Additional clothing increases heat-load in elite female rugby sevens players

Journal:	*International Journal of Sports Physiology and Performance*
Manuscript ID	IJSPP.2020-0620.R2
Manuscript Type:	Original Investigation
Date Submitted by the Author:	n/a
Complete List of Authors:	Henderson, Mitchell; University of Technology Sydney Faculty of Health, Sport and Exercise Science Chrismas, Bryna; Qatar University College of Arts and Sciences, Sport Science Program Stevens, Christopher; Southern Cross University, Scool of Health and Human Scienes Novak, Andrew; University of Technology Sydney, Human Performance Research Centre, Faculty of Health; Fransen, Job; University of Technology Sydney, Sport and Exercise Science, Faculty of Health Coutts, Aaron; University of Technology, Sydney, Sport & Exercise Discipline Group, Faculty of Health Taylor, Lee; Loughborough University, School of Sport, Exercise and Health Sciences; University of Technology Sydney, Human Performance Research Centre
Keywords:	heat, elite, acclimation, hyperthermia

Title: Additional clothing increases heat-load in elite female rugby sevens players

Submission Type: Original Research

Authors: Mitchell J. Henderson[1,2,3], Bryna C.R. Chrismas[4], Christopher J. Stevens[5], Andrew Novak[1,2,3], Job Fransen[1,3], Aaron J. Coutts[1,3], Lee Taylor[6,1,3,7*]

Affiliations:
[1]University of Technology Sydney (UTS), School of Sport, Exercise and Rehabilitation, Faculty of Health, Australia.
[2]Rugby Australia (RA), Sydney, Australia.
[3]University of Technology Sydney (UTS), Human Performance Research Centre, Australia.
[4]Qatar University, Sport Science Program, College of Arts and Science, Doha, Qatar.
[5]Southern Cross University, School of Health and Human Sciences, Coffs Harbour, Australia.
[6]Loughborough University, School of Sport, Exercise and Health Sciences, Loughborough, UK.
[7]ASPETAR, Qatar Orthopaedic and Sports Medicine Hospital, Athlete Health and Performance Research Centre, Doha, Qatar.

***Address for Correspondence**
Dr Lee Taylor, Loughborough University, School of Sport, Exercise and Health Sciences, Loughborough, Leicestershire, LE11 3TU, UK.
Email: l.taylor2@lboro.ac.uk **Phone:** +44 1509 226302

Preferred Running Head: Additional clothing heat-load rugby sevens

Abstract word count: 255
Text-only word count: 3319
Number of figures: 5
Number of tables: 5
References: 33

Abstract

Purpose: To (1) determine whether elite female rugby sevens players are exposed to core temperatures (Tc) during training in the heat that replicate the temperate match demands previously reported, and (2) investigate whether additional clothing worn during a hot training session meaningfully increases the heat load experienced. **Methods:** A randomised parallel group study design was employed with all players completing the same ~70 minute training session (27.5 – 34.8°C wet bulb globe temperature), wearing (i) standardised training ensemble [synthetic rugby shorts and training tee (CON; n = 8)] or (ii) additional clothing [(i) plus compression garments and full tracksuit (AC; n = 6)]. Groupwise differences in Tc, sweat rate, GPS-measured external locomotive output, rating of perceived exertion (RPE), and perceptual thermal load were compared. **Results:** Mean ($p = 0.006$, $\eta_p^2 = 0.88$) and peak ($p < 0.001$, $\eta_p^2 = 0.97$) Tc was higher in AC compared to CON during the training session. There were no differences in external load [$F(4, 9) = 0.155$, $p = 0.956$, Wilk's $\Lambda = 0.935$, $\eta_p^2 = 0.06$] or sweat rate ($p = 0.054$, Cohen's $d = 1.09$). Higher RPE ($p = 0.016$, Cohen's $d = 1.49$) was observed in AC compared to CON. No EHI symptomology was reported in either group. **Conclusions:** Player Tc is similar between training performed in hot environments and match play in temperate conditions when involved for > 6 min. Additional clothing is a viable and effective method to increase heat strain in female rugby sevens players without compromising training specificity or external locomotive capacity.

Keywords: heat, elite, acclimation, hyperthermia

Introduction

Physical preparation best practices for hot and humid competition conditions require carefully prescribed and controlled heat stress [i.e. heat acclimation or acclimatization; (HA)] to promote optimal performance.[1,2] Appropriate training prescription [typically active (i.e. exercise) heat load[3]] promotes physiological adaptations likely to benefit physical capacity/performance in such environments [e.g. reduced resting/exercising core temperatures (Tc) and heart rates (HR), earlier and greater sweat response, greater plasma volume and exercise capacity[2]]. Typical physiological responses to match play in elite women's rugby sevens include high Tc (peak Tc responses from match play: 37.9 – 39.8°C)[4], and HR intensities (most playing time spent between 81 and 90% of maximal HR).[5] Whether routine training for rugby sevens in hot conditions generates the high thermal load observed in elite female match-play [peak Tc median (range) when involved in > 6 min match play: 39.3°C (38.2 – 39.8°C)] within modest wet bulb globe temperatures (WBGT; 18.5 – 20.1°C),[4] has not been established. Evidently, any disparity in this relationship has ramifications for physical preparation strategies - especially - relative to the likely higher Tc that would be observed in this population during match-play in higher WBGT environments (e.g. Tokyo Olympics) compared to the predominately temperate match-play data currently available.[4,6]

