

1 **The impact of environmental temperature deception on perceived exertion during fixed-**
2 **intensity exercise in the heat in trained-cyclists.**

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22 The authors have no conflict of interests to declare. The authors declare that the results of this
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29 **ABSTRACT**

30 **Purpose:** This study examined the impact of environmental temperature deception on the
31 rating of perceived exertion (RPE) during 30 min of fixed-intensity cycling in the heat.

32 **Methods:** Eleven trained male cyclists completed an incremental cycling test and four
33 experimental trials. Trials consisted of 30 min cycling at 50% P_{max} , once in 24 °C (CON) and
34 three times in 33 °C. In the hot trials, participants were provided with accurate temperature
35 feedback (HOT), or were deceived to believe the temperature was 28 °C (DEC_{LOW}) or 38 °C
36 (DEC_{HIGH}). During cycling, RPE was recorded every 5 min. Rectal and skin temperature, heart
37 rate and oxygen uptake were continuously measured. Data were analysed using linear mixed
38 model methods in a Bayesian framework, magnitude-based inferences (Cohens d), and the
39 probability that d exceeded the smallest worthwhile change. **Results:** RPE was higher in the
40 heat compared to CON, but not statistically different between the hot conditions (mean [95%
41 credible interval]; DEC_{LOW}: 13.0 [11.9, 14.1]; HOT: 13.0 [11.9, 14.1]; DEC_{HIGH}: 13.1 [12.0,
42 14.2]). Heart rate was significantly higher in DEC_{HIGH} (141 b·min⁻¹ [132, 149]) compared to
43 all other conditions (DEC_{LOW}: 138 b·min⁻¹ [129, 146]; HOT: 138 b·min⁻¹ [129, 145]) after 10
44 min; however, this did not alter RPE. All other physiological variables did not differ between
45 the hot conditions. **Conclusion:** Participants were under the impression they were cycling in
46 different environments; however, this did not influence RPE. These data suggest that for
47 trained cyclists, an awareness of environmental temperature does not contribute to the
48 generation of RPE when exercising at a fixed intensity in the heat.

49

50 **KEYWORDS:** Exercise, effort, feedback, perception, fatigue, Bayesian

51 **1. INTRODUCTION**

52 The role of the central nervous system in regulating intensity during exercise is well
53 documented [1-6]. Changes in self-selected work rate are thought to occur in a manner which
54 prevents excessive fatigue that may otherwise lead to physical exhaustion and task failure [7].
55 Although the precise mechanism(s) remain unclear, a number of models propose to explain
56 this phenomenon [1-6]. Conceptually, these models consider exercise to be regulated
57 consciously [1,4], subconsciously [2,3,6], or by a combination of both processes [5]. Despite
58 underlying differences, all models recognise the perception of intensity or work rate, measured
59 via the rating of perceived exertion (RPE) scale [8,9], as playing an important role in the
60 regulation of exercise.

61 Despite extensive scientific inquiry, the factors which mediate RPE are poorly
62 understood. Multiple inputs have been shown to contribute to its generation, including exercise
63 endpoint [10-12], environmental temperature [13-15], and afferent feedback [16]. However,
64 the influence of afferent feedback on the generation of RPE is somewhat contentious [17].
65 Aside from its complex formulation, methodological constraints make studying the RPE
66 challenging. Exercise selection (i.e., fixed versus self-paced exercise) is an important
67 consideration, as changes in mechanical work inherently alter RPE responses. Another
68 considerable challenge is isolating the origins of individual contributors (e.g., the
69 thermoregulatory system, exercising muscle), due to the systemic increase in physiological
70 strain associated with exercise. The isolation of individual variables often requires an element
71 of deception to manipulate feedback of that particular variable [18,19]. This is complex, as
72 magnitude of deception needs to be capable of exerting some effect, while avoiding detection
73 from participants.

74 Hot environments are associated with greater physiological strain, higher RPE's, and
75 reduced mechanical work compared with matched performance in temperate conditions

76 [14,15]. However, there is some evidence to suggest that the increase in RPE observed in the
77 heat may stem from an overt awareness of the environmental conditions. Castle et al. [13]
78 found that a combination of body and environment temperature deception lowered RPE
79 responses at the beginning of a 30 min self-paced cycling in 33 °C. A greater amount of work
80 was completed when RPE was lower, ameliorating the heat-induced reduction in performance
81 observed when accurate temperature feedback was provided. In contrast, the isolated deception
82 of ambient temperature was found to have no statistical impact on RPE during a 5 km self-
83 paced run in the heat (31 °C) [20]. Nevertheless, there was a trend for lower RPE responses
84 (~0.6 units) at the start of the run (1 km) compared the accurate feedback condition.

85 Temperature deception has previously been studied using self-paced exercise tasks,
86 where changes in RPE may be masked by alterations in mechanical work [13,20]. Where
87 deception has been shown to improve performance and lower RPE [13], the type of deception
88 has not been used in isolation, making it difficult to conclude the effective source (variable).
89 Identifying the efficacious type of temperature deception carries importance, especially if
90 external temperature awareness contributes to the generation RPE in the heat [13, 21]. If so,
91 environmental forecast could in itself increase RPE and so impede performance without
92 altering physiological costs of performance.

93 This study aimed to examine the impact of an awareness of environmental temperature
94 on RPE, by providing individuals with deceptive ambient temperature feedback prior to, and
95 during cycling at a fixed intensity in hot-humid conditions. It was hypothesised that RPE
96 responses would change in the direction of the deception. For example, participants would rate
97 RPE lower when told the environment was cooler (DEC_{LOW}) due to an expectation of a lower
98 level of exertion, and vice-versa when told the environment was warmer (DEC_{HIGH}).

99

100

101 2. METHODS

102 2.1 Participants

103 Twelve trained male cyclists (level three [22]) were initially recruited; however, one
104 cyclist withdrew after sustaining an injury unrelated to the study. The remaining 11 cyclists
105 trained and/or competed ≥ 2 d·wk⁻¹ (mean \pm SD; 4 \pm 1 sessions·wk⁻¹; 347 \pm 203 min·wk⁻¹; 170 \pm 85
106 km·wk⁻¹) and their characteristics were as follows: age: 26.8 \pm 4.1 years; height: 184.5 \pm 8.0
107 cm; nude mass: 81.1 \pm 13.3 kg; maximal aerobic capacity ($\dot{V}O_{2\max}$): 52.7 \pm 6.1 mL·kg⁻¹·min⁻¹
108 (4.2 \pm 0.7 L·min⁻¹); maximal aerobic power output (P_{\max}): 382 \pm 66 W; maximal heart rate:
109 185 \pm 12 b·min⁻¹. The study was approved by the University Human Research Ethics
110 Committee, and informed consent was obtained from all participants included in the study.

111

112 2.2 Experimental design

113 Participants visited the laboratory on five separate occasions. The first visit involved
114 $\dot{V}O_{2\max}$ testing, and familiarisation to the ergometer (and Zwift), neuromuscular assessment
115 procedures and perceptual scales. During visits two-to-five, participants completed
116 neuromuscular testing before and after 30 min of fixed-intensity cycling at 50% P_{\max} . Trials
117 were completed at the same time of day (± 2 h), with an average of eight days between visits.
118 Testing was conducted during the Australian summer months (outdoor temperature; minimum:
119 17–24 °C; maximum: 26–33 °C). Participants were instructed to avoid alcohol, caffeine and
120 exercise, and to match their dietary intake in the 24 h before each testing session. The
121 consumption of fluids was not permitted during cycling, and no fan cooling was provided.

