

**Examining the Effect of Challenge and Threat States on Endurance Exercise
Capabilities.**

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Running Head: CHALLENGE AND THREAT IN ENDURANCE EXERCISE

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Abstract

Two studies explored the effect of challenge and threat states on endurance exercise capabilities. In study one, relationships between cardiovascular markers of challenge and threat states, ratings of perceived exertion (RPE), and exercise tolerance were explored during moderate- and severe-intensity cycling. Cardiovascular reactivity more reflective of a challenge state (i.e., relatively higher cardiac output and/or lower total peripheral resistance reactivity) predicted lower RPE throughout moderate- but not severe-intensity cycling. Building on these findings, study two experimentally manipulated participants into challenge, threat and neutral groups and compared 16.1 km time-trial performances, where pacing is self-regulated by RPE. Participants completed familiarisation, control, and experimental visits while physiological (oxygen uptake), perceptual (RPE), and performance-based (time to completion [TTC] and power output [PO]) variables were assessed. The challenge group demonstrated a cardiovascular response more indicative of a challenge state, while delivering a faster early-race pace (PO) at similar levels of early-race RPE, compared to the threat group. While there were no significant differences in TTC, results revealed that augmentations in PO for the challenge group were facilitated by tempered perceptions of fatigue. Findings suggest that an individual's pre-exercise psychophysiological state might influence perceived exertion and performance in endurance exercise.

Keywords: biopsychosocial model, cognitive appraisal, perceived exertion, cycling, fatigue

Introduction

Investigations into the determinants of endurance performance have been boosted by participation trends, where growing competition applications increase the relevance of research-led ergogenic strategies (Blanchfield, Hardy, De Morree, Staiano, & Marcora, 2014). While numerous physiological predictors of performance have been pinpointed (Midgley, McNaughton, & Jones, 2007), the mechanistic causes of fatigue (i.e., a transient decrease in the capacity to perform physical actions; Enoka & Duchateau, 2008) remain controversial, and are likely regulated by psychological factors (Abbiss & Laursen, 2005; Tucker & Noakes, 2009; Marcora, 2010). Various psychological skills can affect endurance performance (e.g., self-efficacy, imagery; see McCormick, Meijen, & Marcora, 2015 for review), however, further exploration into cognitive and motivational determinants is required (Smirmaul, Dantas, Nakamura, & Pereira, 2013). The current research is the first to examine the effects of challenge and threat states, determinants of cognitive and behavioural performance (Behnke & Kaczmarek, 2018; Hase, O'Brien, Moore, & Freeman, 2018), on endurance exercise capabilities.

The biopsychosocial model (BPSM) of challenge and threat states (Blascovich & Tomaka, 1996; Blascovich, 2008) offers an opportunity for sport and exercise psychologists to examine prospective psychophysiological determinants of endurance performance using a well-tested theoretical framework. The BPSM explains individual responses to motivated performance situations, where individuals are motivated to attain important self-relevant goals (Seery, 2011). Specifically, the BPSM contends that evaluations of situational demands and perceived coping resources determine the states of challenge and threat, which are considered anchors of a single bipolar continuum (Seery, 2011). Crucially, these dynamic psychophysiological states only emerge when individuals are actively engaged in a task, which is indexed by increases in heart rate (HR) and reductions in cardiac pre-ejection period (Seery, 2011). Furthermore, these states are highly dynamic, and are influenced by numerous interrelated socio-psychological antecedents, including: self-efficacy, task familiarity, required effort, social support and personal skills and abilities (Blascovich, 2008; Jones, Meijen, McCarthy, & Sheffield, 2009). A challenge state occurs when perceived coping resources are

1 evaluated as sufficient to meet or exceed perceived situational demands, whereas a threat state arises
2 when coping resources are evaluated as insufficient to meet situational demands (Seery, 2011).

3 Importantly, challenge and threat states are accompanied by distinct neuroendocrine and
4 cardiovascular reactivity patterns, proposed to result from one's underlying demand and resource
5 evaluations (Seery, 2011). Specifically, a challenge state promotes comparative increases in blood
6 flow and rapid energy mobilisation to large skeletal muscles, empirically quantified by higher cardiac
7 output (CO; the amount of blood pumped by the heart per minute), and lower total peripheral
8 resistance (TPR; a measure of the net constriction versus dilation in the arterial system), reactivity
9 (Blascovich, 2008). Such responses tend to promote superior attentional control, more facilitative
10 emotions and interpretations of emotions, and enhancements in kinematic and/or neuromuscular
11 efficiency, compared to reactivity patterns more consistent with a threat state (Moore, Vine, Wilson,
12 & Freeman, 2012; Moore, Wilson, Vine, Coussens, & Freeman, 2013; Vine, Freeman, Moore,
13 Chandra-Ramanan, & Wilson, 2013). These distinct cardiovascular reactivity patterns are also
14 proposed to provide an objective, indirect measure of underlying demand and resources evaluations
15 (and thus challenge and threat states), which do not rely on conscious attention or reflection
16 (Blascovich, 2008; Seery, 2011). This is important, as the demand and resource evaluation process is
17 said to occur in a more subconscious (i.e., automatic) rather than conscious manner, meaning that
18 individuals cannot always reliably report evaluations of situational demands and personal coping
19 resources (Blascovich, 2008).

20 In line with these proposals, the BPSM provides a testable hypothesis: that the cardiovascular
21 response accompanying a challenge state will predict more adaptive responses to motivated
22 performance situations than those elicited by relative threat states. Indeed, a challenge state has been
23 related to superior sporting performance in closed (e.g., golf putting, Moore et al., 2012; 2013; Moore,
24 Vine, Wilson, & Freeman, 2014; Vine et al., 2013) and open (e.g., cricket, Turner et al., 2013) sport
25 skills. For example, Turner and colleagues (2013) showed that an athlete's pre-exercise
26 cardiovascular reactivity profiles could predict subsequent performances in a pressurised cricket
27 batting task, with responses linked to a challenge state relating to more proficient test scores
28 compared to those reflective of relative threat states. The Theory of Challenge and Threat States in

1 Athletes (TCTSA) further postulates that challenge states facilitate more adaptive outcomes in terms
2 of decision-making and anaerobic power (Jones et al., 2009). However, despite being similarly
3 susceptible to stress-related behavioural variability (Abbiss & Laursen, 2005), a lack of evidence has
4 examined challenge and threat states in motivated *endurance* exercise. This is surprising, as an
5 individual's pre-exercise cognitive and cardiovascular reactivity responses to task-related stress
6 persist during aerobic exercise (Rousselle, Blascovich, & Kelsey, 1995). Similarly, such
7 psychophysiological responses can be strategically manipulated via various interventions that are
8 accessible to endurance athletes (e.g., arousal reappraisal; Jamieson, Mendes, Blackstock, &
9 Schmader, 2010; pre-performance routines; Moore et al., 2013). Therefore, investigations into the
10 effects of challenge and threat states on endurance exercise capabilities offers both practical and
11 theoretical significance to psychologists.

