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Changes in core temperature during an elite female rugby sevens tournament

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<https://doi.org/10.1123/ijsp.2019-0375>

PUBLISHER

Human Kinetics

VERSION

AM (Accepted Manuscript)

PUBLISHER STATEMENT

Accepted author manuscript version reprinted, by permission, from International Journal of Sports Physiology and Performance, 2020, 15 (4): 571-580, <https://doi.org/10.1123/ijsp.2019-0375>. © Human Kinetics, Inc.

LICENCE

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REPOSITORY RECORD

Henderson, Mitchell, Bryna CR Christmas, Christopher J Stevens, Aaron J Coutts, and Lee Taylor. 2020. "Changes in Core Temperature During an Elite Female Rugby Sevens Tournament". Loughborough University. <https://hdl.handle.net/2134/13234898.v1>.

Title: Core temperature changes during an elite female rugby sevens tournament

Submission Type: Original Research

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Preferred Running Head: Core temperature during elite female rugby sevens

Abstract word count: 212

Text-only word count: 3459 (excluding 63 words used for table/figure suggested location)

Number of figures: 4

Number of tables: 5

References: 30

Abstract

Purpose: Characterise player core temperature (T_c) across a World Rugby Women's Sevens Series (WRWSS) tournament day and determine the efficacy of commonly employed cold water immersion (CWI) protocols. **Methods:** T_c was measured in twelve elite female rugby sevens athletes across 3 games (G1-3) from day 1 of the Sydney WRWSS tournament. Exertional heat illness symptoms, perceptual scales, CWI details, playing minutes, external load data (measured by Global Positioning Systems) and wet bulb globe temperature (range: 18.5–20.1°C) were also collected. Linear mixed models and magnitude-based inferences were used to assess differences in T_c between periods [G1-3 and warm-ups (WU)]. **Results:** Average T_c was *very likely* lower (ES; $\pm 90\%$ CL, -0.33; ± 0.18) in G1 compared to G2. Peak T_c was *very likely* (0.71; ± 0.28) associated with increased playing time. CWI did not remove the accumulated T_c due to WU and match-play activity (~ 1 – 2°C rise in T_c still present compared to T_c at WU onset for players ≥ 6 min match-play). **Conclusions:** Elite female WRWSS athletes experienced high T_c during WU (T_c peak 37.9–39.0°C) and matches (T_c peak 37.9–39.8°C), a magnitude known to reduce intermittent high-intensity physical performance ($\geq 39^\circ\text{C}$). The CWI protocol resulted in players (≥ 6 min match-play) with a ~ 1 – 2°C raised T_c compared to T_c at WU onset.

Keywords: heat, elite, telemetric, hyperthermia

Introduction

Rugby sevens is a modified shortened version of 15-a-side rugby union, where teams play with 7 players (5 reserves), across 7-minute halves, on a full-sized rugby-union pitch. The World Rugby Women's Sevens Series (WRWSS) is the premier international rugby sevens series/competition, currently with 6 tournaments per season (changing to 8 from 2019/2020). Tournaments are competed over 2 – 3 day periods, with up to 3 matches per day and ~3 hours between matches. WRWSS match-play is characterised by frequent bouts of high-intensity activity and collisions,¹ with speeds reported as $85.8 \pm 3.9 \text{ m} \cdot \text{min}^{-1}$ with $11 \pm 2.7\%$ performed above $5 \text{ m} \cdot \text{s}^{-1}$.²

The WRWSS tournaments are contested in the southern and northern hemispheres resulting in variable environmental match-day conditions, where teams may travel from their domestic winter months to compete in summer months elsewhere, often facing extremes of heat and/or humidity. Match-play data from the male equivalent (reporting higher physical match intensities²) of the WRWSS within temperate [13.8 – 22.3 wet bulb globe temperature (WBGT); London 2017] and warm (21.4 – 27.0 WBGT; Singapore 2017) WBGT environments, has demonstrated high core body temperatures (T_{c} ; peak T_{c} of 39.9°C and 39.6°C in temperate and warm conditions, respectively³). This presents a challenge to practitioners and players, as a $T_{\text{c}} \geq 39^{\circ}\text{C}$ can impair intermittent/repeated sprint based performance through: (i) reductions in arterial oxygen delivery to the working muscles, (ii) greater reliance on anaerobic energy provision and (iii) accelerated accumulation of H^{+} .⁴

