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

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19

20   **ABSTRACT**

21   **Purpose:** This study examined the effects of daily cold- and hot-water recovery on training

22   load (TL) during 5-days of heat-based training. **Methods:** Eight males completed 5-days of

23   cycle training for 60-min (50% peak power output) in four different conditions, using a block

24   countered-balanced order design. Three conditions were completed in the heat (35 °C) and one

25   in a thermoneutral environment (24 °C, CON). Each day after cycling, participants completed

26   20 min of seated rest (CON and heat-training, HT), or cold- (14 °C; HT_{CWI}) or hot-water

27   immersion (39 °C; HT_{HWI}). Heart rate, rectal temperature, and rating of perceived exertion

28   (RPE) were collected during cycling. A session-RPE was collected 10-min after recovery for

29   the determination of session-RPE TL. Data were analysed using hierarchical regression in a

30   Bayesian framework, Cohens d was calculated, and for session-RPE TL, the probability that d

31   >0.5 was also computed. **Results:** There was evidence that session-RPE TL was increased in

32   HT_{CWI} (d= 2.90) and HT_{HWI} (d= 2.38) compared to HT. The probability that d >0.5 was .99

33   and .96, respectively. The higher session-RPE TL observed in HT_{CWI} coincided with a greater

34   cardiovascular (d= 2.29) and thermoregulatory (d= 2.68) response during cycling compared to

35   HT. This result was not observed for HT_{HWI}. **Conclusion:** These findings may suggest that (1)

36   cold-water recovery may negatively affect TL during 5-days of heat-based training; (2) hot-

37   water recovery could increase session-RPE TL; and (3) the session-RPE method can detect

38   environmental temperature mediated increases in TL in the context of this study.

39

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

41

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

67 perceptual parameters, and improve TL tolerance. However, cooling could interfere with, and

68 possibly impair, processes that facilitate improved heat stress tolerance.[15] Surprisingly, a

69 comparison of post-exercise cold- and hot-water immersion use during a heat-based training

70 intervention does not exist.

71   Quantifying an athlete's tolerance to training in hot environments is complex, as

72 increases in physiological and perceptual responses coincide with reduced physical work.[8]

73 While the physiological responses to heat-based training have been widely considered,[1,3]

74 perceived responses, like the session rating of perceived exertion (session-RPE), have received

75 limited attention.[1] Moreover, the effects of cold- and hot-water recoveries on TL during

76 exertional-heat stress over multiple days are unknown. As such, there is a need to understand

77 the influence of common thermal recoveries on training tolerance, which could be reflected in

78 physiological and perceived training responses.[1,2,5] In a fixed-intensity task, the internal TL

79 response is not confounded by fluctuations in mechanical work. Therefore, changes in

80 physiological and perceived responses are likely to reflect alterations in heat stress tolerance,

81 rather than alterations in mechanical work.

82   This study examined the effects of daily cold- and hot-water recovery on TL, during

83 five consecutive days of heat-based training, using session-RPE as the primary indicator of TL.

84 It was hypothesised that (1) cold-water recovery would reduce session-RPE TL; and (2) hot-

85 water immersion would increase session-RPE TL, compared to heat-training with passive

86 recovery.

87

88 **METHODS**

89 ***Subjects***

90   Eight healthy males (Table 1), classified as performance level 2 cyclists (1 to 5

91 performance level classification scale, with 5 indicating highly trained cyclists) according to

92 the mean peak oxygen consumption ($\dot{V}O_{2peak}$) and peak power output (PPO)[16], provided

93 informed written consent to participate in the study. All participants had no previous experience

94 undertaking a structured heat-based training intervention. All experimental procedures adhered

95 to the standards set by the latest revision of the declaration of Helsinki, except for registration

96 in a database, and were approved by the University Human Research Ethics Committee of

97 Queensland University of Technology (1700000651).

98

99 ***Design***

100 Participants completed four conditions in a block countered-balanced order (Latin

101 Square). Each condition comprised an incremental cycling test and five consecutive days of

102 cycling in temperate (CON; 24 °C; 50% relative humidity, RH) or hot conditions (35 °C; 50%

103 RH; wet bulb globe temperature 29.5 °C). Environments were simulated by a chamber (4.7

104 km·h^{-1} wind speed), and logged (3M QUESTemp, Quest Technologies, USA). Recovery

105 consisted of seated rest (CON and HT), or immersion in cold (HT_{CWI}) or hot water (HT_{HWI}).

106 No fluid was consumed during cycling or recovery. During the study, participants were asked

107 to avoid alcohol and vigorous exercise, and to keep their dietary intake consistent. There was

108 a minimum of 25 days between conditions, with a mean (± standard deviation, SD) of 42±9

109 days.[2] Testing was conducted from November to May in Brisbane, Australia.