Common barriers to best practice HA preparation in team sports include financial (travelling to appropriate locations whilst hiring of facilities with simulated environmental rooms can be expensive) and time constraints (team sports often have congested preparation/competition schedules and are commonly time-poor). A practical option available to all practitioners and teams is wearing additional clothing during physical preparation. This intervention promotes psycho-physiological responses implicated in successful HA protocols [e.g. elevated: Tc and skin temperature (Tsk), sweat-rate, thermal sensation/discomfort, and HR[2]] without the need for hot ambient conditions.[7] Therefore, additional clothing may provide a practically compatible and cheap tool to off-set (partially or otherwise) any potential thermal mismatch between training and matches, increasing training specificity. Many athletes and teams preparing for the Olympic Games in Tokyo (expected to be the hottest modern Olympics to date; ~30°C and relative humidity exceeding 75%[8]) will be training in temperate or cold environments not conducive to HA. Data regarding the thermal dose response to training in additional clothing compared to a control condition is generally lacking within elite team sport populations, particularly females, thus evidence-based decision-making and practice within this paradigm is currently challenging.

This study aims to (1) determine whether elite female rugby sevens players are exposed to a Tc during training in the heat that replicates the temperate match demands previously reported;[4] and, (2) investigate whether additional clothing worn during a full rugby sevens training session in the heat increases the heat load experienced. It is hypothesised that (i) peak Tc and change from baseline to peak during training will not reach the magnitudes observed from available match play data, and (ii) additional clothing worn during an on-field rugby sevens training session will meaningfully increase heat load compared to control without any effect on GPS-derived external locomotive output.

Methods

Subjects

*** Table 1 near here please ***

Data were collected from a total of 14 seasonally heat-acclimatised female athletes (see Table 1 for details) from a single 2018-19 World Rugby Women's Sevens Series team based in Sydney, Australia. The full population of professionally contracted international female rugby sevens athletes in the country, fit at the time of data collection, were recruited. Written informed consent was provided for the project under ethical approval from the Southern Cross University (ECN-18-216) and University of Technology Sydney (ETH19-4051) Human Research Ethics Committees in the spirit of the Helsinki Declaration.

Design

A randomised parallel group study design was employed with all players simultaneously completing the same 70 min training session, wearing (i) standardised training ensemble (synthetic rugby shorts and training tee; CON) or (ii) additional clothing [(i) plus compression garments and full tracksuit; AC]. Players had been in the same time zone ≥ 14 days prior to the training session, thus circadian misalignment in Tc was not a confounding influence. In line with common elite team sport practice, menstrual cycle could not be standardised.

Methodology

Players ingested an e-Celsius™ telemetric capsule (BodyCap, Caen, France) the night prior to the training session. 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.[4,6,9] Tc was sampled at 30 second intervals, with data downloaded at the end of the training session via a wireless data receiver (e-Viewer, BodyCap, Caen, France). Capsules were prepared, calibrated, and handled as outlined previously.[4,6,10] The e-Celsius™ system has been determined valid and reliable for intermittent-running exercise,[10] 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,[11] and has been used previously within elite rugby sevens matches[4,6] and training.[12] In the case of the capsule having been passed prior to the training session (this occurred for one athlete from AC and two from CON), Tc data was not able to be collected.

Wet bulb globe temperature (WBGT) (SD-2010, Reed Instruments, NC, USA) was obtained immediately prior to, during and post training session. Conditions across the data collection period were generally hot (27.8 – 34.8°C WGBT). 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]

Whole-body sweat loss was quantified by determining the change in body mass pre- and post-training (assuming a fluid volume of 1L = 1 kg). Players 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 both fluid intake and urine output but was not corrected for respiratory and metabolic water loss/gain. Drinking behaviour was monitored by the researchers and practitioners to ensure players only drank from their own bottle, did not spit water out, or pour water on themselves.

Activity profiles during the session were measured using 10 Hz GPS devices (EVO, GPSports, Canberra, Australia). These have shown good inter-unit reliability for distance (m) (CV: 0.2% ± 1.5), average speed ($m \cdot min^{-1}$) (CV: 0.2% ± 1.5), max velocity ($m \cdot s^{-1}$) (CV: 0.2% ± 1.5), high-speed running (distance covered > $5 m \cdot s^{-1}$) (CV: 0.5% ± 1.5), and average acceleration/deceleration ($m \cdot s^{-2}$) (CV: 1.2% ± 1.5).[14] Each unit was assigned to an individual player and worn underneath their training shirt in a small upper body garment custom designed by the device manufacturer, positioning the unit between the scapula blades of the player.

Following the session, stored data were downloaded from the devices using the manufacturer's proprietary software (GPSports Console, GPSports, Canberra, Australia). Metrics exported from the GPS data included training duration (min), average speed ($m \cdot min^{-1}$), high-speed running per minute ($HSR \cdot min^{-1}$; average distance covered > 5 $m \cdot s^{-1}$ per minute), very high-speed running per minute ($VHSR \cdot min^{-1}$; average distance covered > 6 $m \cdot s^{-1}$ per minute), and average absolute acceleration/deceleration (Ave Acc/Dec; $m \cdot s^{-2}$).

Thermal sensation (TS) was measured using a 17-point category ratio scale (where 0 = 'unbearably cold' and 8 = 'unbearably hot').[15] Thermal comfort (TC) was measured using a 10-point ordinal scale (where 1 = 'comfortable' and 10 = +1 above 'extremely uncomfortable').[16] Both TS and TC represents how players were feeling when asked (i.e. not a session average). Session rating of perceived exertion (RPE) was measured using CR-10 ordinal scale (where 0 = rest and 10 = maximal).[16]

Statistical Analyses

All statistical analyses were performed, and figures created, using R statistical software.[17] Descriptive statistics are reported as median and range (minimum – maximum) unless otherwise stated. Individual player Tc was collected and averaged for each period, with peak Tc values extracted and individual player change from baseline calculated. Differences between present findings and available match data previously reported[4] were assessed using a one-tailed Welch's *t*-test to account for the observed unequal variances.