Physical and physiological differences in thermoregulation exist between genders (e.g. greater subcutaneous fat content, larger ratio of body surface to body mass, and smaller sweat response to heat load in females).⁵ Coupling this with the known anthropometrics of elite rugby sevens athletes (e.g. females are shorter, lighter with a higher fat content²), female players may be

more susceptible to rapid rises in $T_{\text{c}} \geq 39^{\circ}\text{C}$ and subsequent performance decrements⁴ for the same work produced. Considering the high T_{c} from temperate/warm match-play in males³ capable of reducing physical performance⁴, other hotter tournaments of the WRWSS and Tokyo 2020 [expected to be the hottest modern Olympics to date ($\sim 30^{\circ}\text{C}$, with relative humidity exceeding 75%^{6,7})] may challenge practitioners to manage player body temperatures to achieve optimal performance. This may be of greater importance for female athletes given the performance variation observed across the menstrual cycle in hot, humid conditions.⁸

Cold water immersion (CWI) is a commonly used acute post-game (N.B several games within WRWSS tournament day) recovery tool for rugby sevens athletes, proposed to control hyperthermia, reduce muscle inflammation and damage, and decrease muscle soreness.⁹ However, the efficacy of rugby sevens specific CWI protocols¹⁰, within a real-world elite tournament scenario, is not available [e.g. total heat storage as a consequence of each match plus associated warm-up (WU), and whether the CWI protocol actually removes this]. Telemetric capsules could wirelessly, and relatively non-invasively,¹¹ acquire this within WRWSS tournament day T_{c} characterisation and CWI efficacy data.

This study aims to characterise T_{c} values for elite female athletes within and between matches of a WRWSS tournament day, and the efficacy of post-game CWI protocols. It is hypothesized that (i) WRWSS match play will result in T_{c} values $\geq 39^{\circ}\text{C}$ and (ii) the commonly employed post-game CWI protocol will not entirely remove body heat gained from the WU and match-play.

Methods

Subjects *** Table 1 near here please ***

Data were collected from a total of twelve seasonally **heat-acclimatised** female athletes (see Table 1 for details) from a single 2018-19 WRWSS team **based in Sydney, Australia**, across one tournament day. Written informed consent was provided, under ethical approval from the Southern Cross University Human Research Ethics Committee (ECN-18-216) in the spirit of the Helsinki Declaration.

Design

Data were collected across the first day (three games played, two wins, one loss) of the Australian WRWSS tournament **in Sydney, Australia (February 1-3, 2019)**. Players had been in the same time zone ≥ 14 days prior to the tournament, thus, circadian misalignment was not a confounding influence. In line with elite team sport practice, menstrual cycle could not be controlled.

Methodology

Players ingested an e-Celsius™ telemetric capsule (BodyCap, Caen, France) the night prior to the tournament, and another upon waking on the first match day. Tc data was only included within the statistical model when ≥ 5 hours had elapsed post-ingestion, a criteria used previously to ensure the capsule was in the lower intestine.^{3,12,13} Tc was sampled at 30 second intervals, with data downloaded at the end of the day via a wireless data receiver (e-Viewer, BodyCap, Caen, France). Capsules were set-up, calibrated, and handled as extensively outlined elsewhere.^{3,12,14} The e-Celsius™ system has been shown valid and reliable for intermittent-running exercise,¹⁴ has excellent validity (ICC 1.00), test-retest reliability (ICC 1.00) and inertia in water bath experiments between 36°C and 44°C,¹¹ and has been used previously within elite rugby sevens matches.^{3,11}

131 Playing minutes for individual athletes for each game were collected by the team's sports
132 scientist. Specific pre-defined time periods relative to Tc were employed within analyses
133 (specific timings provided in Table 2):

- 134 - *Baseline (BL)*: 60 minutes prior to prime.
- 135 - *Activation / Primer*: Time spent completing pre-warm up movement.
- 136 - *Warm-up*: Time spent with team undertaking team warm-up.
- 137 - *Game*: Time spent in the game.
- 138 - *CWI*: Time spent submerged in cold water following the match.

139 Signs and symptoms of exertional heat illnesses (EHI) were collected following each game
140 immediately prior to the CWI protocol, using a modified survey instrument.¹⁵ Specifically, the
141 athletes were asked in a yes/no manner if they had experienced (i) cramping; (ii) vomiting; (iii)
142 nausea; (iv) severe headache; (v) collapsing/fainting; or (vi) any other symptom that might
143 relate to heat illness.¹⁵ CWI was provided for teams by the local organisers, with submersion
144 time of day (see Table 2) and duration (see results section) recorded (water temperature range:
145 6.1 – 7.3°C). Players were submerged to hip height for the duration of their CWI intervention.
146 No other post-game cooling intervention methods were used.