122 Participants cycled once in a temperate environment (CON: 24.0 \pm 0.2 °C; 61 \pm 3%
123 relative humidity; RH) and three times in the heat (32.8 \pm 0.3 °C; 58 \pm 2% RH). These
124 environments were simulated by a climatic chamber (wind speed: 4.7 km·h⁻¹) and completed
125 in a randomised order (block Latin Square). During one hot trial, participants were informed

126 of the true ambient temperature (33 °C; HOT). In the other two trials, participants were
127 deceived to believe the ambient temperature was 5 °C cooler (i.e., 28 °C; DEC_{LOW}) or warmer
128 (i.e., 38 °C; DEC_{HIGH}). This level of deception has previously been shown to alter RPE during
129 exercise in the heat while avoiding detection [13].

130 Participants were told the study aimed to determine the reliability of the Zwift cycling
131 software (Zwift Inc., Long Beach, USA) in different ambient temperatures (i.e., 24, 28, 33 and
132 38 °C). Participants were verbally provided with the environment at the start of each
133 experimental day. The temperature was also hand-written on cardboard and situated in front of
134 the ergometer. Immediately before cycling in DEC_{LOW}, the lead investigator commented ‘it
135 doesn’t feel that hot in here today’, and before DEC_{HIGH} ‘it feels really hot in here today’.
136 During cycling, time, power output and cadence were provided through the Zwift interface. No
137 physiological feedback (e.g., HR, rectal temperature) was provided to the participants.

138

139 2.3 Initial visit

140 Participants were pre-screened (Exercise and Sports Science Australia adult pre-
141 exercise screening tool) and had their height and nude mass were recorded. Experimental
142 procedures were explained, and participants were familiarised with the perceptual mood,
143 thermal and exertion measures. Mood was assessed using a modified profile of mood state
144 (POMS) questionnaire (1–5 Likert scale; items: ‘active’, ‘energetic’, ‘restless’, ‘fatigued’,
145 ‘exhausted’ and ‘alert’). Thermal sensation was rated on a modified scale ranging from 5
146 (‘cool’) to 13 (‘unbearably hot’), and comfort from 1 (‘comfortable’) to 5 (‘extremely
147 uncomfortable’) [23]. Perceived exertion was measured using Borg’s 6–20 scale [9], where
148 ratings range from ‘very, very light’ to ‘very, very hard’. RPE was collected with the
149 instructions ‘how do you rate the current level of exertion’ [9]. Participants undertook an
150 extensive familiarisation to the collection of RPE. Prior to the $\dot{V}O_{2max}$ assessment, memory

151 anchoring procedures were performed in accordance with the RPE Laboratory Manual [9].
152 Participants were asked to recall different levels of RPE that corresponded with cycling
153 sessions they had recently performed (e.g., criterium races, training sessions). Secondly,
154 exercise anchoring during the $\dot{V}O_{2\max}$ assessment was performed to anchor low and high RPE
155 points, further confirming participants understanding of RPE [9]. After cycling, session RPE
156 (sRPE) was collected using the CR-10 scale [24].

157 Participants cycled (Wattbike Pro; Wattbike Ltd, Nottingham, England) for 10 min at
158 a self-selected intensity while connected to the Zwift. This served as a familiarisation to
159 experimental ergometer, and a warm-up for the incremental test (commencing at 150 W,
160 increased by 25 W·min⁻¹; Excalibur Sport; Lode, Groningen, Netherlands). During the
161 incremental test, open circuit spirometry (TrueOne 2400, Parvo Medics, Provo, USA) was used
162 to determine $\dot{V}O_{2\max}$ [25]. The corresponding P_{\max} value was calculated, and participants
163 maximal HR was recorded [25]. Following a short break, participants were then familiarised
164 to the maximal voluntary contraction (MVC) protocol during which the interpolated twitch
165 technique was applied.

166

167 2.4 Experimental testing (visits 2–5)

168 Mid-stream urine samples were collected from participants' first void of the day and on
169 laboratory arrival for the assessment of specific gravity (U_{SG} ; PAL-10S; Atagi Ci. Ltd, Tokyo,
170 Japan). The modified POMS questionnaire was completed before a venous blood sample was
171 drawn for the determination of serum osmolality using the freezing-point depression technique
172 (50 μ L; Osmomat 030, Gonotec, Berlin, Germany), and blood glucose concentration (Accu-
173 Chek Performa, Roche Diagnostics Pty Ltd, Castle Hill, Australia). A finger-tip lactate sample
174 (Lactate Scout+, EKF Diagnostics, Cardiff, Wales) was also collected. A 5 min warm up
175 cycling at 100 W during which participants performed a brief (5 s) maximal effort at the

176 beginning of each min (of the warm up) was performed. After the warm up, the pre-cycling
177 neuromuscular assessment was completed.

178 Baseline nude mass was recorded (WB-110AZ; Tanita Corp., Tokyo, Japan), and
179 participants inserted a flexible thermistor (449H; Henleys Medical, Hertfordshire, England) to
180 the depth of ~12 cm for measurements of rectal temperature (T_{re} ; Squirrel SQ2020; Grant
181 Instruments, Cambridge, England). Small iButtons (DS1922L-F50, Maxim Intergrated,
182 Sunnyvale, USA) were then attached (Leuko Sportstape; Beiersdorf, Hamburg, Germany) to
183 eight sites on the forehead, right scapula, left upper chest, right upper arm, left lower arm, left
184 hand, right anterior thigh and left calf for the retrospective calculation of mean skin temperature
185 (\bar{T}_{sk}) as per ISO 9886 [26]. A HR monitor and chest strap (Team²; Polar Electro Oy, Kempele,
186 Finland) was fitted, standardised cycling attire (bibs without a jersey, socks, cleats) donned,
187 and participants entered the climatic chamber. After being equipped with an open circuit
188 spirometry mouthpiece and nose-clip, participants sat quietly while baseline measurements of
189 ventilation, $\dot{V}O_2$, and $\dot{V}CO_2$ were recorded for 2 min.

190 During cycling, HR, T_{re} , \bar{T}_{sk} and expired gas were continuously sampled and recorded,
191 with gas averaged over 30 s. RPE, thermal sensation and thermal comfort were collected every
192 5 min. Upon termination, finger-tip lactate was collected while participants were seated.
193 Participants exited the chamber and removed their rectal thermistor. Post-cycling nude mass
194 was recorded after towelling down, to allow the calculation of non-urine fluid loss. Participants
195 then completed the post-cycling MVC protocol with interpolated twitch technique, and ~10
196 min after exiting the chamber a sRPE was collected.

197

198 2.5 Neuromuscular function

199 The neuromuscular function of the right quadriceps muscle group was assessed pre-
200 and post-cycling on a Biodex Systems 3 Dynamometer (Biodex Medical Systems, New York,

201 USA). Participants completed five isometric knee extension (5 s duration at 90° knee flexion,
202 0° being full extension) warm-up contractions at 50, 50, 80, 80 and 90% of perceived maximal
203 effort. After a 2 min rest, a 5 x 5 s MVC protocol was completed, with 30 s rest separating each
204 contraction. Visual torque production feedback and strong verbal encouragement were
205 provided during contractions [27].