Core temperature: A linear mixed effects analysis was performed using the *lme4*[18] and *lmerTest*[19] packages in R statistical software[17] to determine the relationship between wearing additional clothing during training and Tc measures at different time points during the session (baseline, training average, and training peak). As fixed effects, experimental group and timepoint (with interaction term) were entered into the model including a random intercept to specify repeated measures for each player. P-values were obtained by Kenward-Roger approximation[20] which has been shown to produce acceptable Type 1 error rates even for smaller samples.[21] Approximate partial eta squared effect sizes (η_p^2) were converted from test statistics and degrees of freedom using the *effectsize* R package.[22]

Sweat rate: A one-tailed Mann Whitney U test was used to determine if AC increased sweat rate compared to CON. Normality and equal variance assumptions were checked using the Shapiro-Wilk Test of Normality and Levene's Test respectively, and the non-parametric Mann-Whitney U test was chosen to account for the observed violation of normality.

External load: A multivariate analysis of variance was performed on the collected GPS metrics ($m \cdot min^{-1}$, $HSR \cdot min^{-1}$, $VHSR \cdot min^{-1}$, and Ave Acc/Dec) to assess group differences in locomotion. Assumptions of homogeneity and multivariate normality were checked using Box's Homogeneity of Covariance Matrices Test ($p = 0.666$) and Shapiro-Wilk Multivariate Normality Test ($p = 0.061$), respectively.

Perceptual measures: A one-tailed Mann-Whitney U test was performed to assess differences in RPE between AC and CON. As TS and TC are ordinal data, it would be inappropriate to make statistical inferences from tests requiring a continuous dependent variable (despite similar data sets using an array of these approaches previously[23,24]). To perform the appropriate ordinal regression on this data, a larger sample would be required and is likely not possible with one rugby sevens team and 17-point (TS) and 10-point (TC) scales. Therefore, TS and TC are provided as central tendency (median) and dispersion (range) (see Figure 5) and discussed only in raw unit changes/comparisons.

Results

Raw data for Tc, sweat rate, external load, and perceptual measures for all players are presented in Tables 2, 3, and 4, respectively.

*** Tables 2, 3, and 4 near here please ***

Core temperature: The association between wearing additional clothing and session time point (with interaction) on player Tc is presented in Figure 1 and Table 5. This model displayed a marginal R^2 value (indicating explained variance from fixed effects only) of 0.94 and a conditional R^2 value (indicating explained variance from both fixed and random effects) of 0.98. The baseline Tc reading did not differ between groups [CON: 37.2°C (36.7 - 37.5), AC: 37.1 (36.6 - 37.2); $p = 0.356$], but the mean and peak Tc of AC [mean: 38.4°C (38.1 – 38.7°C); peak: 39.8°C (39.5 – 40.4°C)] was higher compared to CON [mean: 38.2°C (37.7 – 38.4°C); peak: 39.2°C (38.7 – 39.4°C)] during the training session ($p = 0.006$, $\eta_p^2 = 0.88$ and $p < 0.001$, $\eta_p^2 = 0.97$ respectively). Visual inspection of residual plots did not reveal any obvious deviations from homoscedasticity or normality, and the Shapiro-Wilk test performed on the model residuals suggested no evidence of non-normality (p = 0.798).

*** Figure 1 near here please ***

*** Figure 2 near here please ***

*** Table 5 near here please ***

Sweat rate: No difference in sweat rate was found between groups (median in CON = 1.41 L/hr, median in AC = 1.64 L/hr; $U = 11.0$; $p = 0.054$, Cohen's $d = 1.09$).

*** Figure 3 near here please ***

External load: The multivariate analysis found no difference in external load between AC and CON (F [4, 9] = 0.155, p = 0.956, η_p^2 [95% CI] = 0.06 [0.00 – 0.13]; Wilk's Λ = 0.935).

Perceptual measures: There was an increase in RPE values in AC compared to CON (U = 8.00, p = 0.016, Cohen's d = 1.49).

*** Figure 4 near here please ***

Raw unit increase in TS was 3 (3 - 5) in AC and 3 (2 - 4) in CON. Raw unit increase in TC was 7.5 (7 - 8) in AC and 5.5 (4 - 6) in CON.

*** Figure 5 near here please ***

No EHI symptomology was reported in either group.

Discussion

The peak Tc [39.2°C (38.7 – 39.4°C)] and change from baseline to peak Tc [2.0°C (1.9 – 2.4°C)] observed throughout the training session (27.5 – 34.8°C WBGT) in CON (i.e. normal training clothes) did not differ to the magnitudes reported from temperate match play (18.5 – 20.1°C WBGT) when involved for at least 6 min [peak: 39.3°C (38.2 – 39.8°C), p = 0.433; change from baseline to peak: 2.0°C (0.9 – 2.5°C), p = 0.906[4]]. This rejects experimental hypothesis (i) that theorised Tc in hot training would not reach magnitudes observed during temperate match play [although the contrasting ambient WBGT between the present study (27.5 – 34.8 WBGT) and the previously published match-play data[4] (18.5 – 20.1 WBGT) ensures these comparisons must be carefully interpreted]. Thermal load (as measured by player Tc), TS, and TC, were greater in AC compared to CON, without compromising training specificity or external locomotive capacity (i.e. GPS), in support of experimental hypothesis (ii).