147 WBGT (SD-2010, Reed Instruments, NC, USA) was obtained immediately prior to, during and
148 post WU (in the WU area outside of the stadium) and matches (5 m from the sideline). WBGT
149 values obtained within each pre-defined time period were averaged and are presented in Table
150 2. The day prior to the tournament within the stadium WBGT peak was 37.5°C, with
151 expectations that tournament day one would see similar WBGT values, however, conditions
152 on the day were surprisingly mild ($\leq 20^{\circ}\text{C}$ WBGT; see Table 2).

153 *** Table 2 near here please ***

Activity profiles during matches were measured using 10 Hz GPS devices (EVO, GPSports, Canberra, Australia). These have shown good inter-unit reliability for distance (m) (CV: 0.2% $\pm$ 1.5), average speed ($\text{m}\cdot\text{min}^{-1}$) (CV: 0.2% $\pm$ 1.5), max velocity ($\text{m}\cdot\text{s}^{-1}$) (CV: 0.2% $\pm$ 1.5), high-speed running (distance covered $>5\text{m}\cdot\text{s}^{-1}$) (CV: 0.5% $\pm$ 1.5), and **average acceleration/deceleration ($\text{m}\cdot\text{s}^{-2}$)** (CV: 1.2% $\pm$ 1.5).¹⁶ Each unit was assigned to an individual player and worn in a small pouch in their match jersey, positioning the unit between the scapula blades of the player. Following each match, devices were downloaded using the manufacturer's proprietary software (GPSports Console, GPSports, Canberra, Australia). Metrics exported from the GPS data included match duration (min), average speed (**$\text{m}\cdot\text{min}^{-1}$**), high-speed running per minute (**$\text{HSR}\cdot\text{min}^{-1}$** ; **average distance covered at $>5\text{ m}\cdot\text{s}^{-1}$ per minute**), very high-speed running per minute (**$\text{VHSR}\cdot\text{min}^{-1}$** ; **average distance covered at $>6\text{ m}\cdot\text{s}^{-1}$ per minute**), and **average acceleration/deceleration (Ave Acc/Dec; $\text{m}\cdot\text{s}^{-2}$)**.

Thermal sensation (TS) was measured using a 17-point category ratio scale (where 0 = 'unbearably cold' and 8 = 'unbearably hot').¹⁷ Thermal comfort (TC) was measured using a 10-point category ratio scale (where 1 = 'comfortable' and 10 = +1 above 'extremely uncomfortable').¹⁸ Rating of perceived exertion (RPE) was measured using CR-10 category ratio scale (where 0 = rest and 10 = maximal).¹⁸

The TS, TC, RPE (all post-game), Tc and GPS measures were obtained as per Figure 1, by the same practitioner using standardised language and procedures.

*** Figure 1 near here please ***

Statistical Analyses

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 25 (IBM, SPSS Inc, Chicago, IL, USA), and magnitude-based inferences

(MBIs) customizable spreadsheets, using the raw data.¹⁹ Initially, descriptive statistics were generated, and normality checked using quantile-quantile (Q-Q) plots.²⁰ Descriptive statistics are reported as median and range (minimum – maximum) unless otherwise stated. GraphPad Prism 8 (GraphPad Software, CA, USA) was used to create Figures 2 – 4. Individual player Tc was determined and averaged for each pre-defined time period, with peak Tc values for each period also extracted. At each time period the individual player change (delta; Δ) within period, and relative to baseline (BL) were calculated. Additionally, minimum Tc values from each WU (WU 1, WU 2, WU 3) were subtracted from peak Tc values from each game (G1 – 3), to calculate total heat gained across each WU and game pair (ΔTc combined). In order to examine the effectiveness of CWI in removing the total heat gained in ΔTc combined, the ΔTc combined value was subtracted from the ΔCWI , providing a $\Delta \Delta CWI$ value.

