Title: Daily cold-water recovery may impair training load tolerance during heat-based training

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Authors: David Borg[1,2], Ian Stewart[1], John Osborne[1], Christopher Drovandi[3], Joseph T Costello[4], Jamie Stanley[5], Geoff Minett[1]

Affiliations: [1]Queensland University of Technology, Institute of Health and Biomedical Innovation, School of Exercise and Nutrition Sciences
[2]Griffith University Menzies Health Institute Queensland, The Hopkins Centre: Research for Rehabilitation and Resilience
[3]Australian Research Council Centre of Excellence for Mathematical and Statistical Frontiers ; Queensland University of Technology, School of Mathematical Sciences
[4]University of Portsmouth, Extreme Environments Laboratory, Department of Sport and Exercise Science
[5] South Australian Sports Institute, Performance Services; University of South Australia, School of Health Sciences,

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ABSTRACT

Purpose: This study examined the effects of daily cold- and hot-water recovery on training load (TL) during 5-days of heat-based training. **Methods:** Eight males completed 5-days of cycle training for 60-min (50% peak power output) in four different conditions, using a block countered-balanced order design. Three conditions were completed in the heat (35 °C) and one in a thermoneutral environment (24 °C, CON). Each day after cycling, participants completed 20 min of seated rest (CON and heat-training, HT), or cold- (14 °C; HT_{CWI}) or hot-water immersion (39 °C; HT_{HWI}). Heart rate, rectal temperature, and rating of perceived exertion (RPE) were collected during cycling. A session-RPE was collected 10-min after recovery for the determination of session-RPE TL. Data were analysed using hierarchical regression in a Bayesian framework, Cohens *d* was calculated, and for session-RPE TL, the probability that *d* >0.5 was also computed. **Results:** There was evidence that session-RPE TL was increased in HT_{CWI} (*d*= 2.90) and HT_{HWI} (*d*= 2.38) compared to HT. The probability that *d* >0.5 was .99 and .96, respectively. The higher session-RPE TL observed in HT_{CWI} coincided with a greater cardiovascular (*d*= 2.29) and thermoregulatory (*d*= 2.68) response during cycling compared to HT. This result was not observed for HT_{HWI}. **Conclusion:** These findings may suggest that (1) cold-water recovery may negatively affect TL during 5-days of heat-based training; (2) hot-water recovery could increase session-RPE TL; and (3) the session-RPE method can detect environmental temperature mediated increases in TL in the context of this study.

Keywords: Acclimation, fatigue, heat stress, immersion, thermoregulation

INTRODUCTION

Heat-based training is recommended in preparation for competitive endurance performance in hot environments.[1,2] Typically, individuals undertake exertional-heat stress exposures over multiple consecutive days.[1,2] Depending on the thermal stimulus, changes in physiological, perceptual and physical parameters may occur within 5–7 days.[1,3] While post-intervention gains are of highest priority, understanding the acute responses to training could optimise post-intervention performance. Insight into training load (TL) tolerance would enable the review of exercise programming, and could circumvent errors in exercise prescription. This is of importance, as errors in prescription that result in an imbalance between training and recovery could lead to non-functional overreaching, and diminish performance gains.[4-6]

Traditional heat-based training methods have utilised exercise in a hot environment to promote improved heat stress tolerance during exercise.[1,3] However, thermal stress can also be applied through passive strategies, like hot-water immersion.[7] Extending heat stress beyond the training period through the application of hot-water immersion incurs no mechanical and limited financial cost.[7] The additional physiological disturbance (e.g., increased heart rate (HR) and core and skin temperature's) could facilitate improved heat stress tolerance during exercise.[1,7,8] Alternatively, the greater thermal stress provided by hot-water immersion may exacerbate inflammation, induce greater levels of fatigue, and negatively affect TL tolerance.[4,5]

While heat might enhance adaptation, contrastingly, cold application may accelerate thermal recovery.[9] Post-exercise cooling reduces body tissue temperatures, increases venous return, and accelerates the recentralisation of blood volume.[10] It may also alleviate temperature mediated reductions in voluntary activation.[11,12] Cold-water recovery is recommended after an acute exertional-heat stress exposure, and benefits may include the enhanced restoration of cardiovascular[13] and neuromuscular[11,12] function, and perceptions of recovery.[14] In the context of heat-based training, cold recovery could be expected to limit elevations in physiological and perceptual parameters, and improve TL tolerance. However, cooling could interfere with, and possibly impair, processes that facilitate improved heat stress tolerance.[15] Surprisingly, a comparison of post-exercise cold- and hot-water immersion use during a heat-based training intervention does not exist.

Quantifying an athlete's tolerance to training in hot environments is complex, as increases in physiological and perceptual responses coincide with reduced physical work.[8] While the physiological responses to heat-based training have been widely considered,[1,3] perceived responses, like the session rating of perceived exertion (session-RPE), have received limited attention.[1] Moreover, the effects of cold- and hot-water recoveries on TL during exertional-heat stress over multiple days are unknown. As such, there is a need to understand the influence of common thermal recoveries on training tolerance, which could be reflected in physiological and perceived training responses.[1,2,5] In a fixed-intensity task, the internal TL response is not confounded by fluctuations in mechanical work. Therefore, changes in physiological and perceived responses are likely to reflect alterations in heat stress tolerance, rather than alterations in mechanical work.

This study examined the effects of daily cold- and hot-water recovery on TL, during five consecutive days of heat-based training, using session-RPE as the primary indicator of TL. It was hypothesised that (1) cold-water recovery would reduce session-RPE TL; and (2) hot-water immersion would increase session-RPE TL, compared to heat-training with passive recovery.

METHODS

Subjects

Eight healthy males (Table 1), classified as performance level 2 cyclists (1 to 5 performance level classification scale, with 5 indicating highly trained cyclists) according to the mean peak oxygen consumption ($\dot{V}O_{2peak}$) and peak power output (PPO)[16], provided informed written consent to participate in the study. All participants had no previous experience undertaking a structured heat-based training intervention. All experimental procedures adhered to the standards set by the latest revision of the declaration of Helsinki, except for registration in a database, and were approved by the University Human Research Ethics Committee of Queensland University of Technology (1700000651).

