time and the intercept and slope are values obtained from regression analysis of the device vs. the reference standard temperature over the 3-point calibration (Travers et al., 2016). The e-Celsius™ system has been shown valid and reliable for running exercise when adopting the above approach (Travers et al., 2016) whilst excellent validity (ICC 1.00), test-retest reliability (ICC 1.00) and inertia was found in water bath experiments between 36°C and 44°C (Bongers et al., 2018).

Specific pre-defined time periods relative to Tc were employed within analyses:

- *Baseline*: 60 min prior to pre-warm-up.
- *Warm-up*: Time spent with team undertaking team warm-up.
- *Game*: Time spent in the game.
- *Post-game*: Time following the game to the commencement of the next warm-up.

Only the periods where the athlete played in the subsequent game were included in the analyses, irrespective of how long they played for. For example, an athlete who played in Game 1 had their data for the warm-up and post-game 1 included, however those who did not play in this game did not have this data included. Playing minutes for individual athletes for each game were collected by the team's analyst.

Signs and symptoms of exertional heat illnesses (EHI) were collected 5–10 min following each game, using a modified survey instrument (Périard et al., 2017). Specifically, the athletes were asked in a yes/no manner if they had experienced (i) cramping; (ii) vomiting; (iii) nausea; (iv) severe headache; (v) collapsing/fainting; or (vi) any other symptom that might relate to heat illness (Périard et al., 2017). Cold water immersion (CWI) was available in Singapore and London (CWI is provided for teams at all tournaments by the local organizers). Cooling intervention use type (e.g. ice towels, CWI, cold showers, compression with localized cooling etc are provided by the local organizers and/or brought by the teams to all tournaments) and duration was recorded when evident, with these potential interventions available for optional self-selected use by players.

Wet Bulb Globe Temperature (WBGT; SD-2010, Reed Instruments, NC, USA) was obtained immediately prior to, during and post warm-ups (in the warm-up area behind the dead ball line) and matches (on the halfway line 5 m from the sideline). In London, additional WBGT values were obtained within and outside of shaded areas (warm-up area or pitch side as relevant). WBGT values obtained within each pre-defined time period were averaged and used within data analyses.

Statistical analysis

Linear mixed models were used to determine differences in Tc and between all periods within each competition day, between competition days within tournaments, and between periods across tournaments. Specifically, in these models, a nested random effect design was used, where the athlete was nested in either the period (when determining between period comparisons) or within the tournament (when establishing between tournament comparisons). This design estimates the mean differences in individual Tc, but also accounts for the between-player variability in Tc within each period or tournament. The within-subject standard deviation (SD; WSSD) and between-subject SD (BSSD) of these models have also been reported to provide additional information regarding the variability of athlete Tc. Fixed effects were included separately depending on the comparison being made, however they were either 'period' (within each competition day), 'day and period' (between competition days), or 'tournament and period' (across tournament comparisons). The least squares mean test provided pairwise comparisons between fixed effects. Differences were described using standardized effect sizes (ES) and 90% confidence limits (CL), categorized using the thresholds of; <0.2 trivial, 0.21–0.60 small, 0.61–1.20 moderate, 1.21–2.0 large and >2.0 very large (Hopkins, Marshall, Batterham, & Hanin, 2009). These magnitudes were further interpreted using a magnitude-based inference approach, where differences were considered real if there was a >75% likelihood of the observed effect exceeding the smallest worthwhile difference (0.20), and are described as; 75–95% *likely*, 95–99% *very likely* and >99.5%, *most likely* (Hopkins, 2007). The relationship between WBGT and playing minutes on Tc was assessed using linear mixed models, where Tc for game data only, from both tournaments, were included in the models. Tc was included as the dependent variable (outcome) and WBGT and playing minutes were separately entered as fixed effects (predictors). Using a random intercept and slope design, the predictor and athlete identification that was nested within tournament were entered as random effects. This random intercept and slope design separates individual intercepts and slopes, demonstrating the varying effect of the predictor on the outcome measure (Tc) within each tournament. The relationship between Tc and WBGT and playing minutes was standardized, by multiplying the final model slope by 2 × the WSSD (obtained using a mixed model reliability analysis with a random effect for athlete identification) (Higham, Hopkins, Pyne, & Anson, 2014). This method results in the expected change in the outcome measure from a typically low (−1SD) to a typically high value (+1SD) (Hopkins et al., 2009). This effect (expressed as a SD) was then converted to an ES using the BSSD (obtained from the mixed model reliability analysis), that were categorized using the thresholds as described previously, and were also interpreted using a magnitude-based inference approach as stated above. Descriptive statistics are presented as mean ± SD while all other data are reported as ES ± 90% CL, unless otherwise stated. All statistical analyses were performed using customized R Studio statistical software (V 1.1.453), and packages including lme4, lmerTest and emmeans were used.

