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

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COMPETING INTERESTS

The authors have no conflict of interests to declare. The authors declare that the results of this study have been presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

FUNDING

This project was not financially supported.

ABSTRACT

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

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

1. INTRODUCTION

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

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

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

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

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

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

2. METHODS

2.1 Participants

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

2.2 Experimental design

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

Participants cycled once in a temperate environment (CON: 24.0±0.2 °C; 61±3% relative humidity; RH) and three times in the heat (32.8±0.3 °C; 58±2% RH). These environments were simulated by a climatic chamber (wind speed: 4.7 $km \cdot h^{-1}$) and completed in a randomised order (block Latin Square). During one hot trial, participants were informed of the true ambient temperature (33 °C; HOT). In the other two trials, participants were deceived to believe the ambient temperature was 5 °C cooler (i.e., 28 °C; $\mathrm{DEC_{LOW}}$) or warmer (i.e., 38 °C; $\mathrm{DEC_{HIGH}}$). This level of deception has previously been shown to alter RPE during exercise in the heat while avoiding detection [13].

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

2.3 Initial visit

Participants were pre-screened (Exercise and Sports Science Australia adult pre-exercise screening tool) and had their height and nude mass were recorded. Experimental procedures were explained, and participants were familiarised with the perceptual mood, thermal and exertion measures. Mood was assessed using a modified profile of mood state (POMS) questionnaire (1–5 Likert scale; items: ‘active’, ‘energetic’, ‘restless’, ‘fatigued’, ‘exhausted’ and ‘alert’). Thermal sensation was rated on a modified scale ranging from 5 (‘cool’) to 13 (‘unbearably hot’), and comfort from 1 (‘comfortable’) to 5 (‘extremely uncomfortable’) [23]. Perceived exertion was measured using Borg’s 6–20 scale [9], where ratings range from ‘very, very light’ to ‘very, very hard’. RPE was collected with the instructions ‘how do you rate the current level of exertion’ [9]. Participants undertook an extensive familiarisation to the collection of RPE. Prior to the $\dot{V}O_{2max}$ assessment, memory anchoring procedures were performed in accordance with the RPE Laboratory Manual [9]. Participants were asked to recall different levels of RPE that corresponded with cycling sessions they had recently performed (e.g., criterium races, training sessions). Secondly, exercise anchoring during the $\dot{V}O_{2max}$ assessment was performed to anchor low and high RPE points, further confirming participants understanding of RPE [9]. After cycling, session RPE (sRPE) was collected using the CR-10 scale [24].

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

2.4 Experimental testing (visits 2–5)

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

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

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

2.5 Neuromuscular function

The neuromuscular function of the right quadriceps muscle group was assessed pre- and post-cycling on a Biodex Systems 3 Dynamometer (Biodex Medical Systems, New York, USA). Participants completed five isometric knee extension (5 s duration at 90° knee flexion, 0° being full extension) warm-up contractions at 50, 50, 80, 80 and 90% of perceived maximal effort. After a 2 min rest, a 5 x 5 s MVC protocol was completed, with 30 s rest separating each contraction. Visual torque production feedback and strong verbal encouragement were provided during contractions [27].

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

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

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

2.6 Statistical analysis

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

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

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

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

3. RESULTS

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

3.1 Baseline measures

Baseline values for POMS, U_{SG}, nude mass, serum osmolality, lactate and glucose are reported as mean [95% CI] of all four conditions as linear mixed model analysis revealed no statistically significant condition effect for these variables (Table 1). At baseline, thermal sensation (Fig. 1B) and thermal comfort (Fig. 1C) were not statistically different between conditions. POMS items were as follows: active: 3.2 [2.8, 3.5]; energetic: 3.1 [2.8, 3.4]; 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], with no statistically significant differences observed between conditions.

INSERT TABLE 1

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

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

3.2 Cycling measures

Table 2 provides linear mixed model parameter estimates and 95% CI’s for cycling variables. There were statistically significant effects for time and the time*condition interaction for RPE (Table 2). RPE was higher in all conditions compared to CON from 10 min onwards (*d* = 1.13–1.90; P *d* > SWC = 1.00–1.00). No statistical differences between the hot conditions (i.e., $\mathrm{DEC}_{\mathrm{LOW}}$, HOT and $\mathrm{DEC}_{\mathrm{HIGH}}$) were observed (Fig. 1A).

