Responses to a 5-day sport-specific heat acclimatization camp in elite female rugby sevens athletes

https://doi.org/10.1123/ijspp.2021-0406

PUBLISHER

Human Kinetics

VERSION

AM (Accepted Manuscript)

PUBLISHER STATEMENT

Accepted author manuscript version reprinted, by permission, from International Journal of Sports Physiology and Performance, 2022, 17 (6): 969-978, https://doi.org/10.1123/ijspp.2021-0406. © Human Kinetics, Inc.

Title: Responses to a 5-day sport specific heat acclimatisation camp in elite female rugby sevens athletes

Submission Type: Original Research

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Preferred Running Head: Heat acclimatisation in rugby sevens

Abstract word count: 257
Text-only word count: 3830
Number of figures: 6
Number of tables: 6
References: 38

Abstract

Purpose: Describe the physiological (resting core temperature, exercising heart rate, sweat rate) and psychophysical (rating of perceived exertion, thermal sensation, thermal comfort) responses to a short-term heat acclimatisation (HA) training camp in elite female rugby sevens athletes. **Methods:** Nineteen professional female rugby sevens athletes participated in a 5-day HA camp in Darwin, Australia (training average: 32.2°C and 58% relative humidity). Training involved normal team practice prescribed by appropriate staff. Markers of physiological and psychophysical adaptations to HA were collected at various stages during the camp. Partial eta squared effect sizes (from linear mixed effects models), rank-biserial correlations (from Freidman tests), and *p*-values were used to assess changes across the protocol. **Results:** Resting core temperature did not significantly change. Exercising heart rate showed a large and significant reduction from day 1 to day 5 (175 ± 13 vs 171 ± 12 bpm), as did sweat rate (1.1 ± 0.3 vs 1.0 ± 0.2). Thermal sensation showed a large and significant reduction between day 1 and day 5 (median [IQR] = 5 [5 - 5.5] vs 4.5 [4 - 5]). Changes in rating of perceived exertion and thermal comfort were unclear. **Conclusions:** Beneficial cardiovascular adaptations were observed simultaneously across a full squad of elite female rugby sevens players (without expensive facilities/equipment or modifying training content). However, beneficial changes in resting core temperature, sweat rate, and thermal/effort perceptions likely require a greater thermal impulse. These data contribute to the development of evidence-informed practice for minimal effective HA doses in female team sport athletes, who are underrepresented in the current research.

Keywords: heat acclimation, core temperature, football, physiology

Introduction

Appropriately prescribed and regular exposure to hot conditions during a training period promotes positive physiological and psychophysical adaptations beneficial to subsequent performance in the heat.[1,2] Such adaptations include enhanced cardiovascular[3] and thermoregulatory[1] capacities, as well as favourably-altered perceptions of heat and exertion.[4] Consensus recommendations on training and competing in the heat advise that heat acclimation (artificial heat) or acclimatisation (natural heat) protocols (HA) comprise repeated heat exposures over 1 – 2 weeks to obtain a fully-acclimated phenotype. Despite this, early adaptations such as lowered core temperature (T_c) and exercise heart rate (HRex) can be obtained in as little as a few days.[5] Whilst prolonged HA protocols are understood to be the most effective in achieving the desired outcomes, team sport practitioners seeking heat adaptations for their athletes are often challenged by: (1) large athlete numbers; (2) limited or no access to equipment/facilities for procuring HA adaptations (e.g. heat chamber) or monitoring responses (e.g. specialist equipment to assess plasma volume expansion); (3) training specificity / interference effect concerns; (4) congested fixture and travel schedules; and (5) time constraints around technical/tactical training. Pragmatism is required when planning and implementing interventions within these constraints. Protocols that can be performed without sacrificing training specificity or requiring expensive facilities/equipment will be highly regarded. Addressing these concerns, shorter HA options that are viable for a large group, whilst retaining some benefits associated with more comprehensive protocols, will be of value to practitioners working in elite team sport contexts.

Research regarding heat training adaptations has mostly focused on males, limiting applicability to female athletes.[6-8] This limited available evidence suggests females require a stronger HA dose (e.g. longer HA period, greater heat stress, more sessions) to achieve comparable adaptation to males.[9] Although unclear, methodological discrepancies have been suggested as potentially explaining a lower thermal strain being experienced by females for a given thermal stress. Differences in anthropometry, training status, environmental conditions, or reduced T_c during the follicular phase of the menstrual cycle, may account for the lower thermal heat strain.[9] In sport, these differences commonly surface as female athletes possessing a smaller body mass, higher surface area to volume ratio, and reduced absolute exercise capacity (all increasing heat loss capacity), whilst also possessing higher body fat content and less muscle mass (decreasing heat storage capacity) when compared to males of a similar level.[9] As a result, the current evidence supporting short-term HA protocols for procuring beneficial T_c and HRex adaptations (5-7 days; based primarily on male data)[1,2,10] may not be applicable for female athletes. Practitioners supporting female athletes preparing for thermally-challenging events will benefit from a more robust understanding of the minimal effective HA dose to achieve a given response (T_c, HRex, sweat rate).

This study aims to describe the physiological (resting T_c, HRex, sweat rate) and psychophysical [rating of perceived exertion (RPE), thermal sensation, thermal comfort] responses to a short-term (5-day) HA training camp in elite female rugby sevens athletes. Based on previous short-term HA adaptation findings,[1,2,10] it is hypothesised that resting T_c, HRex, and all perceptual measures will show favourable changes in response to the HA camp, but the 5-day duration will be insufficient for meaningful changes in sweat rate.

Methods

Participants

Data were collected from a total of 19 female athletes (24.2 ± 4.4 years, 170 ± 4 cm, 71.6 ± 4.9 kg) from a single 2020 Tokyo Olympic Games rugby sevens extended squad based in Sydney, Australia. The athletes commonly train for 10 - 12 hours per week (including 3 – 4 field sessions, 3 – 4 resistance training sessions, and 1 – 2 cross-training or indoor skills sessions) and had been training consistently for 6 months prior to the camp (due to a COVID19 affected competition season). During this period, accumulated distances on the Yo-Yo Intermittent Recovery Test Level scores were 1509 ± 283 m (estimated VO2max based on test results: 49.1 ± 2.4 $mL \cdot kg \cdot min^{-1}$).[11] The full population of professionally contracted international female rugby sevens athletes in the country, available to play at the time of data collection, were recruited. Written informed consent was provided for the project under ethical approval from the University of Technology Sydney (ETH19-4051) Human Research Ethics Committees in the spirit of the Helsinki Declaration.

Design

A descriptive case series study design was conducted in Darwin, Australia during a short-term HA training camp in June 2021 (Australian winter) as part of preparations prior to the Tokyo 2020 Olympic Games.[12] During the 5-day data collection period, all athletes took part in normal team training as prescribed by the coaches and strength and conditioning staff (normal training content, as is performed in Sydney, was not altered for the purposes of this study). Athletes participated in five field-based rugby and conditioning sessions involving a combination of self-paced and constant work rate exercise, four indoor resistance training sessions (air-conditioned facility), and two outdoor cross-training sessions. The cross-training sessions involved a combination of cycle and rower ergometers, bodyweight strength endurance, boxing, and medicine ball exercises. Non-training related outdoor exposure amounted to multiple hours each day and consisted of group or promotional activities and community functions. Nights were spent in air-conditioned demountable accommodation. Markers of physiological and psychophysical adaptations to HA were collected at various stages during the camp (see Figure 1) to describe the time course of responses. The effect of athletes' menstrual cycles were unable to be accounted for, as these are not typically monitored by medical staff. Within the team, athletes choose to manage their menstrual cycle as they see fit.