110

111 ***Methodology***

112 *Familiarisation and incremental cycling test*

113 Participants were pre-screened (Exercise and Sports Science Australia, Adult Pre-

114 Exercise Screening Tool) and familiarised to all perceptual outcomes. Perceived wellness was

115 measured using a 5-item questionnaire (fatigue, sleep quality, muscle soreness, stress levels

116 and mood).[17] Each item was rated from 1 to 5 (increments of 1). Items were summed, with

117 higher scores reflecting better wellness. RPE was collected using Borg's[18] 6–20 scale, and

118 perceived thermal sensation using the Young et al[19] 0–8 scale. Session-RPE was collected

119 using the 0–10 scale (0 'rest' to 10 'maximal') described by Foster et al[20]. Ratings were

120 collected with the instructions 'how was your workout?', and multiplied by training duration,

121 for the determination of session-RPE TL.[20] A session-RPE was collected 10-min after the

122 recovery period. The session-RPE TL method has been shown to be an internally and externally

123 valid.[5,20]

124   PPO and $\dot{V}O_{2peak}$ were determined via an incremental cycling test (Excalibur Sport;

125 Lode, Netherlands). The test started at 75 W and increased by 25 W·min^{-1} until volitional

126 fatigue. PPO was calculated according to De Pauw et al[16]. Pulmonary gas exchange (TrueOne

127 2400, Parvo Medics, USA) was collected breath-by-breath to provide measures of minute

128 ventilation and oxygen uptake, and HR was recorded (Team 2; Polar Electro Oy, Finland).

129 Data were averaged over 15 seconds, with peak values taken as the highest measurement

130 achieved in the test.

131

132   *Training sessions*

133   Training was undertaken at the same time of day (±2 h). Mid-stream urine samples were

134 collected from the first void and at arrival for the assessment of specific gravity (U_{SG}; PAL-

135 10S; Atagi Ci. Ltd, Japan). The wellness questionnaire, and physical activity (24 h) and food

136 (48 h) diaries were completed, and nude mass recorded (WB-110AZ; Tanita Corp., Japan). A

137 flexible thermistor was inserted ~12 cm past the anal sphincter (449H; Henleys Medical,

138 England) for measurements of rectal temperature (T_{re}). Four iButtons (DS1922L-F50, Maxim

139 Intergrated, USA) were attached (back of the neck, right scapula, left hand, and right shin) with

140 sports tape (Leuko Sportstape; Beiersdorf, Germany). Mean skin temperature ($\overline{T}_{sk}$) was

141 calculated according to international standards, using the equation: $\overline{T}_{sk} = neck * 0.28 +$

142   $scapula * 0.28 + hand * 0.16 + shin * 0.28.$[21] A HR monitor and strap were fitted and

143   thermal sensation was recorded before participants entered the chamber.

144   Participants cycled for 60 min at 50% PPO (Wattbike Pro; Wattbike Ltd, England).

145   Each participants' training attire (bibs without a jersey, socks, and cleats, or sports shorts, socks

146   and rubber-soled shoes), pedals (flat or clipless) and ergometer settings remained consistent.

147   During cycling, RPE and thermal sensation were collected every 10-min. T_{re} and $\overline{T}_{sk}$ were

148   sampled every 30 seconds, and HR continuously recorded. Training was terminated if T_{re}

149   exceeded 39.9 °C (no incidents). After cycling, nude mass was recorded for the calculation of

150   non-urine fluid loss (NUFL).

151

152   *Post-exercise recovery*

153   During a 5-min transition, participants consumed 250 mL of room temperature water,

154   and donned sports shorts. For CON and HT, participants sat quietly for 20-min in the laboratory

155   (24 °C; 50% RH). Cold- and hot-water recovery consisted of immersion in an inflatable bath

156   (iBody, iCoolsport, Australia) to the umbilicus, legs fully extended, and forearms submerged.

157   Cold water was maintained at 14.7±1.4 °C (target: 14 °C),[9,22] and hot water at 39.2±0.6 °C

158   (target: 39 °C) (NIST-certified thermometer, TL1-W, ThermoProbe Inc., USA). The hot target

159   (39 °C) was selected from pilot testing, due to its ability to maintain T_{re} after cycling, and be

160   tolerated by the participants. During recovery, thermal sensation was collected every 5-min,

161   HR continuously recorded, and Tre and $\overline{T}_{sk}$ sampled every 30 seconds. Nude mass was

162   recorded after recovery, and a session-RPE rating collected 10-min later.

163

164   **Statistical analysis**

165   Session-RPE TL and wellness were modelled with Bayesian hierarchical regression

166   with a beta response distribution using the 'zoib' package[23] in R (Version 3.4.4). Before

167   analysis, data were transformed using the equation: $y' = (y - a)/(b - a)$, where 'a' is the

168   smallest possible value (i.e., session-RPE TL 0, wellness 5), 'b' the highest possible value (i.e.,

169   session-RPE TL 600, wellness 25), and 'y' the observed value. Models included participant ID

170   as a random variable, and day, condition and day x condition as fixed factors. Where time or

171   condition, but not time x condition, effects were observed the interaction was removed from

172   the model. Markov chain Monte Carlo (MCMC) methods were used to generate posterior

173   estimates via 2 independent chains, 10,200 MCMC iterations, a 200 iteration burn-in and

174   thinned by a factor of 50. A Normal (mean 0, precision 1/0.001) prior distribution was utilised

175   for regression coefficients, and a Uniform (mean 0, SD 20) prior for the SD of the random

176   effects.

