

Effect of Heat on Psycho-Physiological Responses During a Self-Paced Cycling Time Trial

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Keywords

heat; time-trial; pacing; electroencephalography; motivation; perceived exertion

1 Introduction

As global temperatures rise and competitions increasingly take place in hot environments, understanding the impact of heat on performance is critical (Hunter et al., 2002). Thermal stress induces cardiovascular strain, alters brain activity, and modifies perceptual and motivational responses, affecting pacing and endurance (Périard et al., 2015). While studies have reported changes in heart rate (Girard & Racinais, 2014), muscle oxygenation, and cognitive function under heat (Nybo & Nielsen, 2001), few have focused on self-paced exercise. This study examines how heat affects performance, perceptual responses,

motivation, and neural efficiency in trained cyclists during a simulated self-paced time trial.

2 Material and Methods

2.1 Participants

Twelve trained male elite cyclists (age: 24 ± 3.6 years; body mass = 70.7 ± 8.4 kg; height = 180.1 ± 4.8 cm; BMI = 21.8 ± 2.4 kg/m²; performance level = 4 (De Pauw et al., 2013)) were recruited for this study. Each participant performed two 26.2 km time trials on home trainer in random order: one in temperate (20°C, 60% RH) and one in hot (30°C, 60% RH) conditions. Trials were spaced 7 days apart and conducted at the same time of day.



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2.2 Measurements

Core body temperature was monitored using ingestible telemetry pills (BodyCap, France). Skin temperature was measured via infrared thermography (FLIR EX series). The core-to-skin temperature gradient was determined by subtracting skin temperature from core temperature (Naito et al., 2024). Heart rate (HR) and respiratory frequency (fR) were continuously monitored using the Hexoskin Smart Shirt (Carré Technologies, Canada). Power output (in watts) and cadence (in rpm) were recorded continuously via a CycleOps home trainer. Electroencephalography (EEG) activity was recorded using the Mentalab Explore system with 7 electrodes placed on frontal (Fp1, Fp2), motor (C1–C4), and parietal (P3, P4) regions, following the 10–20 international system. Data were referenced to FCz and filtered (1–40 Hz). Artifacts were removed via independent component analysis (SASICA), and power spectral densities for alpha (8–13 Hz) and beta (13–30 Hz) bands were extracted using Fast Fourier Transform (FFT). Neural efficiency was assessed using the α/β ratio in each brain region. Data were averaged over 30-s windows at each 20% segment of time trial completion for analysis.

Perceptual variables were assessed at baseline and every 20% of time trial distance. These included: i) perceived exertion (RPE) and pain using the Borg CR10 scale (Borg, 1998), ii) perceived pleasure (Baron, 2009), and affective load, calculated as RPE minus pleasure and iii) motivational level was measured using the Multidimensional Motivation Scale in Exercise (MMSE, Baron et al., 2022).

2.3 Statistical Analysis

Mixed ANOVAs were performed to assess condition and time effects. Cohen's d and partial η^2 were used for effect sizes.

3 Results

A significant condition effect was reported for the core to skin gradient temperature (Table 1), with higher gradients in the TEMP condition ($F(1,9) = 409.70$, $p < 0.001$, $\eta^2 = 0.70$). A significant main effect of condition ($F(1,4) = 23.01$, $p < 0.001$, $\eta^2 = 0.24$) for power output was found, with higher values in TEMP than HOT. ANOVA did not reveal any significant difference between condition for RPE, pain but for pleasure ($F(1,4) = 13.30$, $p = 0.004$, $\eta^2 = 0.28$) and for affective load ($F(1,4) = 18.27$, $p = 0.001$, $\eta^2 = 0.18$) (Fig 1). No significant difference was found for heart rate, respiratory rate, α/β ratio on prefrontal, motor, and parietal cortex.

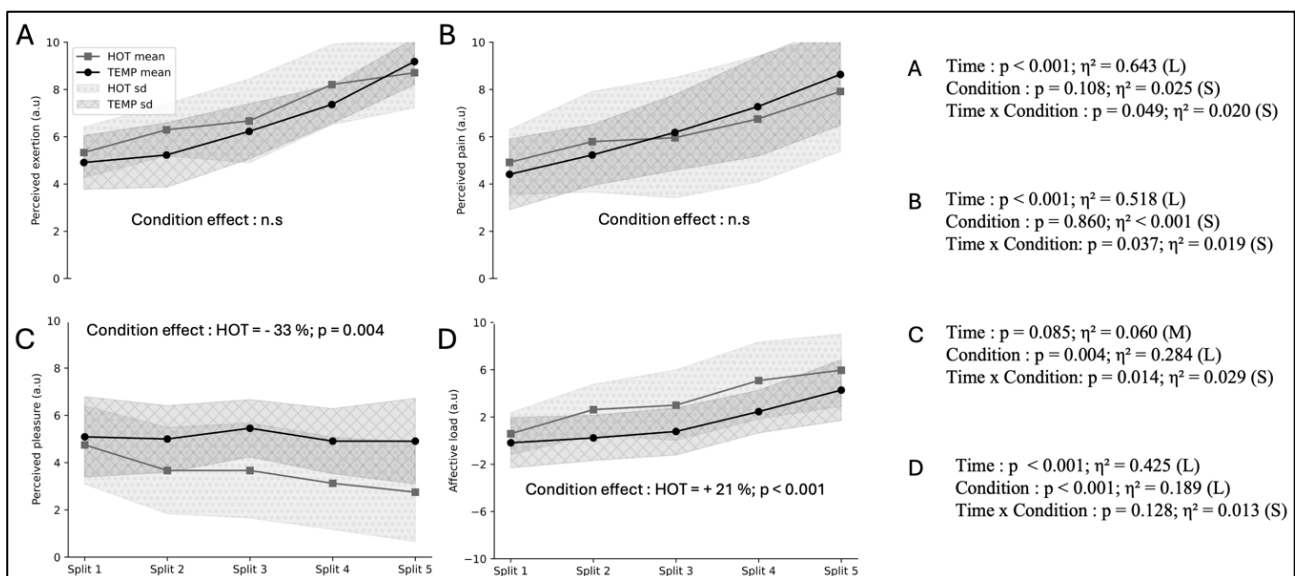


Figure 1. Mean and standard deviation for RPE (A), muscular pain (B), pleasure (C) and affective load (D).