*** Figure 1 near here please ***

Methodology

Training during the month prior to the camp was performed at 14.3 ± 2.6°C ambient temperature and 81 ± 15% relative humidity. Weekly total field training loads [measured by Catapult Vector S7 10Hz dual global navigation satellite system / local position system devices (Catapult Sports, Melbourne, Australia)] for the camp and 8 weeks prior are shown in Figure 2. Field training load for each session within the camp is summarised in Table 1.

*** Figure 2 near here please ***

*** Table 1 near here please ***

Environmental conditions during the camp were generally hot (see Table 2 and Figure 3 for full details). Signs and symptoms of exertional heat illnesses (EHI) were collected following the training session using a modified survey instrument.[13] 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 [13].

*** Table 2 near here please ***

*** Figure 3 near here please ***

Athletes ingested an e-Celsius™ telemetric capsule (BodyCap, Caen, France) the night prior to resting T_c data collection. Resting T_c measures were determined by the presence of a stable period of T_c prior to waking whilst lying in bed (occurring around 5:00 – 5:30am for most). Data were only included within the statistical model when ≥ 5 hours had elapsed post-ingestion, a criterion used previously to ensure the capsule was in the lower intestine.[14-16] Resting T_c was sampled at 15 second intervals, with data downloaded at earliest convenience after waking via a wireless data receiver (e-Viewer, BodyCap, Caen, France). Capsules were prepared, calibrated, and handled as outlined previously.[14,16,17] The e-Celsius™ system has been determined valid and reliable for intermittent-running exercise,[17] as well as excellent validity (ICC 1.00), test-retest reliability (ICC 1.00) and inertia in water bath experiments between 36°C and 44°C.[18] The e-Celsius™ system has also been used previously within elite rugby sevens matches[14,16] and training.[19,20] In the case of technological error or the capsule being passed prior to data collection [this occurred for 6 of the 38 attempted measures (19 participants x 2 measures each)], resting T_c data were not able to be collected.

Cardiovascular fitness changes were indirectly monitored by tracking changes in HRex to a 4-minute submaximal continuous run at 12 $km \cdot h^{-1}$ and recording the final 30 seconds mean value. The submaximal run was conducted as part of the training session's warm up (see Figure 4 for methodology and diagram).[21] Data were collected using Polar H1 heart rate monitors (Polar Electro Oy, Kempele, Finland) worn via a chest strap. This approach of monitoring submaximal HRex is common in elite sport[22,23] and is a highly recommended surveillance tool for monitoring positive aerobic-oriented training adaptations.[24] To account for variable environmental temperature between sessions, HRex measures have been adjusted as recommended previously[25] to avoid misinterpretation (i.e., noise in HRex from different environmental temperatures being interpreted as fitness changes). This is based upon previous work showing a 1% shift in fractional utilisation (sustainable percentage of VO2max) in response to a 10°C difference in ambient temperature during a 4-minute HRex monitoring run.[25]

*** Figure 4 near here please ***

Whole-body sweat loss was quantified by determining the change in body mass pre- and post-training (assuming a fluid volume of 1L = 1kg). Athletes were asked to urinate and/or defecate, if necessary, prior to pre-training measurement and not again until post-training measurement. Body mass was measured wearing only underwear, immediately before and after the training session using calibrated scales (BWB-800-S, Tanita, Tokyo, Japan). Each player was provided with an individually named drink bottle that was weighed before and after training to establish the volume consumed during the training session. Body mass loss was corrected for fluid intake but not for respiratory and metabolic water loss/gain. Athletes were instructed to only drink from their own bottle, not spit water out, or pour water on themselves. Drinking behaviour was monitored by the researchers and practitioners to ensure adherence.

Measurements of RPE (CR-10 scale; where 0 = rest and 10 = maximal),[26] thermal sensation (17-point category ratio scale; where 0 = 'unbearably cold' and 8 = 'unbearably hot'),[27] and thermal comfort (10-point scale; where 1 = 'comfortable' and 10 = +1 above 'extremely uncomfortable')[26] were collected before and immediately following the standardised submaximal run, and upon cessation of the session. All psychophysical data collected from these scales represent how athletes were feeling when asked (i.e., not a session average). In the case of an athlete not completing the standardised submaximal run due to injury or load management concerns, their perceptual data were not collected or used in the analysis of psychophysical responses (this occurred for 4/19 athletes).

All measures were obtained as per Figure 1, by the same practitioner using standardised language and procedures.

Statistical Analyses

All statistical analyses were performed, and figures created, using R statistical software.[28] Descriptive statistics are reported as mean ± SD when data is continuous (resting T_c, HRex, sweat rate) or median (IQR) when data is ordinal (RPE, thermal sensation, thermal comfort).

Linear mixed effects models were fitted on all continuous dependent variables (resting T_c, HRex, sweat rate) using the {lme4} R package[29] to determine the effects of the short-term HA camp (with the ordered categorical independent variable of days across the camp). Intercepts were allowed to vary randomly for each athlete, given that some of the variance in the dependent variables is likely associated with the clustering of repeated observations within a single individual. P-values were obtained by Kenward-Roger approximation[30] which has been shown to produce acceptable Type 1 error rates, even for smaller samples.[31] Pseudo 'variance explained' (R^2) values were calculated[32] to assess model goodness-of-fit. Approximate partial eta squared effect sizes (η_p^2) were converted from test statistics and degrees of freedom using the {effectsize} R package.[33] Both goodness-of-fit (R^2: 0.02 = *weak*, 0.13 = *moderate*, 0.26 = *substantial*) and effect sizes (η_p^2: *small* = 0.01, *medium* = 0.06, *large* = 0.14) were interpreted using Cohen's recommendations.[34]

Ordinal data collected from the psychophysical scales (RPE, thermal sensation, and thermal comfort) were analysed using a Friedman rank sum tests to assess change across the HA protocol. Kendall's *W* effect sizes (normalisation of the Friedman statistic) were calculated and assume values from 0 to 1, indicating no relationship or a perfect relationship, respectively. In the case of a significant Friedman rank sum test, pairwise Wilcoxon signed-rank tests (with Bonferroni correction) were used to identify change between days, and rank-biserial correlations (*r*) effect sizes were calculated to assess magnitude of change between days. Cohen's recommendations were again used for interpreting both *W* and *r* effect sizes (*small* = 0.1 - 0.3, *moderate* = 0.3 - 0.5, *large* > 0.5). [34] All confidence intervals were calculated by using bootstrapping. Using this method, the original data are re-sampled to create many simulated samples from which confidence intervals can be constructed. Perceptual data collected following the standardised submaximal run was used for analysis to determine the effect across the HA camp. Data collected prior to and at the end of training is provided for context and descriptive purposes only, due to variable external loads between sessions making controlled comparisons not possible.

Visual inspection of diagnostic plots did not reveal any obvious deviations from normality or heteroscedasticity. Shapiro-Wilk tests performed on model residuals suggested no evidence of non-normality in all cases except sweat rate, although violations of this assumption within linear models are rarely problematic. The commonly recommended solutions to this problem (e.g. using non-parametric tests, generalized linear models) have been suggested to represent a greater threat to the reliability of conclusions because of their lower flexibility or robustness.[35]

Results

Descriptive data (including athletes with incomplete datasets) for all continuous and ordinal outcome measures are presented in Tables 3 and 4, respectively.

*** Tables 3 & 4 near here please***

Figure 5 depicts the effect of the HA camp on each of the physiological outcomes across each day. Table 5 summarises the statistical results of the physiological data.