177   Bayesian hierarchical regression was utilised to model pre-cycling nude mass, U_{SG}, HR,

178   peak HR, T_{re}, peak T_{re}, $\overline{T}_{sk}$, RPE, thermal sensation, power output, cadence and NUFL. Models

179   were implemented using the 'rjags'[24] and 'R2jags'[25] packages in R. HR, peak HR, T_{re}, peak

180   T_{re}, $\overline{T}_{sk}$, RPE, thermal sensation, power output, and cadence models included day, condition

181   and day x condition as fixed factors. Again, where time or condition, but not interaction, effects

182   were observed the interaction was removed. The NUFL model included time (i.e., before and

183   after cycling, and after recovery), day, condition and their interactions as fixed factors. All

184   models included a random intercept for each participant ID. A Normal (mean 0, precision

185   0.001) prior distribution was utilised for the regression coefficients and Gamma (shape 0.01,

186   scale 0.01) prior for each variance parameter. Posterior estimates were simulated from 50,000

187   MCMC iterations, with 1,000-iteration burn-in and thinned by a factor of 10.

188   Posterior estimates are reported as the mean and 95% credible interval (CI). Cohen's d

189   (and 95% CI) was calculated with the denominator: $\sqrt{\mathrm{var}(d_{kl})}$, where '$d_{kl}$' is the difference

190   between days or conditions 'k' and 'l'.[26,27] Cohen's d values were interpreted as small 0.2,

191   medium 0.5, and large 0.8.[26] For session-RPE TL, the probability that d exceeded 0.5 was also

192 computed where there was evidence of statistical differences between HT and HT_{CWI}, or HT

193 and HT_{HWI}.[27] When the 95% CI of a regression coefficient (β) or MD did not include zero it

194 was concluded that there was evidence of a statistical effect or difference. The convergence of

195 MCMC to the posterior distribution was assessed via trace plots. Posterior predictive checks

196 were performed to assess the suitability of the chosen models.

197

198 **RESULTS**

199 One participant withdrew, for reasons unrelated to the study (interstate relocation),

200 having completed three conditions. Therefore, HT_{CWI} n=7. All other participants completed all

201 four conditions, with no incidents of injury or illness.

202

203 *Incremental cycling test*

204 There was little evidence of statistical differences in $\dot{V}O_{2peak}$, PPO, or peak HR between

205 conditions (Table 1).

206

207 *Perceived training load*

208 Bayesian analysis showed evidence of a condition effect for session-RPE TL ($β_{HTCWI}$:

209 0.6 [0.1, 1.1]; $β_{HTHWI}$: 0.6 [0.1, 1.1]). Session-RPE TL (Figure 1) was statistically higher in the

210 heat versus CON (d= 5.95 to 7.29). There was also evidence that session-RPE TL was

211 statistically higher in HT_{CWI} versus HT (MD [95% CI] = 55 [14, 91]; d [95% CI] = 2.90 [0.74,

212 4.76]), and statistically higher in HT_{HWI} versus HT (MD= 39 [6, 67]; d= 2.38 [0.35, 4.11]). The

213 probability that d >0.5 for these comparisons was .99 and .96, respectively.

214

215 *Pre-cycling outcomes*

216   Perceived wellness, pre-cycling mass, and first void and arrival U_{SG} are shown in Table

217   2. There was little evidence of day, condition, or day x condition effects for wellness, mass, or

218   U_{SG}.

219

220   ***Cycling training***

221   Mean power output and cadence are displayed in Table 2. There was little evidence of

222   day, condition or day x condition effects for power output. There was evidence of a condition

223   effect for cadence (β_{HTHWI}: -6.3 [-11.3, -1.3]). Cadence was statistically lower in HT_{HWI} versus

224   CON (*d* [95% CI] = -2.61 [-4.57, -0.67]), HT (*d*= -2.24 [-4.21, -0.26]), and HT_{CWI} (*d*= -3.93 [-

225   5.89, -2.02]).