206 Superimposed twitch properties were assessed via supramaximal electrical stimulation
207 of the femoral nerve (DS7AH; Digitimer Ltd., Welwyn Garden City, England). Self-adhesive
208 surface electrodes were positioned on the femoral nerve (anode, 3.2 cm diameter; Pals,
209 Axelgaard Manufacturing Co. Ltd., Fallbrook, USA) and at the border of the gluteal fold
210 (cathode, 5 x 9 cm; Pals, Axelgaard Manufacturing Co. Ltd., Fallbrook, USA). A doublet
211 square-wave pulse (500 μ s bandwidth) was manually administered at 110% of maximal resting
212 twitch torque once a plateau in MVC torque was observed [27]. A twitch ramp procedure
213 determined the current required for supramaximal stimulation. A second stimulus was
214 delivered ~2 s after each MVC to examine resting twitch properties [27]. Voluntary activation
215 (VA) was calculated for each MVC using the twitch interpolation technique [28]. Peak
216 isometric voluntary torque was considered the mean 25 ms value preceding the electric stimuli.
217 Superimposed torque was considered the peak value in the 100 ms after the stimuli. In our
218 laboratory, the assessments of peak voluntary torque and VA were found to have ICC's of 0.79
219 and 0.81, respectively.

220 Surface electromyography (EMG) data were recorded (30 x 22 mm; N-00-S; Ambu
221 A/S, Ballerup, Denmark) of the vastus medialis (VM) and vastus lateralis (VL) during all
222 MVCs. A grounding electrode was placed at the site of the lateral epicondyle of the femur.
223 Skin sites were shaved, abraded and cleaned. Raw EMG data were sampled with dynamometer
224 data at 1 kHz (16-bit PowerLab 26T; AD Instruments, Sydney, Australia; amplification=1000;
225 common mode rejection ratio=110 dB, 20–500 Hz bandpass filtered). Voluntary EMG data of

226 VM and VL were summed to indicate global muscle activity and quantified via the root-mean-
227 square method with a 100 ms triangular Bartlett sliding window (LabChart 8.0; AD
228 Instruments, New South Wales, Australia). To remove the stimulation artefact, mean EMG
229 amplitude was taken as the 500 ms period up to 60 ms before supramaximal stimulation. Mean
230 post-cycling EMG amplitudes were then normalised to mean pre-cycling values obtained
231 during MVC's.

232

233 2.6 Statistical analysis

234 Bayesian methods were employed to determine significant differences at baseline,
235 during cycling and from pre-to-post cycling for variables of interest. Linear mixed models were
236 utilised to: (1) confirm participants arrived in a similar state for each testing day (random
237 intercept: participant; parameter: condition); (2) determine differences in cycling variables
238 (random intercept and slope: participant; parameters: time, condition, time*condition); and (3)
239 determine differences from pre-to-post cycling (random intercept: participant; parameters:
240 time, condition, time*condition). Each model included a random intercept term in the mean to
241 account for the correlation between repeated measures on a participant.

242 In a Bayesian framework, parameters are treated as random variables and are
243 considered to have true, but unknown values, which are described by a posterior probability
244 distribution (proportional to likelihood x prior distribution) [29]. The prior is a statistical
245 distribution that captures the uncertainty in a population parameter before data collection [29].
246 The application of Bayesian methods in sports science and a detailed explanation of the
247 statistical framework can be found elsewhere [29]. No empirical evidence was able to be drawn
248 upon from Castle et al. [13] and Hanson et al. [20] for the current study due to differences in
249 methodological design. Therefore, an uninformative prior distribution was used for each
250 parameter to allow inferences to be driven by the observed data [29].

251 Markov chain Monte Carlo (MCMC) procedures (1,000 burnin, 50,000 iterations,
252 thinned by a factor of 10) were used to generate posterior estimates of expected variable values
253 [29,30]. The following posterior estimates were of interest: (1) the mean and 95% CI for each
254 experimental condition; (2) the mean difference (MD; and associated 95% CI) between
255 conditions where statistically significant effects were observed (i.e., the 95% CI did not include
256 zero); (3) Cohen's d for the difference between conditions [31]; and (4) the probability that
257 Cohen's d exceeded the 'smallest worthwhile change' ($P d > SWC$ or $P d < -SWC$), specified
258 as 0.2 [29]. Cohen's d effect sizes were interpreted as small (0.2), medium (0.5) and large (0.8)
259 [32].

260 Model parameters and data are reported as mean [95% CI lower and upper bound]
261 unless otherwise stated. Bayesian models were implemented using the 'rjags' and 'R2jags'
262 packages [33] in the R statistical software package (Version 3.4.1). The convergence of the
263 MCMC to the posterior distribution was assessed visually via trace plots.

264

265 3. RESULTS

266 Participants were debriefed once data collection was completed. All participants
267 reported they were unaware of the deception, still believing the study aimed to validate the
268 Zwift in different ambient temperatures. By design, power output during each condition was
269 as follows (mean \pm SD): CON: 187 \pm 34 W, DEC_{LOW}: 187 \pm 36 W, HOT: 187 \pm 35 W and
270 DEC_{HIGH}: 187 \pm 35 W.

271

272 3.1 Baseline measures

273 Baseline values for POMS, U_{SG} , nude mass, serum osmolality, lactate and glucose are
274 reported as mean [95% CI] of all four conditions as linear mixed model analysis revealed no
275 statistically significant condition effect for these variables (Table 1). At baseline, thermal

276 sensation (Fig. 1B) and thermal comfort (Fig. 1C) were not statistically different between
277 conditions. POMS items were as follows: active: 3.2 [2.8, 3.5]; energetic: 3.1 [2.8, 3.4];
278 restless: 2.2 [1.9, 2.5]; fatigued: 2.8 [2.5, 3.1]; exhausted: 2.6 [2.3, 2.9]; and alert: 3.3 [3.0, 3.6],
279 with no statistically significant differences observed between conditions.

280

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INSERT TABLE 1

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283 Baseline hydration status (first void and arrival U_{SG} , nude mass and serum osmolality)
284 was not statistically different between conditions. First void U_{SG} : 1.020 [0.983, 1.058]; arrival
285 U_{SG} : 1.014 [0.981, 1.047]; nude mass: 79.5 kg [70.2, 87.9]; and osmolality: 291 mOsmol·kg⁻¹
286 [222, 363]. Baseline lactate was 1.7 mmol·L⁻¹ [1.3, 2.0], and glucose 4.8 mmol·L⁻¹ [4.5, 5.2],
287 with no statistical differences observed between conditions (Table 1).

288 Baseline T_{re} (Fig. 2A), HR (Fig. 2C) and $\dot{V}O_2$ (Fig. 2D) were not statistically different
289 between conditions. There was a statistically significant condition effect for \bar{T}_{sk} at baseline
290 (Table 1). \bar{T}_{sk} was higher in all other conditions compared to CON ($d = 10.86$ – 11.29 ; $P >$
291 $SWC = 1.00$ – 1.00); however, this can be explained by participants entering the chamber ~5
292 min before commencing cycling. The absence of differences (with the exception of \bar{T}_{sk}) at
293 baseline indicate that individuals arrived for each testing day in a matched physiological and
294 perceptual state.