12 The generalisability of the BPSM to endurance exercise is reinforced by proposals that fatigue
13 is regulated through psychophysiological mechanisms potentially associated with challenge and threat
14 states. The psychobiological model of endurance (Marcora, Bosio, & de Morree, 2008; Marcora,
15 Staiano, & Manning, 2009; Marcora & Staiano, 2010) contends that motivated performances are
16 ultimately determined by perceived exertion (i.e., conscious sensations of how hard, heavy, and
17 strenuous a physical task is; Marcora, 2010), a dynamic interoceptive process shaped by cognitive,
18 sensory, motivational, and affective elements (Pandolf, 1983). Accordingly, such proposals claim that
19 established determinants of endurance events, including both psychological (e.g., self-efficacy) and
20 physiological inputs (e.g., cardiorespiratory capacities), affect performance *indirectly* through altering
21 this interpretation of afferent sensory information. Notably, antecedents of challenge states have been
22 consistently linked with reducing ratings of perceived exertion (RPE; e.g., high task familiarity,
23 Micklewright, Papadopoulou, Swart, & Noakes, 2010; high self-efficacy, Hutchinson et al., 2008; and
24 low required task effort; Paterson & Marino, 2004), whereas environmental conditions that limit
25 cardiovascular reactivity tend to inflate such perceptions of fatigue (e.g., Gonzalez-Alonso, Calbet, &
26 Nielsen, 1999). Therefore, exploration into the interplay between challenge and threat states,
27 perceived exertion, and performance outcomes presents an exciting line of enquiry for psychologists,

1 as any factor associated with reducing RPE is proposed to enhance endurance exercise capabilities
2 (Marcora, 2010).

3 However, the role of psychophysiological mechanisms in regulating exercise is partly
4 determined by the characteristics of the task itself (Rejeski, 1985; Blanchfield et al., 2014). For
5 example, in ‘open-loop’ tasks, defined by the absence of a known endpoint (e.g., time to exhaustion
6 tests), the rate of increase in RPE will determine how long work can be maintained (Marcora, 2010).
7 Alternatively, in closed-loop tasks (e.g., time-trials), which involve completing a predetermined
8 endpoint, work-rate is self-regulated by the athlete, meaning that any factor altering RPE can result in
9 pacing adjustments. The intensity of exercise further influences relationships between
10 psychophysiological variables, with cognitive influences on RPE greater during moderate- (i.e., below
11 the gas exchange threshold) compared to severe-intensity (i.e., above this threshold) workloads
12 (Ekkekakis, 2003). Consequently, investigation into the predictive value of the BPSM in this complex
13 interdisciplinary domain is required.

14 The present research is the first to explore the effects of challenge and threat states on
15 motivated endurance exercise capabilities. Specifically, we first observed whether the cardiovascular
16 markers of challenge and threat states were related to RPE and exercise tolerance during open-loop
17 cycling (study 1), before furthering our causal understanding by testing whether manipulating
18 challenge and threat states influenced cycling time trial performance (study 2). This two-part design
19 facilitated exploration into the predictive validity of the BPSM; first using an observational design in
20 a relatively controlled setting, and then via a validated experimental intervention design in a more
21 applied setting.

22

23

Study One

24 The first study initiated enquiry into whether a challenge state, a more adaptive response to
25 stress compared to a threat state, can predict endurance exercise performance. Specifically,
26 relationships were investigated between cardiovascular indices of challenge and threat states and
27 measures of RPE and exercise tolerance, during bouts of moderate- and severe-intensity cycling.
28 Here, any delay in time taken to reach exhaustion (TTE) can signify an increase in endurance

1 capabilities (Coyle, Coggan, Hopper, & Walters, 1988). We hypothesised that the cardiovascular
2 markers of challenge and threat states would predict RPE and exercise tolerance, with patterns more
3 indicative of a challenge state (i.e., higher CO and/or lower TPR reactivity) relating to lower RPE and
4 longer TTE. The study received approval from the Department of Sport and Health Sciences Ethics
5 Committee at the University of Exeter, and written informed consent was obtained from participants
6 prior to data collection.

7 **Material and methods**

8 *Participants*

9 In accordance with a power calculation (α : $p = .05$; $1-\beta = 0.8$) using an effect size from a pilot
10 study (via G*Power software, version 3.1.3), nineteen participants were recruited for this study (15
11 male, 4 female; Mean $_{age} = 23.62 \pm 4.84$ years, $\dot{V}O_{2peak} = 40.49 \pm 6.42$ ml.kg⁻¹.min⁻¹). In order to
12 minimise the effects of previous experience on exercise tolerance (Micklewright et al., 2010), all
13 participants were recreationally active, unfamiliar with experimental exercise procedures, and novice
14 cyclists (according to Chapman, Vicenzino, Blanch, & Hodges, 2007). Participants were asked to
15 refrain from consuming caffeine or food in the hour preceding testing, and to arrive rested and
16 hydrated.

17 *Measures*

18 *Cardiovascular markers of challenge and threat.* An impedance cardiograph device
19 (Physioflow, PF05L1, Manatec Biomedical, Paris, France) estimated HR, CO, and TPR. Following
20 skin preparation using alcohol wipes and abrasive gel, spot electrodes were positioned on 6
21 anatomical sites (for a description of the electrode configuration see Moore et al., 2012). The device
22 was calibrated over 30 heart cycles, using resting systolic and diastolic blood pressure values taken
23 immediately before the recording period by a digital monitor (Model UA-767PC, Medical Co.,
24 Saitama, Japan). Participants then sat silently fitted to the device for 5 minutes of rest or baseline, and
25 for a further minute after receiving standardised task instructions (to permit the assessment of

1 cardiovascular reactivity between the final minute of baseline and the minute after the task
2 instructions).