226   There was evidence of a condition effect for mean training HR (β_{HT}: 14.3 [8.4, 20.4];

227   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

228   versus CON (*d*= 8.63 to 10.59). There was evidence that mean HR was statistically higher in

229   HT_{CWI} versus HT (*d* [95% CI] = 2.29 [0.34, 4.26]), and HT_{HWI} (*d*= 2.76 [0.77, 4.70]). There

230   was evidence of a condition effect for peak HR (β_{HT}: 23.8 [17.2, 30.4]; β_{HTCWI}: 24.5 [17.6,

231   31.3]; β_{HTHWI}: 18.709 [12.003, 25.385]). Peak HR (Table 2) was statistically higher in the heat

232   versus CON (*d*= 10.45 to 13.65). Peak HR was also statistically higher in HT_{CWI} versus HT (*d*

233   [95% CI] = 2.63 [0.66, 4.63]) and HT_{CWI} versus HT_{HWI} (*d*= 3.91 [1.90, 5.87]).

234   Bayesian analysis showed some evidence of a condition effect for mean T_{re} (β_{HT}: 0.22

235   [0.01, 0.42]; β_{HTCWI}: 0.205 [-0.003, 0.412]). Mean T_{re} (Figure 2B) was statistically higher in

236   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*=

237   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];

238   β_{HTCWI}: 0.48 [0.31, 0.66]; β_{HTHWI}: 0.41 [0.24, 0.57]). Peak T_{re} (Table 2) was statistically higher

239 in the heat versus CON (d= 9.20 to 12.16). There was also evidence peak T_{re} was higher in

240 HT_{CWI} versus HT (d= 2.84 [0.81, 4.79]), and HT_{HWI} (d= 2.47 [0.49, 4.40]).

241 There was evidence of a condition effect for mean cycling $\overline{T}_{sk}$ (β_{HT}: 3.3 [2.5, 4.2];

242 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

243 the heat compared to CON (d= 16.00 to 19.32), and statistically lower in HT_{HWI} versus HT (d

244 [95% CI] = -3.85 [-5.82, -1.91]) and HT_{CWI} (d= -4.47 [-6.41, -2.51]). There was evidence of a

245 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, -

246 0.3]). NUFL (Table 2) was greater in the heat versus CON (d= 4.47 to 7.09), but not statistically

247 different between the hot conditions.

248 Analysis showed evidence of a condition effect for mean RPE (β_{HT}: 1.2 [0.4, 2.1];

249 β_{HTCWI}: 1.1 [0.2, 2.0]; β_{HTHWI}: 0.9 [0.1, 1.8]). Mean RPE (Figure 2D) was statistically higher

250 in the heat versus CON (d= 5.92 to 7.79), and higher in HT_{CWI} versus HT (d [95% CI] = 2.07

251 [0.13, 4.00]). There was evidence of a condition effect for mean cycling thermal sensation (β_{HT}:

252 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

253 higher in the heat versus CON (d= 9.33 to 11.41). There was little indication perceived thermal

254 sensation was statistically different between the heat-training conditions.

255

256 ***Post-cycling recovery***

257 Bayesian analysis showed evidence of a condition effect for mean recovery HR (β_{HT}:

258 9.8 [2.2, 17.7]; β_{HTHWI}: 26.5 [19.2, 33.8]). Mean recovery HR (Figure 3A) was statistically

259 higher in HT versus CON (d [95% CI] = 3.59 [1.65, 5.50]) and versus HT_{CWI} (d= 2.84 [0.86,

260 4.78]). There was also evidence mean recovery HR was higher in HT_{HWI} compared to all other

261 conditions (d= 12.25 to 15.48).

262   There was some indication of a condition effect for mean recovery T_{re} (β_{HT}: 0.31 [0.02,

263   0.61]; β_{HTCWI}: 0.31 [0.02, 0.59]; β_{HTHWI}: 0.7 [0.4, 0.9]). Recovery T_{re} (Figure 3B) was

264   statistically higher in HT versus CON (d [95% CI] = 3.92 [1.95, 5.91]), and higher in HT_{CWI}

265   versus CON (d= 3.77 [1.84, 5.76]). Recovery T_{re} was also higher in HT_{HWI} compared to all

266   other conditions on all days (d= 6.27 to 10.14).

267   There was evidence of a condition effect for mean recovery $\overline{T}_{sk}$ (β_{HT}: 1.1 [0.1, 2.1];

268   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

269   versus CON (d [95% CI] = 4.44 [2.51, 6.39]), lower in HT_{CWI} compared to all other conditions

270   (d= -49.85 to -19.16), and higher in HT_{HWI} compared to all other conditions (d= 26.11 to 49.85).

271   There was evidence of a condition effect for NUFL during recovery (β_{HTHWI}: -0.4 [-0.5, -0.3]).

272   Recovery NUFL (Table 2) was greater in HT_{HWI} compared to all other conditions (d= -11.47

273   to -5.84).

274   There was evidence of a condition effect for mean recovery thermal sensation (β_{HTCWI}:

275   -2.1 [-2.6, -1.6]; β_{HTHWI}: 2.1 [1.6, 2.6]). Perceived thermal sensation (Figure 3D) was

276   statistically lower in HT_{CWI} compared to all other conditions (d= -40.52 to -18.87), and higher

277   in HT_{HWI} compared to all other conditions (d= 18.65 to 40.52).