Results

Within day comparisons

The group mean, as well as individual mean and maximum Tc for each tournament-day period are illustrated in Figure 1. Differences of each period with baseline and also between games that exceed 75% of the smallest worthwhile difference are described below and are also highlighted within the figure. During Singapore Day One, 6 athletes had a Tc above 39°C, with these high temperatures occurring in game 2, post-match 2, game 3 and post-game 3. On Day Two, 6 athletes had a Tc above 39°C, occurring during game 1, post-game 1 and game 2, game 3 and post-game 3. Within the London tournament, on Day One, 5 athletes had Tc above 39°C, which occurred during post-match 1 and 2, and during warm-up 3 and post-game 3. On Day Two, 5 athletes had Tc above 39°C, occurring within game 1, post-game 1, game 2 and post-game 2.

Singapore Day One: The BSSD and WSSD of Tc on Day One was 0.33 and 0.34 respectively. Compared to baseline, Tc was higher during warm-up 1 (ES; ±90% CL; 1.21; ±0.34), warm-up 2 (1.46; ±0.42), warm-up 3 (2.09; ±0.60), game 1 (2.55; ±0.73), game 2 (2.27; ±0.65), game 3 (2.51; ±0.78), post-game 1 (0.69; ±0.15), post-game 2 (0.51; ±0.15) and post-game 3 (0.83; ±0.24).

Singapore Day Two: The BSSD and WSSD of Tc on Day Two was 0.35 and 0.25 respectively. There was an increase in Tc compared to baseline during warm-up 1 (1.75; ±0.50), warm-up 2 (3.02; ±0.86), warm-up 3 (4.03; ±1.15), game 1 (2.61; ±0.75), game 2 (3.48; ±0.99), game 3 (4.52; ±1.29), post-game 1 (1.46; ±0.42), post-game 2 (1.63; ±0.47)

