Physiological Characterisation of an International Elite Hot/Humid Rugby Sevens Tournament

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Abstract

Purpose: To characterise core temperature (T_c) along with predictors of T_c during an international rugby sevens tournament played in hot/humid conditions. Methods: T_c was collected from 11 elite men's rugby sevens athletes (age 24 ± 3 years) competing in the Oceania sevens tournament in Suva, Fiji. Game specific external load data [playing minutes, total running distance, high speed running distance (HSD)], psychrometric wet bulb temperature (WBT_p) and exertional heat illness (EHI) symptoms were also collected. Cohen's effect sizes (*d*) were used to assess differences in T_c across measurement periods was, while linear regression was used to assess the effect of external load and post warm-up T_c on peak game T_c. Results: Compared to baseline on both tournament days, mean T_c was higher at all subsequent time-points, including between games (all $d > 1.30$). On both tournament days, eight athletes (~73%) reached a peak game T_c > 39.0 °C. with several athletes $reach_{ing}$ > 39.0 °C during warm-ups. The final game of the tournament recorded the highest mean peak T_c (39.1 ± 0.3 °C). Mean T_c was related to playing minutes, total running distance, HSD, and post warm-up T_c (all $p <$ 0.01). Conclusions: T_c during warm-ups and games regularly exceeded those demonstrated to be detrimental to repeated sprint performance (> 39 °C). Warm-up T_c represents the easiest predictor of game peak T_c to control via the use of appropriate pre- and per-cooling strategies. Practitioners should be prepared to modulate warm-ups and other heat preparation strategies based on likely environmental conditions faced in these tournaments.

Introduction

Rugby sevens is a team sport, characterised by repeated bouts of high intensity running, frequent contacts, sprints, skill, and spatial awareness (Ross, Gill, & Cronin, 2015). International level rugby sevens athletes are reported to be large (mean body mass; 96 ± 7 kg) and lean (mean sum of 8 skinfolds; 62 ± 10 mm). A normal season for an international elite men's sevens team involves competing in ten tournaments worldwide, referred to as the World Rugby Sevens Series (WRSS). Each WRSS event normally consists of six games played across two days (pool play on day one, finals on day two) with each game consisting of two 7-min halves, with a 2-min halftime break. Most teams also normally warm up for ~30 min, the intensity and duration of which are likely to vary between teams, and the stage of competition (Taylor, Stevens, Thornton, Poulos, & Chrismas, 2019). In total, this equates to six ~45 min exercise performances across two days. WRSS match-play relative running demands are reported to be ∼113–120 $m \cdot min^{-1}$, often at high (∼19% ≥ 5 $m \cdot s^{-1}$) or very high (∼11% ≥ 6 $m \cdot s^{-1}$) speeds (Fowler, Lumley, Farooq, Murrary, & Taylor, 2017; Ross, Gill, & Cronin, 2014), along with the inclusion of ~10 collision-based game actions per player per game (ball taken into contact, tackles, rucks attended, scrums) (Ross et al., 2015).

Although the game demands have been well characterised recently due to the increasing interest in the sport as a result of its recent inclusion in the summer Olympics, little is known regarding the impact of stressful environmental conditions on these athletes, particularly in an elite setting. The environmental conditions at these events can vary from cold (e.g. London/ Vancouver in local springtime) to moderately hot (e.g. Dubai in December). Performance in extreme environments is also possible, as seen recently when the WRSS experienced its hottest ever day on the tournament, with WBGT reaching 45 °C at the 2020 Sydney tournament (unpublished observations).

Previously, in an elite rugby sevens context it has been shown that individual athletes peak core temperature (T_c) during match play can reach > 39.0 °C in both temperate and hot conditions and the main predictor of peak T_c during match play is reported to be the number of minutes played by each athlete (Taylor, Thornton, Lumley, & Stevens, 2019). This same study indicated that T_c is highest during the final game of a given tournament, suggestive of a cumulative effect of repeated performance on T_c and hence the importance of incorporating cooling strategies across a tournament (Bongers, Hopman, & Eijsvogels, 2017; Taylor, Thornton, et al., 2019).