278

279   **DISCUSSION**

280   This study aimed to investigate the effect of daily cold- and hot-water recovery on TL

281   during 5-days of heat-based training, using session-RPE as the primary indicator of TL.

282   Session-RPE TL was higher in all heat-training conditions compared to temperate environment

283   cycling training (Figure 1). In contrast to our hypothesis, session-RPE TL was higher when

284   using cold-water recovery compared to compared to heat-training with passive recovery

285   (Figure 1). There was also evidence that cold-water recovery increased the cardiovascular

286 response to training (Figure 2; Table 2). In support of our hypothesis, hot-water recovery

287 increased session-RPE TL compared to heat-training with passive recovery (Figure 1). The

288 cardiovascular response to training appeared unaffected by hot-water recovery. Interestingly,

289 there was little evidence that post-exercise hot-water immersion improved heat stress tolerance.

290 Results from this study suggest that (1) cold-water recovery may negatively affect TL during

291 5-days of heat-based training; (2) hot-water could increase session-RPE TL; and (3) the

292 session-RPE method can detect environmental temperature mediated increases in TL during 5-

293 days of cycle training.

294   Cold-water recovery elicited a higher internal TL response compared to passive rest,

295 evident by a statistically higher mean cycling HR, T_{re} and RPE (Figure 2A, 2B and 2D).

296 Importantly, these differences were not attributed to alterations in mechanical work, as power

297 output was matched between conditions (Table 2). It is possible that the higher HR, T_{re} and

298 RPE in HT_{CWI} may explain the session-RPE TL results (Figure 1).[20] Equally, hydrostatic

299 pressure from water immersion, rather than the water temperature per se, may also explain the

300 higher session-RPE TL. In support of this notion, session-RPE TL was higher with hot-water

301 recovery, in the absence of the HR, T_{re} and RPE differences observed in HT_{CWI}. Contrasting

302 our study, Skein et al[28] observed no differences in exercise HR or RPE when daily cold-water

303 recovery was included in 5-days of heat-based training. The water temperature utilised by

304 Skein et al[28] was identical to our study, but the immersion period was 5-min shorter. The longer

305 immersion and shorter training time (30-min less) in our study could explain the disparity in

306 findings. Skein et al[28] did not collect session-RPE meaning we are unable to compare this

307 variable.

308   Consistent with some short-term heat-training interventions[1], there was little evidence

309 that 5-days of cycling in 35 °C (50% RH) induced acclimation (Figure 2; Table 2). As expected,

310 cycling in the heat increased the TL response compared to the temperate environment (Figure

311 1 and 2; Table 2). Interestingly, the 100-min of additional heat stress provided by hot-water

312 immersion did not induce acclimation. It is possible that the lower cadence maintained in

313 HT_{HWI} could partly explain the increased session-RPE TL, as a greater neuromuscular demand

314 could have been required to maintain the same power output, and this may have been reflected

315 in session-RPE ratings (Table 1). However, considering the small differences in cadence,

316 hydrostatic pressure could also explain the higher session-RPE TL. Hot-water immersion for

317 acclimation has been utilised in isolation[29], and after exercise in a temperate environment[7]. In

318 contrast to our findings, these studies[7,29] observed classic signs of heat acclimation (e.g.,

319 reduced HR, greater body mass loss). Differences in intervention length, training duration, and

320 participants' training status may explain the conflicting results.[7,29]

321   Our findings suggest that the session-RPE method can detect environmental temperature

322 mediated increases in TL during 5-days of cycle training.[20] However, the results need to be

323 interpreted with care. Session-RPE was collected 10 min after recovery. As such, it is unclear

324 whether findings would be similar if data were collected at a different time point (e.g., the

325 following morning). Nonetheless, these results may highlight the need to consider the timing

326 of session-RPE collection when recovery strategies are utilised. We explored whether

327 participant dropout (n=1) affected session-RPE TL results. After including the missing

328 individuals mean session-RPE values from HT and HT_{HWI} for HT_{CWI}, the conclusions remained

329 unchanged (β_{HTCWI}: 0.57 [0.03, 1.08]; β_{HTHWI}: 0.55 [0.04, 1.06]). Cold-water recovery is

330 typically associated with improved perceptions of recovery and wellness.[12,28] In the current

331 study, cold-water recovery had little influence on perceived wellness (Table 2). This could

332 suggest differences in time-course of responses[17] or the poor sensitivity of these types of

333 questionnaires as TL monitoring tools.