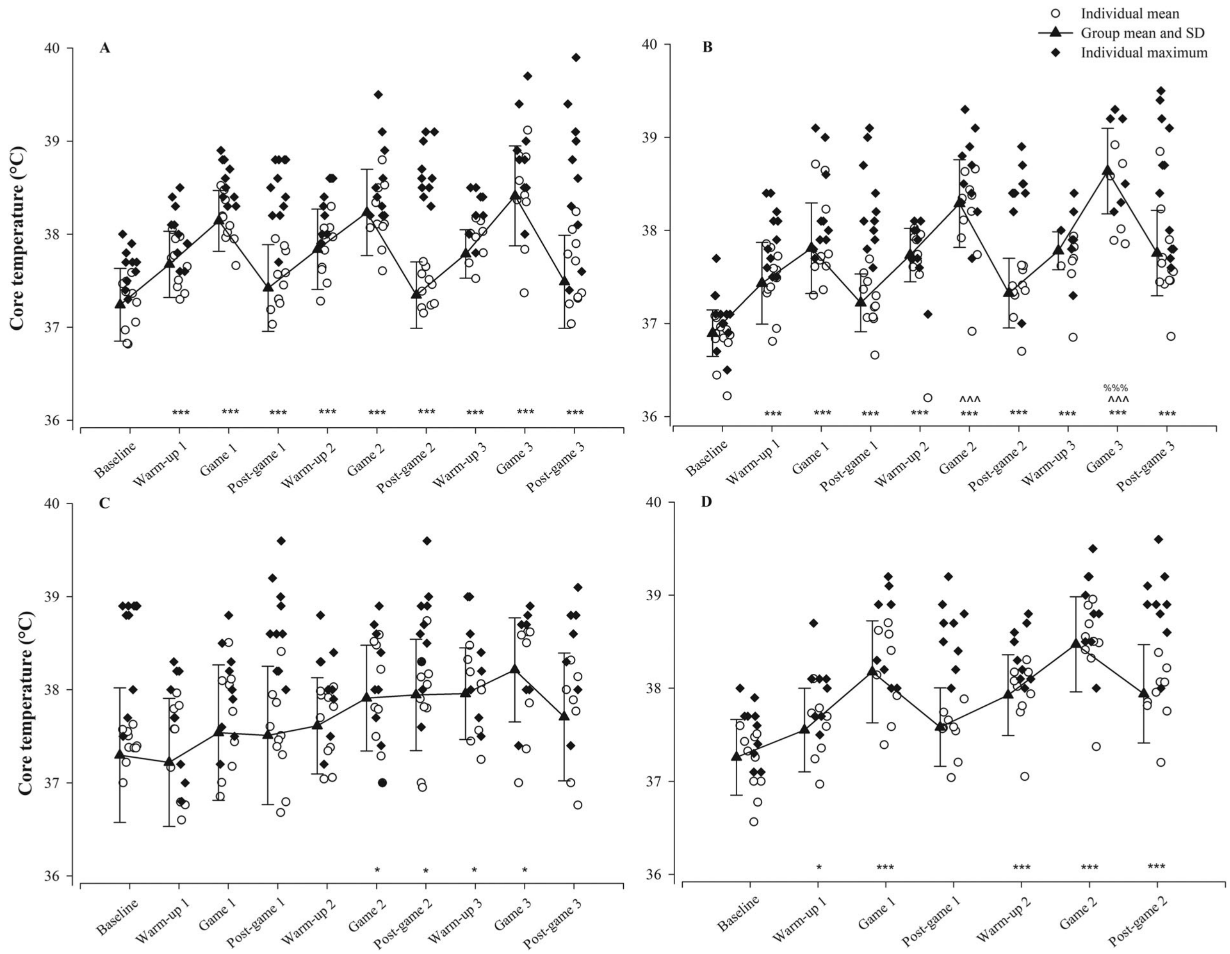

Figure 1. Individual average core temperature (Tc), represented as individual responses and as group mean and standard deviations during Singapore (A = Day One, B = Day Two) and London (C = Day One, D = Day Two). The likelihood of the observed effect exceeding the smallest worthwhile difference (0.2) when compared to a within-day baseline are denoted as; * = *likely*; ** = *very likely* and *** = *most likely*. When compared to game 1, differences are expressed as; ^ = *likely*, ^^ = *very likely* and ^^^ = *most likely*. Compared to game 2, differences are expressed as; % = *likely*, %% = *very likely* and %%% = *most likely*.

and post-game 3 (2.27; ±0.65). Compared to game 1, Tc was higher during game 2 (0.64; ±0.18) and game 3 (1.80; ±0.40), and game 3 was higher than game 2 (0.76; ±0.22).

London Day One: The BSSD and WSSD of Tc on Day One was 0.52 and 0.48 respectively. There was an increase in Tc compared to baseline during warm-up 3 (1.04; ±1.39), game 2 (0.98; ±1.23), game 3 (1.27; ±1.08) and post-game 2 (0.89; ±1.21).

London Day Two: The BSSD and WSSD of Tc on Day Two was 0.35 and 0.34 respectively. There was an increase in Tc at warm up 1 (0.85; ±1.40), warm-up 2 (1.73; ±0.72), game 1 (2.02; ±0.62), game 2 (2.75; ±0.85) and post-game 2 (1.60; ±0.60).