INSERT TABLE 2

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

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

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

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

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

The change in nude mass from pre-to-post cycling was as follows: CON: 79.8 kg [70.2, 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 [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 no statistically significant effects for time, condition, or time*condition interaction (Table 3).

INSERT TABLE 3

Lactate pre-to-post cycling was as follows: CON: 1.7 $mmol \cdot L^{-1}$ [1.1, 2.2] to 1.9 [1.4, 2.4]; DEC_{LOW}: 1.8 $mmol \cdot L^{-1}$ [1.3, 2.3] to 2.4 [1.9, 2.9]; HOT: 1.7 $mmol \cdot L^{-1}$ [1.1, 2.3] to 2.4 [1.9, 2.9]; and DEC_{HIGH}: 1.5 $mmol \cdot L^{-1}$ [1.0, 2.0] to 2.7 [2.2, 3.2]. There was a statistically significant time*temperature interaction effect for lactate (intercept: 1.67 [1.14, 2.22]; β, time: 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}: -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, time*DEC_{HIGH}: 0.97 [0.03, 1.91]). The increase in DEC_{HIGH} was greater than CON (MD: 0.94 $mmol \cdot L^{-1}$ [0.04, 1.83]; *d* = 1.93; P *d* > SWC = 0.95). No statistically significant differences were observed between the hot conditions.

Ratings of sRPE were as follows: CON: 2.8 [2.0, 3.5]; DEC_{LOW}: 3.8 [3.1, 4.6]; HOT: 4.0 [3.2, 4.7]; and DEC_{HIGH}: 4.1 [3.3, 4.8]. There was a statistically significant condition effect (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 [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], 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* =

2.45; P *d* > SWC = 0.99) compared to CON. Ratings of sRPE were not statistically different between hot conditions.

3.3 Neuromuscular function

There were statistically significant effects for condition and the time*condition interaction for MVC torque (Table 3). Pre-cycling MVC torque (Fig. 3A) was greater (trivially) in HOT compared to CON (*d* = 0.14; P *d* > SWC = 0.01) and DEC_{LOW} (*d* = 0.13; P *d* > SWC = 0.99). Therefore, post-cycling torque was normalised to pre (%). Normalised MVC torque was as follows: CON: 95% [90, 100]; DEC_{LOW}: 95 [89, 100]; HOT: 96 [91, 101]; DEC_{HIGH}: 90 [85, 95]. Statistical analysis revealed no significant effects for the change from baseline (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}: -4.9 [-10.9, 1.1]). No statistically significant effects were observed for VA (Fig. 3B; Table 3), evoked twitch torque (Fig. 3C; Table 3) or normalised EMG (Fig. 3D).

4. DISCUSSION

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

Environmental heat stress increased RPE responses, ratings of thermal sensation and comfort (Fig. 1A–C), and induced greater physiological strain (HR, $\overline{T}_{sk}$, $\dot{V}O_2$; Fig. 2B–D) compared to cycling in the CON trial. In the heat, environmental temperature deception did not alter RPE compared to the accurate feedback condition (Fig. 1A). In a thermal deception condition, Castle et al. [13] observed lower RPE's at the beginning of exercise compared to an accurate feedback control. The lower RPE responses coincided with a lower $\overline{T}_{sk}$ [13]. This might suggest that $\overline{T}_{sk}$ rather than deception was responsible for lowering RPE. Our study supports this conclusion, as $\overline{T}_{sk}$ (Fig. 2B) was not different in the heat, and RPE was matched between conditions [14,15,20]. When $\overline{T}_{sk}$, T_{re} and HR were included as standardised covariates [29] of RPE, only $\overline{T}_{sk}$ returned a significant coefficient, explaining the greatest amount of variation in RPE (β: 0.42 [0.09, 0.75]), and sharing a slightly stronger correlation (Pearson's $r = 0.46$) compared to T_{re} (β: -0.40 [-1.04, 0.23]; $r = 0.41$) and HR (β: -0.01 [-0.03, 0.01]; $r = 0.42$) with RPE.