*** Figure 5 near here please ***

*** Table 5 near here please***

Resting core temperature did not significantly change across the protocol (Figure 5A; p = 0.550, η_p^2 = 0.02). Exercise heart rate (Figure 5B) showed a large and significant reduction from day 1 to day 5 (175 ± 13 vs 171 ± 12 bpm; $p < 0.001$; η_p^2 = 0.48). Sweat rate (Figure 5C) also showed a significant reduction between day 1 and day 5 (1.1 ± 0.3 vs 1.0 ± 0.2 $L \cdot hr^{-1}$; p = 0.041, η_p^2 = 0.21).

Figure 6 depicts the effect of the HA camp on each of the psychophysical outcomes across each day. Table 6 summarises the statistical results of the psychophysical data.

*** Figure 6 near here please ***

*** Table 6 near here please***

Thermal sensation (Figure 6B) showed a moderate and significant reduction between day 1 and day 5 (median [IQR] = 5 [5 - 5.5] vs 4.5 [4 - 5]; *p.adj* = 0.039; *r* = 0.74). Changes in RPE (Figure 6A) were variable between days, and the only significant change was an increase between day 2 and day 3 (3 [2.5 - 3.5] vs 4 [3 - 5]; *p.adj* = 0.002; *r* = 0.84). Changes in thermal comfort (Figure 6C) were unclear including a significant increase between day 2 and day 3 (*p.adj* = 0.043; *r* = 0.70) but a significant decrease between day 3 and day 5 (*p.adj* = 0.008; *r* = 0.87).

No EHI symptomology was reported in either group.

Discussion

The present findings show that short-term HA, even as little as 5 days in a hot environment performing moderate-to-high volumes of rugby specific on-field training, can elicit beneficial changes in HRex (-4 ± 2 bpm; supporting our hypothesis and confirming HRex as a marker of early heat adaptation). Conversely, resting T_c and all perceptual measures did not show consistent changes indicative of favourable adaptation over this timeframe (dismissing our hypothesis), with sweat rate even returning a significant decrease (opposite response to hypothesis). These data will aid in the development of evidence-informed practice for minimal effective HA doses in female team sport athletes, who are underrepresented within the current research.

The positive changes in HRex observed in the present study are consistent with the consensus recommendations on short-term HA effects.[5] Despite heterogeneity in study designs and metrics reported in analysed studies, meta-analysis on the effects of HA found that heart rate-based adaptations are among the first to be observed, and the effect is similar whether short (<7 days) or medium-term (7 – 14 days) HA protocols are performed [long-term HA (>14 days) shown to produce the strongest effect].[1] These findings (based primarily upon male participants) are supported by the present observations in elite female team sport athletes, despite reports that females may require a greater thermal impulse for a given response compared to males.[8,9] Heat-induced reductions in HRex can be attributed to plasma volume expansion (typically occurring after 3 - 4 days)[36] allowing increased stroke volume, and therefore maintenance of cardiac output during exercise.[3] Practitioners seeking improvements in cardiovascular stability can confidently use similarly short duration HA protocols to stimulate such adaptations provided thermal overload is sufficient.

The absence of change in resting T_c is in contrast to the majority of HA research investigating short-term protocols. Beneficial changes in resting T_c have been observed in response to a 5-day protocol in trained male cyclists (-0.2°C), although the validity of this finding may be limited in the context of the present study (elite female team sport athletes).[37] Most T_c adaptations are reported to occur within 7 days of HA, and a recent meta-analysis directly assessing short-term HA protocols showed a moderate effect in reducing resting T_c (-0.17 ±

0.12°C; n = 144).[1] Notably however, this meta-analysis (including all HA protocol durations) included a total of only 7% (76/1056) female participants.[9] The low sample of female participants likely biases the results and may conceal any sex-dependent effects that may emerge if equivalent samples were available. It has recently been suggested that females require a greater number of HA sessions to stimulate comparable adaptations to males,[8,9] potentially explaining the lack of effect in the present results. Further, much of the data synthesised within the most recent meta-analysis[1] were not from elite or well-trained participants who likely have a partially HA phenotype year-round due to habitually high training loads. Given the changes in T_c a partially HA phenotype evokes, this may potentially confound the effect of these protocols for elite or well-trained populations. When pursuing reductions in resting T_c from HA in a lower control but highly ecologically valid training protocol (such as the present study design), practitioners supporting female athletes are advised to opt for longer duration protocols or modify the training content to ensure a greater thermal impulse than the current investigation. Practitioners are also recommended to consider the potential for pre-existing HA (partial or otherwise) when interpreting responses to HA protocols in elite or well-trained populations.

The decrease in sweat rate from the Day 1 to Day 5 in the present study is contrary to the expected effect of HA protocols (-0.1 ± 0.2 $L \cdot hr^{-1}$). Modest elevations in sweat rate are commonly observed in response to short-term HA, and large increases following medium and long-term protocols.[1] Increased sweat rate and earlier onset of sweating allow greater evaporative heat loss (primary heat loss pathway during exercise in the heat) and more robust T_c stability.[38] A major confounding factor in the present study regarding the sweat rate findings is the difference in environmental conditions between day 1 (32.6 ± 1.6°C, 61 ± 4% relative humidity) and day 5 (29.7 ± 1.6°C, 50 ± 6% relative humidity). Despite this, both these conditions are much more thermally stressful than the typical environmental conditions during training in Sydney for the month prior to the camp (14.3 ± 2.6°C and 81 ± 15% relative humidity). This objective data is supported by athlete's perceptions of the heat between these days with thermal sensation and thermal comfort results being the lowest on Day 5 at all timepoints (pre-session, post-standardised run, and post-session). The expected sweat rate response to short-term HA (modest increase or no conclusive change) is likely obscured by this weather variability, and the observed changes in sweat rate are more likely related to changes in environmental conditions than physiological adaptation. Without greater standardisation of environmental conditions between measures (difficult to achieve in common team sport training environments), it is difficult to draw strong inferences on the dose-response relationship for sweat rate adaptations based upon the present data.

Changes in psychophysical response to heat as a result of short-term HA in the present study were variable, with a combination of positive, negative, significant, and non-significant results. Reductions in thermal sensation were observed (in line with previous reports)[1] on Day 5 but the cooler and less humid environmental conditions on this day prevent an appropriately standardised comparison. Although limited, the available data suggests that HA can reduce perceived levels of effort and thermal perception[37] (theorised drivers of volitional behaviour enabling higher self-selected exercise intensities).[4] These findings may be explained by the thermal impulse (duration and/or intensity of heat exposure) in the current study being insufficient for perceptual changes to be realised. The presence of positive and negative results across days in RPE and thermal comfort suggests biological noise is being detected rather than psychophysical adaptation. If tight control of thermal stress is not possible (e.g., outdoor training) and psychophysical adaptation to heat is required, practitioners are advised to prolong HA protocols beyond 5 days or modify training content to ensure the thermal stimulus is sufficient to drive adaptation.

Whilst the present study examined an under investigated population (i.e., elite female athletes) performing in a field environment during the preparation for a major international sporting event, findings must be interpreted in the context of the limitations. The case series study design, involving no control or comparison group, is prone to selection bias and relatively low on the level of evidence hierarchy. Causality of any responses should therefore not be inferred from this data alone. Beyond being in a location with a consistently hot climate, thermal stress from the outside environmental conditions was uncontrolled and likely modulated observed responses. Perceptual measures used for analysis were collected after only a 4-minute standardised bout of continuous exercise, a short period for psychophysical responses to develop (although the alternative of using post-session measures is confounded by unstandardized external loads during the sessions). Despite these important limitations, this study presents the real-world challenges of both delivering a HA camp and determining its efficacy, without access to specialist equipment and/or being able to perform maximal capacity tests due to periodisation and taper demands/restrictions (even if you could, highly likely weather conditions differ day-to-day).