295

296 3.2 Cycling measures

297 Table 2 provides linear mixed model parameter estimates and 95% CI's for cycling
298 variables. There were statistically significant effects for time and the time*condition interaction
299 for RPE (Table 2). RPE was higher in all conditions compared to CON from 10 min onwards

300 ($d = 1.13$ – 1.90 ; $P d > \text{SWC} = 1.00$ – 1.00). No statistical differences between the hot conditions
301 (i.e., DEC_{LOW} , HOT and DEC_{HIGH}) were observed (Fig. 1A).

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INSERT TABLE 2

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305 Linear mixed model analysis revealed statistically significant time and condition effects
306 for thermal sensation (Table 2). Thermal sensation was higher in all other conditions versus
307 CON at all times ($d = 2.45$ – 5.48 ; $P d > \text{SWC} = 1.00$ – 1.00 ; Fig. 1B). Thermal sensation was not
308 different between HOT and DEC_{LOW} or DEC_{HIGH} , but was statistically different between
309 DEC_{LOW} and DEC_{HIGH} at 10, 15 and 20 min ($d = 0.48$ – 0.92 ; $P d > \text{SWC} = 0.71$ – 0.80 ; Fig. 1B).

310 Table 2 shows there was a statistically significant condition effect for thermal comfort,
311 with ratings higher (less comfortable) in all conditions versus CON ($d = 1.30$ – 3.60 ; $P d > \text{SWC}$
312 $= 0.99$ – 1.00 ; Fig. 1C). Comfort was not statistically different between the hot conditions.

313 Linear mixed model analysis revealed no statistically significant effects for T_{re} (Table
314 2; Fig. 2A). There was a statistically significant condition effect for \bar{T}_{sk} (Table 2), with \bar{T}_{sk}
315 higher in all conditions versus CON ($d = 3.39$ – 16.57 ; $P d > \text{SWC} = 1.00$ – 1.00 ; Fig. 2B). \bar{T}_{sk}
316 was not statistically different between the hot conditions.

317 There were statistically significant effects for time and the time*condition interaction
318 for HR (Table 2). Fig. 2C shows HR was higher in DEC_{LOW} and HOT compared to CON from
319 10 min onwards ($d = 0.70$ – 1.86 ; $P d > \text{SWC} = 0.99$ – 1.00), and in DEC_{HIGH} versus CON at all
320 times ($d = 0.91$ – 2.40 ; $P d > \text{SWC} = 0.99$ – 1.00). HR in DEC_{HIGH} was greater versus DEC_{LOW}
321 after 5 min ($d = 0.49$ – 0.54 ; $P d > \text{SWC} = 0.99$ – 1.00), and versus HOT from 10 min onwards
322 ($d = 0.55$ – 0.58 ; $P d > \text{SWC} = 0.98$ – 1.00).

323 Statistical analysis revealed a significant condition effect for $\dot{V}O_2$ (Table 2). $\dot{V}O_2$ was
324 higher in all conditions compared to CON ($d = 0.13$ – 0.57 ; $P d > SWC = 0.00001$ – 0.043 ; Fig.
325 2D). Oxygen consumption was not statistically different between the hot conditions.

326 The change in nude mass from pre-to-post cycling was as follows: CON: 79.8 kg [70.2,
327 88.6] to 79.3 [70.0, 88.1]; DEC_{LOW}: 79.6 kg [70.0, 88.4] to 78.8 [69.1, 87.7]; HOT: 79.6 kg
328 [70.0, 88.5] to 78.8 [69.2, 87.6]; DEC_{HIGH}: 79.5 kg [69.8, 88.3] to 78.7 [69.1, 87.6]. There were
329 no statistically significant effects for time, condition, or time*condition interaction (Table 3).

330

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INSERT TABLE 3

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333 Lactate pre-to-post cycling was as follows: CON: 1.7 mmol·L⁻¹ [1.1, 2.2] to 1.9 [1.4,
334 2.4]; DEC_{LOW}: 1.8 mmol·L⁻¹ [1.3, 2.3] to 2.4 [1.9, 2.9]; HOT: 1.7 mmol·L⁻¹ [1.1, 2.3] to 2.4
335 [1.9, 2.9]; and DEC_{HIGH}: 1.5 mmol·L⁻¹ [1.0, 2.0] to 2.7 [2.2, 3.2]. There was a statistically
336 significant time*temperature interaction effect for lactate (intercept: 1.67 [1.14, 2.22]; β , time:
337 0.33 [-0.42, 0.92]; β , DEC_{LOW}: 0.02 [-0.70, 0.74]; β , HOT: 0.02 [-0.70, 0.74]; β , DEC_{HIGH}: -
338 0.22 [-0.89, 0.44]; β , time*DEC_{LOW}: 0.33 [-0.55, 1.25]; β , time*HOT: 0.47 [-0.49, 1.42]; β ,
339 time*DEC_{HIGH}: 0.97 [0.03, 1.91]). The increase in DEC_{HIGH} was greater than CON (MD: 0.94
340 mmol·L⁻¹ [0.04, 1.83]; $d = 1.93$; $P d > SWC = 0.95$). No statistically significant differences
341 were observed between the hot conditions.

342 Ratings of sRPE were as follows: CON: 2.8 [2.0, 3.5]; DEC_{LOW}: 3.8 [3.1, 4.6]; HOT:
343 4.0 [3.2, 4.7]; and DEC_{HIGH}: 4.1 [3.3, 4.8]. There was a statistically significant condition effect
344 (intercept: 2.8 [2.0, 3.5]; β , DEC_{LOW}: 1.1 [0.3, 1.9]; β , HOT: 1.2 [0.4, 2.0]; β , DEC_{HIGH}: 1.3
345 [0.5, 2.1]). Ratings were higher in DEC_{LOW} (MD: 1.1 [0.3, 1.9]; $d = 1.90$; $P d > SWC = 0.98$),
346 HOT (MD: 1.2 [0.4, 2.0]; $d = 2.24$; $P d > SWC = 0.99$) and DEC_{HIGH} (MD: 1.3 [0.5, 2.1]; $d =$

347 2.45; $P d > \text{SWC} = 0.99$) compared to CON. Ratings of sRPE were not statistically different
348 between hot conditions.

349

350 3.3 Neuromuscular function

351 There were statistically significant effects for condition and the time*condition
352 interaction for MVC torque (Table 3). Pre-cycling MVC torque (Fig. 3A) was greater (trivially)
353 in HOT compared to CON ($d = 0.14$; $P d > \text{SWC} = 0.01$) and DEC_{Low} ($d = 0.13$; $P d > \text{SWC}$
354 $= 0.99$). Therefore, post-cycling torque was normalised to pre (%). Normalised MVC torque
355 was as follows: CON: 95% [90, 100]; DEC_{Low} : 95 [89, 100]; HOT: 96 [91, 101]; DEC_{High} :
356 90 [85, 95]. Statistical analysis revealed no significant effects for the change from baseline
357 (intercept: 95.3 [89.9, 100.1]; β , DEC_{Low} : -0.8 [-6.6, 5.3]; β , HOT: 0.6 [-5.4, 6.9]; β , DEC_{High} :
358 -4.9 [-10.9, 1.1]). No statistically significant effects were observed for VA (Fig. 3B; Table 3),
359 evoked twitch torque (Fig. 3C; Table 3) or normalised EMG (Fig. 3D).