3 Task engagement was assessed using HR reactivity, with greater increases reflecting greater
4 engagement (Seery, 2011). Furthermore, challenge and threat states were assessed using CO and TPR
5 reactivity (as in Moore et al., 2012), with TPR calculated from the formula: [mean arterial pressure \times
6 80/CO] (Sherwood, Allen, Fahrenberg, Kelsey, Lovallo, & van Doornen, 1990). Mean arterial
7 pressure was calculated using: [(2 \times diastolic blood pressure) + systolic blood pressure/3] (Cywinski
8 & Tardieu, 1980). Cardiovascular data during the final minute of baseline recording were missing for
9 two participants, both due to equipment failure, and were replaced using the mean from the previous
10 successfully recorded minute (i.e. minutes 3-4 of baseline recording). No post-instruction
11 cardiovascular data were identified as missing. Reactivity values were converted into z-scores,
12 assigning TPR a weight of -1 and CO a weight of +1. Z-scores were then combined to provide a
13 challenge and threat index (CTI; as in Seery, Weisbuch, & Blascovich, 2009), representing a single
14 measure of CO and TPR reactivity whereby higher values denoted a cardiovascular response more
15 indicative of a challenge state (i.e., higher CO and/or lower TPR reactivity)¹.

16 ***Physiological responses to exercise.*** Pulmonary gas exchange and ventilation were measured
17 breath-by-breath using an online gas analyser (Cortex Metalyzer 2R, Cortex, Leipzig, Germany).
18 Before analysis, data were averaged over consecutive 10s periods, and values for pulmonary oxygen
19 uptake ($\dot{V}O_2$), expired carbon dioxide ($\dot{V}CO_2$), and minute ventilation (\dot{V}_E) were taken for each minute
20 of exercise. During the incremental test, $\dot{V}O_{2\text{ peak}}$ was determined as the highest 30s average value
21 attained before volitional exhaustion. The gas exchange threshold was defined as: the first
22 disproportionate increase in $\dot{V}CO_2$ from visual inspection of individual plots of $\dot{V}CO_2$ versus $\dot{V}O_2$; and
23 an increase in $\dot{V}_E/\dot{V}O_2$ with no increase in $\dot{V}_E/\dot{V}CO_2$.

24 ***Perceived exertion.*** RPE was recorded during the final 15s of each minute, using Borg's 15-
25 point scale (Borg, 1970), which was displayed throughout the cycling test. Participants were
26 instructed to verbally report how "hard, heavy, and strenuous" the task felt using this widely-used

1 scale for reference. Values ranging from 6 (no exertion at all) to 20 (maximal exertion) were averaged
2 over moderate-intensity exercise (RPE₀₋₁₀), where they stabilised, but not during severe-intensity
3 exercise, where they increased exponentially. To enable temporal comparisons of RPE during severe-
4 intensity exercise, ratings at 11 min, 50%TTE, and 100%TTE were recorded (as in Blanchfield et al.,
5 2014).

6 ***Exercise tolerance.*** Time to exhaustion (TTE) was measured in seconds from the onset of
7 severe-intensity exercise until volitional exhaustion, operationally defined as a pedal frequency of less
8 than 60 rpm for more than 5 s (as in Marcora et al., 2009).

9 ***Procedures***

10 Participants attended two laboratory sessions within a two-week period, separated by at least
11 72 hours, and scheduled for the same time of day (± 1 h) under constant laboratory conditions (18-
12 22°C; 45–60% humidity). All exercise was performed on the same cycle ergometer (Monark
13 Ergomic 894 E Peak Bike friction-braked ergometer, Monark Exercise AB, Vansbro, Sweden).

14 ***Visit one.*** Following a 3-minute self-paced warm-up, participants completed a step
15 incremental exercise test ($60\text{W} + 30\text{W}\cdot\text{min}^{-1}$) for determination of workloads in experimental
16 exercise. Participants cycled at a fixed cadence (80 rpm) at progressively increasing workloads
17 ($+30\text{W}\cdot\text{min}^{-1}$) until exhaustion (defined above). Saddle and handlebar height were adjusted for each
18 participant, and recorded for replicability. Participants were familiarised with Borg's RPE scale
19 (Borg, 1970) by rating perceived exertion at each work-rate. Workloads equating to 90% of the gas
20 exchange threshold (90%GET), and 80% of the difference between gas exchange threshold and $\dot{V}\text{O}_2$
21 _{peak} (80% Δ) were calculated.

22 ***Visit two.*** Participants sat quietly for baseline and post-instruction cardiovascular
23 measurements, which were dispersed around the delivery of neutral standardised task instructions.
24 Despite highlighting consistent task demands, these instructions (see Supplementary files) asked
25 participants to 'cycle for as long as possible' to 'improve the accuracy' of their results, highlighting
26 the evaluative nature of the exercise test. Such emphasis on the importance and meaningfulness of

1 results was targeted to promote active engagement, thus inducing challenge and threat states (Vine,
2 Moore, & Wilson, 2016). Following these resting cardiovascular measurements, participants
3 completed a constant work-rate exercise protocol. This consisted of a single bout, involving a self-
4 paced warm-up (3 min) prior to moderate- (90% GET, 10 min) and severe- (80% Δ) intensity
5 workloads, performed without any rest or verbal encouragement until volitional exhaustion.
6 Pulmonary gas exchange and HR were measured continuously, RPE was recorded every minute, and
7 TTE was noted upon exercise termination.

8 *Statistical Analyses*

9 First, the data was screened, with no univariate outliers being detected (>3.29 SD \pm mean, $p <$
10 $.001$; as recommended by Osbourne, 2013). As a manipulation check, a dependent t-test assessed
11 whether HR significantly increased following the delivery of task instructions. Furthermore, to assess
12 the efficacy of workload normalisation procedures, implemented to minimise the influence of aerobic
13 fitness on experimental exercise capacities (as proposed by Lansley, Dimenna, Bailey, & Jones,
14 2011), Pearson's correlation analyses identified associations between $\dot{V}O_2$ peak and TTE. Hierarchal
15 multiple regression analyses examined the extent to which CTI predicted RPE during moderate-
16 (RPE₀₋₁₀) and severe- (11min, 50%TTE, and 100%TTE) intensity exercise. RPE was entered as the
17 dependent variable, with age (step 1), body mass (2), and CTI (3) values entered respectively.
18 Identical models identified the extent to which CTI predicted TTE. Effect sizes were estimated using
19 Cohen's d values (Cohen, 1992). Significance was accepted at $p < 0.05$, and mean data is presented as
20 \pm SD.