Within and between tournament comparisons

Table 1 illustrates the Tc, WBGT and local time of day across the tournaments in each specific period. There were substantial differences in Tc during the games between competition days, including an increase in Tc on Day Two compared to Day One for game 3 in Singapore and for both games in London. There were no differences in Tc between the separate tournaments in the different environments. The WBGT and game time data are also presented in Table 1.

Effects of WBGT and playing minutes on Tc

The relationships between WBGT and playing minutes and individual Tc are demonstrated in Table 2. As depicted in Table 2, an increase in WBGT only resulted in a trivial and unclear increase in Tc (0.16; ±0.25), however an increase playing minutes resulted in a *likely* small increase in Tc (0.38; ±0.20).

EHI Signs and Symptoms: No signs and symptoms of EHI were reported by any player.

Table 1. Core body temperature (Tc), wet-bulb globe temperature (WBGT) and local time of day (time) across the tournaments in each specific period.

Period	Singapore				London				Tournament Difference
	Day one	Day two	Difference	Combined	Day one	Day two	Difference	Combined	
Baseline									
Absolute Tc	37.24 ± 0.392.00	36.90 ± 0.252.90	−1.32; ±0.44	37.00 ± 0.342.00	37.30 ± 0.722.90	37.26 ± 0.412.00	−0.28; ±0.09	37.28 ± 0.602.90	0.48; ±0.42
Tc range	(36.00–38.00)	(36.00–37.70)	Large	(36.00–38.00)	(36.00–38.90)	(36.00–38.00)	Small	(36.00–38.90)	Small
			^^^				*		#
Warm up 1									
Absolute Tc	37.68 ± 0.361.80	37.43 ± 0.442.30	−0.66; ±0.22	37.52 ± 0.432.40	37.22 ± 0.692.30	37.55 ± 0.452.60	0.23; ±0.20	37.35 ± 0.632.70	−0.50; ±0.57
Tc range	(36.70–38.50)	(36.10–38.40)	Moderate	(36.10–38.50)	(36.00–38.30)	(36.10–38.70)	Small	(36.00–38.70)	Small
WBGT/Time	22.4/12:47	21.4/10:25	^^^^		22.3/10:06	17.7/10:57			#
Game 1									
Absolute Tc	38.14 ± 0.331.60	37.81 ± 0.492.30	−0.71; ±0.24	37.98 ± 0.442.30	37.54 ± 0.732.80	38.18 ± 0.553.10	0.71; ±0.24	37.85 ± 0.722.70	−0.45; ±0.68
Tc range	(37.30–38.90)	(36.80–39.10)	Moderate	(36.80–39.10)	(36.00–38.80)	(36.10–39.20)	Moderate	(36.00–39.20)	Unclear
WBGT/Time	27.0/13:14	25.1/11:00	^^^		19.2/10:36	17.7/11:42	***		
Post-game 1									
Absolute Tc	37.42 ± 0.462.80	37.22 ± 0.313.00	−0.53; ±0.18	37.25 ± 0.353.10	37.51 ± 0.743.60	37.58 ± 0.422.40	0.12; ±0.04	37.55 ± 0.613.60	0.38; ±0.38
Tc range	(36.00–38.80)	(36.10–39.10)	Small	(36.00–39.10)	(36.00–39.60)	(36.80–39.20)	Trivial	(36.00–39.60)	Small
			^^^						#
Warm up 2									
Absolute Tc	37.84 ± 0.431.70	37.74 ± 0.292.00	−0.07; ±0.89	37.81 ± 0.402.40	37.61 ± 0.522.80	37.93 ± 0.431.80	0.57; ±0.19	37.77 ± 0.502.80	−0.10; ±0.50
Tc range	(36.90–38.50)	(36.10–38.10)	Unclear	(36.10–38.50)	(36.00–38.80)	(37.00–38.80)	Small	(36.00–38.80)	Unclear
WBGT/Time	22.4/16:05	22.2/14:58			15.8/13:15	19.0/14:19	***		
Game 2									
Absolute Tc	38.23 ± 0.463.10	38.29 ± 0.472.60	0.08; ±4.65	38.27 ± 0.273.10	38.21 ± 0.612.50	38.47 ± 0.512.50	0.91; ±0.31	38.30 ± 0.592.50	0.15; ±0.54
Tc range	(36.40–39.50)	(36.70–39.30)	Unclear	(36.40–39.50)	(37.00–39.50)	(37.00–39.50)	Moderate	(37.00–39.50)	Unclear
WBGT/Time	27.0/16:34	26.1/15:12			13.8/13:42	19.0/14:48	***		
Post-game 2									
Absolute Tc	37.35 ± 0.363.10	37.33 ± 0.372.80	−0.19; ±0.06	37.34 ± 0.373.10	37.94 ± 0.603.60	37.94 ± 0.532.60	−0.08; ±0.12	37.94 ± 0.573.60	1.03; ±0.46
Tc range	(36.00–39.10)	(36.10–38.90)	Trivial	(36.00–39.10)	(36.00–39.60)	(37.00–39.20)	Trivial	(36.00–39.60)	Moderate
									###
Warm up 3									
Absolute Tc	37.79 ± 0.261.20	37.78 ± 0.201.10	−0.49; ±0.30	37.79 ± 0.241.20	37.96 ± 0.492.00	-	-	-	-
Tc range	(37.30–38.50)	(37.30–38.40)	Small	(37.30–38.50)	(37.00–39.00)				
WBGT/Time	21.4/19:59	21.8/18:42	^		17.5/16:20				
Game 3									
Absolute Tc	38.41 ± 0.543.30	38.64 ± 0.461.80	0.46; ±0.20	38.53 ± 0.503.30	38.21 ± 0.562.00	-	-	-	-
Tc range	(36.40–39.70)	(37.60–39.40)	Small	(36.40–39.70)	(37.00–39.00)				
WBGT/Time	25.4/20:28	25.4/19:06	^^^		14.2/16:48				
Post-game 3									
Absolute Tc	37.49 ± 0.503.40	37.76 ± 0.462.60	0.15; ±0.05	37.59 ± 0.513.40	37.71 ± 0.693.10	-	-	-	-
Tc range	(36.50–39.90)	(36.90–39.50)	Trivial	(36.50–39.90)	(36.00–39.10)				