As sporting teams approach competition, training specificity is increasingly prioritised to maximise transfer to sporting movements.[25] As such, practitioners tasked with preparing rugby sevens teams for tournaments should be aware of the likely thermal demands of tournaments (combination of predicted approximate physical demands and environmental conditions) and ensure appropriate training (e.g. HA) occurs to develop the necessary adaptations to maximise performance and protect athlete health [particularly in female athletes who may be more susceptible to hyperthermia[4]]. This is the first study to directly compare player Tc recorded in training to the only available match play Tc data in women's rugby sevens. The findings support that training in hot environments (27.5 – 34.8°C WBGT in the current study) may provide a comparable heat stress to the previously reported temperate match-play data, albeit and emphasising an important distinction, in temperate (18.5 – 20.1°C WBGT) match-play conditions[4] compared to the hot (27.5 – 34.8°C WBGT) training conditions in the present study (Figure 1). Given training in hot conditions generates a comparable thermal load to temperate match-play, it seems logical (as shown elsewhere[26]) that the responses to matches in hot conditions would likely not be replicated within these training conditions (i.e. players would not get hot enough in training to mimic thermal demands on hot matchdays). This expectation is based on the higher Tc observed during higher ambient temperatures in Australian rules football with comparable intermittent, high-intensity, bioenergetic demands[26] to rugby sevens.[5] This may require a further intervention such as wearing additional clothing during hot training to facilitate the desired phenotypic HA signals and adaptations (e.g. decreased Tc and HR at a given intensity etc.), which in turn, provide protection against impaired performance capacity and EHI associated with exercise-induced hyperthermia.[1]

Longer term (> 14 days) HA strategies have been shown to provide the greatest protection to performance decrements and EHI,[1] yet traditionally have often been impractical in elite team sport due to highly demanding physical preparation programs, pre-set competition schedules, and travel demands.[27] The observed increases in Tc and perceived thermal load in AC are likely to stimulate a greater physiological response compared to CON and may contribute to more pronounced HA adaptations or faster procurement of a fully HA phenotype[2]; N.B. a higher HA-session Tc does not always promote 'greater' HA adaptations.[28] These findings provide proof-of-concept for additional clothing and its ability to increase thermal load and elicit associated perceptual changes within the utilised population. Adoption of additional clothing within training scenarios may (subject to further confirmatory work) solve some, but not all, common challenges to practice regarding barriers to HA protocols within team sports. Future work should use a repeated measures design to provide more detail on the physiological (including key variables associated within HA procurement not adopted within the present design, e.g. HR, skin temperature, etc.), technical, and training load responses to an acute session. This could precede more prolonged additional clothing implementations within a team sport scenario and determine whether such an intervention can elicit a fully HA phenotype.

The AC group in the present study reached very high peak Tc values (range: 39.5 – 40.4°C) but external locomotive work output was not affected compared to CON (with five of the ten drills completed after warm-up involving a degree of internally governed locomotion). It has been proposed that a Tc > 39°C can compromise central nervous system function,[29] repeat sprint ability (<60 s between efforts),[29,30] and intermittent sprint performance (60-300 s between efforts),[31] but the present study was not able to reproduce these locomotive movement decrements, nor any undesirable EHI associated pathologies, despite surpassing the Tc threshold proposed to affect performance.[29] A possible explanation for this finding is that some CON group Tc also surpassed 39°C (range: 38.7 – 39.4), although not to the same magnitude as AC, suggesting a potential non-linear relationship between Tc (greater than 39°C) and locomotive capacity. Similarly, meaningful differences in external locomotive capacity may be hidden by the large variability observed in physical performance for rugby sevens due to contextual sport demands.[32] This makes meaningful inferences from interventions difficult to ascertain as key physical performance measures during invasive team sports (e.g. high speed running) show poor reliability and demand practically unrealistic sample sizes [e.g. elite soccer sample required is 80 players[33]].

Whilst this study provides proof-of-concept that wearing additional clothing can increase thermal load and its perception, the lack of a repeated measures design and a small sample of athletes (n = 14) from one team with likely similar acclimatisation status limit the broader generalisability of the findings. Although the sample size in the present investigation is limited, it represents the full population of professionally contracted international female rugby sevens athletes in the country, that were fit, at the time of data collection. Future research using a larger sample of athletes from different teams and home climates (multi-team studies likely required, albeit evidently challenging to deliver due to competitive advantage concerns) is needed to provide more confidence in the comparisons between training and match play Tc. Similarly, replication studies across a range of different ambient WBGT temperatures will strengthen our understanding through a more robust assessment of the independent effects of additional clothing interventions, and standardised comparisons of training to available match Tc data. Finally, the magnitude in Tc response (see Figure 1) demonstrated some individual variability (see Figure 2), which practitioners should consider when physical preparation strategies for hot and humid competitions are being considered/prescribed.

Practical Applications

- Wearing additional clothing (compression garments and full tracksuit) during rugby sevens training is an accessible and valid method to achieve increased Tc and perceived exertion; without negatively affecting external locomotive output or compromising training specificity.

Conclusions

Elite female rugby sevens athletes generate high Tc when competing [peak Tc median (range) when involved in > 6 min match play: 39.3°C (38.2 – 39.8°C)] in temperate conditions.[4] This study showed that when training is performed in hot environments, player Tc reflect the magnitudes experienced when involved in > 6 min of match play in temperate conditions. Further, previous approaches to HA have experienced limited adoption due to logistical and financial obstacles in elite team sports. This research has found additional clothing to be a viable and effective method to increase heat strain in elite female rugby sevens players without introducing undesirable EHI associated pathologies or compromising training specificity / external locomotive capacity. These findings provide evidence to rugby sevens practitioners tasked with preparing athletes for the thermal demands of the sport; and provide practitioners an accessible, evidence-based tool to help deliver a physical thermal load associated with the procurement of a HA phenotype, but further confirmatory work is required to strengthen these initial findings.