Linear mixed models (LMM) were used to determine differences in: (i) Tc (peak, average, Δ period, Δ BL, Δ combined) across all periods, and between WU and games; (ii) RPE, TS, TC, minutes played, and all **external load (GPS)** variables between games; and (iii) $\Delta \Delta CWI$ between each period (i.e. CWI 1, CWI 2, CWI 3). Specifically, fixed (i.e. period) and random (i.e. participant) effects for the LMM were fit for each dependent variable,²¹ and a nested effect design was used, where player was nested in the period. This design estimates mean differences in individual Tc, and also models the between-player variability in Tc within each period. The most appropriate model was chosen using the smallest Hurvich and Tsai criterion (AICC)²² in accordance with the principle of parsimony. The least squares mean test provided pairwise comparisons between the fixed effect. Raw differences are reported as mean (95% confidence intervals). Normality and homogeneity of variance of the residuals were checked using Q-Q plots, and scatter plots respectively, and deemed plausible in each instance. Furthermore, the relationship between minutes played and all **external load (GPS)** variables on peak Tc was assessed using LMM (**random coefficient model**). Peak Tc for all three games was included in

the model as a dependent variable (outcome), and minutes played and all **external load (GPS)** variables (all three games combined) were separately entered as fixed effects (predictors). Using a random intercept and slope design, player identification was nested within the predictors. All analyses were initially performed with all players, and subsequently with players who had ≥ 6 min ($\sim 40\%$ of game time) match-play per game only. Perceptual and **external load (GPS)** data was modelled only for those players with ≥ 6 min match-play per game only. Cohen's d effect sizes (ES), and 90% confidence limits (CLs) were obtained using the MBI spreadsheets, and categorized using standardised thresholds of; < 0.2 trivial, $0.21 - 0.60$ small, $0.61 - 1.20$ moderate, $1.21 - 2.0$ large, and > 2.0 very large¹⁹ only when the LMM results showed a significant p value (**significance was accepted as $p \leq 0.05$**). Differences were considered real if there was a $> 75\%$ likelihood of the observed effect exceeding the smallest worthwhile effect ($0.20 \times$ between subject SD), using the following qualitative descriptions; $75 - 95\%$ *likely*, $95 - 99.5\%$ *very likely*, and $> 99.5\%$ *most likely*.¹⁹ Data is reported as ES; $\pm 90\%$ CL.

Results

Raw data for Tc for all players, and perceptual and GPS data for players who had ≥ 6 min match-play are presented in Tables 2 and 3 respectively.

*** Table 3 near here please ***

Core temperature across all periods: Peak Tc was $\geq 39^\circ\text{C}$ for five players in game 1, and six players in games 2 and 3 (Figure 2). Peak and average Tc, when compared to BL, was higher throughout all periods for all players ($p < 0.001$; $p < 0.001$ respectively) and in those who had ≥ 6 min match-play ($p < 0.001$; $p < 0.001$, respectively). Differences are reported in Table 4 and Figure 2.

225 *** Table 4 near here please ***

226 *** Figure 2 near here please ***

227 *Core temperature between WU and games (all players):* Differences ($p = 0.04$) in average Tc
228 was seen between games. Players *very likely* ($-0.33; \pm 0.18$) had a lower average Tc in game 1
229 compared to game 2 [-0.27 (-0.09 to -0.49°C); $p = 0.007$] with no further Tc derived differences
230 evident between games ($p \geq 0.24$) or between WU ($p \geq 0.13$) across day, see Figure 2.

231 *Core temperature between WU and games (only players > 6 min):* Differences ($p = 0.04$) in
232 ΔTc within period between games were evident. Players *most likely* ($0.91; \pm 0.31$) had a greater
233 ΔTc in game 1 compared to game 2 [0.39 (0.14 to 0.63°C); $p = 0.006$] and *very likely* ($0.45;$
234 ± 0.35) greater ΔTc in game 1 compared to game 3 [0.30 (0 to 0.61°C); $p = 0.05$]. No differences
235 for any other Tc derived measure was evident between games ($p \geq 0.27$) or between WU ($p \geq$
236 0.53).

237 *Effects of minutes played and external load (GPS) variables on peak Tc (all players):* Minutes
238 played was associated with peak Tc ($p = 0.04$). Minutes played *very likely* ($0.71; \pm 0.28$) resulted
239 in an increased peak Tc. There was no association between any of the external load (GPS)
240 variables and peak Tc ($p \geq 0.22$).

241 *Effects of minutes played and external load (GPS) variables on peak Tc (only players ≥ 6 min):*
242 No association ($p = 0.11$) between minutes played and peak Tc. There was no association
243 between any of the external load (GPS) variables and peak Tc ($p \geq 0.34$).