21 **Results and Discussion**

22 *Manipulation Checks*

23 HR reactivity was significantly elevated following task-instructions (mean difference: $6.43 \pm$
24 5.43 bpm; $t_{[16]} = -4.89$, $p < .001$, $d = 1.19$), with increases evident in all participants, confirming task
25 engagement and permitting the investigation of challenge and threat states via CTI (Blascovich,
26 2008). Data from two participants were excluded from statistical analyses after showing $\dot{V}O_2$ kinetic

1 profiles indicative of workloads above the gas exchange threshold. The remaining physiological data
2 ($n = 17$; Figure 1) suggest that exercise was performed within the targeted intensity domains.
3 Correspondingly, TTE and $\dot{V}O_{2\text{ peak}}$ values were unrelated ($p > .05$), suggesting that the impact of
4 physical fitness on exercise capacity was neutralised through the normalisation procedures (Lansley et
5 al., 2011).

6 ***Insert Figure 1 near here***

7

8 **Primary Analysis**

9 As hypothesised, hierarchal regression analyses (Table 1) revealed that CTI significantly
10 predicted RPE during moderate- (RPE₀₋₁₀: $\Delta R^2 = .29$, $\beta = -.57$, $p = .031$) and severe- (11 min: $\Delta R^2 =$
11 $.32$, $\beta = -.59$, $p = .017$) intensity exercise, over and above age and body mass (RPE₀₋₁₀: $R^2 = .06$;
12 11min: $R^2 = .14$; 50%TTE: $R^2 = .05$), although these associations became non-significant towards the
13 end of exercise (50%TTE: $\Delta R^2 = .10$, $\beta = -.33$, $p > .05$). Thus, in general, participants who responded
14 to the task instructions with a cardiovascular response more indicative of a challenge state (i.e.,
15 relatively higher CO and/or lower TPR reactivity) reported lower RPE than those who reacted with a
16 response more indicative of a threat state. Therefore, this study is the first to suggest that there may be
17 an association between cardiovascular markers of challenge and threat states and RPE. Although these
18 results are novel, links between reduced blood flow and increased perceived exertion have long been
19 established (e.g., Bainbridge, 1931). Therefore, observed relationships are perhaps unsurprising
20 between inflated RPE and cardiovascular markers of relative threat states (i.e., reduced CO and/or
21 increased TPR reactivity), which are indicative of reduced blood flow (Seery, 2011). Our results also
22 align with previous observations that psychophysiological factors exert more influence on RPE during
23 moderate- as opposed to severe-intensity workloads (Ekkekakis, 2003), since relationships became
24 non-significant towards the latter stages of the exercise (Table 1). This effect may have resulted from
25 homogenous preferences towards internally-focused attentional stimuli (e.g., muscle pain) at
26 heightened levels of fatigue, which dilutes the influence of motivational factors on RPE (Tenenbaum
27 et al., 2001).

1 higher PO's than those manipulated into a threat state, and that this would result in comparatively
2 faster completion times.

3 **Material and methods**

4 *Participants*

5 A different sample of 21 novice cyclists were recruited for study 2 (see Table 2 for
6 characteristics), with a sample of 18 deemed sufficiently powered ($1-\beta: .8$) to detect significant effects
7 in cardiovascular indices of challenge and threat, RPE, and performance ($\alpha: p = .05$), according to
8 analysis of previous studies (Marcora et al., 2009; Micklewright et al., 2010; Moore et al., 2012;
9 calculated using G*power software, version 3.1). To limit excessive baseline variability in
10 antecedents of challenge and threat (e.g., knowledge, skills, and ability), participants were included if
11 they had no time-trial experience, but engaged in regular training for alternative endurance-based
12 sports (≥ 2 weekly sessions; Runners $n = 15$, Rowers: $n = 3$, Swimmers: $n = 3$). Participants
13 completed 48-hour food diaries before testing, and were required to replicate dietary behaviours
14 across visits. Furthermore, they were instructed to arrive hydrated, rested, and free of injury and
15 illness, as well as to abstain from caffeine (for 12h), alcohol (48h), and vigorous exercise (48h) before
16 visits. Participants remained naïve to the objectives of the study until completion of all visits.
17 Institutional ethical approval was granted, and written informed consent was obtained from each
18 participant before data collection.

19 ***Insert Table 2 here***

20

21 *Measures*

22 *Manipulation checks.* Task engagement and challenge and threat states were assessed using
23 HR reactivity and CTI respectively (following the same procedures as in study 1).

24 *Exercise responses.* As in study 1, RPE were reported verbally using Borg's 15-point scale
25 (Borg, 1970), at the end of warm-ups and at 4-km race quartiles (4 km: RPE_{Q1}, 8 km: RPE_{Q2}, 12 km:
26 RPE_{Q3}, 16km: RPE_{Q4}). Pulmonary gas exchange measures ($\dot{V}O_2$) were recorded using an online gas

1 analyser (Cortex Metalyzer 2R, Cortex, Leipzig, Germany; as in study 1), with average values taken
2 for warm-ups, each 4.025-km race quartile, and for the overall race duration.

3 **Performance.** Power output (PO; converted into $W \cdot kg^{-1}$), distance (km), and time (min) were
4 monitored continuously by a PowerTap power meter (CycleOps, Madison, USA), a device proven
5 valid and reliable for research purposes, which consists of an onboard data logger, sensor cable, and
6 an eight-strain-gauge instrumented rear-wheel hub (Bertucci, Duc, Villerius, Pernin, & Grappe, 2005).
7 The power meter was calibrated in accordance with manufacturer instructions (as in Bertucci et al.,
8 2005). The time taken to complete 16.1 km (time to completion; TTC) was measured from the onset
9 of cycling to trial completion. To illustrate pacing profiles, average PO for each warm-up, 4.025 km
10 race quartile (0-4 km: PO_{Q1} ; 4-8km: PO_{Q2} ; 8-12km: PO_{Q3} ; 12-16km: PO_{Q4}), and for the overall 16.1
11 km were taken.

12 **Procedures**

13 Following a single-blind, randomised control design, participants attended three sessions,
14 separated by a minimum of 48 hours, and scheduled for the same time of day ($\pm 1h$). To control for the
15 effects of familiarity and previous task experience on challenge and threat states (Blascovich, 2008),
16 visits were performed in the same order for all participants. Each visit involved completing a 16.1 km
17 trial on a time-trial bike (Planet X, Sheffield, UK) fitted with a Powertap G3 Hub (Powertap,
18 Wisconsin, USA), and mounted on a turbo-trainer (Cycleops Super Magneto, Wisconsin, USA).
19 Before starting trials from a 'natural' position, participants undertook a 3-minute self-paced warm-up
20 and selected a starting gear. Participants were blinded from performance feedback apart from elapsed
21 distance.