Practical Applications

- Beneficial cardiovascular adaptations can be obtained and monitored from a 5-day HA protocol simultaneously across a full squad of elite female rugby sevens players (without expensive facilities/equipment or changing training content).
- Substantive changes in resting T_c, sweat rate, and thermal/effort perceptions likely require a greater thermal impulse.

Conclusions

Beneficial cardiovascular adaptations were obtained and monitored during the 5-day HA protocol simultaneously across a full squad of elite female rugby sevens players (without expensive facilities/equipment or changing training content). However, substantive changes in resting T_c, sweat rate, and thermal/effort perceptions likely require a greater thermal impulse. These data contribute to the development of evidence-informed practice for minimal effective HA doses in female team sport athletes, who are underrepresented in the current research.

Declarations/Acknowledgements

The authors thank the athletes, team staff, and everyone at the Michael Long Learning and Leadership Centre in Darwin, Australia for their willingness, professionalism, engagement, and time throughout the executed research project – without which – the project would not have been viable. The authors would additionally like to thank for the loan of core temperature measurement equipment: (1) Antony Stadnyk and the New South Wales Institute of Sport (NSWIS), (2) Peta Maloney and Jo Miller from the Australian Institute of Sport (AIS), (3) Christopher Stevens from Southern Cross University, and (4) Ben Greenaway and Louella Carvalho from BMedical Pty Ltd. The authors also thank Chris Esh from Aspetar and Loughborough University for technical support during the project. Mitchell J. Henderson was supported by the RTP scholarship (Australia) for this project. Aside from the above there was no further potential conflict of interests for any author in this study.

References

1. Tyler CJ, Reeve T, Hodges GJ, Cheung SS. The effects of heat adaptation on physiology, perception and exercise performance in the heat: a meta-analysis. *Sports Med.* 2016;46(11):1699-1724.
2. Daanen HAM, Racinais S, Periard JD. Heat acclimation decay and re-induction: a systematic review and meta-analysis. *Sports Med.* 2018;48(2):409-430.
3. Kissling LS, Akerman AP, Cotter JD. Heat-induced hypervolemia: Does the mode of acclimation matter and what are the implications for performance at Tokyo 2020? *Temperature (Austin).* 2020;7(2):129-148.
4. Flouris AD, Schlader ZJ. Human behavioral thermoregulation during exercise in the heat. *Scand J Med Sci Sports.* 2015;25(S1):52-64.
5. Racinais S, Alonso JM, Coutts AJ, et al. Consensus recommendations on training and competing in the heat. *Br J Sports Med.* 2015;49(18):1164-1173.
6. Giersch GEW, Morrissey MC, Katch RK, et al. Menstrual cycle and thermoregulation during exercise in the heat: A systematic review and meta-analysis. *J Sci Med Sport.* 2020;23(12):1134-1140.
7. Hutchins KP, Borg DN, Bach AJE, Bon JJ, Minett GM, Stewart IB. Female (under) representation in exercise thermoregulation research. *Sports Med Open.* 2021;7(1):43.
8. Kirby NV, Lucas SJE, Cable TG, Armstrong OJ, Weaver SR, Lucas RAI. Sex differences in adaptation to intermittent post-exercise sauna bathing in trained middle-distance runners. *Sports Med Open.* 2021;7(1):51.
9. Wickham KA, Wallace PJ, Cheung SS. Sex differences in the physiological adaptations to heat acclimation: a state-of-the-art review. *Eur J Appl Physiol.* 2020:15.
10. Guy J, Deakin G, Edwards A, Miller C, Pyne D. Adaptation to hot environmental conditions: an exploration of the performance basis, procedures and future directions to optimise opportunities for elite athletes. *Sports Med.* 2015;45(3):303-311.
11. Bangsbo J, Iaia FM, Krustrup P. The Yo-Yo Intermittent Recovery Test. *Sports Med.* 2008;38(1):37-51.
12. de Korte JQ, Bongers CCWG, Hopman MTE, Eijsvogels TMH. Exercise performance and thermoregulatory responses of elite athletes exercising in the heat: outcomes of the thermo Tokyo study. *Sports Med.* 2021.
13. Periard JD, Racinais S, Timpka T, et al. Strategies and factors associated with preparing for competing in the heat: a cohort study at the 2015 IAAF World Athletics Championships. *Br J Sports Med.* 2017;51(4):264-270.
14. Henderson MJ, Chrismas BCR, Stevens CJ, Coutts AJ, Taylor L. Changes in core temperature during an elite female rugby sevens tournament. *Int J Sports Physiol Perform.* 2020;15(4):571-580.
15. Byrne C, Lim CL. The ingestible telemetric body core temperature sensor: a review of validity and exercise applications. *Br J Sports Med.* 2007;41(3):126-133.
16. Taylor L, Thornton HR, Lumley N, Stevens CJ. Alterations in core temperature during World Rugby Sevens Series tournaments in temperate and warm environments. *Eur J Sport Sci.* 2018;19(4):432-441.
17. Travers GJS, Nichols DS, Farooq A, Racinais S, Périard JD. Validation of an ingestible temperature data logging and telemetry system during exercise in the heat. *Temperature (Austin).* 2016;3(2):208-219.
18. Bongers C, Daanen HAM, Bogerd CP, Hopman MTE, Eijsvogels TMH. Validity, reliability, and inertia of four different temperature capsule systems. *Med Sci Sports Exerc.* 2018;50(1):169-175.

19. Taylor L, Stevens CJ, Thornton HR, Poulos N, Chrismas BCR. Limiting the rise in core temperature during a rugby sevens warm-up with an ice vest. *Int J Sports Physiol Perform.* 2019;14(9):1212-1218.
20. Henderson MJ, Chrismas BCR, Stevens CJ, et al. Additional clothing increases heat-load in elite female rugby sevens players. *Int J Sports Physiol Perform.* 2021:1-8.
21. Buchheit M, Simpson BM, Lacome M. Monitoring cardiorespiratory fitness in professional soccer players: is it worth the prick? *Int J Sports Physiol Perform.* 2020;15(10):1437-1441.
22. Thorpe RT, Strudwick AJ, Buchheit M, Atkinson G, Drust B, Gregson W. Tracking morning fatigue status across in-season training weeks in elite soccer players. *Int J Sports Physiol Perform.* 2016;11(7):947-952.
23. Buchheit M, Cholley Y, Lambert P. Psychometric and physiological responses to a preseason competitive camp in the heat with a 6-hour time difference in elite soccer players. *Int J Sports Physiol Perform.* 2016;11(2):176-181.
24. Buchheit M, Simpson MB, Al Haddad H, Bourdon PC, Mendez-Villanueva A. Monitoring changes in physical performance with heart rate measures in young soccer players. *Eur J Appl Physiol.* 2012;112(2):711-723.
25. Lacome M, Simpson B, Buchheit M. Monitoring training status with player-tracking technology. Still on the road to Rome. Part 1. *Aspetar Journal.* 2018;7:55-63.
26. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc.* 1982;14(5):377-381.
27. Young AJ, Sawka MN, Epstein Y, Decristofano B, Pandolf KB. Cooling different body surfaces during upper and lower body exercise. *J Appl Physiol.* 1987;63(3):1218-1223.
28. R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. 2019: https://www.R-project.org/.
29. Bates D, Maechler M, Bolker B, Walker S. Fitting linear mixed-effects models using lme4. *J Stat Softw.* 2015;67(1):1-48.
30. Kenward MG, Roger JH. Small sample inference for fixed effects from restricted maximum likelihood. *Biometrics.* 1997;53(3):983-997.
31. Luke SG. Evaluating significance in linear mixed-effects models in R. *Behav Res Methods.* 2017;49(4):1494-1502.
32. Nakagawa S, Schielzeth H. A general and simple method for obtaining R2 from generalized linear mixed-effects models. *Methods Ecol Evol.* 2013;4(2):133-142.
33. Ben-Shachar MS, Makowski D, Lüdecke D. Compute and interpret indices of effect size. *R package.* 2020; https://github.com/easystats/effectsize.
34. Cohen J. *Statistical Power Analysis for the Behavioral Sciences.* Hillsdale, N.J.: L. Erlbaum Associates; 1988.
35. Knief U, Forstmeier W. Violating the normality assumption may be the lesser of two evils. *bioRxiv.* 2018:498931.
36. Senay LC, Mitchell D, Wyndham CH. Acclimatization in a hot, humid environment: body fluid adjustments. *J Appl Physiol.* 1976;40(5):786-796.
37. Neal RA, Corbett J, Massey HC, Tipton MJ. Effect of short-term heat acclimation with permissive dehydration on thermoregulation and temperate exercise performance. *Scand J Med Sci Sports.* 2016;26(8):875-884.
38. Sawka MN, Leon LR, Montain SJ, Sonna LA. Integrated physiological mechanisms of exercise performance, adaptation, and maladaptation to heat stress. *Compr Physiol.* 2011;1(4):1883-1928.