Design

Participants completed four conditions in a block countered-balanced order (Latin Square). Each condition comprised an incremental cycling test and five consecutive days of cycling in temperate (CON; 24 °C; 50% relative humidity, RH) or hot conditions (35 °C; 50% RH; wet bulb globe temperature 29.5 °C). Environments were simulated by a chamber (4.7 $km \cdot h^{-1}$ wind speed), and logged (3M QUESTemp, Quest Technologies, USA). Recovery consisted of seated rest (CON and HT), or immersion in cold (HT_{CWI}) or hot water (HT_{HWI}). No fluid was consumed during cycling or recovery. During the study, participants were asked to avoid alcohol and vigorous exercise, and to keep their dietary intake consistent. There was a minimum of 25 days between conditions, with a mean (± standard deviation, SD) of 42±9 days.[2] Testing was conducted from November to May in Brisbane, Australia.

Methodology

Familiarisation and incremental cycling test

Participants were pre-screened (Exercise and Sports Science Australia, Adult Pre-Exercise Screening Tool) and familiarised to all perceptual outcomes. Perceived wellness was measured using a 5-item questionnaire (fatigue, sleep quality, muscle soreness, stress levels and mood).[17] Each item was rated from 1 to 5 (increments of 1). Items were summed, with higher scores reflecting better wellness. RPE was collected using Borg's[18] 6–20 scale, and perceived thermal sensation using the Young et al[19] 0–8 scale. Session-RPE was collected using the 0–10 scale (0 'rest' to 10 'maximal') described by Foster et al[20]. Ratings were collected with the instructions 'how was your workout?', and multiplied by training duration, for the determination of session-RPE TL.[20] A session-RPE was collected 10-min after the recovery period. The session-RPE TL method has been shown to be an internally and externally valid.[5,20]

PPO and $\dot{V}O_{2peak}$ were determined via an incremental cycling test (Excalibur Sport; Lode, Netherlands). The test started at 75 W and increased by 25 $W \cdot min^{-1}$ until volitional fatigue. PPO was calculated according to De Pauw et al[16]. Pulmonary gas exchange (TrueOne 2400, Parvo Medics, USA) was collected breath-by-breath to provide measures of minute ventilation and oxygen uptake, and HR was recorded (Team 2; Polar Electro Oy, Finland). Data were averaged over 15 seconds, with peak values taken as the highest measurement achieved in the test.

Training sessions

Training was undertaken at the same time of day (±2 h). Mid-stream urine samples were collected from the first void and at arrival for the assessment of specific gravity (U_{SG}; PAL-10S; Atagi Ci. Ltd, Japan). The wellness questionnaire, and physical activity (24 h) and food (48 h) diaries were completed, and nude mass recorded (WB-110AZ; Tanita Corp., Japan). A flexible thermistor was inserted ~12 cm past the anal sphincter (449H; Henleys Medical, England) for measurements of rectal temperature (T_{re}). Four iButtons (DS1922L-F50, Maxim Intergrated, USA) were attached (back of the neck, right scapula, left hand, and right shin) with sports tape (Leuko Sportstape; Beiersdorf, Germany). Mean skin temperature ($\overline{T}_{sk}$) was calculated according to international standards, using the equation: $\overline{T}_{sk} = neck * 0.28 +$

$scapula * 0.28 + hand * 0.16 + shin * 0.28$.[21] A HR monitor and strap were fitted and thermal sensation was recorded before participants entered the chamber.

Participants cycled for 60 min at 50% PPO (Wattbike Pro; Wattbike Ltd, England). Each participants' training attire (bibs without a jersey, socks, and cleats, or sports shorts, socks and rubber-soled shoes), pedals (flat or clipless) and ergometer settings remained consistent. During cycling, RPE and thermal sensation were collected every 10-min. T_{re} and $\overline{T}_{sk}$ were sampled every 30 seconds, and HR continuously recorded. Training was terminated if T_{re} exceeded 39.9 °C (no incidents). After cycling, nude mass was recorded for the calculation of non-urine fluid loss (NUFL).

Post-exercise recovery

During a 5-min transition, participants consumed 250 mL of room temperature water, and donned sports shorts. For CON and HT, participants sat quietly for 20-min in the laboratory (24 °C; 50% RH). Cold- and hot-water recovery consisted of immersion in an inflatable bath (iBody, iCoolsport, Australia) to the umbilicus, legs fully extended, and forearms submerged. Cold water was maintained at 14.7±1.4 °C (target: 14 °C),[9,22] and hot water at 39.2±0.6 °C (target: 39 °C) (NIST-certified thermometer, TL1-W, ThermoProbe Inc., USA). The hot target (39 °C) was selected from pilot testing, due to its ability to maintain T_{re} after cycling, and be tolerated by the participants. During recovery, thermal sensation was collected every 5-min, HR continuously recorded, and Tre and $\overline{T}_{sk}$ sampled every 30 seconds. Nude mass was recorded after recovery, and a session-RPE rating collected 10-min later.

Statistical analysis

Session-RPE TL and wellness were modelled with Bayesian hierarchical regression with a beta response distribution using the 'zoib' package[23] in R (Version 3.4.4). Before analysis, data were transformed using the equation: $y' = (y - a)/(b - a)$, where 'a' is the smallest possible value (i.e., session-RPE TL 0, wellness 5), 'b' the highest possible value (i.e., session-RPE TL 600, wellness 25), and 'y' the observed value. Models included participant ID as a random variable, and day, condition and day x condition as fixed factors. Where time or condition, but not time x condition, effects were observed the interaction was removed from the model. Markov chain Monte Carlo (MCMC) methods were used to generate posterior estimates via 2 independent chains, 10,200 MCMC iterations, a 200 iteration burn-in and thinned by a factor of 50. A Normal (mean 0, precision 1/0.001) prior distribution was utilised for regression coefficients, and a Uniform (mean 0, SD 20) prior for the SD of the random effects.

Bayesian hierarchical regression was utilised to model pre-cycling nude mass, U_{SG}, HR, peak HR, T_{re}, peak T_{re}, $\overline{T}_{sk}$, RPE, thermal sensation, power output, cadence and NUFL. Models were implemented using the 'rjags'[24] and 'R2jags'[25] packages in R. HR, peak HR, T_{re}, peak T_{re}, $\overline{T}_{sk}$, RPE, thermal sensation, power output, and cadence models included day, condition and day x condition as fixed factors. Again, where time or condition, but not interaction, effects were observed the interaction was removed. The NUFL model included time (i.e., before and after cycling, and after recovery), day, condition and their interactions as fixed factors. All models included a random intercept for each participant ID. A Normal (mean 0, precision 0.001) prior distribution was utilised for the regression coefficients and Gamma (shape 0.01, scale 0.01) prior for each variance parameter. Posterior estimates were simulated from 50,000 MCMC iterations, with 1,000-iteration burn-in and thinned by a factor of 10.