Note: Data are expressed as mean ± standard deviation and range (minimum – maximum value). Differences are expressed as standardized effect sizes (comparing day two to day one); ±90% confidence limits and likelihood of the observed effect exceeding the smallest worthwhile difference (0.2).
Differences between competition days within Singapore are denoted as; ^*likely*, ^^*very likely and* ^^^*most likely*. Differences between competition days within London are denoted as; **likely*, ***very likely* and *** *most likely*. Differences between tournaments within periods are denoted as; # *likely* and ### *most likely*. Effects were classified as unclear where the ± 90% confidence limits of the ES crossed the boundaries of the smallest worthwhile difference (0.20)

Table 2. The effect of wet-bulb globe temperature (WBGT) and playing minutes on individual core temperature.

		Estimate	Standard error	T statistic	P value	Effect (SD)	WSSD	BSSD	Effect size ± 90% CL
WBGT	Intercept	36.88	1.29	28.55	<0.001	–	–	–	–
	Slope	0.06	0.05	2.61	0.02	0.05	0.49	0.35	0.16; ±0.25
Playing minutes	Intercept	37.27	0.34	110.37	<0.001	–	–	–	–
	Slope	0.14	0.04	3.38	<0.05	0.13	0.49	0.35	0.38; ±0.20*

WSSD = within-subject standard deviation, BSSD = between-subject standard deviation, CL = confidence limits. **Likely* that the certainty of the effect is >75% greater than the smallest worthwhile difference (0.2).