Tables

Table 1. External load for each on-field training session within the camp. Data is presented as mean ± SD.

	Day 1	Day 2		Day 3	Day 4	Day 5
Daily Session	1	1 (AM)	2 (PM)	1	NA	1
Duration (min)	59.4 ± 3.1	52.6 ± 2	64.7 ± 2.6	64.9 ± 3	NA	61 ± 7.6
Distance (m)	4845 ± 309	4943 ± 252	4682 ± 235	5080 ± 422	NA	5669 ± 839
HSR (m > 5 $m \cdot s^{-1}$)	390 ± 110	574 ± 128	387 ± 193	418 ± 167	NA	739 ± 208
VHSR (m > 6 $m \cdot s^{-1}$)	99 ± 48	276 ± 84	108 ± 68	124 ± 55	NA	288 ± 90
Acceleration Load (AU)	1241 ± 102	1223 ± 115	1240 ± 79	1259 ± 154	NA	1387 ± 213
Acceleration Count (> 2.5 $m \cdot s^{-2}$)	34 ± 9	33 ± 8	36 ± 10	37 ± 9	NA	40 ± 12

AU = arbitrary units

Table 2. Environmental conditions during outdoor field-based training sessions across the short-term heat acclimatisation camp. All data collected via 1 Hz portable weather station (Kestrel 5500, Nielsen-Kellerman Co. USA) during each outdoor training session and presented as mean ± SD.

	Day 1	Day 2	Day 3	Day 4	Day 5
Temperature (°C)	32.6 ± 1.6	33.0 ± 1.2	33.4 ± 1.3	NA	29.7 ± 1.6
Wet Bulb Temperature (°C)	26.2 ± 1.0	26.1 ± 1.2	27.2 ± 0.9	NA	21.8 ± 0.9
Relative Humidity (%)	61 ± 4	58 ± 4	62 ± 4	NA	50 ± 6
Barometric Pressure (mb)	1011.0 ± 0.3	1011.4 ± 0.4	1011.7 ± 0.3	NA	1013.6 ± 0.1
Wind Speed ($m \cdot s^{-1}$)	0.7 ± 0.5	0.6 ± 0.5	0.6 ± 0.5	NA	0.3 ± 0.5
Dew Point (°C)	24.1 ± 1.0	23.7 ± 1.5	25.2 ± 1.0	NA	18.2 ± 1.2

mb = millibars

Table 3. Descriptive data for all continuous outcome measures. Data presented as mean ± SD (top row) and minimum – maximum (middle row).

	Day 1	Day 2	Day 3	Day 4	Day 5
Resting T_c (°C)	36.8 ± 0.3 36.3 – 37.2 n = 18	NA	NA	NA	36.8 ± 0.2 36.3 – 37.0 n = 14
HRex (bpm)	175 ± 13 146 - 199 n = 19	170 ± 12 144 - 190 n = 15	170 ± 12 140 - 187 n = 17	NA	171 ± 12 142 - 190 n = 19
Sweat rate (L·hr^{-1})	1.1 ± 0.3 0.8 – 1.8 n = 19	NA	NA	NA	1.0 ± 0.2 0.7 – 1.4 n = 19

T_c = core temperature; HRex = exercise heart rate

Table 4. Descriptive data for all ordinal outcome measures. Data presented as median (interquartile range).

		Day 1	Day 2	Day 3	Day 4	Day 5
Pre-session	RPE	NA	NA	NA	NA	NA
	Thermal sensation	4 (3.75 - 4) n = 19	3.25 (3 - 4) n = 16	3.25 (3 - 4) n = 18	NA	3 (3 - 3.5) n = 19
	Thermal comfort	1 (1 - 1) n = 19	1 (1 - 1) n = 16	1 (1 - 1) n = 18	NA	1 (1 - 1) n = 19
Post-standardised run	RPE	3.5 (2.75 - 4) n = 19	3 (2.5 - 3.5) n = 16	4 (3 - 5) n = 17	NA	3 (2.5 - 4) n = 19
	Thermal sensation	5 (5 - 5.5) n = 19	5 (4.375 - 5.5) n = 16	5 (5 - 5.5) n = 17	NA	4.5 (4 - 5) n = 19
	Thermal comfort	3 (2.5 - 3) n = 19	3 (2.375 - 4) n = 16	4 (3 - 5) n = 17	NA	3 (2 - 3) n = 19
Post-session	RPE	5.5 (4.625 - 7) n = 18	6.25 (5 - 7.625) n = 16	7 (6.25 - 7.375) n = 18	NA	5 (4.125 - 6) n = 19
	Thermal sensation	6 (5.125 - 6.5) n = 18	6 (5.5 - 6.5) n = 16	6.5 (6 - 6.875) n = 18	NA	5 (4.25 - 5.75) n = 19
	Thermal comfort	4.5 (3 - 6) n = 18	5 (5 - 6) n = 16	5.5 (5 - 6.5) n = 18	NA	4 (2.5 - 4.5) n = 19

RPE = rating of perceived exertion

Table 5. Linear mixed effect model results for all continuous outcome measures.