334   The primary limitations of the current study are the sample size and intervention length.

335 Hierarchical regression models and estimation methods were utilised in an attempt to handle

336   the small sample.[27] Despite utilising a rigorous counter-balance design, the elongated data

337   collection period may have resulted in some parameters being affected by seasonal, training or

338   dietary variations.[30] For example, $\overline{T}_{sk}$ was lower in HT_{HWI} (Figure 2C). We explored whether

339   an order effect could explain our session-RPE TL findings—but found little evidence to

340   support this line of inquiry. An order effect may have been expected because our participants

341   had no previous experience with heat-based training protocols. Finally, it is unknown whether

342   session-RPE TL findings would remain the same if both cadence and power output had been

343   fixed. Future investigations should replicate this study utilising a longer training intervention;

344   explore the effect of cool (e.g., 20 °C), rather than cold, water-recovery on session-RPE TL;

345   and examine the influence of multiple rest days after the intervention on performance.

346

347   **PRACTICAL IMPLICATIONS**

348   •   The session rating of perceived exertion method can detect environmental temperature

349   mediated increases in training load during 5-days of cycle training.

350   •   Results from the current study may indicate that cold-water immersion should not be

351   utilised in conjunction with heat-based training.

352   •   Twenty-minutes of daily post-exercise hot-water immersion may not improve heat

353   stress tolerance after 5-days of heat-based training.

354

355   **CONCLUSION**

356   This is the first study to examine the effects of daily cold- and hot-water recovery on

357   TL during 5-days of heat-based training. There was evidence that cold-water increased session-

358   RPE TL and the cardiovascular response to training. Hot-water recovery also increased

359   session-RPE TL, but not the cardiovascular response to training. There was little evidence that

360   that added thermal stimulus provided by hot-water immersion improved heat stress tolerance.

361　Our findings suggest that (1) cold-water recovery may negatively affect TL during 5-days of

362　heat-based training; (2) hot-water recovery could negatively impact session-RPE TL; and (3)

363　the session-RPE method can detect environmental temperature mediated increases in the

364　context of this study.