22 **Familiarisation trial (TT_{FAM}).** After documentation of demographic information (i.e., age,
23 height, weight, sport, competitive-level, and experience), participants completed their first 16.1 km
24 time-trial, which served to familiarise them with the associated demands and procedures of each test.
25 Before exercise, individual bike positioning was adjusted, recorded, and later reproduced in
26 subsequent trials. Upon completion, participants were matched into trios, according to demographics

1 and TTC (Table 2), which were then split and randomly allocated (using <https://www.randomizer.org>)
2 to one of the three experimental groups (Challenge, $n = 7$; Threat, $n = 7$; Neutral-Control, $n = 7$).

3 **Control trial (TT_{CON}).** The second trial served as a control (TT_{CON}), whereby all participants
4 received identical ‘neutral’ task instructions (see Supplementary files) as cardiovascular reactivity
5 data were recorded. Participants remained seated silently while task instructions were delivered, with
6 these instructions emphasising the comparative and evaluative nature of the task to elevate pressure
7 (as Moore et al., 2012). Specifically, as in study one, maximal effort was encouraged to ‘improve the
8 accuracy’ of the results. Furthermore, instructions stated that performances would be published on a
9 leaderboard, and that top performers would be awarded prizes and worst performers would be
10 interviewed about their poor performance. Thereafter, participants completed a warm-up and the
11 subsequent time-trial, while physiological ($\dot{V}O_2$), perceptual (RPE), and performance (TTC, PO)
12 measures were assessed.

13 **Experimental trial (TT_{EXP}).** Manipulation check and time-trial procedures were replicated in
14 the third visit (TT_{EXP}), although different task instructions were provided to participants according to
15 their experimental group. While instructions remained identical to TT_{CON} for the neutral group, verbal
16 instructions were used to manipulate perceptions of task demands and personal coping resources for
17 the challenge and threat groups (see supplementary files). The challenge group received instructions
18 that reduced perceptions of task demands and increased perceptions of personal coping resources
19 (e.g., people tend to “perform well”), whereas the threat group received instructions that inflated
20 perceived demands and diminished perceived coping resources (e.g., emphasising that people have
21 “struggled to perform well”). Similar, group-based instructions have been used previously to
22 successfully elicit the expected stress response prior to the performance of a lab-based sporting task
23 (Moore et al., 2012).

24 **Statistical Analysis**

25 One-way ANOVAs were employed to detect any between-group differences in demographic,
26 familiarisation, and warm-up variables. Task engagement was assessed using dependent t -tests to

1 examine whether HR increased significantly following the manipulation instructions in both TT_{CON}
 2 and TT_{EXP}. A manipulation check was conducted using a 2 (trial: TT_{CON}, TT_{EXP}) x 3 (group:
 3 challenge, threat, neutral) mixed ANOVA with CTI as the dependent variable. Thereafter, a series of
 4 2 (trial: TT_{CON}, TT_{EXP}) x 3 (group: challenge, threat, neutral) x 4 (sector: Q1, Q2, Q3, Q4) ANOVAs
 5 examined group-by-trial differences in performance and exercise responses over time (i.e., PO, $\dot{V}O_2$,
 6 and RPE). Finally, overall group-by-trial alterations in performance were examined using a 2 (trial:
 7 TT_{CON}, TT_{EXP}) x 3 (group: challenge, threat, neutral) mixed ANOVA, with TTC as the dependent
 8 variable. Planned post-hoc comparisons utilised dependent and independent *t*-tests (adjusted using the
 9 Bonferroni correction). Where the sphericity assumption was violated, Greenhouse–Geisser
 10 corrections were applied. Significance was accepted at $p < 0.05$, and mean data is presented \pm SD.

11 **Results and Discussion**

12 *Manipulation Checks*

13 There were no missing data or univariate outliers ($p < .001$) in the dataset, although two
 14 participants withdrew due to training-related injury, and one was excluded prior to statistical analyses
 15 after reporting illness, affording a final sample of 18 (Challenge group, $n = 7$; Threat group, $n = 6$;
 16 Neutral-Control group, $n = 5$). There were no significant differences between groups in terms of the
 17 demographic or body size variables (all $ps > .05$). Furthermore, there were no significant differences
 18 between groups in relation to TTC ($F_{(2, 15)} = .38, p > .05$) or average PO ($F_{(2, 15)} = 0.09, p > .05$) during
 19 TT_{FAM}, suggesting matched-randomisation of groups was successful (Table 2). Finally, no significant
 20 between-group differences emerged for warm-up $\dot{V}O_2$, RPE, or PO (all $ps > .05$).

21 HR increased significantly following task instructions in TT_{CON} (mean difference: 4.89 ± 3.31
 22 bpm^{-1} ; $t_{[17]} = 6.27, p < .001, d = 1.48$) and TT_{EXP} (mean difference: $4.29 \pm 4.69 \text{ bpm}^{-1}$; $t_{[17]} = 3.88, p =$
 23 $.001, d = 0.91$). This confirms task engagement, permitting further investigation of challenge and
 24 threat states (via CTI). ANOVA revealed a significant ‘trial-by-group’ interaction for CTI ($F_{[2,15]} =$
 25 $14.32, p < .001$). CTI significantly increased between TT_{CON} and TT_{EXP} for the challenge group (mean
 26 difference: 2.20 ± 1.05 ; $t_{[6]} = 5.55, p = .001, d = 2.10$), decreased for the threat group (mean

1 difference: -2.48 ± 1.97 ; $t_{[6]} = -3.09$, $p = .027$, $d = -1.26$), and showed no significant changes in the
2 neutral group (mean difference: -0.10 ± 1.67 ; $t_{[4]} = 0.14$, $p > .05$). This suggests that the instructions
3 were successful in manipulating participants into challenge, threat, and neutral states (Table 3).

4 ****Insert Table 3 here****

5 **Primary Analysis**

6 As hypothesised, a significant group-by-trial-by-distance interaction occurred for PO
7 ($F_{[2,66,19,95]} = 3.22$, $p = .049$), highlighting that manipulation-dependent changes in workload emerged.
8 Specifically, changes in PO_{Q1} between trials were greater in the challenge group compared to the
9 threat group ($t_{[10,78]} = 2.63$, $p = .024$, $d = 1.25$), who utilised a more cautious early-race pacing profile,
10 although these augmentations were not maintained into the middle sectors of the trial (Figure 2).
11 Therefore, this study shows that, through manipulating challenge and threat states, one can alter
12 pacing behaviour during endurance events. Specifically, results indicate that the adoption of a more
13 ‘challenge-like’ cardiovascular response can prompt athletes to select higher work-rates during early
14 stages of exercise. Notably though, in line with findings from study one, there were no significant
15 group-by-trial-by-distance interactions for RPE ($F_{[6,45]} = 2.07$, $p > .05$), *despite* these differences in
16 early-race pacing. This shows that the challenge group were able to adopt higher workloads than the
17 threat group at a given RPE. Such differences reinforce the BPSM’s proposals that a challenge state,
18 as opposed to a threat state, promotes more favourable responses in motivated performance situations
19 (Blascovich, 2008). Interestingly, given the distinct cardiovascular reactivity patterns displayed in
20 each group (Table 3), no significant interaction effects for $\dot{V}O_2$ emerged ($F_{[3,28,24,57]} = 1.56$, $p > .05$).
21 Therefore, results infer that discrepancies in RPE and pacing stem from subtle alterations in anaerobic
22 energy systems and/or distortions in interoceptive accuracy (i.e., in the *perception* of sensory
23 information).