Rugby sevens incorporates large volumes of repeated sprint exercise, and the impairment of repeated sprint exercise has been extensively described when T_c >39.0 °C (Beaven, Kilduff, & Cook, 2018; Drust, Rasmussen, Mohr, Nielsen, & Nybo, 2005; Girard, Brocherie, & Bishop, 2015). Repeated sprint performance is a key metric used in describing the overall exercise demands of rugby sevens, therefore, elite teams use individual portable GPS systems to monitor training and game demands. Most notably, practitioners commonly measure high-speed distance [HSD; an individually defined threshold speed; most commonly > $5 m \cdot s^{-1}$ (Ross et al., 2015)]. The relationship between game metrics (distance, high-speed distance) and T_c has never been described in the field. Further, other physiologically important variables such as hydration status, sweat loss and sweat composition have never been characterised during an international elite rugby sevens tournament in hot/humid conditions.

Therefore, the purpose of the current study was to characterise physiological and performance metrics that mediate T_c, along with characterising T_c itself, across two days of an international rugby sevens tournament performed in hot and humid conditions.

Methods

Subjects

Data were collected from 11 male athletes (age 24 ± 3 years; 94.3 ± 7.5 kg; height 187 ± 5 cm) from the same world champion international elite rugby sevens team during the Oceania rugby sevens tournament in Suva, Fiji. All participants provided informed consent prior to testing, and ethical approval for the study was obtained through the institution's Human Research Ethics Committee.

Design

The Oceania rugby sevens tournament consisted of five games across two days (two games on day one and three games on day two). Details of the game time and environmental conditions are displayed in Table 1.

Methodology

Core Temperature (T_c)

Players ingested a core temperature telemetry pill (e-CelciusTM BodyCap, Caen, France) upon waking on each tournament day, allowing for at least five hours before the first game time measurement. Data was sampled every 30 s and downloaded at the end of the day via a wireless data receiver (e-Viewer, BodyCap, Caen, France). This downloaded data was used for all pre-defined T_c measurement periods (pre-primer, post-primer, pre warm-up, post warm-up, during game, between game), whereby the individual mean was taken and used in the final analysis. Given that the Oceania sevens tournament (and all WRSS tournaments) involve games scheduled at various times across a day from morning to evening, a small (by ~0.2-0.3 °C) influence of circadian variation in T_c is entrenched in the current study design (West, Cook, Beaven, & Kilduff, 2014).

Sweat electrolytes, hydration, cooling use, and exertional heat illness (EHI) symptoms

Before the start of the warm-up for game two and game four the skin of the right shoulder blade was cleaned with distilled water and dried, before adhesive gauze sweat patches (Tegaderm+Pad, 3M, Loughborough, UK) were applied directly to the skin. At the completion of these games, sweat patches were immediately placed into sealed containers and frozen until analysis, whereby concentrations of sweat sodium, potassium and chloride were determined using absorbance photometry (Cobas C111 analyser, Roche, AG Basel Switzerland). Games two and four were chosen as they were the second match of each day, with similar environmental conditions. Body mass was collected before the start of each warmup and at the conclusion of each game using portable electronic scales (Tanita HD-351, Tanita Health Equipment H.K. Limited). Fluid intake was allowed *ad libitum* during each tournament day (not recorded), hence the reported body mass loss is despite *ad libitum* access to fluid. Signs and symptoms of exertional heat illnesses (EHI) were collected ~10 min after each game using a modified survey instrument (Périard et al., 2017). Specifically, the athletes were asked if they had experienced (i) cramping; (ii) vomiting; (iii) nausea; (iv) light headedness or headache; (v) collapsing/fainting; or (vi) any other symptom that might relate to heat illness.

Cold-water immersion (CWI; using small rectangular tubs of 2 m length x 2 m width x 1 m depth) was available *ad libitum* post-game with the duration of any exposure being recorded by a researcher.

Environmental conditions

Psychrometric wet bulb temperature (WBTp) was calculated based upon measurements of temperature, humidity, wind speed and atmospheric pressure (Kestrel 4200, Nielsen-Kellerman Co, Boothwyn, PA, USA) that were obtained immediately prior to, during and post matches (behind the dead ball line). Due to the nature of the psychrometric ratio for a water-air system, the WBTp approximates the thermodynamic wet-bulb globe temperature (a traditional measure of human heat stress). The mean of these respective WBTp measurements at their associated timepoints were used in the analysis.

External predictors of T_c

Individual match running data (distance, high-speed distance) was collected using a wearable 10 Hz global positioning system (GPS; VxSport, Wellington, New Zealand). Individual game playing minutes for each athlete were collected by the team's performance analyst. Only periods where an athlete was involved in a subsequent game were included in the analysis, i.e. an athlete that played in Game One had their data included for all timepoints pre, during and post that game (until the between game measurement).