360

361 4. DISCUSSION

362 This is the first study to investigate the effect of bidirectional ambient temperature
363 deception on RPE during fixed-intensity exercise in the heat. Contrary to our hypothesis, RPE
364 was not different between the deceptive conditions and the accurate feedback trial (HOT). This
365 study suggests that in well trained-cyclists, the generation of RPE is not mediated by an
366 awareness of external environmental temperature feedback when exercising for 30 min at 50%
367 P_{max} in the heat.

368 Environmental heat stress increased RPE responses, ratings of thermal sensation and
369 comfort (Fig. 1A–C), and induced greater physiological strain (HR, \bar{T}_{sk} , $\dot{V}\text{O}_2$; Fig. 2B–D)
370 compared to cycling in the CON trial. In the heat, environmental temperature deception did not
371 alter RPE compared to the accurate feedback condition (Fig. 1A). In a thermal deception

372 condition, Castle et al. [13] observed lower RPE's at the beginning of exercise compared to an
373 accurate feedback control. The lower RPE responses coincided with a lower \bar{T}_{sk} [13]. This
374 might suggest that \bar{T}_{sk} rather than deception was responsible for lowering RPE. Our study
375 supports this conclusion, as \bar{T}_{sk} (Fig. 2B) was not different in the heat, and RPE was matched
376 between conditions [14,15,20]. When \bar{T}_{sk} , T_{re} and HR were included as standardised covariates
377 [29] of RPE, only \bar{T}_{sk} returned a significant coefficient, explaining the greatest amount of
378 variation in RPE (β : 0.42 [0.09, 0.75]), and sharing a slightly stronger correlation (Pearson's r
379 = 0.46) compared to T_{re} (β : -0.40 [-1.04, 0.23]; $r = 0.41$) and HR (β : -0.01 [-0.03, 0.01]; $r =$
380 0.42) with RPE.

381 Following data collection, participants were informed of the true study aim and given
382 a synopsis of the study results. Prior to receiving this information, participants were asked what
383 they believed the aim of the study was, and to comment on their performance. All participations
384 confirmed they had no knowledge of the true study aim, reporting they did not suspect the use
385 of deception. Interestingly, despite a belief they were cycling in different ambient temperatures,
386 this was not reflected in thermal sensation and comfort ratings [13,20]. Thermal sensation was
387 statistically lower in DEC_{LOW} compared to DEC_{HIGH} from 10–20 min (Fig. 1B); however, the
388 0.3 unit difference (9-point scale) over this period cannot be considered practically meaningful,
389 and despite medium-to-large effect sizes ($d = 0.48$ – 0.92 ; $P d > SWC = 0.71$ – 0.80) most likely
390 represents sampling variability within the measure.

391

392

INSERT FIGURE 1

393

394 There is statistical evidence to suggest the warmer deception altered the cardiovascular
395 response of the fixed-intensity cycling task (Fig. 2C). No previous investigation has included
396 a 'warmer' deception condition, making this observation unique to the current study.

397 Participants in DEC_{HIGH} had a statistically higher HR from 10 min onwards compared to HOT
398 (Fig. 2C). The timing of the higher HR in DEC_{HIGH} coincides with the onset of cardiovascular
399 drift [34]. To be highly speculative, participants' expectation of the hotter environment may
400 have elicited a feedforward reflex, potentially initiating a cardiovascular drift-like response
401 [35]. The higher HR (in DEC_{HIGH}) might have been expected to increase RPE [36], yet this
402 was not the case (Fig. 1A). In support of this, previous research has shown that elevations in
403 HR do not elicit proportional increases in RPE when exercising in hot conditions [37]. Despite
404 confidence in the presence of a medium effect ($d = 0.55$ – 0.58 ; $P d > \text{SWC} = 0.98$ – 1.00), the
405 magnitude of difference in HR between DEC_{HIGH} and the other hot conditions (3 – $4 \text{ b}\cdot\text{min}^{-1}$)
406 may not be physiologically meaningful enough to impact the generation of RPE. Given the
407 scalar association between HR and RPE, it might be expected that a $\sim 10 \text{ b}\cdot\text{min}^{-1}$ difference
408 would be required to alter RPE [9]. There was no evidence in other collected variables to
409 suggest the source responsible for the elevation in HR observed in DEC_{HIGH}.

410

411

INSERT FIGURE 2

412

413 Previous research has demonstrated an inverse relationship between an elevation in
414 body (core) temperature and a reduction in VA [38]. Neural afferent inputs from skeletal
415 muscle have been suggested to influence VA by inhibiting central motor drive [39], and this
416 has been shown to occur in the absence of altered function at a peripheral muscle level [40]. In
417 a fixed-intensity cycling task, environmental heat might be expected to exacerbate reductions
418 in VA from pre- to post-cycling compared to matched performance in temperate conditions.
419 However, Fig. 3B shows environmental temperature did not effect VA. This might be
420 explained by the limited change in T_{re} ($< 1 \text{ }^\circ\text{C}$; Fig. 2A) during task, with previous reports
421 indicating hyperthermia-induced reductions in VA occur after a $1 \text{ }^\circ\text{C}$ increase in T_{re} ,

422 independent of exercise [41]. As expected, there was no evidence to suggest that participants
423 experienced any altered function of the quadriceps muscle group at a peripheral level, as
424 indicated by evoked twitch torque (Fig. 3C).

425

426

INSERT FIGURE 3

427

428 The present study adds insight into the influence an inaccurate awareness of
429 environmental temperature might have on RPE. However, it is prudent that several limitations
430 are acknowledged. In the heat, the prescribed exercise-intensity resulted in final mean RPE
431 responses of ~14.5 units, and only modest elevations in T_{re} from resting values (Fig. 2A).
432 Therefore, it is unclear whether the observations of the current study would hold at higher
433 exercise intensities eliciting higher RPE votes and greater thermoregulatory strain. Moreover,
434 it is unclear whether similar observations would be seen during a longer duration exercise task.
435 We found the cardiovascular response in DEC_{HIGH} interesting and perplexing. Based on
436 previous literature, it might be expected that differences could occur at the start of the task, in
437 an anticipatory manner. However, this was not the case, and support for these findings cannot
438 be taken from observations of any relevant research [12,18].

439 The use of trained-cyclists in this study may have contributed to RPE being unaffected
440 by the deception, with previous research suggesting the psychological component of RPE is
441 less relevant in trained individuals [42]. Finally, it is 'unclear' what constitutes successful
442 temperature deception. In this study, participants reported having no knowledge they were
443 cycling in the same hot environment, with all individuals believing the temperature was
444 different for each experimental visit. However, these beliefs were not reflected in thermal
445 sensation and comfort votes. We interpreted the lack of detection as 'successful' deception;

446 however, how these findings (no detection, but absence of change in thermal perceptions) are
447 interpreted with respect to deception success is unclear and warrants further exploration.

448

449 **5. CONCLUSION**

450 Despite participants being under the impression they were cycling in different ambient
451 temperatures, RPE was not different between the hot conditions. Nor was this belief reflected
452 in thermal sensation and comfort votes. Although HR was higher when participants believed
453 they were cycling in a warmer environment, this did not impact RPE responses. Therefore,
454 these data suggest that an awareness of environmental temperature does not contribute to the
455 generation of RPE for trained-cyclists when exercising at a fixed-intensity in the hot-humid
456 conditions.

457

458 **PERSPECTIVES**

- 459 • A fabricated awareness of the external temperature did not contribute to the generation
460 of RPE responses when exercising at a fixed-intensity in the heat.
- 461 • Warmer deception resulted in a higher heart rate response to the exercise task; however,
462 this did not influence RPE.
- 463 • Despite participants believing they were exercising in different environments, this was
464 not reflected in thermal sensation and comfort votes.