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.

References

1. 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.
2. 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.
3. Gibson OR, James CA, Mee JA, et al. Heat alleviation strategies for athletic performance: A review and practitioner guidelines. *Temperature.* 2019;7(1):3-36.
4. 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.* 2020:1-10.
5. Suarez-Arrones L, Nuñez FJ, Portillo J, Mendez-Villanueva A. Match Running Performance and Exercise Intensity in Elite Female Rugby Sevens. *The Journal of Strength & Conditioning Research.* 2012;26(7):1858-1862.
6. 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.* 2019;19(4):432-441.
7. Tyler CJ. *Maximising Performance in Hot Environments: A Problem-Based Learning Approach.* Routledge; 2019.
8. Taylor L, Carter S, Stellingwerff T. Cooling at Tokyo 2020(1): the why and how for endurance and team sport athletes. *Br J Sports Med.* 2020.
9. 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.
10. 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.* 2016;3(2):208-219.
11. 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.
12. 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.* 2019:1-20.
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. Thornton HR, Nelson AR, Delaney JA, Serpiello FR, Duthie GM. Interunit reliability and effect of data-processing methods of Global Positioning Systems. *Int J Sports Physiol Perform.* 2019;14(4):432-438.
15. 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.
16. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc.* 1982;14(5):377-381.
17. R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. 2019: https://www.R-project.org/.

18. Bates D, Maechler M, Bolker B, Walker S. Fitting linear mixed-effects models using lme4. *J Stat Softw.* 2015;67(1):1-48.
19. Kuznetsova A, Brockhoff PB, Christensen RHB. lmerTest: Tests in linear mixed effects models. *J Stat Softw.* 2016;82(13):1-26.
20. Kenward MG, Roger JH. Small Sample Inference for Fixed Effects from Restricted Maximum Likelihood. *Biometrics.* 1997;53(3):983-997.
21. Luke SG. Evaluating significance in linear mixed-effects models in R. *Behav Res Methods.* 2017;49(4):1494-1502.
22. Ben-Shachar MS, Makowski D, Lüdecke D. Compute and interpret indices of effect size. *R package.* 2020; https://github.com/easystats/effectsize.
23. Périard JD, Racinais S, Knez WL, Herrera CP, Christian RJ, Girard O. Thermal, physiological and perceptual strain mediate alterations in match-play tennis under heat stress. *Br J Sports Med.* 2014;48(Suppl 1):i32.
24. Stephens J, Argus C, Driller M. The Relationship between Body Composition and Thermal Responses to Hot and Cold Water Immersion. *J Hum Perform Extreme Environ.* 2014;11:1.
25. Brearley S, Bishop C. Transfer of Training: How Specific Should We Be? *Strength Cond J.* 2019;41(3):97-109.
26. Aughey RJ, Goodman CA, McKenna MJ. Greater chance of high core temperatures with modified pacing strategy during team sport in the heat. *J Sci Med Sport.* 2014;17(1):113-118.
27. Casadio JR, Kilding AE, Cotter JD, Laursen PB. From Lab to Real World: Heat Acclimation Considerations for Elite Athletes. *Sports Med.* 2017;47(8):1467-1476.
28. Gibson OR, Mee JA, Tuttle JA, Taylor L, Watt PW, Maxwell NS. Isothermic and fixed intensity heat acclimation methods induce similar heat adaptation following short and long-term timescales. *Journal of thermal biology.* 2015;49-50:55-65.
29. Girard O, Brocherie F, Bishop DJ. Sprint performance under heat stress: A review. *Scand J Med Sci Sports.* 2015;25 Suppl 1:79-89.
30. Drust B, Rasmussen P, Mohr M, Nielsen B, Nybo L. Elevations in core and muscle temperature impairs repeated sprint performance. *Acta Physiol Scand.* 2005;183(2):181-190.
31. Sunderland C, Nevill ME. High-intensity intermittent running and field hockey skill performance in the heat. *J Sports Sci.* 2005;23(5):531-540.
32. Henderson MJ, Fransen J, McGrath JJ, Harries SK, Poulos N, Coutts AJ. Individual Factors Affecting Rugby Sevens Match Performance. *Int J Sports Physiol Perform.* 2019;14(5):620-626.
33. Gregson W, Drust B, Atkinson G, Di Salvo V. Match-to-Match Variability of High-Speed Activities in Premier League Soccer. *Int J Sports Med.* 2010;31:237-242.

Figure captions

Figure 1. Individual baseline, mean, and peak core temperature (2A) and change from baseline to mean and peak core temperature (2B) for all players. Filled circles represent predicted group means from a linear mixed model at each timepoint, lines represent 95% confidence interval of the predicted group means, and unfilled circles represent individual data for additional clothing (black) and control (grey) conditions.

Figure 2. Individual core temperature traces during the training session for athletes recording the median peak core temperature (raw: 2A; delta: 2C) and largest peak core temperature

disparity (raw: 2B; delta: 2D) in the additional clothing group (black) and control group (grey). Extremes of core temperature responses in 2B and 2D are shown to demonstrate variability between individuals. Five-point moving mean smoothing was applied to the data to minimise noise.

Figure 3. Individual sweat rates for all players. Solid horizontal lines represent group median and circles represent individual data for additional clothing (black) and control (grey) conditions. L/hr = Litres per hour; ns = non-significant.

Figure 4. Individual post-session rating of perceived exertion for all players. Solid horizontal lines represent group median and circles represent individual data for additional clothing (black) and control (grey) conditions. AU = arbitrary units; * = $p < 0.05$.