Statistical analysis

To determine differences in T_c from baseline, the change in the mean for each measurement period was determined and expressed as standardised effect sizes (ES; Cohen's *d*) and 90% confidence limits (CL). Cohen's *d* effect sizes (± 90% CL) were also determined to compare differences in T_c across different games (Game One – Five) and warm-ups (post warm-up one – five). Differences were described using standard thresholds of < 0.20 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). If the 90% CL overlapped positive and negative trivial (± 0.20) *d* values, the effect was deemed unclear.

Individual linear regression were used to assess any relationship between Game T_c and other independent predictor variables (playing minutes, high speed running distance (HSD), running distance, Post warm-up T_c, and Body mass difference) with T_c as the dependent variable and the other variables entered separately as independent variables. Independence of observations was assessed using the Durbin-Watson statistic, homoscedasticity was assumed, and residuals were normally distributed. Additionally, hierarchical multiple linear regression was used to assess whether any of the above variables predicted game T_c over and above that of playing minutes [which has previously been described (Taylor, Thornton, et al., 2019)]. In this instance Game T_c was set as the dependent variable, with playing minutes as the first independent variable and other game variables (as above) added separately as the 2nd independent variable. Paired t tests were used to analyse differences in sweat electrolyte concentration between games two and four, these data are reported as mean ± SD, with an alpha level of 0.05.

Results

Daily core temperature profile

On Day One, eight athletes (~73%) reached a T_c > 39.0 °C during games, with one athlete reaching a T_c of > 39.0 °C during both games. On Day Two, eight athletes reached a T_c > 39.0 °C, with four of these reaching a T_c of > 39.0 °C on more than one occasion. On Day One, five athletes (~45%) reached a T_c > 39.0 °C during a warm-up, whereas on Day Two, two athletes reached a T_c > 39.0 °C during warm-up. Group mean differences and individual maximum temperatures across pre-defined measurement periods for Day One and Day Two are shown in Figure 1. Game Three included a 4.5 min injury break during the second half, whereby all athletes were required to remain on the field in a similar manner to a half time break. Game Five (the tournament cup final) went to overtime (the scores were tied at the end of full time). In this instance, there was a two-min break between full time and overtime, and the overtime lasted for a further 3.8 minutes (golden point rules).

Sweat electrolytes, hydration and EHI symptoms

There were no differences in sweat sodium (41 ± 16; 39 ± 15 mmol·L^{-1}), potassium (4 ± 1; 4 ± 1 mmol·L^{-1}), or chloride (34 ± 13; 32 ± 12 mmol·L^{-1}) between Game Two and Game Four (all $p > 0.05$). Body mass change (despite *ad libitum* access to fluid) across each combined warm-up and game period is shown in Table 1. One symptom (light headedness or headache) of EHI was reported by one athlete on two occasions (post-Game Four; peak game T_c = 39.6 °C, post-Game Five; peak game T_c = 40.0 °C). No other athletes reported any EHI symptoms throughout the tournament.

Predictors of peak game T_c

There were moderate differences in running distance and HSD between games on both Day One and Day Two, whereas there was no clear differences in mean playing minutes or body mass change between any games; see Table 1 for full results. Individual linear regression established that playing minutes, post warm-up T_c, total running distance and HSD were all significant predictors of peak game T_c, whereas body mass change was not; see Table 2 for full details on each regression model. Hierarchical multiple regression revealed that the addition of post warm-up T_c led to a statistically significant prediction of Game T_c, over and above that of playing minutes alone ($R^2 = 0.322$, $F_{1,47} = 4.361$, $p < 0.05$). Neither running distance or HSD improved the prediction of Game $T_{c,}$ over and above playing minutes.

Discussion

This novel characterisation of an international elite rugby sevens tournament played in hot and humid conditions demonstrated that numerous players had significantly elevated T_c throughout the course of the two-day tournament, and that these temperatures were related to playing minutes and post warm-up T_c. Numerous athletes experienced T_c approaching and above those associated with impaired repeated sprint performance [39 °C (Girard et al., 2015)], and EHI symptoms [40 °C (Racinais et al., 2015)]. Notably, some of these instances of $T_c \geq 39.0$ °C occurred during warm-ups before games.

Each day, there were game on game increases in mean T_c post warm-up. Additionally, all post-baseline measures were *likely* – *most likely* to be greater than baseline on Day One and Day Two, respectively, both findings indicative of a cumulative increase in T_c across the tournament. During the current investigation, playing minutes, post warm-up T_c, total distance, and HSD were all significant predictors of game peak T_c. These findings are further supported by post warm-up T_c leading to a significant prediction of Game T_c, over and above that of playing minutes alone. This novel finding, has important implications for practitioners, considering that, of all the predictors of game peak T_c, post warm-up T_c has the most potential to be modulated via altering the time and intensity of a warm-up period and/or via the use of pre- and per-cooling strategies.