Resting T_c

Marginal R^2 = 0.01 | Conditional R^2 = 0.27

Parameter	Coefficient (95% CI)	SE	*t*	df error	*p*	η_p^2	Magnitude
Day 1 (Intercept)	36.75 (36.63 - 36.87)	0.06	640.40	27.41	< 0.001		
Day 5	-0.05 (-0.22 - 0.12)	0.08	-0.61	14.71	0.550	0.02 (0.00 - 0.30)	*Small*

HRex

Marginal R^2 = 0.01 | Conditional R^2 = 0.98

Parameter	Coefficient (95% CI)	SE	*t*	df error	*p*	η_p^2	Magnitude
Day 1 (Intercept)	175 (169 - 181)	2.74	63.99	18.55	< 0.001		
Day 2	-5 (-6 - -3)	0.61	-7.50	48.03	< 0.001	0.54 (0.34 - 0.67)	*Large*
Day 3	-5 (-6 - -4)	0.58	-8.16	48.02	< 0.001	0.58 (0.39 - 0.70)	*Large*
Day 5	-4 (-5 - -3)	0.56	-6.71	48.00	< 0.001	0.48 (0.28 - 0.63)	*Large*

Sweat rate

Marginal R^2 = 0.06 | Conditional R^2 = 0.55

Parameter	Coefficient (95% CI)	SE	*t*	df error	*p*	η_p^2	Magnitude
Day 1 (Intercept)	1.13 (1.02 - 1.24)	0.05	21.40	28.29	< 0.001		
Day 5	-0.11 (-0.22 - -0.01)	0.05	-2.20	18.00	0.041	0.21 (0.00 - 0.50)	*Large*

T_c: core body temperature; R^2: coefficient of determination; CI: confidence interval; SE: standard error; df: degrees of freedom; η_p^2: approximate partial eta squared; HRex: exercise heart rate

Table 6. Friedman test and pairwise Wilcoxon signed-rank test results for all ordinal outcome measures.

RPE

Friedman test: χ^2 (3) = 12.8, *p* = 0.005, Kendall's *W* = 0.28 (95% CI: 0.16 - 0.55), n = 15

Reference	Comparison	*W*	*p*	*p.adj*	*r* (95% CI)	Magnitude
Day 1	Day 2	46.5	0.244	1.000	0.35 (0.02 - 0.76)	*Moderate*
Day 1	Day 3	23.5	0.128	0.768	0.43 (0.04 - 0.85)	*Moderate*
Day 1	Day 5	43.5	0.916	1.000	0.04 (0.01 - 0.60)	*Small*
Day 2	Day 3	0.0	0.002	0.002	0.84 (0.76 - 0.89)	*Large*
Day 2	Day 5	16.0	0.075	0.448	0.47 (0.04 - 0.84)	*Moderate*
Day 3	Day 5	49.5	0.152	0.912	0.40 (0.03 - 0.77)	*Moderate*

Thermal sensation

Friedman test: χ^2 (3) = 19.5, *p* < 0.001, Kendall's W = 0.43 (95% CI: 0.21 - 0.71), n = 15

Reference	Comparison	*W*	*p*	*p.adj*	*r* (95% CI)	Magnitude
Day 1	Day 2	46.5	0.057	0.341	0.59 (0.20 - 0.86)	*Large*
Day 1	Day 3	19.0	0.440	1.000	0.15 (0.01 - 0.59)	*Small*
Day 1	Day 5	84.5	0.006	0.039	0.74 (0.45 - 0.89)	*Large*
Day 2	Day 3	13.5	0.078	0.466	0.45 (0.04 - 0.78)	*Moderate*
Day 2	Day 5	45.0	0.078	0.469	0.49 (0.07 - 0.81)	*Moderate*
Day 3	Day 5	66.0	0.003	0.019	0.82 (0.72 - 0.89)	*Large*

Thermal comfort

Friedman test: χ^2 (3) = 16.0, *p* = 0.001, Kendall's W = 0.36 (95% CI: 0.24 - 0.59), n = 15

Reference	Comparison	*W*	*p*	*p.adj*	*r* (95% CI)	Magnitude
Day 1	Day 2	34.0	0.964	1.000	0.02 (0.01 - 0.57)	*Small*
Day 1	Day 3	12.5	0.072	0.433	0.46 (0.06 - 0.80)	*Moderate*
Day 1	Day 5	47.0	0.221	1.000	0.36 (0.03 - 0.80)	*Moderate*
Day 2	Day 3	1.0	0.007	0.043	0.70 (0.39 - 0.86)	*Large*
Day 2	Day 5	50.0	0.131	0.786	0.47 (0.04 - 0.86)	*Moderate*
Day 3	Day 5	91.0	0.001	0.008	0.87 (0.79 - 0.91)	*Large*

RPE: rating of perceived exertion; χ^2: chi-squared; CI: confidence interval; *W* : Wilcoxon test statistic; *p.adj* : adjusted *p* value after Bonferroni correction for multiple comparisons; *r* : rank-biserial correlation

Figures

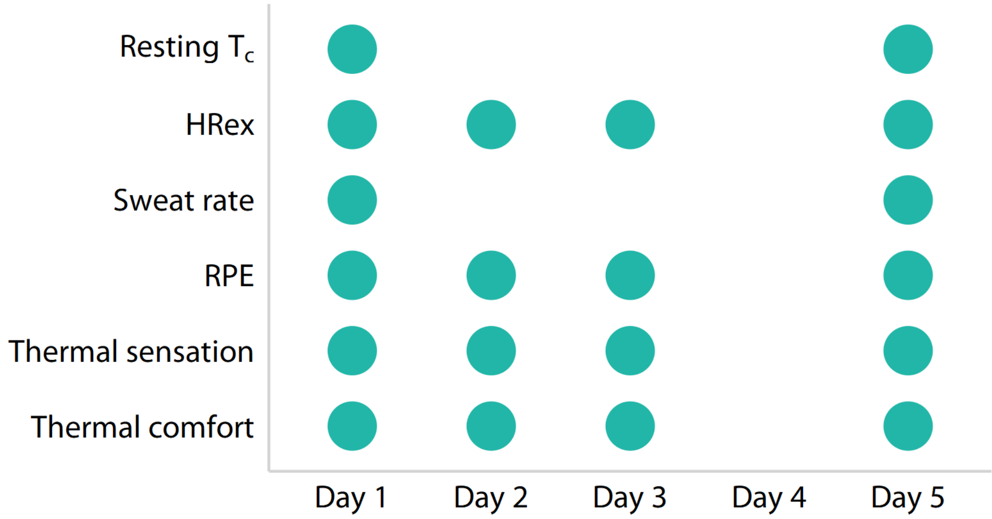

Figure 1. Summary of data collection type and frequency from the short-term heat acclimatisation camp. Each dot represents the type of data on the y-axis was collected on the corresponding day on the x-axis. T_c = core temperature; HRex = exercise heart rate; RPE = rating of perceived exertion.