*, significant different TEMP vs HOT; $\eta^2 < 0.06$ = small (S); 0.06 to 0.14 = moderate (M) and > 0.14 = large (L); n.s. = non-significant

Table 1. Physiological, biomechanical, and neurologic responses during the time trial.

		Split 1		Split 2		Split 3		Split 4		Split 5		Time			ANOVA Condition			Time x Condition		
		mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	F	P	η^2	F	P	η^2	F	P	η^2
Power (W)	TEMP	323	33	296	31	298	25	294	45	319	33	16.220	< 0.001	0.300	23.013	< 0.001	0.241	2.469	0.058	0.026
	HOT	311	25	261	31	262	23	255	34	291	31									
Cadence (rpm)	TEMP	91.2	5.2	99.4	5.7	97.9	5.8	91.7	14.1	100.7	8.1	9.571	< 0.001	0.322	1.484	0.249	0.011	0.024	0.999	0.001
	HOT	89.5	7.3	97.8	7.6	96.7	7.3	90.5	6.9	99.2	8.2									
Heart rate (bpm)	TEMP	174.3	11	173.6	10.1	173.7	9.3	177.8	11.3	180.3	11.6	5.465	0.003	0.341	0.008	0.931	0.001	0.476	0.753	0.002
	HOT	177.8	9.6	174.1	10.3	171.8	11.7	176.4	13.5	183.9	16									
Respiratory frequency (mvt/min)	TEMP	47.9	10.55	52.02	9.38	54.62	8.81	61.96	9.87	69.71	13.41	19.053	< 0.001	0.441	0.509	0.490	0.007	2.824	0.036	0.032
	HOT	54.21	13.82	55.18	12.08	57.09	13.54	60.16	11.38	67.1	14.8									
Core temperature (°C)	TEMP	37.6	0.7	37.6	0.9	37.6	1	37.7	1.1	37.8	1.2	2.195	0.085	0.033	0.056	0.818	0.003	0.630	0.644	0.009
	HOT	37.4	0.8	37.6	0.9	37.7	1	37.7	0.9	37.7	1									
Skin temperature (°C)	TEMP	27.7	1.5	28.4	1.3	27.9	1.3	28.1	1.3	27	1	4.398	0.010	0.010	269.416	< 0.001	0.942	6.218	0.002	0.011
	HOT	32.5	1.1	32.7	0.7	33	0.9	33	1.1	33.5	0.5									
Core-to-skin gradient temperature (°C)	TEMP	9.9	1.7	9.1	1.5	9.8	1.4	9.7	1.5	10.9	1.1	2.950	0.046	0.008	292.397	< 0.001	0.946	8.036	< 0.001	0.010
	HOT	4.9	1.2	4.9	1.1	4.7	1.2	4.8	1.4	4.3	1.3									
α/β ratio Central	TEMP	4.98	3	4.14	2.27	3.42	1.61	3.43	0.89	3.15	1.5	2.308	0.077	0.076	0.066	0.803	0.002	1.612	0.192	0.058
	HOT	3.68	1.3	4.03	1.32	3.58	1.22	4.25	1.87	3.33	1.51									
α/β ratio Frontal	TEMP	3.57	1.64	2.93	1.23	3.22	1.46	4.28	2.06	3.23	1.54	2.982	0.032	0.127	0.038	0.851	0.001	0.206	0.933	0.008
	HOT	3.89	1.02	3.38	1.52	3.55	1.62	4.07	2	3.4	1.44									
α/β ratio Parietal	TEMP	3.24	0.97	3.48	1.07	3.17	1.17	3.65	1.14	3.1	1.85	0.892	0.479	0.050	0.029	0.870	0.001	0.737	0.573	0.030
	HOT	3.32	1.21	3.13	1.76	3.16	1.58	3.76	2.09	3.35	1.8									

4 Discussion

This study reveals that performance during a self-paced TT is negatively impacted by heat, primarily due to reduced core to skin temperature gradient and altered perceptual responses. Core temperature alone did not differentiate performance, suggesting that skin temperature and heat dissipation capacity (core-to-skin gradient) are more relevant. Despite reduced power output, cyclists maintained cognitive functions linked to effort management, likely due to anticipatory pacing strategies. Perceived pleasure, seem to be a key factor in self-regulated exercise, decreased in the heat. Neural efficiency remained stable, contrasting with previous findings of impaired EEG markers during paced heat studies (Nybo et al., 2012). The self-regulated nature of the exercise likely enabled participants to limit cognitive strain by adjusting effort in real time.

5 Practical Applications

Incorporating heat training may improve core-to-skin gradient control and enhance pacing regulation in these conditions. Tracking

thermal sensation and pleasure could serve as useful proxies for heat-induced fatigue risk and performance.

6 Conclusions

Exercising in hot conditions impairs cycling performance primarily through the decrease of core to skin temperature gradient and, reduced perceived pleasure. Despite this, RPE, pain, motivation, and neural efficiency remain intact, indicating that self-pacing allows athletes to regulate their effort to avoid a catastrophic failure.

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Conflicts of Interest: The authors declare no conflict of interest.

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