Posterior estimates are reported as the mean and 95% credible interval (CI). Cohen's *d* (and 95% CI) was calculated with the denominator: $\sqrt{\text{var}(d_{kl})}$, where '$d_{kl}$' is the difference between days or conditions 'k' and 'l'.[26,27] Cohen's *d* values were interpreted as small 0.2, medium 0.5, and large 0.8.[26] For session-RPE TL, the probability that *d* exceeded 0.5 was also computed where there was evidence of statistical differences between HT and HT_{CWI}, or HT and HT_{HWI}.[27] When the 95% CI of a regression coefficient (β) or MD did not include zero it was concluded that there was evidence of a statistical effect or difference. The convergence of MCMC to the posterior distribution was assessed via trace plots. Posterior predictive checks were performed to assess the suitability of the chosen models.

RESULTS

One participant withdrew, for reasons unrelated to the study (interstate relocation), having completed three conditions. Therefore, HT_{CWI} n=7. All other participants completed all four conditions, with no incidents of injury or illness.

Incremental cycling test

There was little evidence of statistical differences in $\dot{V}O_{2peak}$, PPO, or peak HR between conditions (Table 1).

Perceived training load

Bayesian analysis showed evidence of a condition effect for session-RPE TL (β_{HTCWI}: 0.6 [0.1, 1.1]; β_{HTHWI}: 0.6 [0.1, 1.1]). Session-RPE TL (Figure 1) was statistically higher in the heat versus CON (*d*= 5.95 to 7.29). There was also evidence that session-RPE TL was statistically higher in HT_{CWI} versus HT (MD [95% CI] = 55 [14, 91]; *d* [95% CI] = 2.90 [0.74, 4.76]), and statistically higher in HT_{HWI} versus HT (MD= 39 [6, 67]; *d*= 2.38 [0.35, 4.11]). The probability that *d* >0.5 for these comparisons was .99 and .96, respectively.

Pre-cycling outcomes

Perceived wellness, pre-cycling mass, and first void and arrival U_{SG} are shown in Table 2. There was little evidence of day, condition, or day x condition effects for wellness, mass, or U_{SG}.

Cycling training

Mean power output and cadence are displayed in Table 2. There was little evidence of day, condition or day x condition effects for power output. There was evidence of a condition effect for cadence (β_{HTHWI}: -6.3 [-11.3, -1.3]). Cadence was statistically lower in HT_{HWI} versus CON (*d* [95% CI] = -2.61 [-4.57, -0.67]), HT (*d*= -2.24 [-4.21, -0.26]), and HT_{CWI} (*d*= -3.93 [-5.89, -2.02]).

There was evidence of a condition effect for mean training HR (β_{HT}: 14.3 [8.4, 20.4]; β_{HTCWI}: 12.1 [5.9, 18.5]; β_{HTHWI}: 11.3 [5.3, 17.3]). Mean HR (Figure 2A) was higher in the heat versus CON (*d*= 8.63 to 10.59). There was evidence that mean HR was statistically higher in HT_{CWI} versus HT (*d* [95% CI] = 2.29 [0.34, 4.26]), and HT_{HWI} (*d*= 2.76 [0.77, 4.70]). There was evidence of a condition effect for peak HR (β_{HT}: 23.8 [17.2, 30.4]; β_{HTCWI}: 24.5 [17.6, 31.3]; β_{HTHWI}: 18.709 [12.003, 25.385]). Peak HR (Table 2) was statistically higher in the heat versus CON (*d*= 10.45 to 13.65). Peak HR was also statistically higher in HT_{CWI} versus HT (*d* [95% CI] = 2.63 [0.66, 4.63]) and HT_{CWI} versus HT_{HWI} (*d*= 3.91 [1.90, 5.87]).

Bayesian analysis showed some evidence of a condition effect for mean T_{re} (β_{HT}: 0.22 [0.01, 0.42]; β_{HTCWI}: 0.205 [-0.003, 0.412]). Mean T_{re} (Figure 2B) was statistically higher in HT_{CWI} versus CON (*d* [95% CI] = 3.83 [1.84, 5.78]), HT (*d*= 2.68 [0.69, 4.64]) and HT_{HWI} (*d*= 2.06 [0.11, 4.07]). There was evidence of a condition effect for peak T_{re} (β_{HT}: 0.51 [0.33, 0.69]; β_{HTCWI}: 0.48 [0.31, 0.66]; β_{HTHWI}: 0.41 [0.24, 0.57]). Peak T_{re} (Table 2) was statistically higher in the heat versus CON (*d*= 9.20 to 12.16). There was also evidence peak T_{re} was higher in HT_{CWI} versus HT (*d*= 2.84 [0.81, 4.79]), and HT_{HWI} (*d*= 2.47 [0.49, 4.40]).

There was evidence of a condition effect for mean cycling $\overline{T}_{sk}$ (β_{HT}: 3.3 [2.5, 4.2]; β_{HTCWI}: 3.4 [2.5, 4.3]; β_{HTHWI}: 2.7 [1.8, 3.5]). Mean $\overline{T}_{sk}$ (Figure 2C) was statistically higher in the heat compared to CON (*d*= 16.00 to 19.32), and statistically lower in HT_{HWI} versus HT (*d* [95% CI] = -3.85 [-5.82, -1.91]) and HT_{CWI} (*d*= -4.47 [-6.41, -2.51]). There was evidence of a condition effect for NUFL (β_{HT}: -0.4 [-0.6, -0.3]; β_{HTCWI}: -0.4 [-0.5, -0.2]; β_{HTHWI}: -0.5 [-0.6, -0.3]). NUFL (Table 2) was greater in the heat versus CON (*d*= 4.47 to 7.09), but not statistically different between the hot conditions.