24 ****Insert Figure 2 here****

25

1 No significant group-by-trial interactions emerged for TTC ($F_{[2,15]} = 1.36, p > .05$), meaning
2 that no overall performance effects were observed. This was due to differences in the latter stages of
3 TT_{EXP} , with more pronounced ‘end-spurts’ evident in the threat group relative to the challenge group
4 (Figure 2). While seemingly contradictory to the propositions of the psychobiological model of
5 endurance (i.e., that any factor which reduces one’s RPE will enhance performance; Marcora, 2010),
6 these null performance effects could be explained by the dynamic nature of challenge and threat states
7 (Seery et al., 2009). It is possible that, in the threat group, increases in ‘end-spurt’ workloads
8 coincided with individuals beginning to view the task as more of a challenge towards the end of
9 exercise (e.g., due to lower perceived task demands and/or higher personal coping resources).
10 Similarly, an increased focus towards movement execution, potentially resulting from increased
11 reinvestment (Jones et al., 2009), may have facilitated these more pronounced compensatory end-
12 spurts. Therefore, the dynamic interplay between performance, RPE, and challenge and threat states
13 requires further investigation.

14

15 **General Discussion**

16 The present research investigated the effects of the cardiovascular markers of challenge and
17 threat states on endurance exercise capabilities. Collectively, the results are the first to show that
18 relative to a cardiovascular response more akin to a threat state, a response more indicative of a
19 challenge state can promote more favourable responses during endurance exercise, including
20 reductions in RPE and increases in self-selected pacing. However, no overall performance effects
21 were observed, suggesting that the applicability of the BPSM to endurance-based tasks is likely to be
22 complex.

23 Reductions in RPE relative to individual work-rates were linked to a challenge state during
24 both studies. Although novel, various antecedents of challenge and threat states have been linked to
25 perceptions of fatigue in previous research. For example, during prolonged endurance events,
26 reductions in RPE have been shown to correspond with higher pre-exercise levels of self-efficacy and
27 task familiarity (Hutchinson et al., 2008; Micklewright et al., 2010), factors proposed to underpin

1 relative challenge states through increase perceived coping resources relative to situational demands
2 (Blascovich, 2008; Jones et al., 2009). In study two, these decreases in RPE facilitated increases in
3 self-selected workloads during early stages of exercise, effects produced by various ergogenic
4 interventions (e.g., motivational self-talk, Blanchfield et al., 2013; caffeine ingestion, Cole et al.,
5 1996). The findings therefore suggest that the adaptive psychophysiological responses fostered by a
6 challenge state (i.e., reduced RPE) may enhance behaviour during metabolically-demanding events.
7 However, while stress-related enrichments in muscular blood flow likely persist during exercise
8 (Rousselle et al., 1995), and proposed enhancements in anaerobic oxygen-independent mechanisms
9 remain possible (Jones et al., 2009), no physiological enhancements were detected during exercise in
10 either study. Further research into distorted interoceptive accuracy, potentially via threat-related
11 perceptual biases (see Vine et al., 2016), is particularly promising, as attentional mechanisms have
12 been prominently linked with RPE (LaCaille, Masters, & Heath, 2004; Pennebaker and Lightner,
13 1980; Rejeski, 1985). Such investigations may wish to focus on the potentially-mediating effects of
14 associative and dissociative cognitive processes, strategies proven to alter both RPE and performance
15 in endurance events (Morgan, Horstman, Cymerman, & Stokes, 1983; McCormick et al., 2015).

16 Interestingly, no overall performance effects emerged in either study, contesting suggestions
17 that the adoption of a cardiovascular response more consistent with a challenge state will enhance
18 performance more than the response akin to a threat state (Blascovich, 2008). Our data instead
19 presents a more complex picture, particularly in the latter stages of exercise, where cardiovascular
20 reactivity (i.e., CTI) became unrelated to RPE (Table 1), and more pronounced ‘end-sprints’ occurred
21 for those participants who displayed reactivity more indicative of a threat state (Figure 2). These
22 findings align with a meta-analysis recently conducted by Behnke and Kaczmarek (2018), who found
23 that the majority of performance variance in research remains unexplained after accounting for the
24 effects of challenge and threat states. Results also reinforce observations that the effects of perceived
25 exertion becomes less predictable towards the end of endurance events (Tucker & Noakes, 2009),
26 where heightened markers of fatigue dilute central influences on RPE (Rejeski & Ribisl, 1980).

27 **Implications and Future Research**

1 The present research supports interdisciplinary explanations of human performance. First, the
2 results offer novel evidence for the theories of challenge and threat states (e.g., BPSM and TCTSA),
3 reinforcing views that a challenge state can enhance individual responses (i.e., reduce RPE) during
4 motivated performance situations. While no performance effects were revealed, the likely role of
5 compensatory processes in minimising such effects support recent interpretations that a threat state is
6 not always detrimental to performance if additional resources are mobilised (e.g., effort; Vine et al.,
7 2016). Second, the results also support propositions made by the psychobiological model of
8 endurance (Marcora et al., 2008; 2009; Marcora & Staiano, 2010) that self-selected work-rates are
9 reduced by predictors of inflated RPE. To further integrate these theories, future research should
10 analyse the precise mechanisms through which these effects occur, with the examination of specific
11 attentional bias tendencies (e.g., associative or dissociative cues), warranting particular exploration.