Figure 5. Individual pre- and post-session thermal sensation (5A) and thermal comfort (5B) for all players. Solid horizontal lines represent group median and circles represent individual data for additional clothing (black) and control (grey) conditions. AU = arbitrary units.

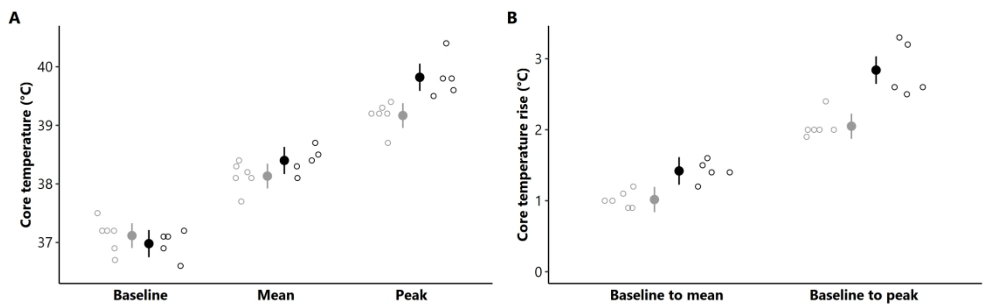

Figure 1. Individual baseline, mean, and peak core temperature (2A) and change from baseline to mean and peak core temperature (2B) for all players. Filled circles represent predicted group means from a linear mixed model at each timepoint, lines represent 95% confidence interval of the predicted group means, and unfilled circles represent individual data for additional clothing (black) and control (grey) conditions.

299x95mm (300 x 300 DPI)

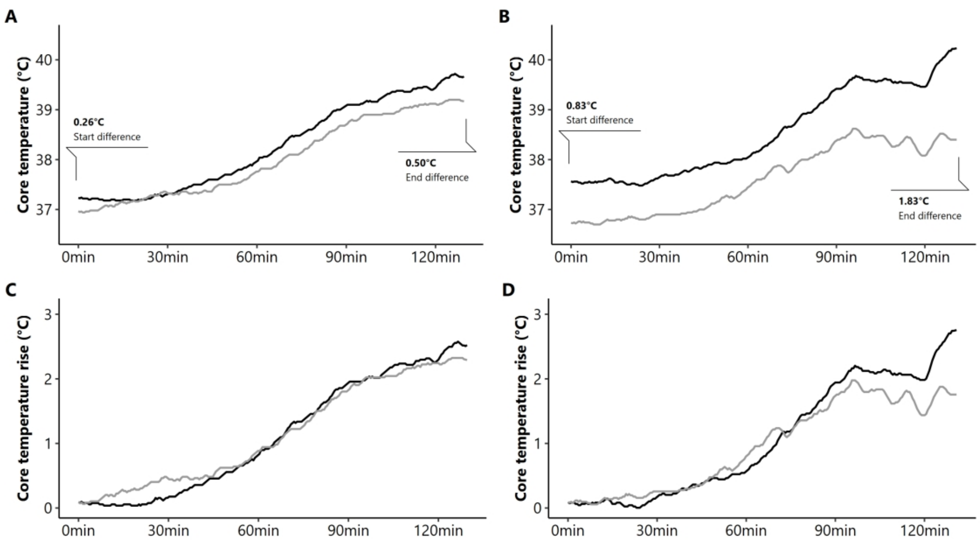

Figure 2. Individual core temperature traces during the training session for athletes recording the median peak core temperature (raw: 2A; delta: 2C) and largest peak core temperature disparity (raw: 2B; delta: 2D) in the additional clothing group (black) and control group (grey). Extremes of core temperature responses in 2B and 2D are shown to demonstrate variability between individuals. Five-point moving mean smoothing was applied to the data to minimise noise.

277x155mm (300 x 300 DPI)