Analysis showed evidence of a condition effect for mean RPE (β_{HT}: 1.2 [0.4, 2.1]; β_{HTCWI}: 1.1 [0.2, 2.0]; β_{HTHWI}: 0.9 [0.1, 1.8]). Mean RPE (Figure 2D) was statistically higher in the heat versus CON (*d*= 5.92 to 7.79), and higher in HT_{CWI} versus HT (*d* [95% CI] = 2.07 [0.13, 4.00]). There was evidence of a condition effect for mean cycling thermal sensation (β_{HT}: 1.0 [0.6, 1.4]; β_{HTCWI}: 0.9 [0.4, 1.3]; β_{HTHWI}: 0.9 [0.5, 1.3]). Thermal sensation (Figure 2E) was higher in the heat versus CON (*d*= 9.33 to 11.41). There was little indication perceived thermal sensation was statistically different between the heat-training conditions.

Post-cycling recovery

Bayesian analysis showed evidence of a condition effect for mean recovery HR (β_{HT}: 9.8 [2.2, 17.7]; β_{HTHWI}: 26.5 [19.2, 33.8]). Mean recovery HR (Figure 3A) was statistically higher in HT versus CON (*d* [95% CI] = 3.59 [1.65, 5.50]) and versus HT_{CWI} (*d*= 2.84 [0.86, 4.78]). There was also evidence mean recovery HR was higher in HT_{HWI} compared to all other conditions (*d*= 12.25 to 15.48).

There was some indication of a condition effect for mean recovery T_{re} (β_{HT}: 0.31 [0.02, 0.61]; β_{HTCWI}: 0.31 [0.02, 0.59]; β_{HTHWI}: 0.7 [0.4, 0.9]). Recovery T_{re} (Figure 3B) was statistically higher in HT versus CON (*d* [95% CI] = 3.92 [1.95, 5.91]), and higher in HT_{CWI} versus CON (*d*= 3.77 [1.84, 5.76]). Recovery T_{re} was also higher in HT_{HWI} compared to all other conditions on all days (*d*= 6.27 to 10.14).

There was evidence of a condition effect for mean recovery $\overline{T}_{sk}$ (β_{HT}: 1.1 [0.1, 2.1]; β_{HTCWI}: -3.6 [-4.7, -2.5]; β_{HTHWI}: 6.1 [5.1, 7.1]). Recovery $\overline{T}_{sk}$ (Figure 3C) was higher in HT versus CON (*d* [95% CI] = 4.44 [2.51, 6.39]), lower in HT_{CWI} compared to all other conditions (*d*= -49.85 to -19.16), and higher in HT_{HWI} compared to all other conditions (*d*= 26.11 to 49.85). There was evidence of a condition effect for NUFL during recovery (β_{HTHWI}: -0.4 [-0.5, -0.3]). Recovery NUFL (Table 2) was greater in HT_{HWI} compared to all other conditions (*d*= -11.47 to -5.84).

There was evidence of a condition effect for mean recovery thermal sensation (β_{HTCWI}: -2.1 [-2.6, -1.6]; β_{HTHWI}: 2.1 [1.6, 2.6]). Perceived thermal sensation (Figure 3D) was statistically lower in HT_{CWI} compared to all other conditions (*d*= -40.52 to -18.87), and higher in HT_{HWI} compared to all other conditions (*d*= 18.65 to 40.52).

DISCUSSION

This study aimed to investigate the effect of daily cold- and hot-water recovery on TL during 5-days of heat-based training, using session-RPE as the primary indicator of TL. Session-RPE TL was higher in all heat-training conditions compared to temperate environment cycling training (Figure 1). In contrast to our hypothesis, session-RPE TL was higher when using cold-water recovery compared to compared to heat-training with passive recovery (Figure 1). There was also evidence that cold-water recovery increased the cardiovascular response to training (Figure 2; Table 2). In support of our hypothesis, hot-water recovery increased session-RPE TL compared to heat-training with passive recovery (Figure 1). The cardiovascular response to training appeared unaffected by hot-water recovery. Interestingly, there was little evidence that post-exercise hot-water immersion improved heat stress tolerance. Results from this study suggest that (1) cold-water recovery may negatively affect TL during 5-days of heat-based training; (2) hot-water could increase session-RPE TL; and (3) the session-RPE method can detect environmental temperature mediated increases in TL during 5-days of cycle training.

Cold-water recovery elicited a higher internal TL response compared to passive rest, evident by a statistically higher mean cycling HR, T_{re} and RPE (Figure 2A, 2B and 2D). Importantly, these differences were not attributed to alterations in mechanical work, as power output was matched between conditions (Table 2). It is possible that the higher HR, T_{re} and RPE in HT_{CWI} may explain the session-RPE TL results (Figure 1).[20] Equally, hydrostatic pressure from water immersion, rather than the water temperature per se, may also explain the higher session-RPE TL. In support of this notion, session-RPE TL was higher with hot-water recovery, in the absence of the HR, T_{re} and RPE differences observed in HT_{CWI}. Contrasting our study, Skein et al[28] observed no differences in exercise HR or RPE when daily cold-water recovery was included in 5-days of heat-based training. The water temperature utilised by Skein et al[28] was identical to our study, but the immersion period was 5-min shorter. The longer immersion and shorter training time (30-min less) in our study could explain the disparity in findings. Skein et al[28] did not collect session-RPE meaning we are unable to compare this variable.

Consistent with some short-term heat-training interventions[1], there was little evidence that 5-days of cycling in 35 °C (50% RH) induced acclimation (Figure 2; Table 2). As expected, cycling in the heat increased the TL response compared to the temperate environment (Figure

1 and 2; Table 2). Interestingly, the 100-min of additional heat stress provided by hot-water immersion did not induce acclimation. It is possible that the lower cadence maintained in HT_{HWI} could partly explain the increased session-RPE TL, as a greater neuromuscular demand could have been required to maintain the same power output, and this may have been reflected in session-RPE ratings (Table 1). However, considering the small differences in cadence, hydrostatic pressure could also explain the higher session-RPE TL. Hot-water immersion for acclimation has been utilised in isolation[29], and after exercise in a temperate environment[7]. In contrast to our findings, these studies[7,29] observed classic signs of heat acclimation (e.g., reduced HR, greater body mass loss). Differences in intervention length, training duration, and participants' training status may explain the conflicting results.[7,29]

Our findings suggest that the session-RPE method can detect environmental temperature mediated increases in TL during 5-days of cycle training.[20] However, the results need to be interpreted with care. Session-RPE was collected 10 min after recovery. As such, it is unclear whether findings would be similar if data were collected at a different time point (e.g., the following morning). Nonetheless, these results may highlight the need to consider the timing of session-RPE collection when recovery strategies are utilised. We explored whether participant dropout (n=1) affected session-RPE TL results. After including the missing individuals mean session-RPE values from HT and HT_{HWI} for HT_{CWI}, the conclusions remained unchanged (β_{HTCWI}: 0.57 [0.03, 1.08]; β_{HTHWI}: 0.55 [0.04, 1.06]). Cold-water recovery is typically associated with improved perceptions of recovery and wellness.[12,28] In the current study, cold-water recovery had little influence on perceived wellness (Table 2). This could suggest differences in time-course of responses[17] or the poor sensitivity of these types of questionnaires as TL monitoring tools.