Cooling Intervention Use: CWI use was not mandatory for players and its use was minimal. On average only two players per game engaged in CWI post-game, with exposure time not exceeding 1 min and CWI was not used in a pre-cooling capacity by any player. Pre-, during- or post-game cooling strategies such as cooling vests/jackets, ice slurries or CWI (aside from afore described) were not employed.

Discussion

Across the WRSS tournaments investigated, several players experienced high peak Tc values approaching thresholds associated with EHI and exceeding thresholds associated with hindered repeated sprint performance. The highest mean Tc values were observed in the final game on all days and in Singapore Day Two, there were substantial game-on-game increases in mean Tc. Playing minutes, but not WBGT, modified these Tc responses. As such, there were no differences in Tc between the two tournaments in the different environments. Despite high individual peak Tc values (Singapore 39.9°C; London 39.6°C), no signs and symptoms of EHI were reported, voluntary post-game cooling usage was minimal, and pre- and mid-cooling strategies were not implemented.

High peak match-play Tc values (>39°C) were observed (see Figure 1) in some players in both the warm and temperate conditions of the two tournaments. Enhanced short-term (<30 s) power output or single-sprint performance, resulting from transient heat exposure (muscle temperature rise), can be attributed to improved muscle contractility (Girard et al., 2015). However, progressively poorer intermittent-sprint performance is consistently observed with core temperatures >39°C (Girard et al., 2015). Furthermore, arterial oxygen delivery to exercising musculature can be compromized with high body temperatures, due to reduced cardiac output and increasing reliance on anaerobic energy provision resulting in greater H^+ accumulation (Girard et al., 2015). Importantly, this system is heavily utilized during WRSS match-play and linked to favourable game actions and running performance (Couderc et al., 2016; Mitchell, Pumpa, & Pyne, 2017; Ross, Gill, Cronin, & Malcata, 2015; Schuster et al., 2018). The presented data show that the highest Tc occurs in the final match of the day and substantial game-on-game increases in Tc can occur (see Figure 1B), which can be modified by playing minutes (see Table 2). The circadian variation in Tc likely contributed to the increased Tc observed (by approximately 0.2°C–0.3°C) across each tournament day (West et al., 2014) considering game times were scheduled from 10:36 to 20:28 (see Table 1), but nevertheless, the vast majority of the Tc increase was caused by movement demands of the warm-ups and matches themselves. Therefore practitioners should carefully consider individualizing player match-loads (i.e. playing minutes in the absence of activity data) and developing individualized post-game cooling protocols/load management strategies to optimize player preparedness for the final games of each tournament day (Schuster et al., 2018), which, evidently, have the highest Tc demands.

Given the challenges in managing individual athlete playing-time across a WRSS tournament (i.e. player quality, squad size and injury), removing a player from a warm-up due to high Tc (or reduction in duration and/or intensity) may be a useful load management strategy to reduce Tc in certain players. Another suitable solution may be to utilize a light-weight cooling garment (e.g. a phase change cooling vest) during warm-ups to minimize Tc increase, whilst allowing locomotive muscle temperature to rise and key metabolic pathways to be activated immediately prior to a match. The use of pre-cooling (prior-to warm-ups or matches) and mid-cooling (during warm-ups, match-play breaks, half time) has been shown effective in improving repeated sprint performance, alongside reducing peak body temperature responses in warm and hot conditions across a range of sports (Aldous et al., 2018; Bongers et al., 2017; Bongers, Thijssen, Veltmeijer, Hopman, & Eijsvogels, 2015). Additionally, breaks during match-play may offer themselves to ad-hoc cooling/mid-cooling such as facial water spray and ingestion/mouth rinsing of cold/menthol beverages (Stevens et al., 2017a; Stevens et al., 2017b; Stevens, Taylor, & Dascombe, 2017c). However, piloting of such cooling strategies with specificity to WRSS practice, particularly dose responses and player tolerances, is required.