365

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442

443

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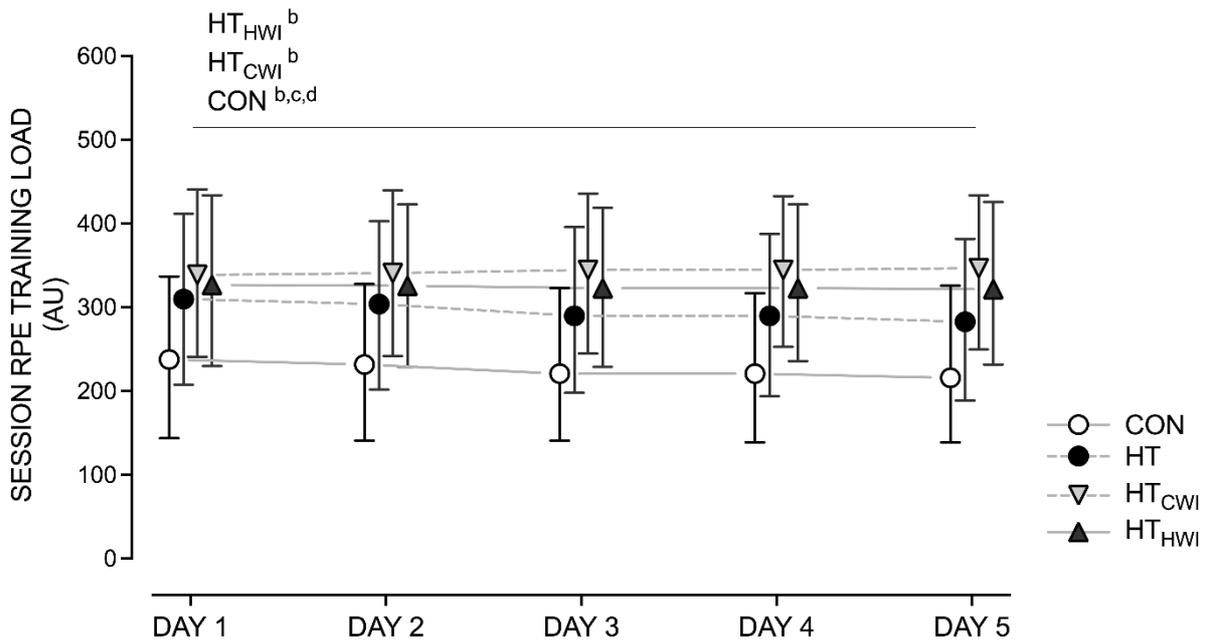
Figure 1. Posterior mean (and 95% credible interval) session rating of perceived exertion training load (i.e., session-R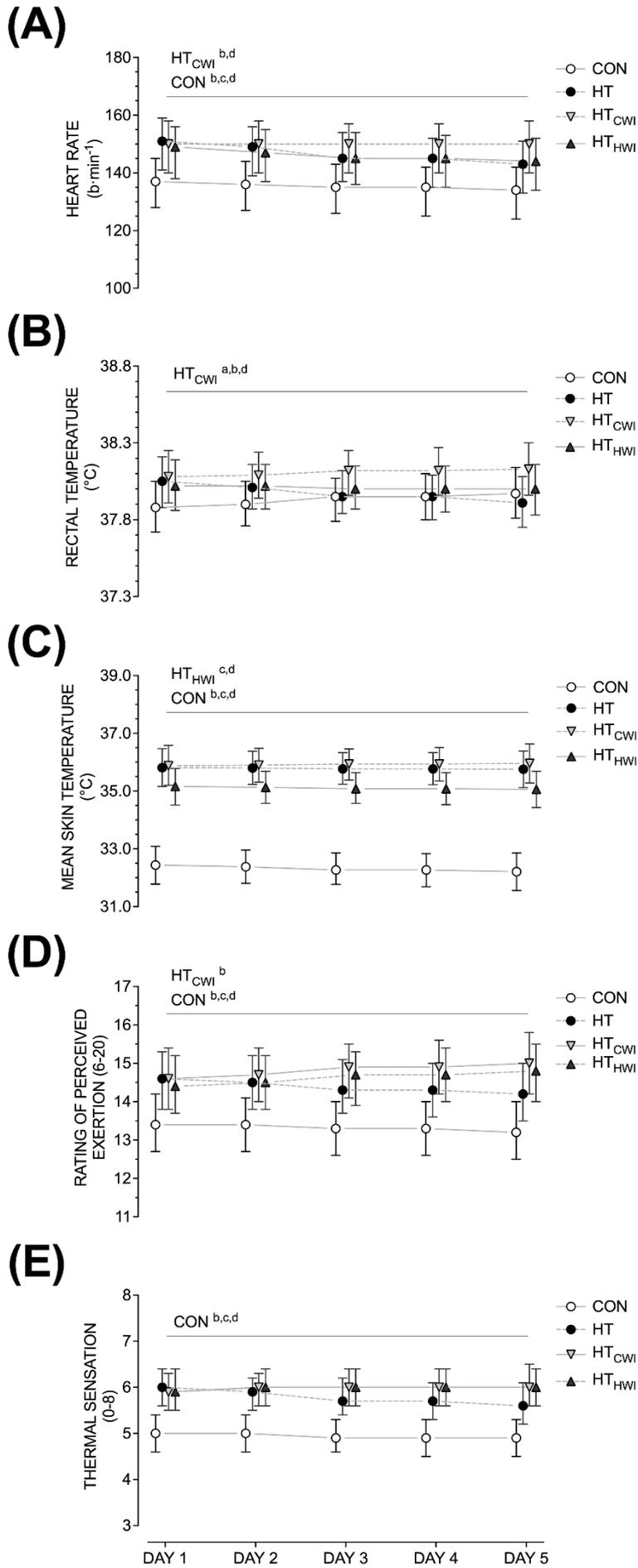PE x training duration) across the 5-day intervention. CON = temperate training with seated rest recovery, HT = heat training with seated rest recovery, HT_{CWI} = heat training with cold-water recovery, HT_{HWI} = heat training with hot-water recovery, [b] statistically different to HT, [c] statistically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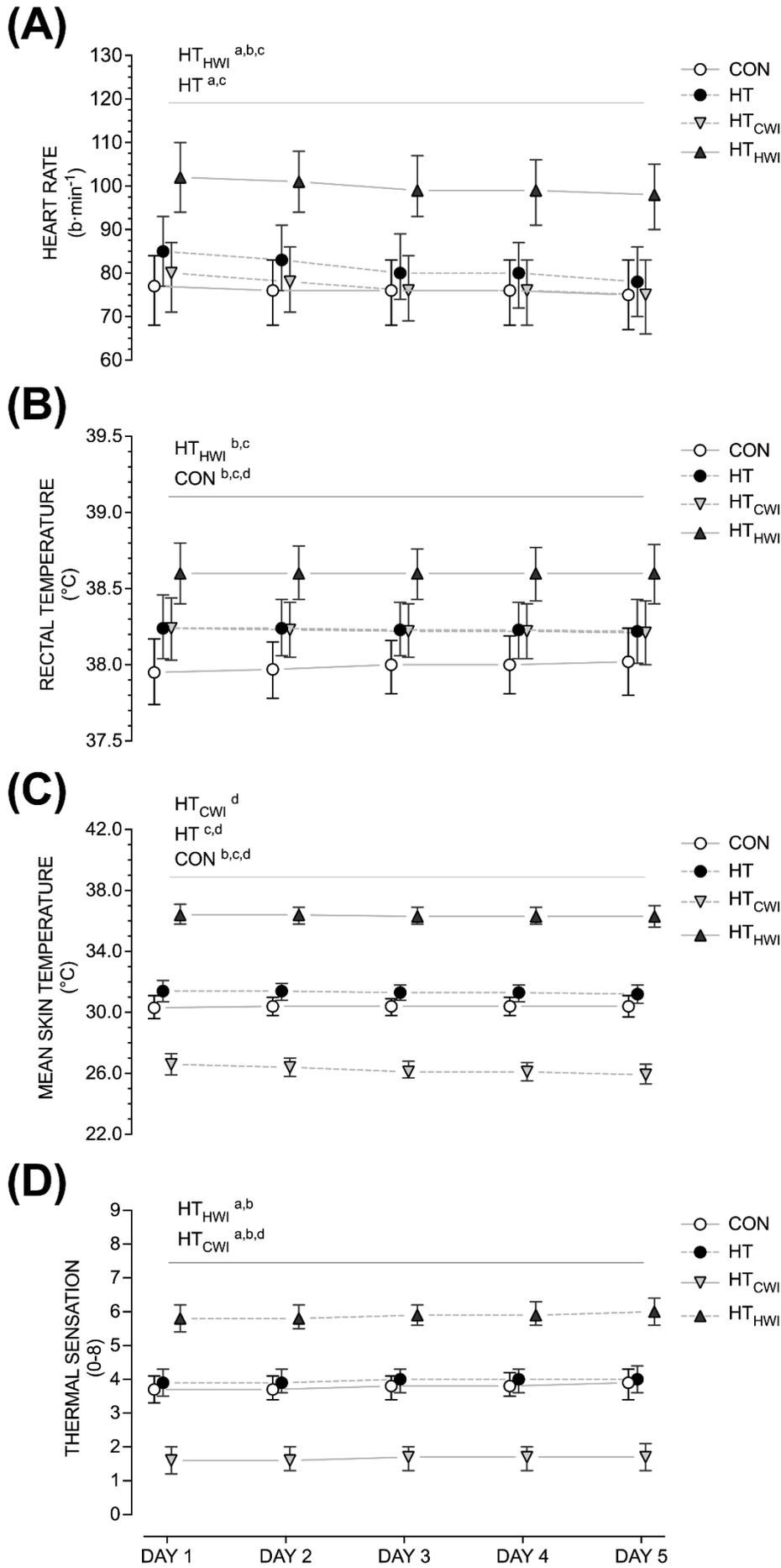
(A)