The primary limitations of the current study are the sample size and intervention length. Hierarchical regression models and estimation methods were utilised in an attempt to handle the small sample.[27] Despite utilising a rigorous counter-balance design, the elongated data collection period may have resulted in some parameters being affected by seasonal, training or dietary variations.[30] For example, $\overline{T}_{sk}$ was lower in HT_{HWI} (Figure 2C). We explored whether an order effect could explain our session-RPE TL findings—but found little evidence to support this line of inquiry. An order effect may have been expected because our participants had no previous experience with heat-based training protocols. Finally, it is unknown whether session-RPE TL findings would remain the same if both cadence and power output had been fixed. Future investigations should replicate this study utilising a longer training intervention; explore the effect of cool (e.g., 20 °C), rather than cold, water-recovery on session-RPE TL; and examine the influence of multiple rest days after the intervention on performance.

PRACTICAL IMPLICATIONS

- The session rating of perceived exertion method can detect environmental temperature mediated increases in training load during 5-days of cycle training.
- Results from the current study may indicate that cold-water immersion should not be utilised in conjunction with heat-based training.
- Twenty-minutes of daily post-exercise hot-water immersion may not improve heat stress tolerance after 5-days of heat-based training.

CONCLUSION

This is the first study to examine the effects of daily cold- and hot-water recovery on TL during 5-days of heat-based training. There was evidence that cold-water increased session-RPE TL and the cardiovascular response to training. Hot-water recovery also increased session-RPE TL, but not the cardiovascular response to training. There was little evidence that that added thermal stimulus provided by hot-water immersion improved heat stress tolerance.

Our findings suggest that (1) cold-water recovery may negatively affect TL during 5-days of heat-based training; (2) hot-water recovery could negatively impact session-RPE TL; and (3) the session-RPE method can detect environmental temperature mediated increases in the context of this study.

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FIGURE CAPTIONS

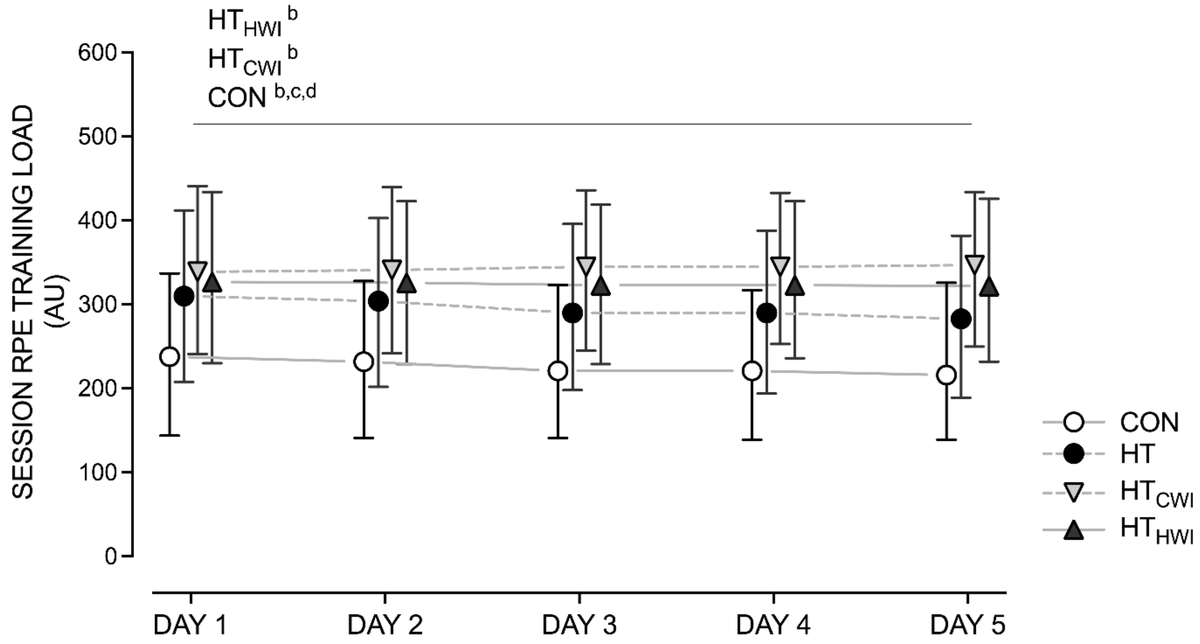
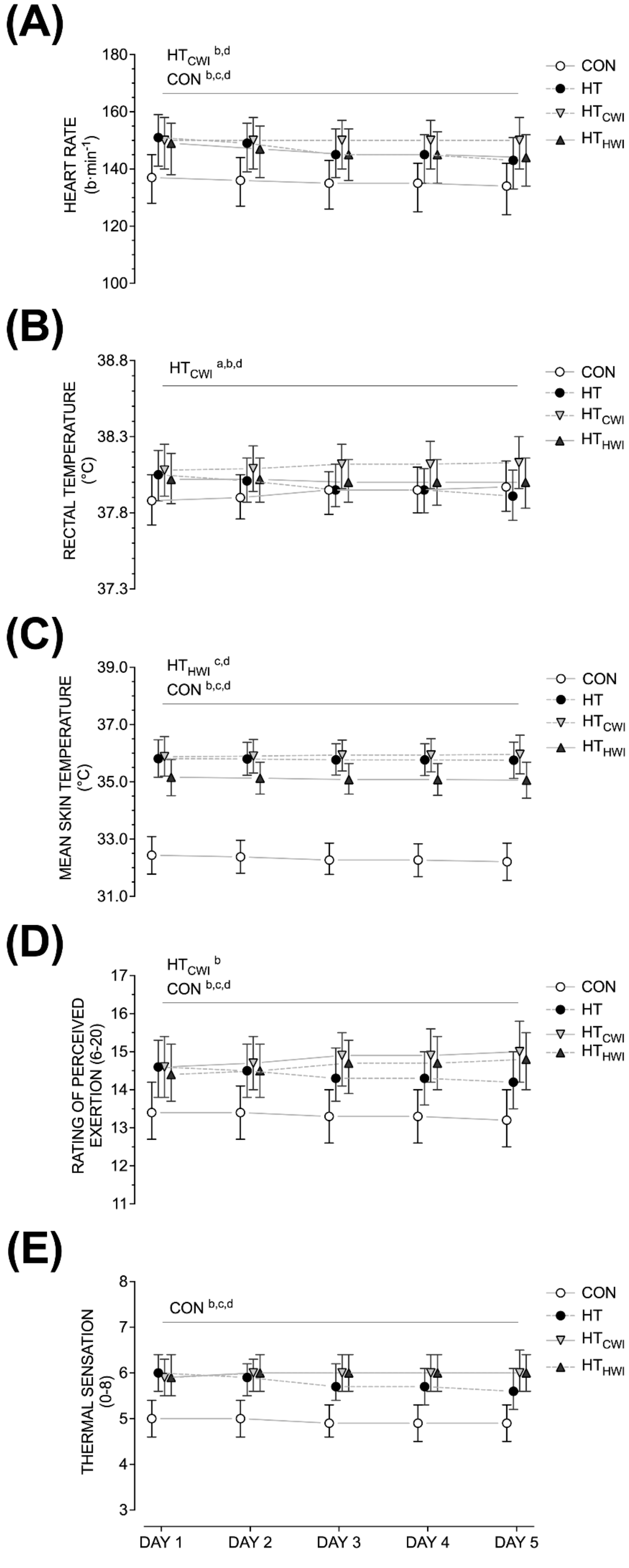