465

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566 TABLES

567 Table 1.

568 Linear mixed model parameter estimates [95% credible interval] for baseline measures.

Variable	Intercept	β_1 , DEC _{LOW}	β_2 , HOT	β_3 , DEC _{HIGH}
Thermal sensation	5.8 [5.1, 6.5]*	0.4 [-0.4, 1.2]	0.4 [-0.4, 1.1]	0.5 [-0.2, 1.3]
Thermal comfort	1.14 [0.89, 1.39]*	0.09 [-0.23, 0.41]	0.04 [-0.27, 0.37]	0.13 [-0.18, 0.46]
POMS: Active	3.2 [2.7, 3.6]*	-0.2 [-0.7, 0.3]	0.2 [-0.3, 0.7]	0.0 [-0.5, 0.5]
POMS: Energetic	2.9 [2.5, 3.3]*	0.2 [-0.3, 0.7]	0.4 [-0.2, 0.9]	0.3 [-0.2, 0.8]
POMS: Restless	2.2 [1.7, 2.7]*	0.0 [-0.7, 0.7]	-0.2 [-0.9, 0.5]	0.3 [-0.4, 0.9]
POMS: Fatigued	2.6 [2.1, 3.1]*	0.4 [-0.2, 1.1]	0.1 [-0.6, 0.7]	0.1 [-0.6, 0.8]
POMS: Exhausted	2.6 [2.2, 3.1]*	-0.2 [-0.8, 0.4]	-0.2 [-0.8, 0.4]	-0.1 [-0.7, 0.5]
POMS: Alert	3.2 [2.8, 3.6]*	0.0 [-0.5, 0.5]	0.4 [-0.1, 0.8]	0.1 [-0.4, 0.5]
Rectal temperature	37.19 [36.92, 37.46]*	0.19 [-0.04, 0.43]	0.10 [-0.14, 0.35]	0.18 [-0.11, 0.46]
Mean skin temperature	32.0 [31.7, 32.3]*	2.4 [2.1, 2.6]*	2.4 [2.1, 2.6]*	2.5 [2.2, 2.7]*
Heart rate	73.5 [66.2, 80.3]*	1.2 [-6.1, 8.7]	1.0 [-8.1, 6.4]	3.2 [-4.1, 10.4]
Oxygen consumption	0.42 [0.33, 0.51]*	0.05 [-0.02, 0.12]	0.03 [-0.04, 0.10]	0.05 [-0.02, 0.12]
Glucose	4.80 [4.24, 5.37]*	-0.16 [-0.91, 0.57]	0.02 [-0.72, 0.78]	0.23 [-0.53, 0.95]
First void U _{SG}	1.020 [0.979, 1.062]*	-0.001 [-0.032, 0.031]	-0.002 [-0.032, 0.029]	0.002 [-0.032, 0.036]
Laboratory arrival U _{SG}	1.0134 [0.9777, 1.0490]*	-0.0010 [-0.0234, 0.0206]	0.0017 [-0.0221, 0.0254]	0.0002 [-0.0221, 0.0229]
Serum osmolality	289.9 [211.5, 363.6]*	-0.8 [-44.9, 43.0]	0.1 [-44.6, 45.2]	0.4 [-45.1, 45.1]

569 POMS = Profile of mood states; U_{SG} = Urine specific gravity. *Indicates statistically significant model effect (i.e., the 95% credible interval does
570 not include zero). Values are reported to at least one significant decimal place.

571 **Table 2.**

572 Linear mixed model parameter estimates [95% credible interval] for variables measured during cycling.

Parameter	Perceived exertion	Thermal sensation	Thermal comfort	Rectal temperature	Mean skin temperature	Heart rate	Oxygen consumption
Intercept	10.55 [9.64, 11.48]*	6.754 [6.220, 7.250]*	1.167 [1.430, 1.910]*	37.140 [36.870, 37.410]*	32.053 [31.817, 32.294]*	125.3 [116.7, 132.9]*	2.420 [2.133, 2.711]*
β_1 , time	0.07 [0.03, 0.12]*	0.042 [0.003, 0.082]*	0.027 [-0.004, 0.060]	0.029 [-0.011, 0.071]	0.030 [-0.003, 0.063]	0.3 [0.1, 0.5]*	0.003 [-0.028, 0.033]
β_2 , DEC _{LOW}	0.21 [-0.46, 0.89]	1.381 [0.814, 1.939]*	0.381 [0.102, 0.671]*	0.131 [-0.020, 0.280]	2.702 [2.431, 2.970]*	0.5 [-3.2, 4.2]	0.118 [0.025, 0.209]*
β_3 , HOT	0.13 [-0.53, 0.79]	1.598 [1.047, 2.149]*	0.547 [0.260, 0.835]*	0.070 [-0.078, 0.210]	2.706 [2.446, 2.971]*	0.0 [-3.7, 3.7]	0.135 [0.045, 0.224]*
β_4 , DEC _{HIGH}	0.12 [-0.53, 0.79]	1.799 [1.242, 2.328]*	0.543 [0.261, 0.838]*	0.137 [-0.013, 0.028]	2.841 [2.593, 3.093]*	3.0 [-0.8, 6.8]	0.145 [0.053, 0.239]*
β_5 , time*DEC _{LOW}	0.05 [0.02, 0.09]*	0.020 [-0.008, 0.049]	0.017 [-0.001, 0.031]	0.001 [-0.006, 0.009]	0.000 [-0.134, 0.014]	0.4 [0.2, 0.6]*	-0.001 [-0.006, 0.004]
β_6 , time*HOT	0.06 [0.03, 0.10]*	0.182 [-0.011, 0.047]	0.013 [-0.001, 0.025]	-0.001 [-0.009, 0.007]	0.003 [-0.010, 0.017]	0.4 [0.2, 0.6]*	0.001 [-0.005, 0.005]
β_7 , time*DEC _{HIGH}	0.06 [0.03, 0.10]*	0.013 [-0.015, 0.041]	0.011 [-0.002, 0.025]	0.002 [-0.006, 0.009]	-0.001 [-0.014, 0.012]	0.4 [0.2, 0.6]*	-0.002 [-0.007, 0.003]

573 *Indicates statistically significant model effect (i.e., the 95% credible interval does not include zero). Values are reported to at least one

574 significant decimal place.