A similar investigation had previously demonstrated that playing minutes are *likely* to have an effect on individual peak game T_c during international rugby sevens tournaments played in both hot (WGBT ~25.0 °C) and temperate (WGBT ~16.0 °C) conditions (Taylor, Thornton, et al., 2019). Interestingly, that investigation showed no differences in game T_c experienced by athletes between the different tournaments (hot vs temperate environments), concluding that practitioners should prepare their athletes for high T_c regardless of environmental conditions. In both this earlier, and the current investigation, neither group undertook any form of heat acclimation (HA) before competing in a hot environment, nor did they undertake any form of mandated cooling practises (such as pre-, per- and post-cooling).

It is expected that HA would result in a decrease in baseline T_c, along with a decrease in the slope of T_c rise (Tyler, Reeve, Hodges, & Cheung, 2016), however, there has been limited investigations into how HA would best fit into an elite rugby sevens environment due to the competing influences of other training demands, travel and tournaments (Casadio, Kilding, Cotter, & Laursen, 2017). Common pre-cooling strategies used in team sports incorporate the ingestion of ice slushy (Beaven et al., 2018; Brade, Dawson, & Wallman, 2014), application of ice-towels (Duffield, Steinbacher, & Fairchild, 2009; Minett, Duffield, Marino, & Portus, 2012) and ice vests pre and during warm up (Taylor, Stevens, et al., 2019). Undertaking mixed-methods pre and per cooling has been suggested as best practice in team sports (Aldous et al., 2018; Tyler, Sunderland, & Cheung, 2015), which may mitigate the decrease the rise in T_c seen in the current study, however, this is yet to be investigated in a rugby sevens context. Sweat electrolyte concentrations have never been assessed in the field in the current context and are similar to those reported by in a cohort of elite rugby union (15-a-side) athletes (Black, Black, Baker, & Fairbairn, 2018), along with previous cross-sectional studies of athletes in other team sports such as soccer (Shirreffs et al., 2005), American football (Stofan et al., 2003), and indoor sports (Hamouti, Coso, Estevez, & Mora-Rodriguez, 2010).

In the current investigation, between game T_c was above baseline on all occasions. Post-cooling (via cold water immersion) was available for use in the current study; however, *ad libitum* use by athletes was minimal (only used by 4/11 athletes throughout the tournament; every exposure was < 75 s), and hence insufficient to produce any acute T_c decrease, after drop in T_c (Bongers et al., 2017), or decrease or indices of cumulative fatigue (Montgomery et al., 2008). Given that CWI has an unrivalled ability to decrease

T_c, and easily obtainable external load data (playing minutes, distance, HSD) are most likely to predict peak game T_c, practitioners should consider an individualised prescription of cooling strategies that consider these external load variables along with the known relationship between body mass and exercise heat stress (Gibson, Willmott, James, Hayes, & Maxwell, 2017), with the goal to return T_c to an intraday baseline. Measurement of T_c via telemetry pill is not likely to be practical in most circumstances; however, practical measurements of T_c, such as tympanic temperature can provide a valid measurement tool when exercising in the heat (Fenemor, Gill, Sims, Beaven, & Driller, 2020). Given that the current, and previous research has shown that T_c can consistently reach > 39.0 °C in hot/humid environmental conditions, and that measuring T_c during games is practically challenging, we postulate that metrics of relative running intensity, alongside practical and valid body temperature monitoring equipment could be used to guide cooling and recovery protocols throughout an elite rugby sevens tournament played in hot/ humid conditions.

Practical Applications

The current study outlines the potential cumulative thermal strain that international rugby sevens athletes can be exposed to when competing in a tournament played in hot/ humid environmental conditions. These findings, along with known temperature extremes at WRSS tournaments, and the expected environmental conditions at the (delayed) Tokyo 2020 summer Olympics indicate the importance for rugby sevens practitioners to incorporate heat management strategies into their preparation. Most importantly, this should include a sports-specific heat acclimation process (Gibson et al., 2019), along with appropriate cooling strategies (Bongers et al., 2017). Furthermore, the current findings suggest that commonly measured external load data, alongside a valid temperature monitoring tool could be useful to create individualised recovery protocols for repeated performances across a tournament.