244 *External load (GPS) data (only players ≥ 6 min):* Differences in average speed ($\text{m} \cdot \text{min}^{-1}$) ($f =$
245 6.81 , $p = 0.009$), HSR $\cdot \text{min}^{-1}$ ($f = 10.74$, $p = 0.002$), VHSR $\cdot \text{min}^{-1}$ ($f = 65.86$, $p < 0.001$), and
246 Ave Acc/Dec ($\text{m} \cdot \text{s}^{-2}$) ($f = 6.17$, $p = 0.007$) were evident (see Table 5 for specifics).

247 *** Table 5 near here please ***

248 *Cooling intervention use (only players ≥ 6 min)*: For the first CWI players had different
249 exposure times [6 (4 – 6 min)]. The second and third exposure was standardised to 5 and 6 min
250 respectively. Differences were not seen for $\Delta\Delta\text{CWI}$ ($p = 0.10$), see Figure 3. Player cooling
251 rates were calculated by dividing the $\Delta\Delta\text{CWI}$ by CWI duration ($\Delta\Delta\text{CWI } ^\circ\text{C}\cdot\text{min}^{-1}$), and then by
252 lean body mass (LBM; $\Delta\Delta\text{CWI } ^\circ\text{C}\cdot\text{min}^{-1}\cdot\text{LBM}$), see Figure 3.

253 *** Figure 3 near here please ***

254 *Perceptual data (only players ≥ 6 min)*: Differences ($p = 0.001$) in TC between games were
255 evident (see Table 3). Players *most likely* ($-3.2; \pm 0.57$) felt more ‘comfortable’ with the
256 temperature of their body in game 3 compared to game 1 [-1.06 (-0.6 to -1.6); $p = 0.001$], and
257 game 2 [-1.04 (-0.5 to -1.5); $-4.0; \pm 1.20$; $p = 0.001$]. No differences were evident regarding
258 RPE ($p = 0.30$) or TS ($p = 0.12$), see Figure 4.

259 *** Figure 4 near here please ***

260 *EHI signs and symptoms*: no signs and symptoms of EHI were reported by any player.

261 **Discussion**

262 Approximately 50% of players demonstrated a peak $T_c \geq 39^\circ\text{C}$ in response to WRWSS match-
263 play within mild WBGT, a magnitude proposed to decrease high-intensity intermittent physical
264 performance⁴; accepting experimental hypothesis (i) and in line with male player data.³
265 Additionally, the employed CWI protocol left players (≥ 6 min match-play) with a $\sim 1 - 2^\circ\text{C}$
266 raised T_c , compared to T_c at WU onset (Figure 3) in acceptance of hypothesis (ii). Together
267 this demonstrates that despite brief match-play duration within modest WBGT environments,
268 athletes can experience a T_c rise that decreases performance⁴; whilst the CWI protocol

269 employed fails to acquiesce the majority of the acquired Tc rise (e.g. transient hyperthermia)
270 during each game.

271 Despite modest/low WBGT (18.5 – 20.1°C), high peak Tc values (37.9 – 39.8°C; ~50% ≥
272 39°C) were observed (particularly in those with ≥ 6 min match-play) reaching magnitudes
273 known to reduce repeat sprint ability.⁴ Research from other sports sharing high-intensity,
274 intermittent physical demands (soccer and tennis) has reported elite females recording similar
275 peak Tc values (38 - 40°C).^{23,24} Given the relationship [*very likely* (0.71; ±0.28)] seen between
276 minutes played and peak Tc, practitioners and coaches seeking to control player Tc and
277 maximise performance may benefit from pre or per-cooling interventions in the short term or
278 increasing heat tolerance in the longer term. Long-term heat acclimation strategies, although
279 not always practically compatible with training/competition,²⁵ have been shown to provide the
280 greatest protection to performance decrements and EHI.²⁶

281 Alternatively, opting for an alternate WU environment with more controlled conditions (e.g.
282 indoor) or modifying the WU volume/duration/intensity and thus reducing body heat storage
283 from it, may provide a greater Tc reserve until a ≥ 39°C is reached during match-play (i.e.
284 players start the match-cooler). Indeed, body heat storage from the employed WU could be
285 considered ‘too much’ (Figure 2) given a peak Tc of 39°C was seen for two players and
286 exceeding 38.5°C in > 50% of players. Practically however, such titration of WU may be
287 challenging to achieve, given often divergent player needs and the dynamic nature of individual
288 Tc change across the day. There are obvious practical and logistical advantages in allowing all
289 squad members to complete the same WU, as a team, during a WRWSS match-day. This may
290 be possible if augmented heat loss was facilitated during the WU, which through the use of a
291 phase change cooling vest has shown promise as an effective and ecologically valid strategy to
292 reduce Tc, without altering selected WU characteristics or performance measures in elite men’s