(B)

(C)

(D)

(E)

454   **Figure 2.** Posterior mean (and 95% credible interval) heart rate (A), rectal temperature (B),

455   four-site mean skin temperature (C), rating of perceived exertion (D), and perceived thermal

456   sensation (E) during cycle training. CON = temperate training with seated rest recovery, HT =

457   heat training with seated rest recovery, HT_{CWI} = heat training with cold-water recovery, HT_{HWI}

458   = heat training with hot-water recovery. [a] statistically different to CON, [b] statistically different

459   to HT, [c] statistically different to HT_{CWI}, [d] statistically different to HT_{HWI}.

460

(A)

HT_{HWI} [a,b,c]
HT [a,c]

HEART RATE
(b·min⁻¹)

Legend: CON, HT, HT_{CWI}, HT_{HWI}

(B)

HT_{HWI} [b,c]
CON [b,c,d]

RECTAL TEMPERATURE
(°C)

Legend: CON, HT, HT_{CWI}, HT_{HWI}

(C)

HT_{CWI} [d]
HT [c,d]
CON [b,c,d]

MEAN SKIN TEMPERATURE
(°C)

Legend: CON, HT, HT_{CWI}, HT_{HWI}

(D)

HT_{HWI} [a,b]
HT_{CWI} [a,b,d]

THERMAL SENSATION
(0-8)

Legend: CON, HT, HT_{CWI}, HT_{HWI}

DAY 1   DAY 2   DAY 3   DAY 4   DAY 5

461

23

462   **Figure 3.** Posterior mean (and 95% credible interval) heart rate (A), rectal temperature (B),

463   four-site mean skin temperature (C), and perceived thermal sensation (D) during the 20 min

464   recovery period. CON = temperate training with seated rest recovery, HT = heat training with

465   seated rest recovery, HT_{CWI} = heat training with cold-water recovery, HT_{HWI} = heat training

466   with hot-water recovery. [a] statistically different to CON, [b] statistically different to HT, [c]

467   statistically different to HT_{CWI}, [d] statistically different to HT_{HWI}.

468

469 **Table 1.** Participant characteristics (mean ± standard deviation (range)) and incremental
470 cycling test outcomes (posterior mean and 95% credible interval).
471

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* ($mL \cdot kg^{-1} \cdot min^{-1}$)		49.3 ± 4.9 (45.2–60.5)
Training activities** ($sessions \cdot week^{-1}$)		3.6 ± 1.3 (2.0–5.0)
Training minutes** ($min \cdot week^{-1}$)		191 ± 63 (120–280)
Incremental cycling test outcomes		
Peak oxygen consumption ($L \cdot min^{-1}$)	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 ($b \cdot min^{-1}$)	CON	183 [173, 192]
	HT	184 [175, 194]
	HT_{CWI}	184 [174, 194]
	HT_{HWI}	184 [174, 193]

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

476 **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·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 [71, 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·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]

477
478 *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}.
479