575

576 **Table 3.**

577 Linear mixed model parameter estimates [95% credible interval] for pre- to post-cycling measures.

Parameter	Maximal voluntary torque	Voluntary activation	Evoked twitch torque	Nude body mass	Lactate
Intercept	163.4 [19.9, 220.7]*	94.6 [91.7, 97.4]*	61.4 [38.1, 78.0]*	79.8 [70.2, 88.6]*	1.67 [1.14, 2.22]*
β_1 , time	-7.7 [-17.1, 1.7]	-0.9 [-4.6, 2.9]	-6.0 [-14.0, 1.8]	-0.5 [-1.1, 0.1]	0.25 [-0.42, 0.92]
β_2 , DEC _{LOW}	0.3 [-9.0, 9.7]	-0.8 [-4.8, 3.0]	0.3 [-8.2, 8.8]	-0.2 [-0.8, 0.3]	0.02 [-0.70, 0.74]
β_3 , HOT	12.1 [2.7, 21.6]*	0.2 [-3.9, 4.5]	5.8 [-3.1, 14.7]	-0.2 [-0.7, 0.4]	0.02 [-0.70, 0.74]
β_4 , DEC _{HIGH}	7.4 [-2.0, 17.1]	-2.2 [-3.9, 3.5]	5.5 [-2.3, 13.3]	-0.3 [-0.9, 0.2]	-0.22 [-0.89, 0.44]
β_5 , time*DEC _{LOW}	-3.4 [-16.3, 9.5]	-0.4 [-5.9, 5.1]	1.4 [-10.4, 13.3]	-0.3 [-1.1, 0.5]	0.33 [-0.55, 1.25]
β_6 , time*HOT	-0.8 [-13.8, 12.0]	0.1 [-5.7, 5.9]	2.8 [-9.9, 15.1]	-0.3 [-1.1, 0.5]	0.47 [-0.49, 1.42]
β_7 , time*DEC _{HIGH}	-13.2 [-26.4, -0.2]*	0.3 [-4.8, 5.5]	-4.2 [-15.0, 7.0]	-0.3 [-1.0, 0.5]	0.97 [0.03, 1.91]*

578 *Indicates statistically significant model effect (i.e., the 95% credible does not include zero). Values are reported to at least one significant

579 decimal place.

580

581

582 **FIGURE CAPTIONS**

583 **Figure 1.** Mean and 95% credible interval for perceived exertion (A); thermal sensation (B);
584 and thermal comfort (C). *indicates CON significantly different to all other conditions at the
585 same time point; ^indicates DEC_{LOW} significantly different to DEC_{HIGH} at the same time point.

586

587 **Figure 2.** Mean and 95% credible interval for rectal temperature (A); mean skin temperature
588 (B); heart rate (C); and oxygen consumption (D) during cycling. *indicates CON significantly
589 different to all other conditions at the same time point; ^^indicates CON significantly different
590 to DEC_{HIGH} at the same time point; †indicates DEC_{HIGH} significantly different to DEC_{LOW} and
591 HOT at same time point

592

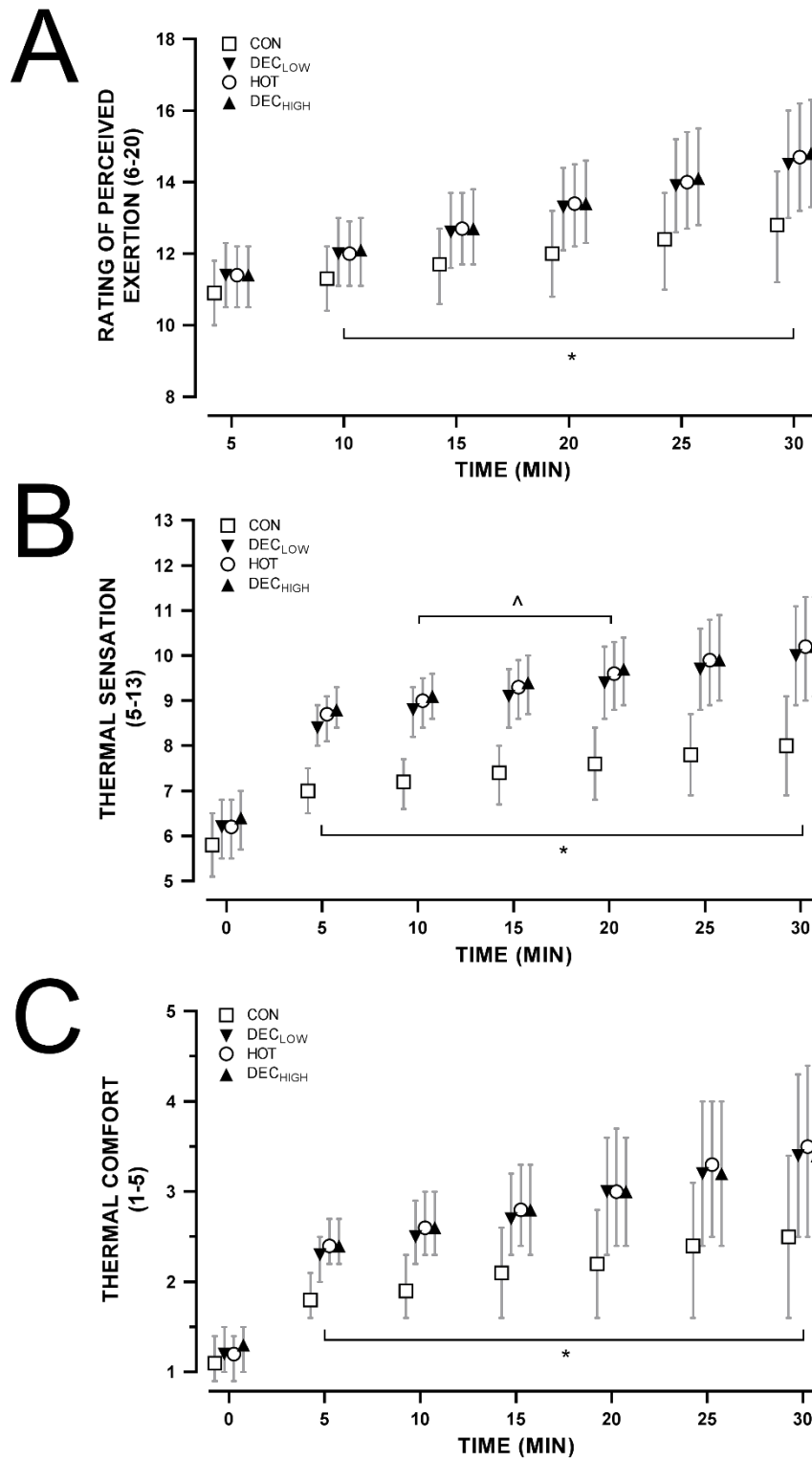
593 **Figure 3.** Mean and 95% credible interval for maximal voluntary torque (A); voluntary
594 activation (B); evoked twitch torque (C); and normalised electromyography (D). #indicates
595 HOT significantly different to CON and DEC_{LOW} at the same time point (i.e., pre).