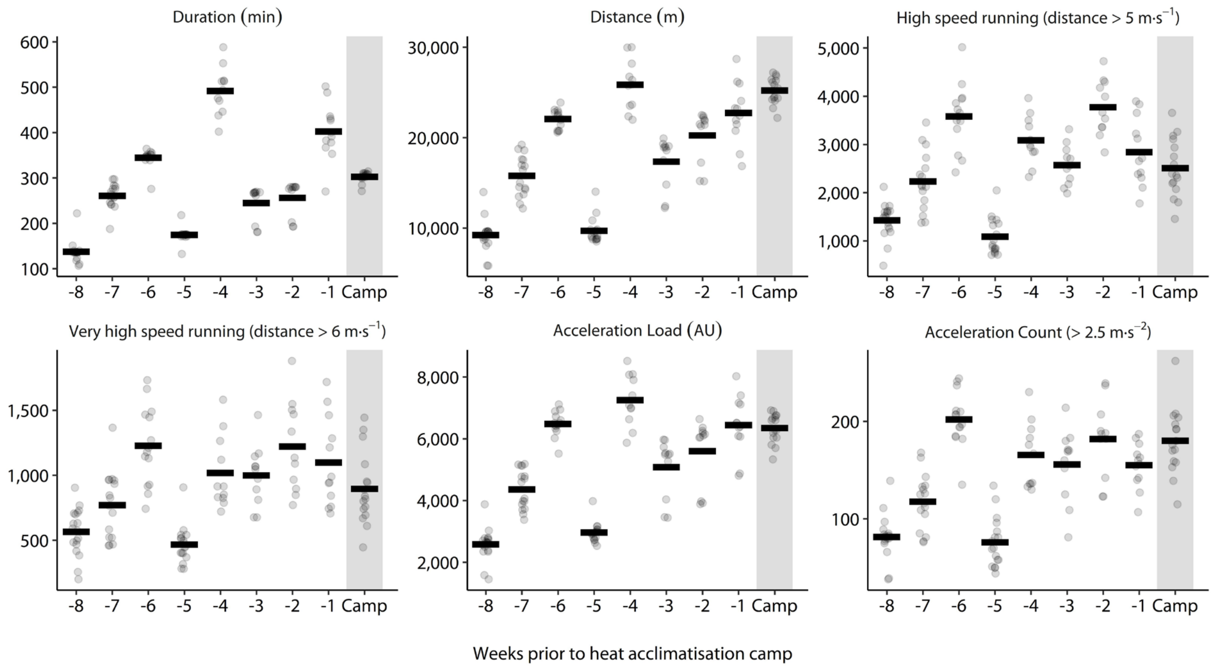

Figure 2. Key on-field training volume metrics. Black lines represent squad average value for each week and grey circles represent individual weekly totals for each squad member. Shaded area indicates data from the training camp in this study. AU = arbitrary units.

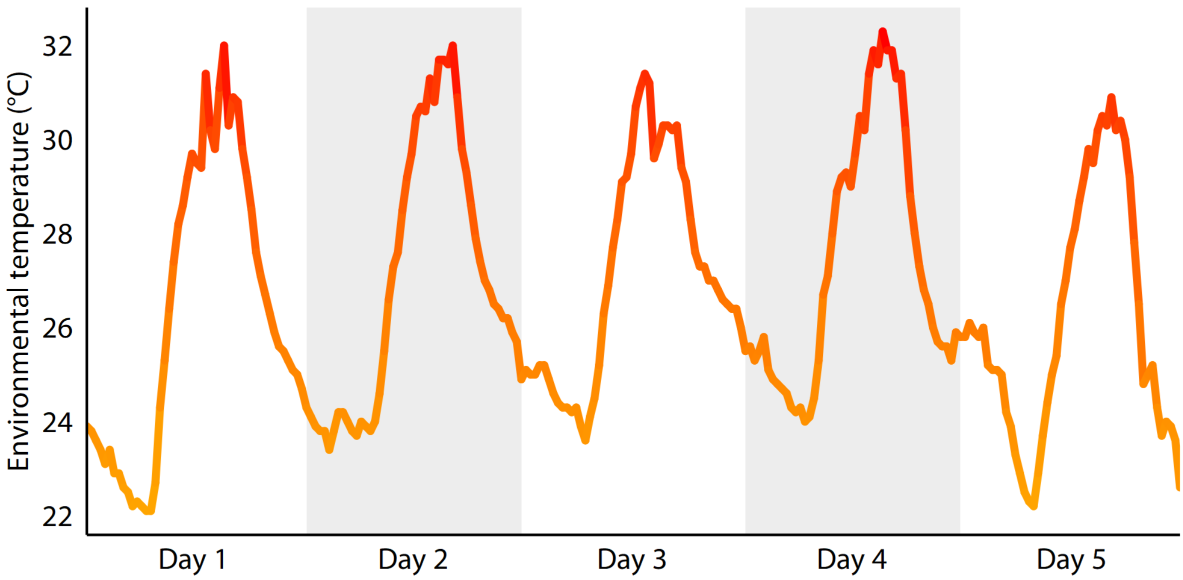

Figure 3. Daily variation in environmental temperature across the entire short-term heat acclimatisation camp. Data collected via the Australian Government Bureau of Meteorology website (http://www.bom.gov.au/products/IDD60901/IDD60901.94120.shtml) at 30-minute intervals from a weather station less than 3 km from the team's training base and accommodation.

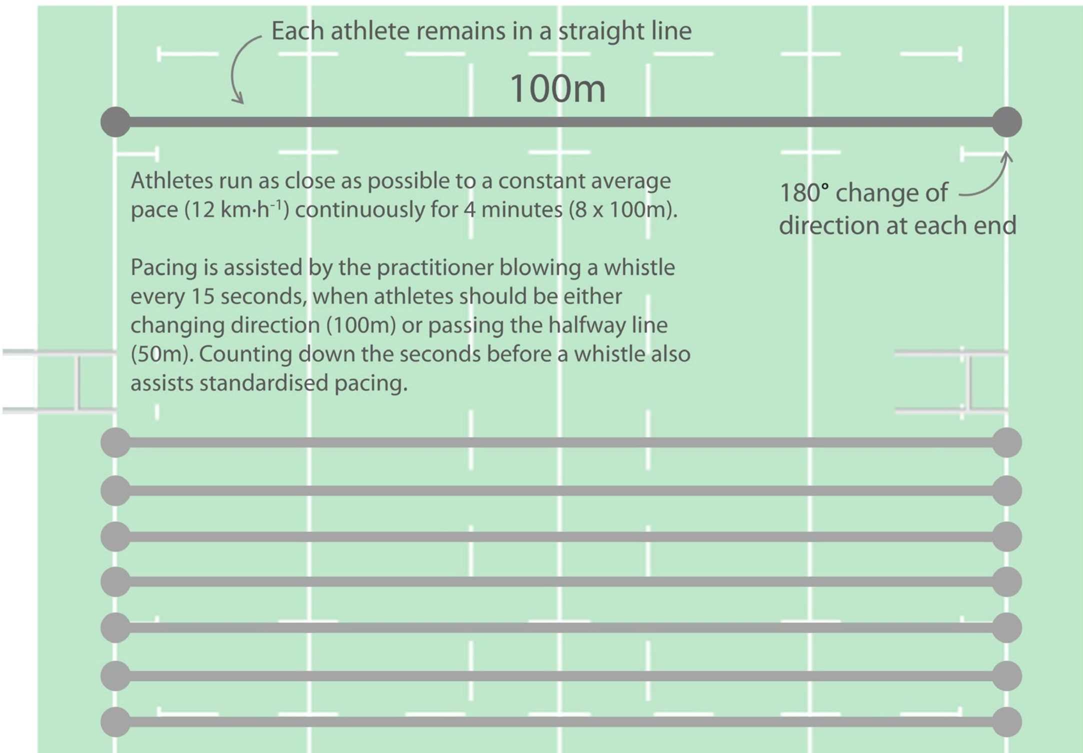

Figure 4. Diagram and description of the submaximal standardised 4-minute continuous run method.