rugby sevens.¹² However, specific to the WRWSS there is currently no evidence regarding the efficacy of such interventions, which may be different to those presented for elite male sevens players¹² (for reasons outlined in the introduction). Further, the T_c responses discussed above from modest WBGT environments, would likely be exacerbated in high WBGT environments, such as those experienced commonly in other WRWSS tournaments and expected at Tokyo 2020.^{6,7} During or proximal to the warm-up, strategies to minimise hyperthermia risk and/or increase the T_c heat-sink (and associated favourable perceptual changes) prior to competition, appear prudent. These include, amongst others, wearing a phase change cooling vest, ice-slurry ingestion after the sweat response has been observed, ice towel application, performing the warm-up in an air-conditioned indoor environment (with simulated wind velocity), or outdoors with appropriate wind velocity (N.B. such approaches require extensive piloting and should not compromise the desired outcome of an effective warm-up).

Quickly removing the majority of the rise in T_c due to match-play appears prudent, given the accumulation of T_c between games, despite similar work rates across games. Indeed, average T_c values in the present data were *most likely* higher in game 2 than game 1, and *very likely* higher in game 3 than game 2 (players with ≥ 6 minutes involvement time), in support of similar findings in elite men's rugby sevens who did not perform any in-competition cooling.³ However, the employed CWI protocol left players (≥ 6 min match-play) with a $\sim 1 - 2^{\circ}\text{C}$ raised T_c compared to T_c at WU onset (Figure 3). Evidently, the lack of individualisation of CWI time (e.g. by match-play minutes) and that players only immersed themselves to hip height, contributed to the cooling responses seen (despite the CWI water temperature range $6.1 - 7.3^{\circ}\text{C}$). Piloting of both these CWI protocol modifications [e.g. individualised immersion based on minutes played and shoulder-depth immersion (to maximise conductive heat dissipation²⁷)] is recommended, to produce a practice ready individualised solution.

Although previous research has indicated that high Tc values ($> 39^{\circ}\text{C}$) are detrimental to repeat and intermittent sprint performance,⁴ the present study found no link between changes in Tc and reductions in external load measures (GPS). This could be due to individual variation in the relationship between high Tc and repeat and intermittent sprint performance as discussed elsewhere,⁴ or technical/tactical contextual factors of the matches influencing their physical demands,²⁸ or a sample size ($n = 12$; 3 matches) too small to detect a meaningful change in external load (GPS) metrics.²⁹ A lack of robust data regarding the relationship between altered thermal perceptions and their effect on performance capacities in elite athletes (e.g. particularly repeat sprint ability), renders performance-based inferences on perceptual measures uncertain within the present design; although reductions in thermal sensation without accompanying physical body temperature decreases can within some scenarios (predominately endurance exercise) prove ergogenic to exercise performance in the heat.^{12,30} Future research should look to include multiple match-days and/or tournaments so contextual variance due to technical/tactical factors is less pronounced, and greater statistical power can be attained.

Practical Applications

- Modifying the WU volume/duration/intensity to reduce body heat storage may provide a greater Tc reserve until a $\geq 39^{\circ}\text{C}$ is reached during match-play (i.e. players start the match-cooler).
- Individualised CWI protocols based on minutes played and shoulder-depth immersion is recommended to produce a practice-ready individualised solution to heat dissipation.

Conclusions

Like their male counterparts, elite female rugby sevens athletes experience high Tc during WU and matches on WRWSS match-days, even in modest WBGT environments. Strategies and

modifications to match-day protocols likely to result in improved thermoregulatory function, and subsequent physical performance for athletes are available, yet they lack empirical data to inform practice with specificity to the WRWSS.

Declarations/Acknowledgements

The authors thank the players and staff for their willingness, professionalism, engagement and time pre, during and post the executed research project – without which – the project would not have been viable. Lee Taylor (and co-authors) thanks the Aspire Zone Foundation (AZF; Doha, Qatar) for the funding and support to complete the presented research project. Additional thanks go to BodyCap (Caen, France) for the loan of 12 e-Viewers (plus general technical and logistical support) to complete the presented research project. Mitchell J. Henderson was supported by the RTP scholarship (Australia) and a research scholarship from Rugby Australia for this project. Aside from the above there was no further potential conflict of interests for any author in this study. Each author contributed to experimental design, data collection and data analysis, manuscript drafting and agreed to the submitted version of the manuscript.