Figure 1. Posterior mean (and 95% credible interval) session rating of perceived exertion training load (i.e., session-RPE x training duration) across the 5-day intervention. CON = temperate training with seated rest recovery, HT = heat training with seated rest recovery, HT_{CWI} = heat training with cold-water recovery, HT_{HWI} = heat training with hot-water recovery, [b] statistically different to HT, [c] statistically different to HT_{CWI}, [d] statistically different to HT_{HWI}.


(A)
HT_CWI b,d
CON b,c,d
HEART RATE (b·min-1)
180
160
140
120
100
CON
HT
HT_CWI
HT_HWI
(B)
HT_CWI a,b,d
RECTAL TEMPERATURE (°C)
38.8
38.3
37.8
37.3
(C)
HT_HWI c,d
CON b,c,d
MEAN SKIN TEMPERATURE (°C)
39.0
37.0
35.0
33.0
31.0
(D)
HT_CWI b
CON b,c,d
RATING OF PERCEIVED EXERTION (6-20)
17
16
15
14
13
12
11
(E)
CON b,c,d
THERMAL SENSATION (0-8)
8
7
6
5
4
3
DAY 1
DAY 2
DAY 3
DAY 4
DAY 5

453

Figure 2. Posterior mean (and 95% credible interval) heart rate (A), rectal temperature (B), four-site mean skin temperature (C), rating of perceived exertion (D), and perceived thermal sensation (E) during cycle training. CON = temperate training with seated rest recovery, HT = heat training with seated rest recovery, HT_{CWI} = heat training with cold-water recovery, HT_{HWI} = heat training with hot-water recovery. [a] statistically different to CON, [b] statistically different to HT, [c] statistically different to HT_{CWI}, [d] statistically different to HT_{HWI}.