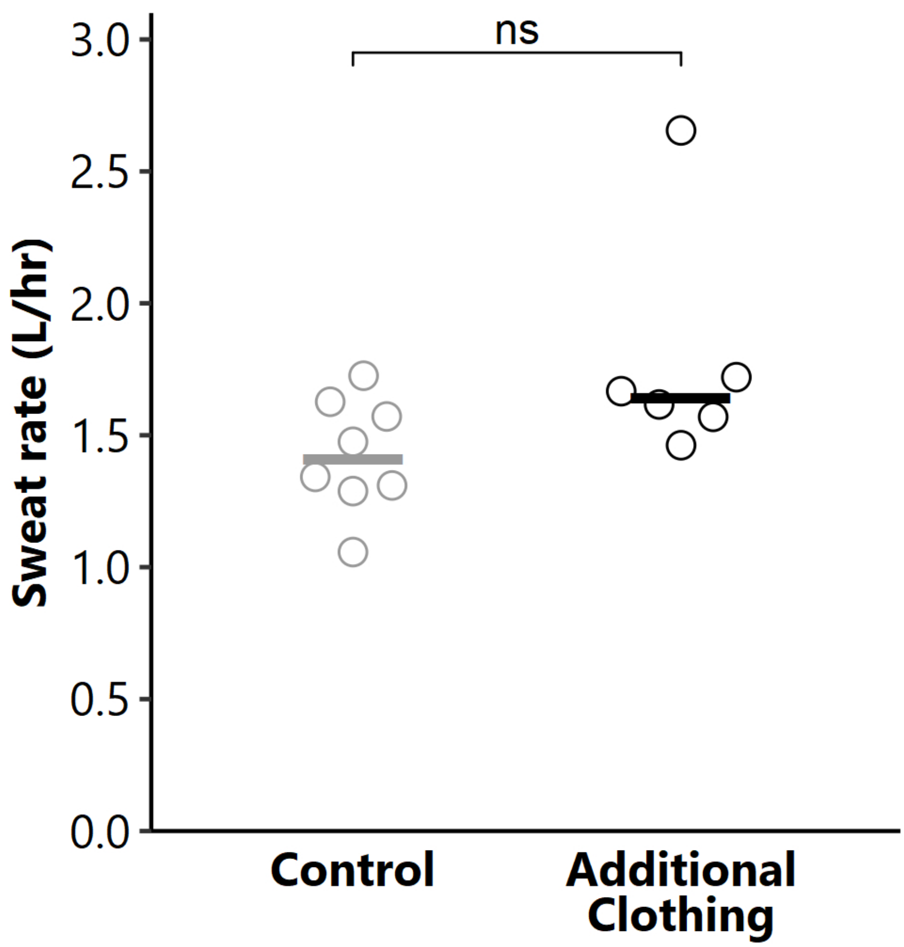

Figure 3. Individual sweat rates for all players. Solid horizontal lines represent group median and circles represent individual data for additional clothing (black) and control (grey) conditions. L/hr = Litres per hour; ns = non-significant.

89x93mm (300 x 300 DPI)

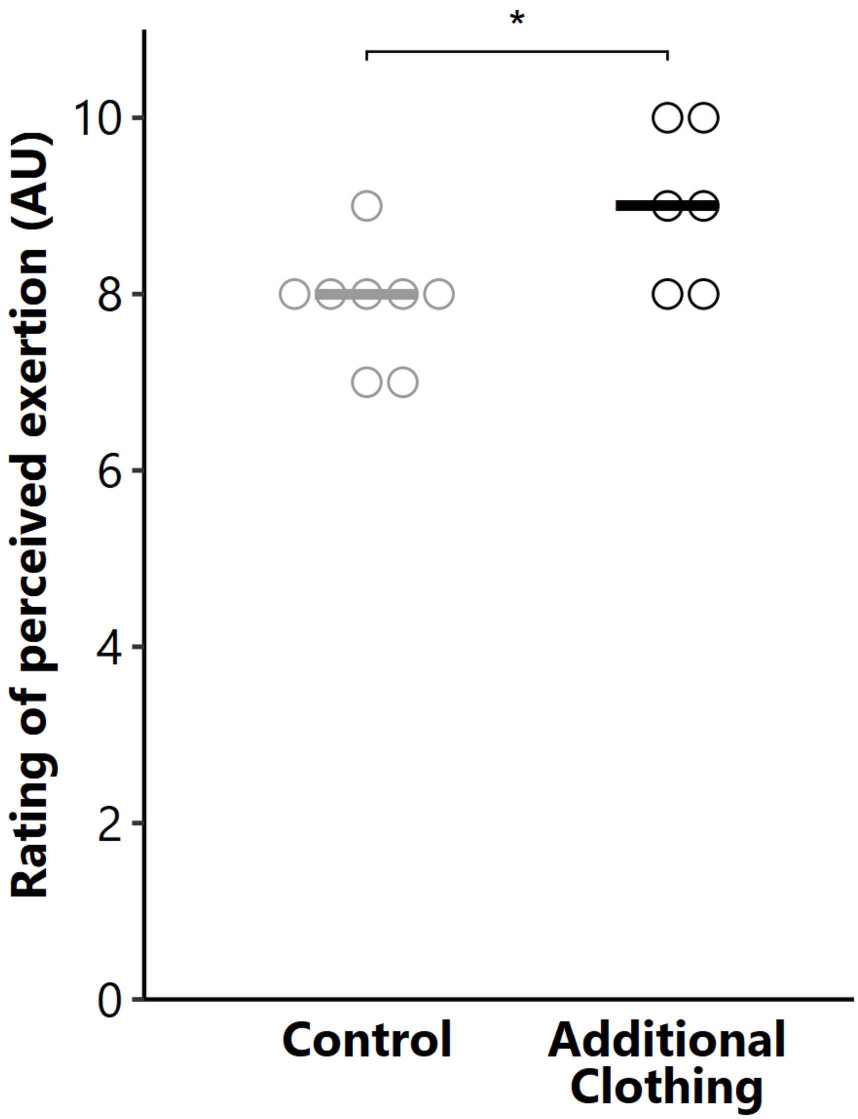

Figure 4. Individual post-session rating of perceived exertion for all players. Solid horizontal lines represent group median and circles represent individual data for additional clothing (black) and control (grey) conditions. AU = arbitrary units; * = $p < 0.05$.

83x104mm (300 x 300 DPI)

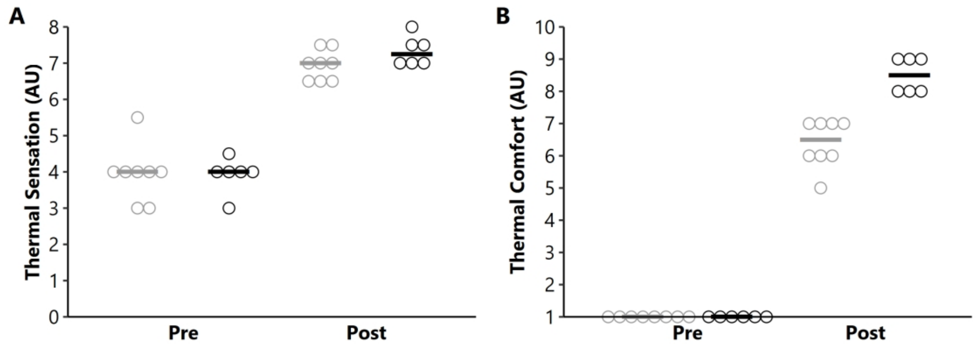

Figure 5. Individual pre- and post-session thermal sensation (5A) and thermal comfort (5B) for all players. Solid horizontal lines represent group median and circles represent individual data for additional clothing (black) and control (grey) conditions. AU = arbitrary units.