Conclusion

During this international rugby sevens tournament played in hot/humid conditions T_c during warm-ups and games regularly exceeded those demonstrated to be detrimental to repeated sprint performance (> 39 °C). Peak game T_c can be predicted by playing minutes and T_c achieved during warm-up. Subsequently, warm-up T_c represents the easiest predictor of game peak T_c to control via the use of appropriate pre- and per-cooling strategies. Practitioners should be prepared to modulate warm-ups based on environmental conditions, along with including team-specific heat acclimation before competing in hot/humid environmental conditions to maximise game preparation. Future research should focus on the development and assessment of best practise cooling and heat acclimation strategies in a rugby sevens context.

Table 1. Local time, environmental conditions, playing minutes, running distance (m), game high speed distance (m), and pre- post game body mass difference (kg) for one international team during games 1-5 at the 2018 Oceania men's rugby sevens tournament. Data (except local time and environmental conditions) are represented as mean ± SD. Differences between games (shaded panels) are represented as standardised effect sizes (Cohen's *d* ± 90% confidence limits).

	Game # (local time)	**Game Temp. (°C), rH (%), WBT_p (°C)**	**Playing Minutes**	**Running Distance (m)**	**High Speed Distance (m)**	**Body mass Difference (kg)**
Day One	Game 1 (16:36)	31.3; 71%; 26.4	10.5 ± 4.8	1409 ± 297	115 ± 55	0.5 ± 0.4
	Game 2 (19:46)	29.0; 73%; 25.0	8.8 ± 4.8	1300 ± 367	147 ± 35	0.8 ± 0.5
Day Two	Game 3 (11:26)	30.4; 73%; 26.1	9.8 ± 3.4	1138 ± 359	117 ± 80	0.5 ± 0.3
	Game 4 (15:18)	29.9; 75%; 25.3	9.5 ± 4.6	1190 ± 263	89 ± 31	0.6 ± 0.4
	Game 5 (20:20)	26.0; 81%; 23.6	11.9 ± 4.4	1410 ± 522	154 ± 77	0.5 ± 0.5
Game 1 vs. Game 2	-	-	-0.31 ± 0.77 *Unclear*	-0.29 ± 0.80 *Unclear*	0.61 ± 0.77 ***Moderate***	0.52 ± 0.77 *Unclear*
Game 3 vs. Game 4	-	-	-0.06 ± 0.73 *Unclear*	-0.17 ± 0.73 *Unclear*	0.58 ± 0.72 *Moderate*	0.28 ± 0.73 *Unclear*
Game 3 vs. Game 5	-	-	0.48 ± 0.71 *Unclear*	1.06 ± 0.73 ***Moderate***	0.61 ± 0.72 *Moderate*	0.10 ± 0.71 *Unclear*
Game 4 vs. Game 5^	-	-	0.33 ± 0.74 *Unclear*	0.47 ± 0.73 ***Small***	0.97 ± 0.72 ***Moderate***	-0.15 ± 0.73 *Unclear*
Game 1 vs. Game 5^	-	-	0.27 ± 0.73 *Unclear*	-0.02 ± 0.72 *Unclear*	0.48 ± 0.72 *Unclear*	-0.04 ± 0.76 *Unclear*

^Game 5 was the cup final which included a total of 3.8 min of overtime. rH = relative humidity; WBT_p = Psychrometric Wet Bulb Temperature

Table 2. Results of linear regression assessing the effect of Playing Minutes, High Speed Distance, Distance, Post Warm Up T_c, and Body mass difference on individual core temperature across all games for one international team during the 2018 Oceania men's rugby sevens tournament.

		Estimate	Standard Error	T statistic	P Value	R^2	F
Playing Minutes	Intercept	38.5	0.126	304.6	<0.0001	0.289	19.509
	Slope	0.050	0.011	4.417	<0.0001	-	-
High Speed Distance	Intercept	38.6	0.116	333.0	<0.0001	0.18	10.316
	Slope	0.003	0.001	3.454	0.001	-	-
Distance	Intercept	38.1	0.198	192.22	<0.0001	0.301	0.465
	Slope	0.001	0.000	4.403	<0.0001	-	-
Post Warm Up T_c	Intercept	23.7	5.259	4.506	<0.0001	0.149	17.907
	Slope	0.398	0.137	2.903	0.006	-	-
Body mass difference	Intercept	38.9	0.097	400.5	<0.0001	-0.020	0.048
	Slope	0.030	0.135	0.219	0.827	-	