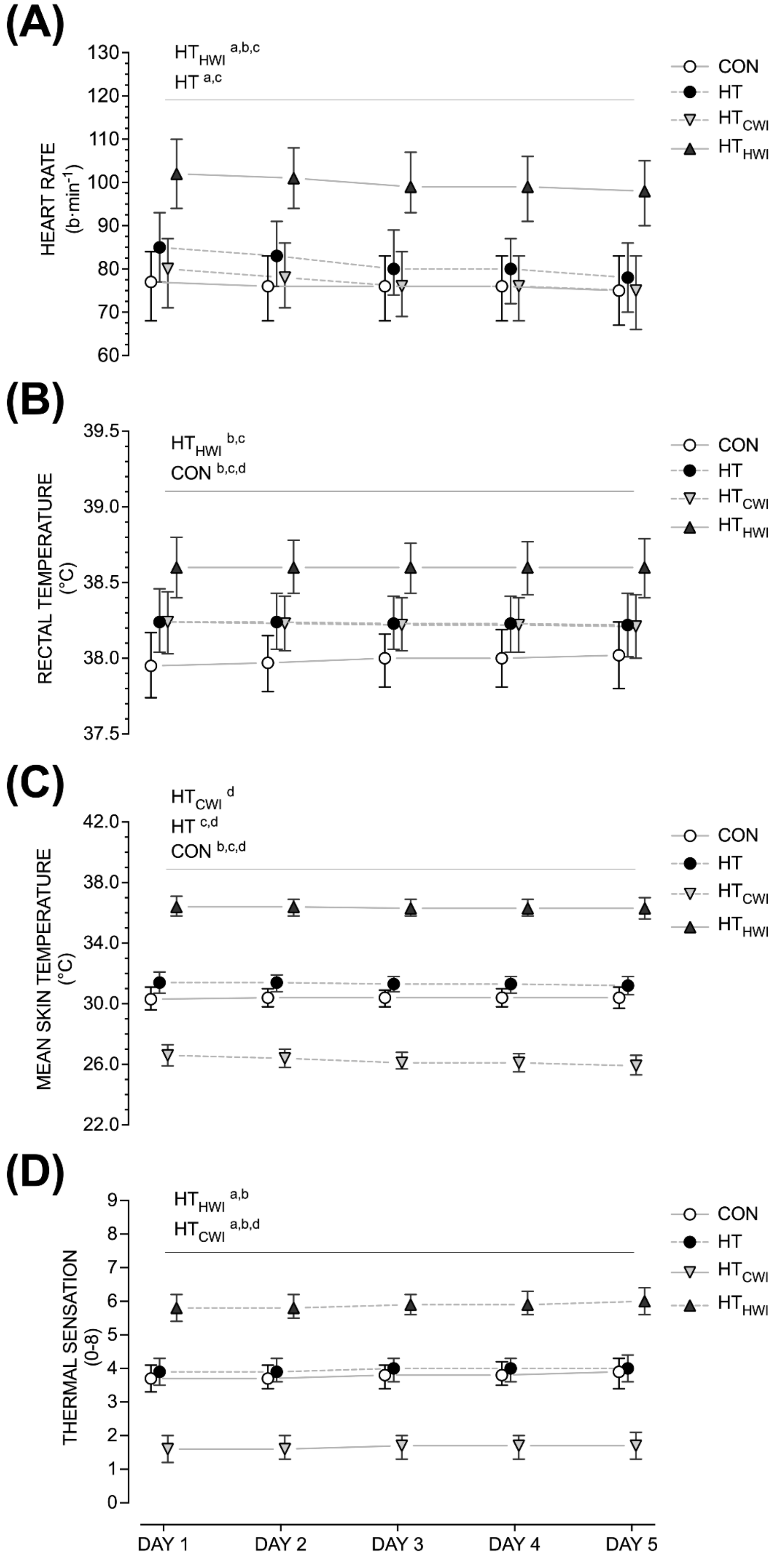

(A)
HT_HWI a,b,c
HT a,c
HEART RATE (b·min-1)
CON
HT
HT_CWI
HT_HWI
(B)
HT_HWI b,c
CON b,c,d
RECTAL TEMPERATURE (°C)
(C)
HT_CWI d
HT c,d
CON b,c,d
MEAN SKIN TEMPERATURE (°C)
(D)
HT_HWI a,b
HT_CWI a,b,d
THERMAL SENSATION (0-8)
DAY 1
DAY 2
DAY 3
DAY 4
DAY 5

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Figure 3. Posterior mean (and 95% credible interval) heart rate (A), rectal temperature (B), four-site mean skin temperature (C), and perceived thermal sensation (D) during the 20 min recovery period. CON = temperate training with seated rest recovery, HT = heat training with seated rest recovery, HT_{CWI} = heat training with cold-water recovery, HT_{HWI} = heat training with hot-water recovery. [a] statistically different to CON, [b] statistically different to HT, [c] statistically different to HT_{CWI}, [d] statistically different to HT_{HWI}.

Table 1. Participant characteristics (mean ± standard deviation (range)) and incremental cycling test outcomes (posterior mean and 95% credible interval).

Variable		
Participant characteristics		
Age (years)		26.5 ± 1.8 (24.3–29.2)
Height (cm)		181 ± 9 (163–190)
Nude body mass (kg)		81.5 ± 11.9 (57.5–99.8)
Peak oxygen consumption* (mL·kg^{-1}·min^{-1})		49.3 ± 4.9 (45.2–60.5)
Training activities** (sessions·week^{-1})		3.6 ± 1.3 (2.0–5.0)
Training minutes** (min·week^{-1})		191 ± 63 (120–280)
Incremental cycling test outcomes		
Peak oxygen consumption (L·min^{-1})	CON	3.99 [3.45, 4.53]
	HT	4.08 [3.56, 4.62]
	HT_{CWI}	3.92 [3.40, 4.44]
	HT_{HWI}	4.10 [3.58, 4.63]
Peak power output (W)	CON	346 [312, 381]
	HT	347 [314, 382]
	HT_{CWI}	346 [312, 382]
	HT_{HWI}	350 [316, 385]
Peak heart rate (b·min^{-1})	CON	183 [173, 192]
	HT	184 [175, 194]
	HT_{CWI}	184 [174, 194]
	HT_{HWI}	184 [174, 193]

Note. HT_{CWI} n = 7; * Value taken from participants' first incremental cycling test; ** Training activities based on the previous 4-weeks at study commencement; CON = temperate training with seated rest recovery; HT = heat training with seated rest recovery; HT_{CWI} = heat training with cold-water recovery; HT_{HWI} = heat training with hot-water recovery.

Table 2. Posterior mean (and 95% credible interval) responses for pre-cycling, cycling and post-cycling recovery variables.