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Figure captions

Figure 1. Experimental schematic. Tc = core temperature (ingestible telemetric pill); GPS = Global Positioning Systems; TS = thermal sensation; TC = thermal comfort; RPE = rating of perceived exertion; CWI = cold water immersion; WU = warm-up.

Figure 2. Individual average (A), peak (B), Δ period (C) and Δ baseline (D) core temperature (Tc) responses across all periods of the tournament for all players. The solid black line represents the mean for all players. The dashed line represents 39°C. Open circles represent players who had ≥ 6 min match-play. The likelihood of the observed effect exceeding the smallest worthwhile change ($0.2 \times$ between subject SD) when compared to baseline are denoted as; ** = *very likely*, *** = *most likely*. When compared to game 1 differences are expressed as; †† = *very likely*. When compared to game 1 only for players with ≥ 6 min match-play, differences are expressed as ^^ = *very likely*, and ^^ = *most likely*. BL = baseline; WU = warm-up; G = game; CWI = cold water immersion.

Figure 3. Individual Δ combined (A), $\Delta\Delta$ CWI (B), cooling rate ($^{\circ}\text{C} \cdot \text{min}^{-1}$) (C) and relative cooling rate ($^{\circ}\text{C} \cdot \text{min}^{-1} \cdot \text{LBM}$) (D) core temperature (Tc) responses to cold water immersion (CWI) and games respectively, for all players. The solid black line represents the mean. Open circles represent players who had ≥ 6 min match-play.

Figure 4. Individual RPE (A), TC (B) and TS (C) responses to games 1, 2 and 3 for all players. The solid black line represents the mean. Open circles represent players who had ≥ 6 min match-play. The likelihood of the observed effect exceeding the smallest worthwhile change ($0.2 \times$ between subject SD) when compared to game 1 are denoted as; *** = *most likely*. When compared to game 2 differences are expressed as; ††† = *most likely*. RPE = rating of perceived exertion; TC = thermal comfort; TS = thermal sensation.

Table 1. Player characteristics, anthropometry and body composition. Data is presented as median (minimum – maximum).

Measure	
Age (y)	
	67.9 (60.0 – 79.5)
Sum SF (mm)	63.3 (40.7 – 78.1)
Triceps SF (mm)	6.9 (3.6 – 8.7)
Subscapular SF (mm)	8.5 (5.6 – 14.8)
Bicep SF (mm)	4.0 (2.5 – 5.8)
Supraspinale SF (mm)	7.9 (4.5 – 15.0)
Abdomen SF(mm)	11.2 (4.1 – 17.0)
Thigh SF (mm)	15.9 (8.5 – 21.6)
Calf SF (mm)	7.4 (3.0 – 9.5)
Body fat (%)	19.2 (12.6 – 26)
LBM (kg)	54.7 (49.8 – 66.6)

SF = skinfold; LBM = lean body mass

Table 2. Core body temperature (Tc), wet-bulb globe temperature (WBGT), and local time of day (time) across each specific period of day 1 of the Sydney tournament. Data is presented as median (minimum – maximum) for all players. Match play data is also presented for players who had ≥ 6 min match-play only [game 1 (n = 6), game 2 (n = 7), game 3 (n = 9)].