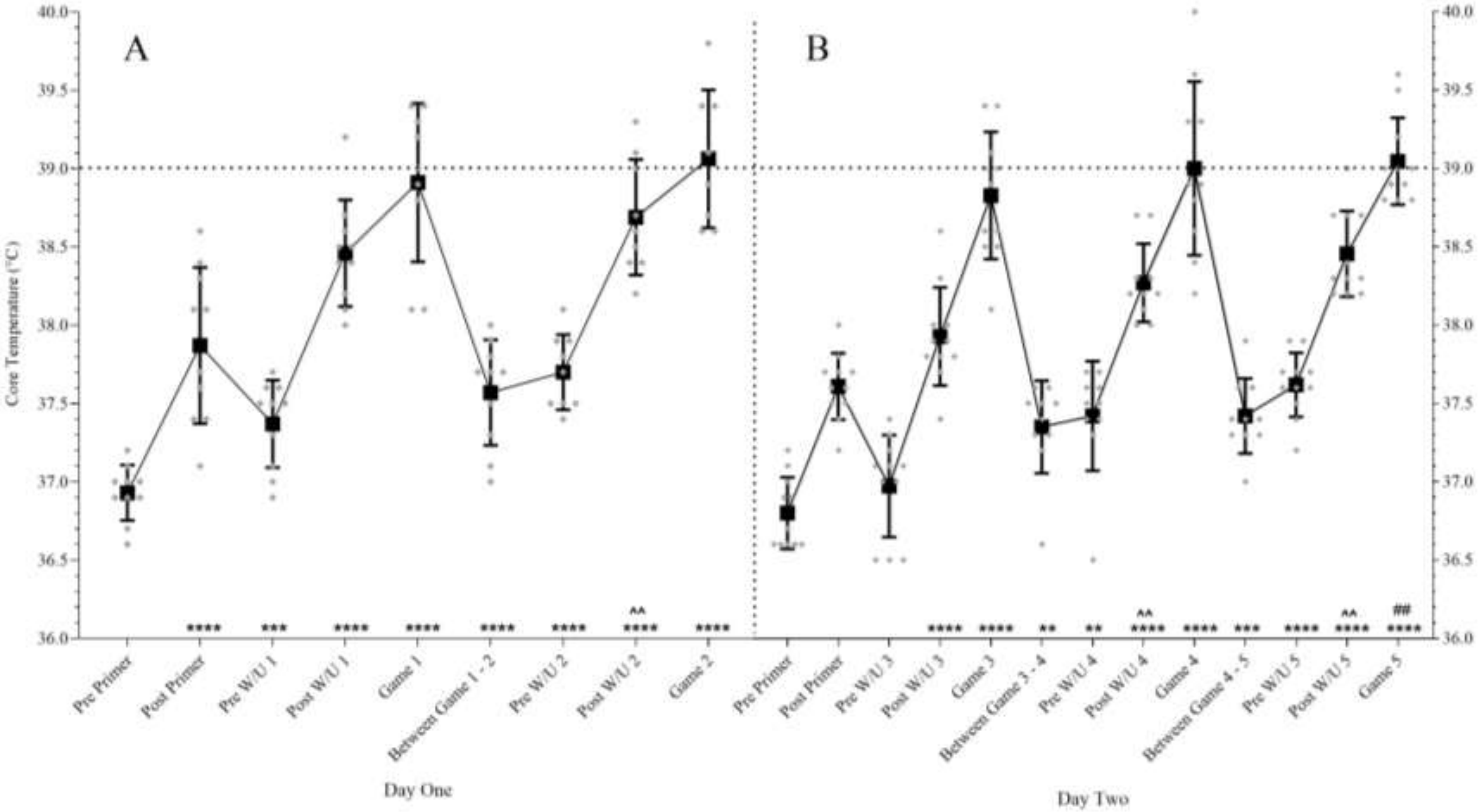

Figure 1. Individual Core Temperature (°C) during day one (panel A) and day two (panel B) for one international team during the Oceania rugby sevens tournament. Individual responses are represented as solid grey diamonds while closed black squares represent group mean (± SD). Symbols above the x-axis represent standardised effect sizes (Cohen's *d*) for the following comparisons: * = compared to a within-day baseline; ^ = compared to the previous warm-up; # = compared to game 3. The number of symbols represent the size of the effect; 1 = small, 2 = moderate, 3 = large, and 4 = very large. The dotted line at 39.0 °C represents a T_c threshold whereby a T_c above this has been demonstrated to reduce repeated sprint performance. W/U = warm-up.

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