216x81mm (300 x 300 DPI)

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

Measure	Control	Additional Clothing
Age (y)	24 (19 - 29)	23 (17 – 30)
Height (m)	1.69 (1.65 - 1.74)	1.69 (1.65 – 1.71)
Body mass (kg)	67.8 (59.2 - 74.0)	67.5 (63.9 – 77.7)
Sum SF (mm)	70.1 (38.9 - 82.5)	69.6 (51.6 – 84.3)
Triceps SF (mm)	6.8 (3.8 - 11.8)	7.4 (4.8 – 10.1)
Subscapular SF (mm)	9.4 (6.5 - 15.2)	9.6 (6.9 – 13.5)
Bicep SF (mm)	4.2 (2.9 - 6.7)	4.3 (3.2 – 6.0)
Supraspinale SF (mm)	8.2 (5.2 - 16.8)	8.5 (3.8 – 11.3)
Abdomen SF (mm)	11.7 (8.7 – 20.0)	11.9 (7.6 – 13.6)
Thigh SF (mm)	17.2 (8.5 – 26.0)	17.1 (14.8 – 25.4)
Calf SF (mm)	9.1 (3.0 – 12.0)	8.1 (6.0 – 12.0)
Body fat (%)	19.1 (14.7 - 25.4)	20.4 (13.6 – 22.0)
LBM (kg)	54.9 (49.8 - 63.1)	54.4 (49.9 – 62.5)

SF = skinfold; LBM = lean body mass

Table 2. Core body temperature (Tc) and sweat rate across each timepoint and group. Data is presented as median (range) for all players.

Timepoint	Group	Tc (°C)	ΔTc from Baseline (°C)	Sweat rate (L/hr)
Baseline	Control	37.2 (36.7 - 37.5)	N/A	N/A
	Additional Clothing	37.1 (36.6 - 37.2)	N/A	N/A
Training Average	Control	38.2 (37.7 - 38.4)	1.0 (0.9 - 1.2)	1.41 (1.06 – 1.73)
	Additional Clothing	38.4 (38.1 - 38.7)	1.4 (1.2 - 1.6)	1.64 (1.46 – 2.66)
Training Peak	Control	39.2 (38.7 - 39.4)	2.0 (1.9 - 2.4)	N/A
	Additional Clothing	39.8 (39.5 - 40.4)	2.6 (2.5 - 3.3)	N/A

Tc: core temperature

Table 3. Global Positioning Systems (GPS) measures between experimental groups during the session. Data is presented as median (range) for all players.

Group	m·min^{-1}	HSR·min^{-1}	VHSR·min^{-1}	Ave Acc/Dec
Control	44.6 (36.7 - 45.9)	1.5 (1.2 - 2.0)	0.40 (0.16 - 0.69)	0.33 (0.29 - 0.35)
Additional Clothing	41.8 (39.3 - 48.5)	1.5 (1.4 - 1.9)	0.48 (0.27 - 0.66)	0.32 (0.28 - 0.38)

m·min^{-1}: metres per minute; HSR·min^{-1}: metres per minute covered at greater than 5 metres per second; VHSR·min^{-1}: metres per minute covered at greater than 6 metres per second; Ave Acc/Dec: average acceleration/deceleration in m·s·s^{-2}.

Table 4. Perceptual measures recorded pre- and post-session between experimental groups. Data is presented as median (range) for all players.

Period	Group	RPE	Thermal Sensation	Thermal Comfort
Pre	Control	NA	4.0 (3.0 - 5.5)	1.0 (1.0 – 1.0)
	Additional Clothing	NA	4.0 (3.0 - 4.5)	1.0 (1.0 – 1.0)
Post	Control	8 (7 - 9)	7.0 (6.5 - 7.5)	6.5 (5.0 – 7.0)
	Additional Clothing	9 (8 -10)	7.3 (7.0 – 8.0)	8.5 (8.0 – 9.0)

RPE: Rating of perceived exertion

Table 5. Linear mixed effects model assessing the effect of experimental group and timepoint (with interaction) on player core temperature.

	Core temperature						
Predictors	*Estimates (95% CI)*	*std. Error*	*t*	*df*	*p*	η_p^2 *(95% CI)*	*ES interpretation*
(Intercept)	37.12 (36.90 – 37.33)	0.11	343.54	21.23	**<0.001**		
Control			*Reference*				
Intervention	-0.14 (-0.45 – 0.18)	0.16	-0.85	21.23	0.408	0.05 (0.00 - 0.36)	*small*
Group: Intervention | Timepoint: Training Average	0.40 (0.15 – 0.66)	0.13	3.1	26.89	**0.006**	0.88 (0.75 - 0.93)	*large*
Group: Intervention | Timepoint: Training Peak	0.79 (0.54 – 1.04)	0.13	6.08	26.89	**<0.001**	0.97 (0.93 - 0.98)	*large*
Baseline			*Reference*				
Training Average	1.02 (0.84 – 1.19)	0.09	11.6	26.89	**<0.001**	0.35 (0.04 – 0.61)	*large*
Training Peak	2.05 (1.88 – 2.22)	0.09	23.39	26.89	**<0.001**	0.67 (0.37 – 0.81)	*large*
$N_{Players}$			11				
Observations			33				
Marginal R^2 / Conditional R^2			0.937 / 0.979				

CI: confidence interval; *df*: degrees of freedom; η_p^2: approximate partial eta squared; *ES*: effect size