Access to CWI, including immediately post-match, was available to players at both tournaments, though utilization was low and not individualized. CWI has the greatest efficacy to reduce high body temperatures and associated thermal sensations post exercise. Water has 24 times greater thermal conductivity than air [heat-transfer coefficient of water (0.58 k) compared to air (0.024 k)]. Thus, contextually regarding deep body temperature, water cooling is approximately three times that of air (Smith & Hanna, 1975) and superior to other team sport appropriate cooling strategies (Bleakley, Bieuzen, Davison, & Costello, 2014). At the very least CWI has a placebo effect with regards to accelerating recovery processes, with some empirical evidence demonstrating a positive effect on certain pain/discomfort, inflammatory and perceptual responses post exercise (Bongers et al., 2017; Ihsan, Watson, & Abbiss, 2016; Stephens, Halson, Miller, Slater, & Askew, 2017). In discussions with practitioners and players, the most common responses for avoiding CWI was that the players simply did not like it, concerns about infection and concerns of cooling lower limb tendons 'too much' and hence, these issues should be addressed by practitioners.

Heat acclimation/acclimatization (HA) provides robust protection to thermally mediated (e.g. increases in Tc and their perception) reductions in endurance (Racinais et al., 2015) and repeated sprint based exercise performance in warm and hot environments (Girard et al., 2015), and against heat illnesses (Racinais et al., 2015). Hence, physical preparation coaches should consider implementing HA interventions for these purposes. Implementation of a HA preparation strategy may be practically challenging (Casadio, Kilding, Cotter, & Laursen, 2017) for teams to action (facility access, interference with pre-competition taper, clash with travel requirements/ recovery etc.), particularly for teams residing in cold climates, and therefore carful planning is required.

There were no signs or symptoms of EHI reported by players in the current study (despite Tc values approaching 40°C). Further, the team that were investigated won the London tournament and evidently, their preparation and day-to-day practice was successful. Nevertheless, performance may have been improved through better management of player Tc. Therefore, future research should investigate whether high Tc (as per the data presented) results in deteriorated performance in the context of Rugby Sevens. Secondly, the effects of the suggested heat acclimation and cooling practices (especially the use of light-weight cooling vest during warm-up) on thermoregulation and various measures of physical and cognitive-perceptual performance should be investigated.

In this investigation, there were no differences in the Tc demands experienced between the different tournaments in the warm and temperate environments. Therefore, practitioners should prepare for high player Tc regardless of environmental conditions. Practitioners reported the conditions within the stadium at Singapore to be unusually mild compared to recent seasons however, and it is possible that a tournament in a hotter environment would produce higher Tc values. The WBGT varied across the competition days, with the nuances of this range relative to each time period outlined in Table 1. WBGT variance in Singapore (near fully enclosed air-conditioned stadium) was likely due to moisture from the varying crowd size, turf and players, coupled with variations in external stadium environmental conditions. In London, WBGT variance was likely due to the outdoor stadium experiencing intermittent cloud cover/wind and the percentage of the pitch that was in the shade.

The employed e-Celsius system could be used to determine individualized Tc interventions, including those related to jet-lag symptomology management and/or cooling prescription prior to or post match-related activity. The system provides near instantaneous real-time Tc values to inform such prescription, provided the data logger is within close proximity to the player. The benefits of Tc monitoring must be considered relative to the high cost of the system and the necessary consumables, as well as the additional time investment from the practitioner.

Practical applications

- Teams should prepare for high Tc responses during WRSS tournaments regardless of the environmental conditions.
- Cooling interventions and heat acclimation strategies should be trialled and implemented to attenuate increases in core temperature across a WRSS tournament day.
- Technology is available to monitor core temperature during WRSS competition and to provide individualized recommendations for players.

Conclusions

Despite the very short game duration, several players experienced high peak Tc values approaching thresholds associated with EHI and exceeding thresholds associated with hindered repeated sprint performance. The highest Tc values were observed in the final game on all days, highlighting the importance of Tc recovery across a tournament day. Playing minutes modified the increase in Tc, but considering this is difficult to manage across a WRSS tournament, practitioners are recommended to implement cooling strategies and heat acclimatization/acclimation where possible.

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