Period	Tc peak (°C)	Tc min (°C)	Tc average (°C)	Δ Tc period (°C)	Δ Tc BL (°C)	Combined Δ (°C)	$\Delta\Delta$ CWI(°C)	WBGT (°C)	Time
BL	37.5 (37.2 – 37.7)	37.0 (36.7 – 37.3)	37.3 (37.0 – 37.5)						
Prime	38.5 (38.1 – 38.8)	37.4 (37.1 – 37.9)	38.0 (37.5 – 38.2)	1.1 (0.6 – 1.5)	1.2 (0.8 – 1.5)				12:16 – 12:36
WU 1	38.5 (37.9 – 39.0)	37.8 (36.9 – 38.1)	38.2 (37.4 – 38.5)	0.9 (0.4 – 1.2)	1.3 (0.6 –				
					2.3 (1.2 – 2.4)	1.7 (0.6 – 2.7)			
CWI 1	38.4 (37.8 – 39.3)	37.5 (37.0 – 38.0)	37.9 (37.5 – 38.4)	0.8 (0.4 – 1.8)	1.2 (0.5 – 1.9)		0.2 (-1.1 – 2.0)	6.1	14:25 – 14:44
WU 2	38.6 (38.2 – 39.0)	37.6 (37.0 – 38.1)	38.2 (37.7 – 38.6)	1.0 (0.8 – 1.4)	1.3 (0.9 – 1.9)			19.2 – 19.6	16:00 – 16:20
Game 2	39.0 (38.2 – 39.8)	38.4 (37.4 – 38.7)	38.7 (37.9 – 39.3)	0.7 (0.2 – 1.2)	1.8 (0.9 – 2.5)	1.3 (0.8 – 2.4)		18.9 – 20.0	16:38 – 16:55
>6 min	39.1 (38.2 – 39.8)	38.4 (37.4 – 38.7)	38.9 (37.9 – 39.3)	0.7 (0.5 – 1.2)	1.9 (0.9 – 2.5)	1.3 (1.0 – 2.4)			
CWI 2	38.4 (37.5 – 39.1)	37.8 (37.0 – 38.2)	38.1 (37.3 – 38.4)	0.5 (0.2 – 1.0)	1.2 (0.3 – 1.7)		0.8 (-0.1 – 1.9)	7.3	17:16 – 17:32
WU 3	38.6 (38.1 – 38.9)	37.5 (37.0 – 38.0)	38.1 (37.6 – 38.4)	1.1 (0.6 – 1.8)	1.4 (0.8 – 1.9)			18.5 – 18.8	18:22 – 18:42
Game 3	39.0 (38.4 – 39.6)	38.3 (37.9 – 38.5)	38.6 (38.2 – 39.6)	0.6 (0.3 – 1.3)	1.8 (1.1 – 2.3)	1.6 (1.0 – 2.2)		18.9 – 20.1	18:56 – 19:17
>6 min	39.3 (38.4 – 39.6)	38.4 (37.9 – 38.5)	38.9 (38.2 – 39.0)	0.8 (0.3 – 1.3)	2.0 (1.1 – 2.3)	1.6 (1.1 – 2.2)			
CWI 3	38.0 (37.8 – 38.6)	37.7 (37.2 – 38.0)	37.9 (37.7 – 38.2)	0.4 (0.3 – 0.7)	0.8 (0.6 – 1.2)		1.2 (0.7 – 1.6)	6.6	19:50 – 20:06

BL = baseline; WU = warm-up; CWI = cold water immersion; Tc = core temperature; WBGT = wet bulb globe temperature

Minutes played (min)	15.1 (8.5 – 16.5)	11.1 (8.9 – 14.6)	11.4 (6.1 – 17.3)
RPE	7 (5 – 8)	6 (3 – 8)	5 (3 – 8)
TS	5 (2.5 – 5.5)	5.5 (3 – 6)	4 (3 – 5)
TC	3 (1 – 4)	3 (1 – 4)	2 (1 – 2) ***†††
Average speed (m·min ⁻¹)	99.2 (92.9 – 102.9)	99.3 (96.3 – 114.0)	91.0 (80.6 – 104.0)
HSR·min ⁻¹	14.4 (8.9 – 18.6)	19.4 (12.9 – 30.3)	8.1 (6.1 – 15.4)
VHSR·min ⁻¹	5.1 (0.3 – 9.4)	8.3 (2.4 – 19.8)	3.9 (0 – 8.8)
Ave Acc/Dec (m·s ⁻²)	0.55 (0.53 – 0.58)	0.51 (0.46 – 0.55)	0.55 (0.51 – 0.57)

RPE = rate of perceived exertion; TS = thermal sensation; TC = thermal comfort; HSR = high speed running; VHSR = very high speed running. Ave Acc/Dec = average acceleration/deceleration. The likelihood of the observed effect exceeding the smallest worthwhile change (0.2 x between subject SD) when compared to game 1 are denoted as; *** = most likely. When compared to game 2 differences are expressed as; ††† = most likely.

Table 4. Differences in core body temperature (Tc) for each period compared to baseline. Data is presented as mean (95% CI) for all players and for players who had ≥ 6 min match-play only [game 1 (n = 6), game 2 (n = 7), game 3 (n = 9)]. Only significant data is shown.

[illegible]

BL = baseline; WU = warm-up; CWI = cold water immersion; Tc = core temperature; diff = difference; avg = average; ES = effect size. The likelihood of the observed effect exceeding the smallest worthwhile change (0.2 x between subject SD) when compared to baseline are denoted as; ** = very likely, and *** = most likely.