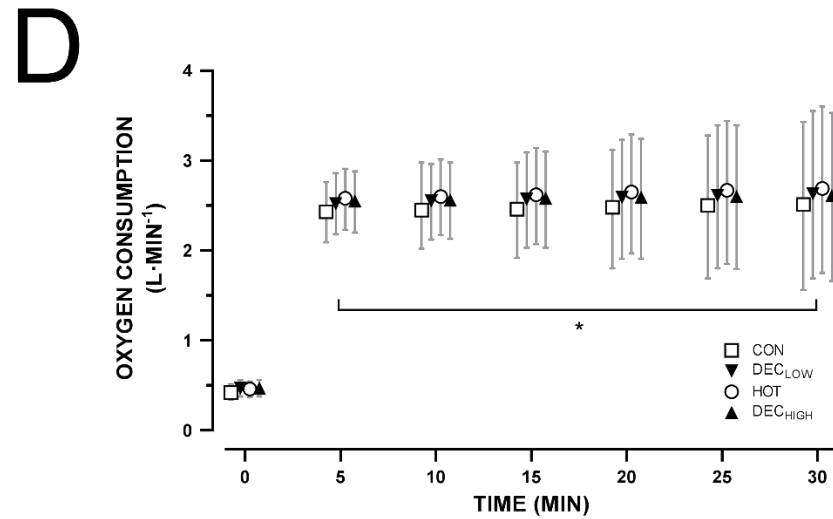
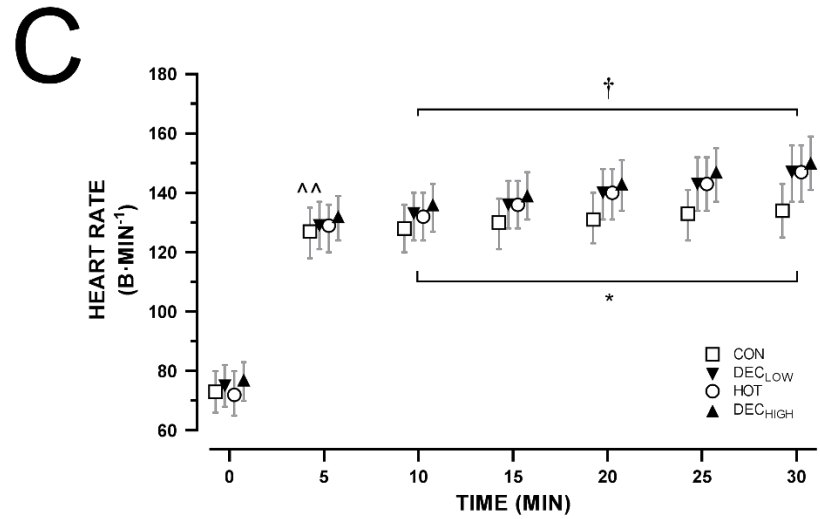
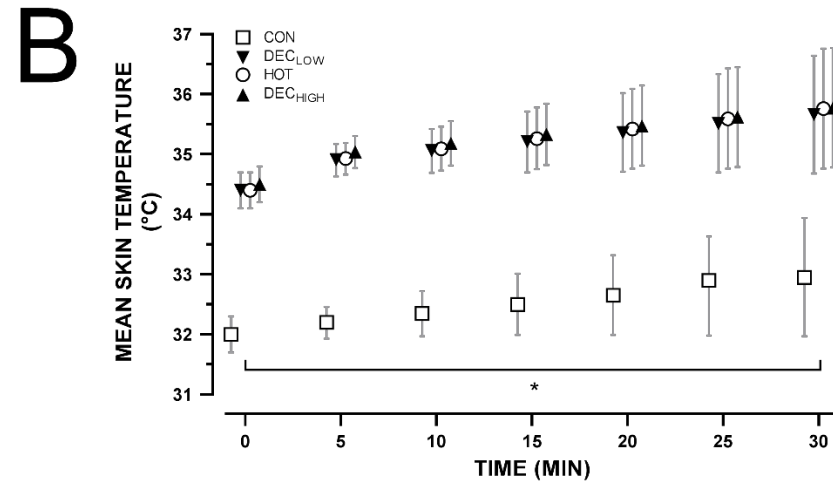
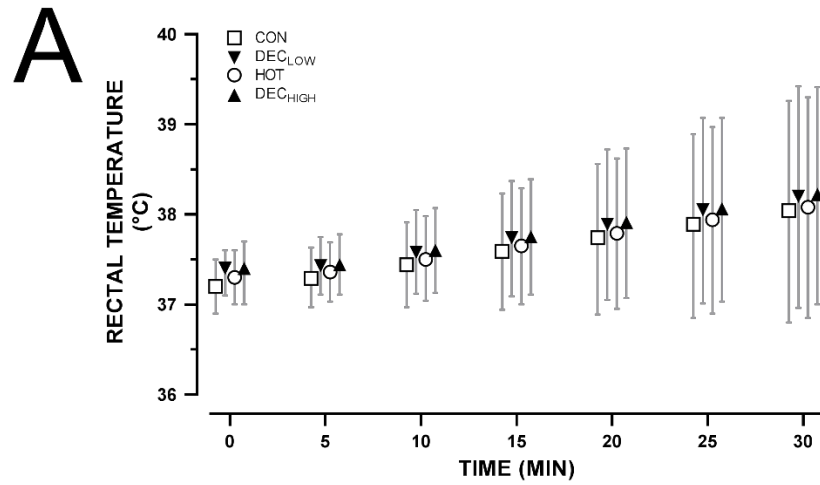
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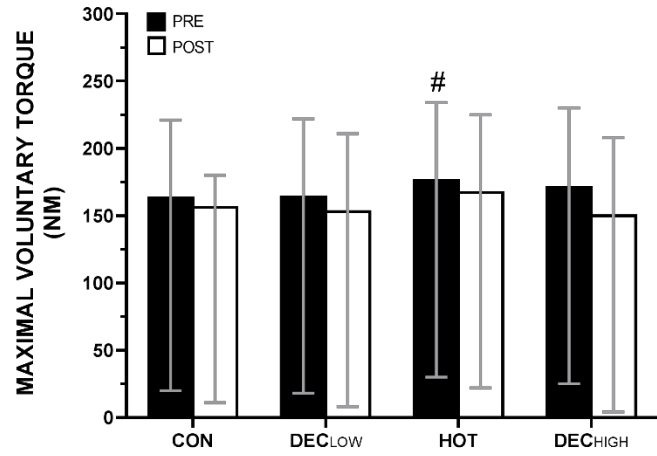
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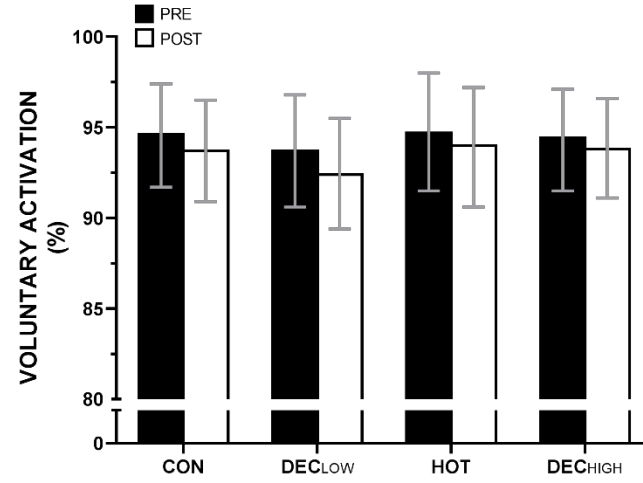




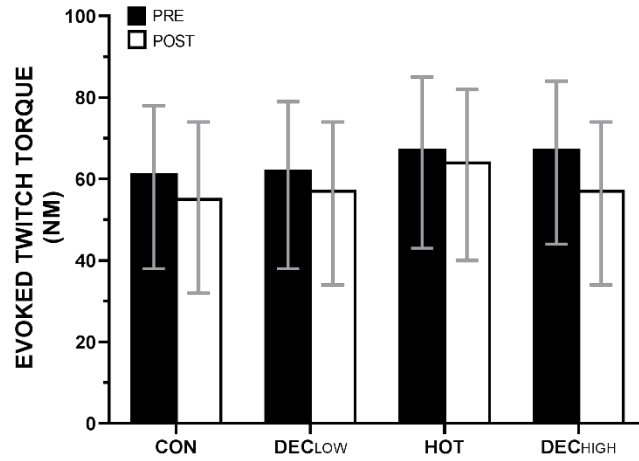
A



B



C



D