Variable	Condition	Day 1	Day 2	Day 3	Day 4	Day 5
Pre-cycling						
Perceived wellness (5-25)	CON	16 [14, 18]	16 [14, 18]	16 [14, 18]	16 [14, 18]	16 [14, 18]
	HT	17 [15, 19]	17 [15, 18]	16 [15, 18]	16 [14, 18]	16 [14, 18]
	HT$_{CWI}$	15 [13, 17]	15 [13, 16]	14 [12, 16]	14 [12, 16]	13 [11, 16]
	HT$_{HWI}$	15 [13, 17]	15 [13, 16]	14 [13, 16]	14 [13, 16]	14 [12, 16]
Pre-cycling mass (kg)	CON	79.1 [68.7, 88.4]	79.1 [68.6, 88.3]	79.0 [68.7, 88.4]	79.0 [68.6, 88.3]	78.9 [68.5, 88.0]
	HT	78.7 [68.3, 88.0]	78.5 [68.1, 87.8]	78.7 [68.2, 87.8]	78.7 [68.3, 87.9]	78.8 [68.1, 87.9]
	HT$_{CWI}$	79.3 [68.9, 88.6]	79.0 [68.6, 88.2]	78.7 [68.4, 88.0]	78.7 [68.2, 87.9]	78.6 [68.1, 88.0]
	HT$_{HWI}$	79.6 [69.1, 88.9]	79.3 [68.9, 88.5]	79.6 [68.8, 88.4]	79.6 [69.3, 88.8]	79.2 [68.7, 88.4]
First void urine specific gravity	CON	1.020 [1.016, 1.025]	1.021 [1.017, 1.024]	1.022 [1.018, 1.025]	1.022 [1.018, 1.025]	1.022 [1.018, 1.026]
	HT	1.022 [1.017, 1.027]	1.021 [1.017, 1.026]	1.020 [1.017, 1.024]	1.020 [1.015, 1.024]	1.019 [1.014, 1.024]
	HT$_{CWI}$	1.021 [1.017, 1.026]	1.022 [1.018, 1.026]	1.023 [1.019, 1.026]	1.023 [1.019, 1.027]	1.023 [1.019, 1.028]
	HT$_{HWI}$	1.021 [1.017, 1.026]	1.022 [1.018, 1.026]	1.022 [1.018, 1.026]	1.022 [1.019, 1.026]	1.023 [1.018, 1.027]
Arrival urine specific gravity	CON	1.015 [1.010, 1.020]	1.016 [1.013, 1.020]	1.020 [1.015, 1.022]	1.020 [1.015, 1.022]	1.020 [1.017, 1.027]
	HT	1.017 [1.012, 1.022]	1.017 [1.013, 1.021]	1.016 [1.013, 1.020]	1.016 [1.012, 1.021]	1.016 [1.011, 1.022]
	HT$_{CWI}$	1.016 [1.010, 1.021]	1.016 [1.011, 1.020]	1.015 [1.012, 1.019]	1.015 [1.011, 1.020]	1.015 [1.010, 1.020]
	HT$_{HWI}$	1.016 [1.011, 1.021]	1.016 [1.012, 1.020]	1.017 [1.014, 1.020]	1.017 [1.014, 1.021]	1.018 [1.013, 1.023]
Cycling training						
Mean power output (W)	CON	171 [149, 195]	171 [150, 195]	173 [150, 196]	173 [151, 197]	174 [151, 198]
	HT	171 [149, 195]	170 [149, 194]	170 [149, 194]	170 [148, 194]	170 [148, 194]
	HT$_{CWI}$	165 [144, 189]	166 [145, 190]	168 [146, 190]	168 [146, 192]	169 [147, 193]
	HT$_{HWI}$	169 [147, 193]	170 [148, 193]	170 [148, 194]	170 [148, 195]	170 [148, 195]
Mean cadence ($r \cdot min^{-1}$)	CON	78 [71, 85]	78 [71, 84]	77 [71, 84]	77 [70, 83]	77 [69, 83]
	HT	78 [71, 85]	78 [71, 84]	77 [70, 83]	77 [70, 83]	76 [69, 83]
	HT$_{CWI}$	80 [72, 86]	80 [72, 86]	79 [72, 85]	79 [72, 85]	79 [71, 85]
	HT$_{HWI}$	**73 [66, 80]**[a,b,c]	**74 [67, 80]**[a,b,c]	**75 [68, 81]**[a,b,c]	**75 [68, 82]**[a,b,c]	**76 [69, 83]**[a,b,c]
Peak heart rate ($b \cdot min^{-1}$)	CON	**145 [136, 153]**[b,c,d]	**145 [136, 152]**[b,c,d]	**144 [135, 151]**[b,c,d]	**144 [135, 151]**[b,c,d]	**143 [134, 151]**[b,c,d]
	HT	167 [157, 175]	165 [155, 172]	160 [153, 169]	160 [150, 167]	157 [147, 165]
	HT$_{CWI}$	**169 [159, 177]**[b,d]	**168 [158, 175]**[b,d]	**165 [157, 174]**[b,d]	**165 [156, 172]**[b,d]	**164 [154, 172]**[b,d]
	HT$_{HWI}$	163 [154, 170]	162 [152, 169]	159 [151, 167]	159 [149, 166]	157 [147, 165]
Peak rectal temperature (°C)	CON	**38.36 [38.17, 38.54]**[b,c,d]	**38.36 [38.18, 38.53]**[b,c,d]	**38.35 [38.18, 38.53]**[b,c,d]	**38.35 [38.18, 38.53]**[b,c,d]	**38.35 [38.16, 38.54]**[b,c,d]
	HT	38.82 [38.63, 39.01]	38.77 [38.60, 38.95]	38.67 [38.55, 38.90]	38.67 [38.50, 38.85]	38.63 [38.44, 38.81]
	HT$_{CWI}$	**38.83 [38.64, 39.03]**[b,d]	**38.83 [38.65, 39.01]**[b,d]	**38.83 [38.66, 39.01]**[b,d]	**38.83 [38.66, 39.01]**[b,d]	**38.83 [38.64, 39.02]**[b,d]
	HT$_{HWI}$	38.76 [38.58, 38.94]	38.75 [38.58, 38.92]	38.74 [38.57, 38.92]	38.74 [38.56, 38.91]	38.73 [38.55, 38.91]
Non-urine fluid loss (kg)	CON	**-1.0 [-1.2, -0.7]**[b,c,d]	**-1.0 [-1.2, -0.7]**[b,c,d]	**-1.0 [-1.2, -0.7]**[b,c,d]	**-1.0 [-1.2, -0.7]**[b,c,d]	**-1.0 [-1.3, -0.8]**[b,c,d]
	HT	-1.4 [-1.6, -1.2]	-1.4 [-1.7, -1.2]	-1.4 [-1.6, -1.1]	-1.4 [-1.7, -1.2]	-1.4 [-1.7, -1.2]
	HT$_{CWI}$	-1.3 [-1.6, -1.1]	-1.4 [-1.6, -1.1]	-1.4 [-1.6, -1.1]	-1.4 [-1.6, -1.1]	-1.4 [-1.6, -1.1]
	HT$_{HWI}$	-1.4 [-1.7, -1.2]	-1.4 [-1.7, -1.2]	-1.4 [-1.6, -1.2]	-1.4 [-1.6, -1.2]	-1.4 [-1.7, -1.2]
Post-cycling recovery						
Non-urine fluid loss (kg)	CON	-0.1 [-0.2, 0.0]	-0.1 [-0.2, 0.0]	0.0 [-0.2, 0.0]	0.0 [-0.1, 0.0]	-0.1 [-0.2, 0.0]
	HT	-0.1 [-0.2, 0.0]	-0.1 [-0.2, 0.0]	-0.1 [-0.2, 0.0]	-0.1 [-0.2, 0.0]	-0.2 [-0.2, 0.0]
	HT$_{CWI}$	-0.1 [-0.2, 0.0]	-0.1 [-0.2, 0.0]	-0.1 [-0.2, 0.0]	-0.1 [-0.2, 0.0]	-0.1 [-0.2, 0.0]
	HT$_{HWI}$	**-0.4 [-0.5, -0.3]**[a,b,c]	**-0.5 [-0.6, -0.4]**[a,b,c]	**-0.5 [-0.6, -0.4]**[a,b,c]	**-0.5 [-0.6, -0.4]**[a,b,c]	**-0.5 [-0.6, -0.4]**[a,b,c]

Note. HT$_{CWI}$ n = 7; CON = thermoneutral training with seated rest recovery; HT = heat-training with seated rest recovery; HT$_{CWI}$ = heat-training with cold-water recovery; HT$_{HWI}$ = heat-training with hot-water recovery; statistical differences are shown in bold; [a] statistically different to CON; [b] statistically different to HT; [c] statistically different to HT$_{CWI}$; [d] statistically different to HT$_{HWI}$.