12 The findings reported here, that important determinants of endurance performance (e.g., RPE
13 and pacing) can be altered through the verbal manipulation of challenge and threat states, has
14 implications for sporting and non-sporting contexts (e.g., cycling, team-based activities, armed forces,
15 health settings). Notably, the reductions in RPE associated with a challenge state could be targeted, as
16 they prove predictive of numerous favourable outcomes such as enhanced endurance capabilities,
17 reduced internal training load, and proficient motor performances (Marcora et al., 2008; 2009; Royal
18 et al., 2006; Snyder, Jeukendrup, Hesselink, Kuipers, & Foster, 1993). Various interventions have
19 been shown to promote ‘challenge-like’ cardiovascular responses (e.g., arousal reappraisal; Jamieson,
20 Mendes, Blackstock, & Schmader, 2010; Moore, Vine, Wilson, & Freeman, 2015; Sammy et al.,
21 2017), which, on the basis of the present research, offer potentially-adaptive outcomes in fatigue-
22 related domains. Future research should examine whether these interventions can enhance
23 performance-based, and/or health-related outcomes that are associated with RPE, such as overtraining
24 syndrome (Matos, Winsley, & Williams, 2011) and/or adherence to physical activity (Ekkekakis &
25 Lind, 2006).

26 Limitations of the present research also highlight directions for prospective research. First,
27 alterations in the cardiovascular markers of challenge and threat states were not monitored during

1 exercise in either study, due to validity concerns surrounding the influence of movement artefacts
2 (Siebenmann et al., 2015). The interpretation of effects occurring at the end of exercise are therefore
3 speculative, as evaluated demands and personal coping resources will have likely differed from when
4 they were measured. For example, increases in self-efficacy, an antecedent of challenge states (Jones
5 et al., 2009), would be expected as uncertainties surrounding one's ability to complete the task are
6 reduced (Tucker & Noakes, 2009). As such, future investigations should attempt to monitor challenge
7 and threat states *during* exercise, potentially via self-report items and/or salivary
8 catecholamines/cortisol (as in Jamieson et al., 2010). Second, the absence of self-report measures of
9 demand and resource evaluations limits our overall understanding of how challenge and threat states
10 influence RPE and exercise capabilities. Although experimental task instructions in study two
11 specifically targeted perceptions relating to task demands and ability to cope with these demands,
12 further scrutiny is warranted into the potentially-influential roles of the cognitive, social, and
13 physiological components integrated within the BPSM (e.g., uncertainty, social support,
14 neuroendocrine activity, Blascovich 2008; Seery, 2011). Future research should utilise multiple
15 psychological and physiological assessments of challenge and threat states to enable a more complete
16 picture. Such scrutiny could not only aid our theoretical understanding, but also the development of
17 future applied interventions in endurance sports (McCormick et al., 2015).

18 To conclude, the present research is the first to demonstrate that the cardiovascular reactivity
19 patterns marking challenge and threat states impact upon perceptions of fatigue and physical
20 functioning during endurance-based exercise. A cardiovascular response more indicative of a
21 challenge state, as opposed to a threat state, was associated with reduced RPE at a given work-rate,
22 and quicker pacing during the beginning of endurance exercise, although no overall performance
23 effects were observed. Future investigations into whether a challenge state can be manipulated to
24 reduce perceptions of fatigue, and thus potentially alter exercise capabilities, is warranted.

References

- Abbiss, C. R., & Laursen, P. B. (2005). Models to explain fatigue during prolonged endurance cycling. *Sports Medicine*, 35(10), 865-898.

- Amann, M., & Dempsey, J. A. (2008). Locomotor muscle fatigue modifies central motor drive in healthy humans and imposes a limitation to exercise performance. *The Journal of Physiology*, 586(1), 161-173.
- Bainbridge, F. A. (1931). *The Physiology of Muscular Exercise*. London: Longmans, Green and Co.
- Baumeister, R. F., & Showers, C. J. (1986). A review of paradoxical performance effects: Choking under pressure in sports and mental tests. *European Journal of Social Psychology*, 16(4), 361-383.
- Behnke, M., & Kaczmarek, L. D. (2018). Successful performance and cardiovascular markers of challenge and threat: A meta-analysis. *International journal of psychophysiology*.
- Bertucci, W., Duc, S., Villerius, V., Pernin, J. N., & Grappe, F. (2005). Validity and reliability of the PowerTap mobile cycling powermeter when compared with the SRM device. *International Journal of Sports Medicine*, 26(10), 868-873.
- Blanchfield, A. W., Hardy, J., De Morree, H. M., Staiano, W., & Marcora, S. M. (2014). Talking yourself out of exhaustion: the effects of self-talk on endurance performance. *Med Sci Sports Exerc*, 46(5), 998-1007.
- Blascovich, J. (2008). Challenge and Threat. In A. J. Elliot. *Handbook of approach and avoidance motivation* (pp. 431-445). New York, NY: Psychology Press.
- Blascovich, J., & Tomaka, J. (1996). The biopsychosocial model of arousal regulation. In M. Zanna (Ed.), *Advances in Experimental Social Psychology* (pp. 1-51). New York; Academic Press.
- Borg, G. (1970). Perceived exertion as an indicator of somatic stress. *Scandinavian Journal of Rehabilitation Medicine*, 2(2), 92-98.
- Chapman, A. R., Vicenzino, B., Blanch, P., & Hodges, P. W. (2007). Leg muscle recruitment during cycling is less developed in triathletes than cyclists despite matched cycling training loads. *Experimental Brain Research*, 181(3), 503-518.
- Cohen, J. (1992). A power primer. *Psychological bulletin*, 112(1), 155.
- Cole, K. J., Costill, D. L., Starling, R. D., Goodpaster, B. H., Trappe, S. W., & Fink, W. J. (1996). Effect of caffeine ingestion on perception of effort and subsequent work production. *International Journal of Sport Nutrition*, 6(1), 14-23.
- Coyle, E. F., Coggan, A. R., Hopper, M. K., & Walters, T. J. (1988). Determinants of endurance in well-trained cyclists. *Journal of Applied Physiology*, 64(6), 2622-2630.
- Cywinski, J., & Tardieu, B. (1980). *The essentials in pressure monitoring: Blood and other body fluids*. Martinus Nijhoff Medical Division.