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

INSERT FIGURE 1

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

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

INSERT FIGURE 2

Previous research has demonstrated an inverse relationship between an elevation in bokdy (core) temperature and a reduction in VA [38]. Neural afferent inputs from skeletal muscle have been suggested to influence VA by inhibiting central motor drive [39], and this has been shown to occur in the absence of altered function at a peripheral muscle level [40]. In a fixed-intensity cycling task, environmental heat might be expected to exacerbate reductions in VA from pre- to post-cycling compared to matched performance in temperate conditions. However, Fig. 3B shows environmental temperature did not effect VA. This might be explained by the limited change in T_{re} (<1 °C; Fig. 2A) during task, with previous reports indicating hyperthermia-induced reductions in VA occur after a 1 °C increase in T_{re}, independent of exercise [41]. As expected, there was no evidence to suggest that participants experienced any altered function of the quadriceps muscle group at a peripheral level, as indicated by evoked twitch torque (Fig. 3C).

INSERT FIGURE 3

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

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

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

5. CONCLUSION

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

PERSPECTIVES

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

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TABLES

Table 1.

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]

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

Table 2.

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]

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

Table 3.

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]*

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

FIGURE CAPTIONS

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

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

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

FIGURES

Figure 1.

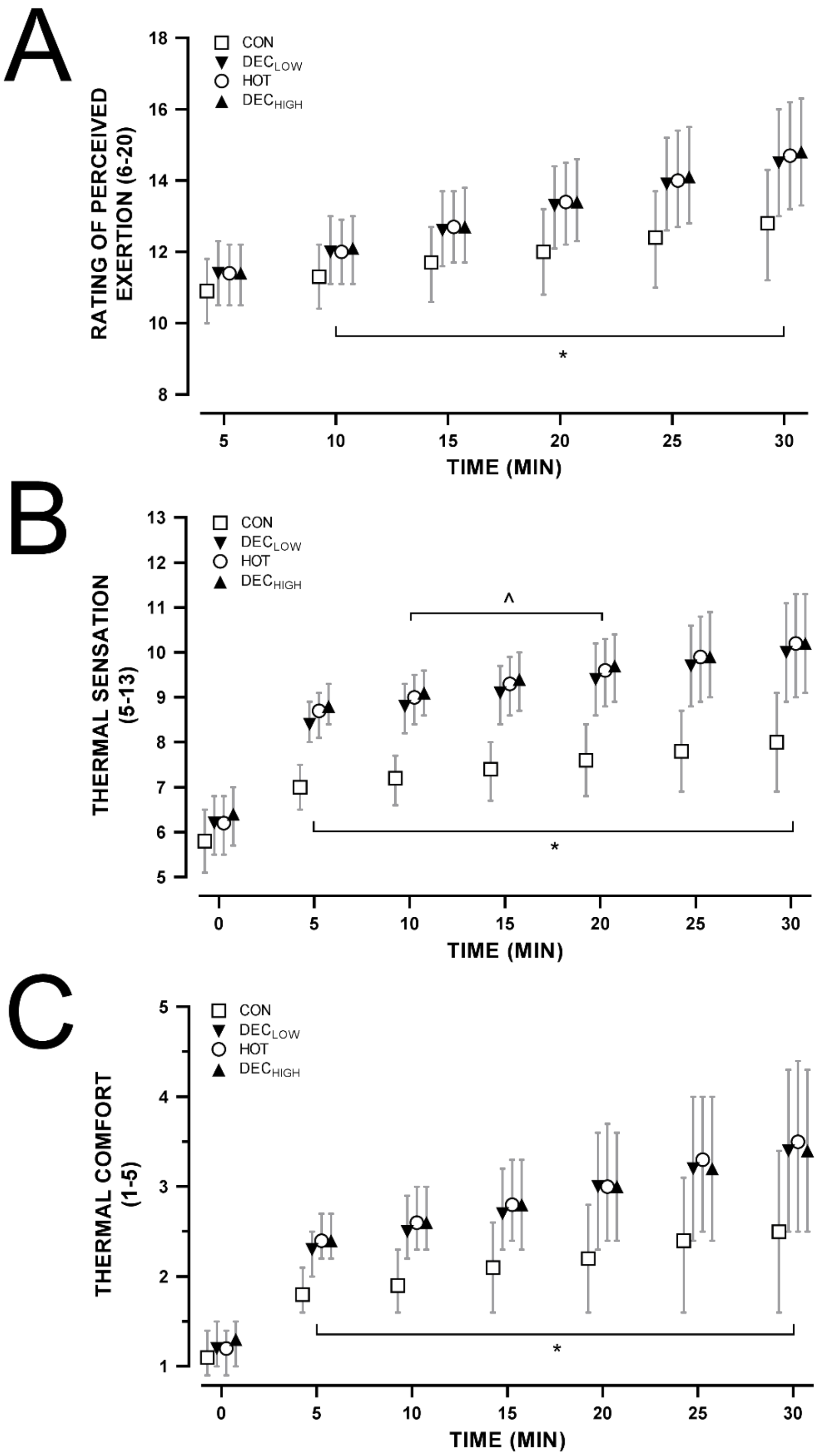
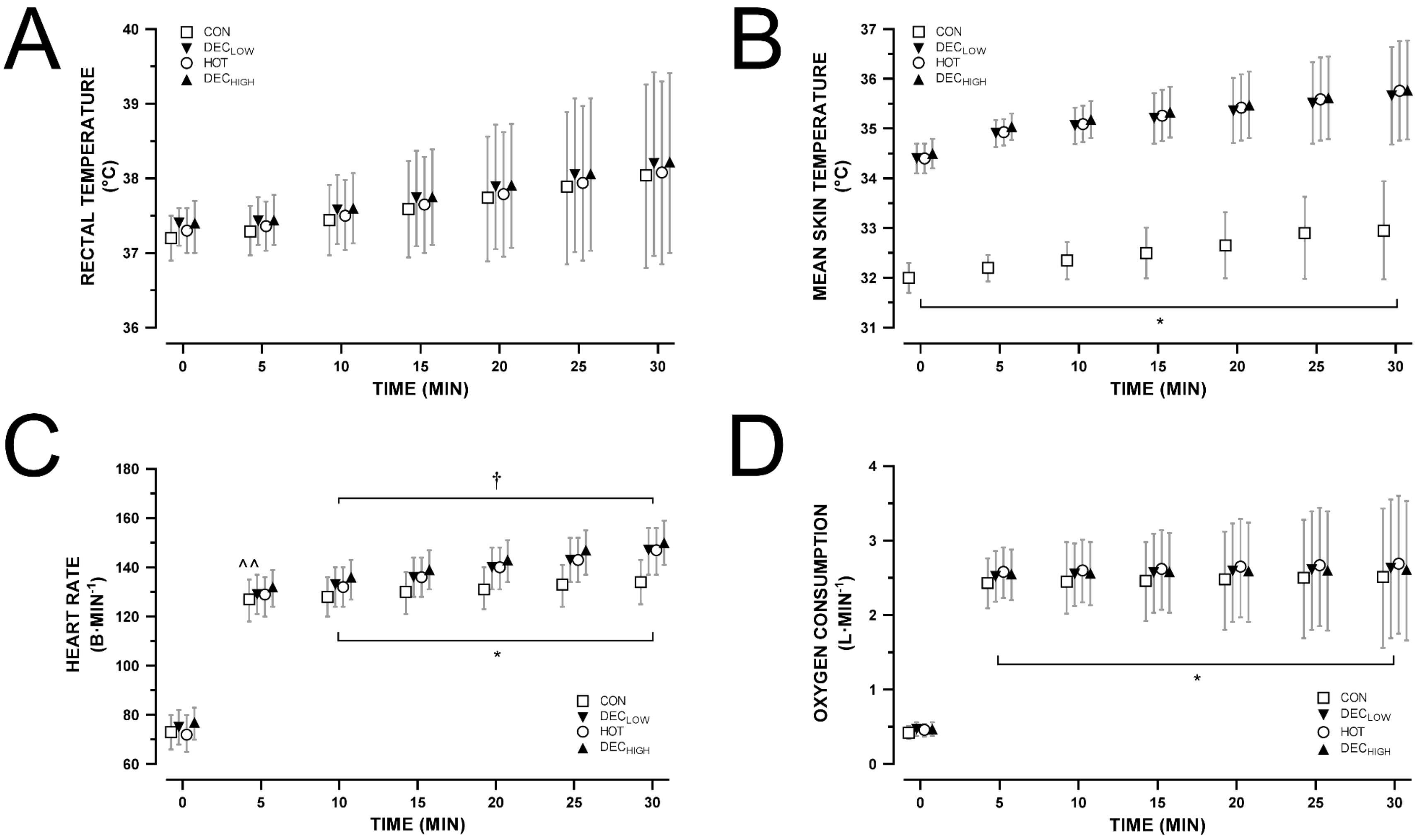