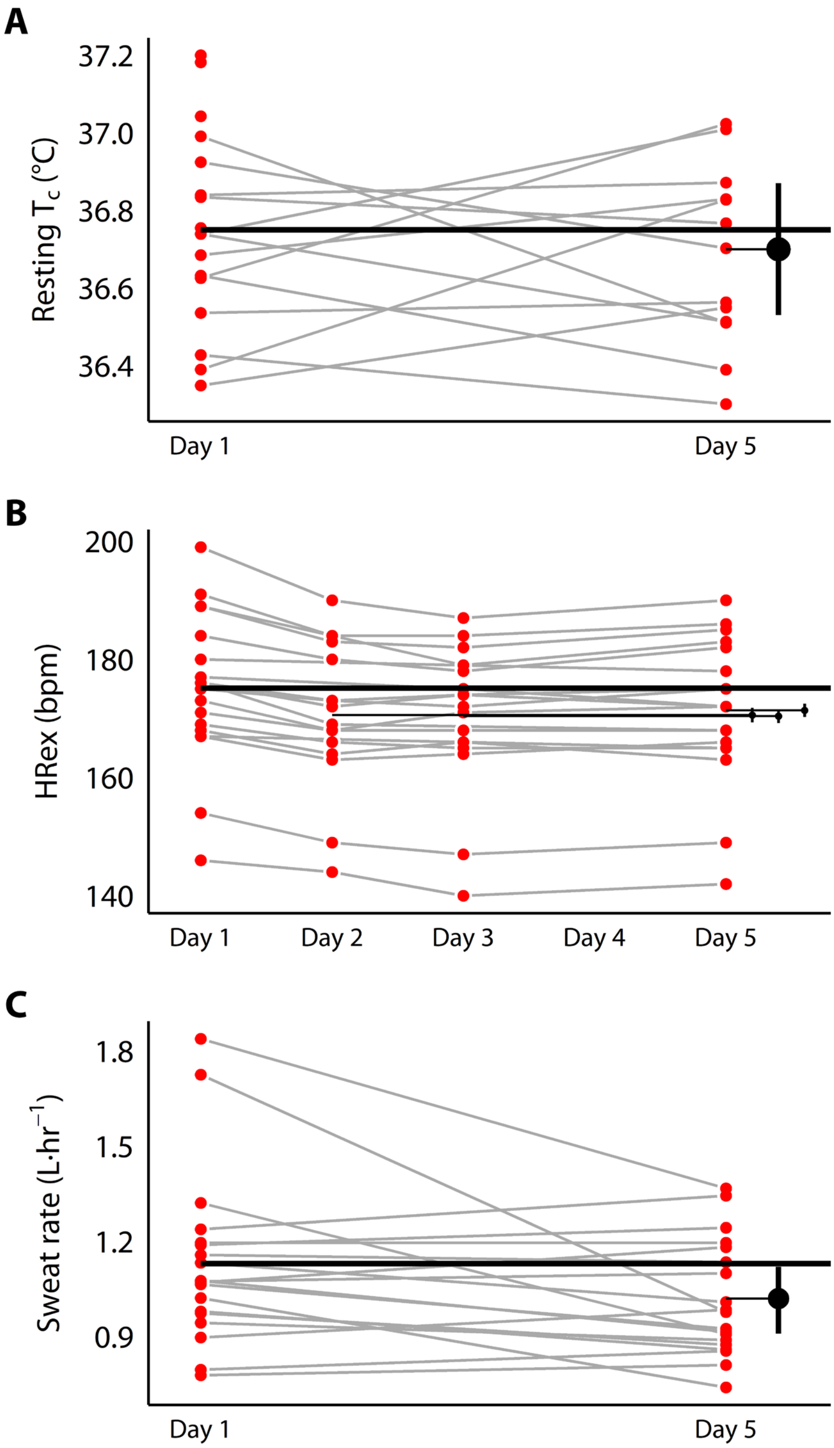

Figure 5. Individual data (red circles) for each continuous outcome measure (paired observations connected by grey lines). The thick black horizontal line through the entire figure represents the model's intercept (Day 1 estimate). The thinner black lines projecting from each subsequent timepoint represent the model's estimate at that point. The black dots and vertical error bars to the right represent the model's estimate and associated 95% confidence interval

for each timepoint in comparison to the intercept (Day 1). T_c = core body temperature; HRex = exercise heart rate.

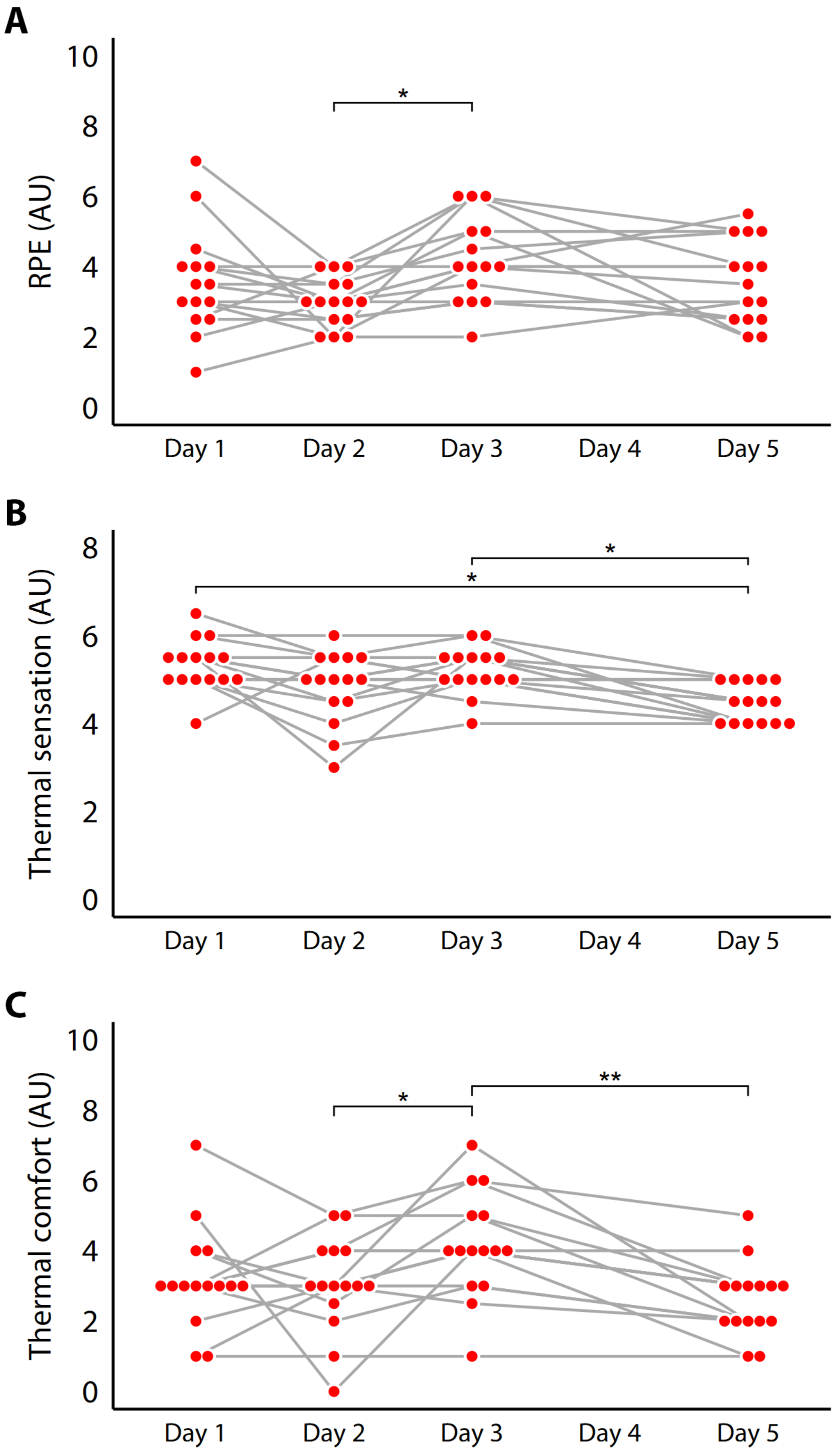

Figure 6. Individual data (red circles) for each ordinal outcome measure (paired observations connected by grey lines). Statistically significant differences between days signified by * ($p < 0.05$) and ** ($p < 0.01$). RPE = rating of perceived exertion.