Figure 2.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DEC$_{LOW}$
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B
MEAN SKIN TEMPERATURE (°C)
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32
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TIME (MIN)
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HEART RATE (B·MIN^{-1})
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140
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0
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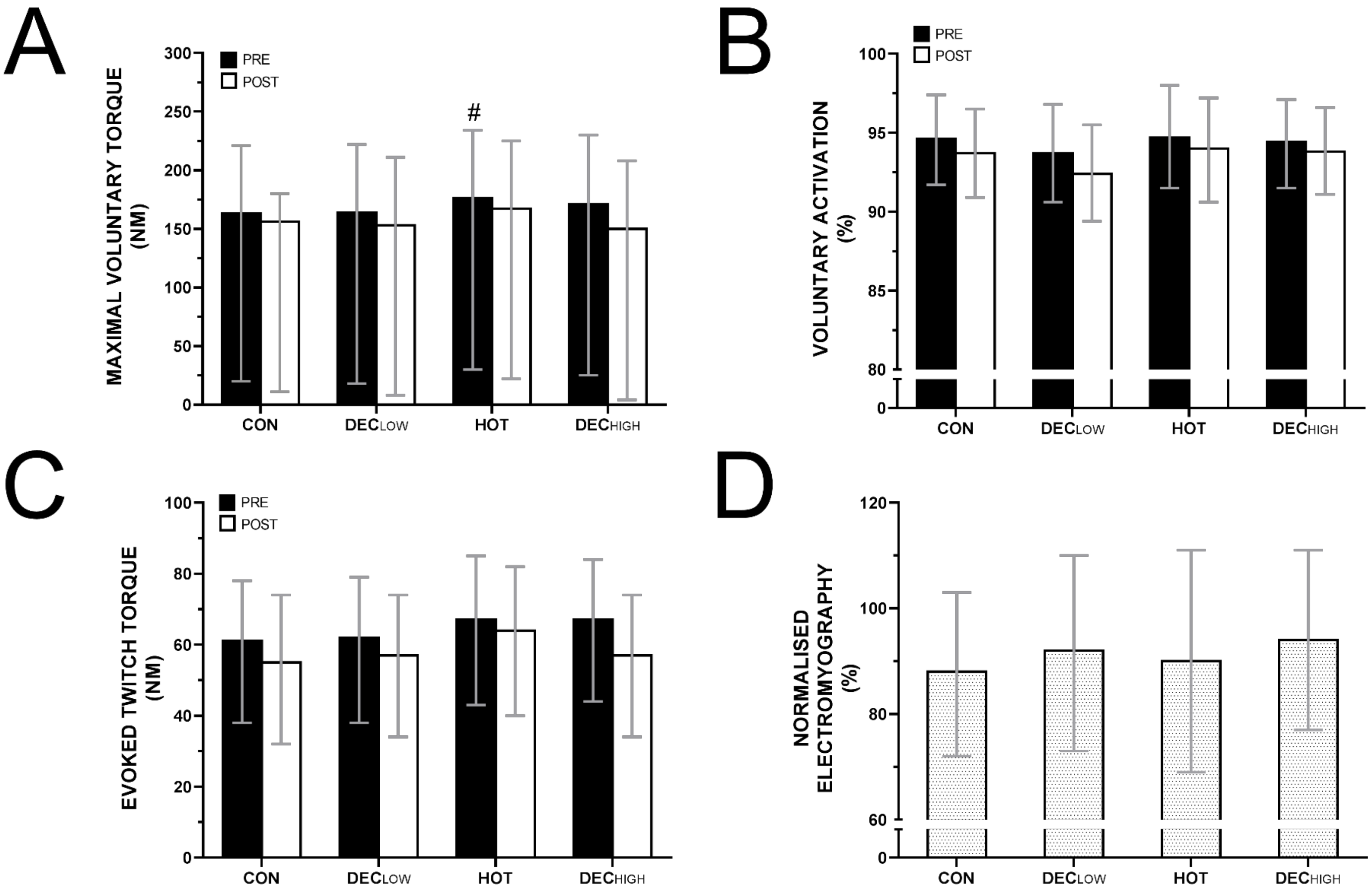
TIME (MIN)

Figure 3.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100
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VOLUNTARY ACTIVATION (%)
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PRE
POST
CON
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HOT
DECHIGH
C
EVOKED TWITCH TORQUE (NM)
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80
60
40
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0
PRE
POST
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HOT
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D
NORMALISED ELECTROMYOGRAPHY (%)
120
100
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0
CON
DECLOW
HOT
DECHIGH