- de Koning, J. J., Bobbert, M. F., & Foster, C. (1999). Determination of optimal pacing strategy in track cycling with an energy flow model. *Journal of Science and Medicine in Sport*, 2(3), 266-277.
- Derks, B., Scheepers, D., Van Laar, C., & Ellemers, N. (2011). The threat vs. challenge of car parking for women: How self-and group affirmation affect cardiovascular responses. *Journal of Experimental Social Psychology*, 47(1), 178-183.
- Ekkekakis, P. (2003). Pleasure and displeasure from the body: Perspectives from exercise. *Cognition & Emotion*, 17(2), 213-239.
- Ekkekakis, P., & Lind, E. (2006). Exercise does not feel the same when you are overweight: the impact of self-selected and imposed intensity on affect and exertion. *International Journal of Obesity*, 30(4), 652.
- Feinberg, J. M., & Aiello, J. R. (2010). The effect of challenge and threat appraisals under evaluative presence. *Journal of Applied Social Psychology*, 40(8), 2071-2104.
- González- Alonso, J., Calbet, J. A., & Nielsen, B. (1999). Metabolic and thermodynamic responses to dehydration- induced reductions in muscle blood flow in exercising humans. *The Journal of Physiology*, 520(2), 577-589.
- Hase, A., O'Brien, J., Moore, L. J., & Freeman, P. (2018). The relationship between challenge and threat states and performance: A systematic review. *Sport, Exercise, and Performance Psychology*.
- Hutchinson, J. C., Sherman, T., Martinovic, N., & Tenenbaum, G. (2008). The effect of manipulated self-efficacy on perceived and sustained effort. *Journal of Applied Sport Psychology*, 20(4), 457-472.
- Jamieson, J. P., Mendes, W. B., Blackstock, E., & Schmader, T. (2010). Turning the knots in your stomach into bows: Reappraising arousal improves performance on the GRE. *Journal of Experimental Social Psychology*, 46(1), 208-212.
- Jones, M., Meijen, C., McCarthy, P. J., & Sheffield, D. (2009). A theory of challenge and threat states in athletes. *International Review of Sport and Exercise Psychology*, 2(2), 161-180.
- LaCaille, R. A., Masters, K. S., & Heath, E. M. (2004). Effects of cognitive strategy and exercise setting on running performance, perceived exertion, affect, and satisfaction. *Psychology of Sport and Exercise*, 5(4), 461-476.
- Lansley, K. E., Dimenna, F. J., Bailey, S. J., & Jones, A. M. (2011). A 'new' method to normalise exercise intensity. *International Journal of Sports Medicine*, 32(07), 535-541.

- Lazarus, R. S. (2000). How emotions influence performance in competitive sports. *The sport Psychologist, 14*(3), 229-252.
- Marcora, S. M. (2010). Effort: perception of. In E. B. Goldstein. *Encyclopedia of Perception* (pp. 380-383). Los Angeles, LA: Sage.
- Marcora, S. M., Bosio, A., & de Morree, H. M. (2008). Locomotor muscle fatigue increases cardiorespiratory responses and reduces performance during intense cycling exercise independently from metabolic stress. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 294*(3), 874-883.
- Marcora, S. M., & Staiano, W. (2010). The limit to exercise tolerance in humans: mind over muscle?. *European Journal of Applied Physiology, 109*(4), 763-770.
- Marcora, S. M., Staiano, W., & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of Applied Physiology, 106*(3), 857-864.
- Matos, N. F., Winsley, R. J., & Williams, C. A. (2011). Prevalence of nonfunctional overreaching/overtraining in young English athletes. *Medicine & Science in Sports & Exercise, 43*(7), 1287-1294.
- Mauger, A. R., Jones, A. M., & Williams, C. A. (2010). Influence of acetaminophen on performance during time trial cycling. *Journal of Applied Physiology, 108*(1), 98-104.
- McCormick, A., Meijen, C., & Marcora, S. (2015). Psychological determinants of whole-body endurance performance. *Sports Medicine, 45*(7), 997-1015.
- Micklewright, D., Papadopoulou, E., Swart, J., & Noakes, T. (2010). Previous experience influences pacing during 20 km time trial cycling. *British Journal of Sports Medicine, 44*(13), 952-960.
- Midgley, A. W., McNaughton, L. R., & Jones, A. M. (2007). Training to enhance the physiological determinants of long-distance running performance. *Sports Medicine, 37*(10), 857-880.
- Moore, L. J., Vine, S. J., Wilson, M. R., & Freeman, P. (2012). The effect of challenge and threat states on performance: An examination of potential mechanisms. *Psychophysiology, 49*(10), 1417-1425.
- Moore, L. J., Vine, S. J., Wilson, M. R., & Freeman, P. (2014). Examining the antecedents of challenge and threat states: The influence of perceived required effort and support availability. *International Journal of Psychophysiology, 93*(2), 267-273.
- Moore, L. J., Vine, S. J., Wilson, M. R., & Freeman, P. (2015). Reappraising threat: How to optimize performance under pressure. *Journal of Sport and Exercise Psychology, 37*(3), 339-343.

- Moore, L. J., Wilson, M. R., Vine, S. J., Coussens, A. H., & Freeman, P. (2013). Champ or chump?: Challenge and threat states during pressurized competition. *Journal of Sport and Exercise Psychology, 35*(6), 551-562.
- Morgan, W. P., Horstman, D. H., Cymerman, A., & Stokes, J. (1983). Facilitation of physical performance by means of a cognitive strategy. *Cognitive Therapy and Research, 7*(3), 251-264.
- Noakes, T. D. (2000). Physiological models to understand exercise fatigue and the adaptations that predict or enhance athletic performance. *Scandinavian Journal of Medicine & Science in Sports, 10*(3), 123-145.
- Noakes, T. D. (2012). The Central Governor Model in 2012. *British Journal of Sports Medicine, 46*(1), 1-3.
- Osbourne, J.W. (2013). *Best practices in data cleaning: A complete guide to everything you need to do before and after collecting your data*. Thousand Oaks, CA: Sage Publications.
- Pandolf, K. B. (1983). Advances in the study and application of perceived exertion. *Exercise and Sport Sciences Reviews, 11*(1), 118-158.
- Paterson, S., & Marino, F. E. (2004). Effect of deception of distance on prolonged cycling performance. *Perceptual and Motor Skills, 98*(3), 1017-1026.
- Pennebaker, J. W., & Lightner, J. M. (1980). Competition of internal and external information in an exercise setting. *Journal of Personality and Social Psychology, 39*(1), 165.
- Rejeski, W. J. (1985). Perceived exertion: An active or passive process?. *Journal of Sport Psychology, 7*(4), 371-378.
- Rejeski, W. J., & Ribisl, P. M. (1980). Expected task duration and perceived effort: an attributional analysis. *Journal of Sport Psychology, 2*(3), 227-236.
- Rousselle, J. G., Blascovich, J., & Kelsey, R. M. (1995). Cardiorespiratory response under combined psychological and exercise stress. *International Journal of Psychophysiology, 20*(1), 49-58.
- Royal, K. A., Farrow, D., Mujika, I., Halson, S. L., Pyne, D., & Abernethy, B. (2006). The effects of fatigue on decision making and shooting skill performance in water polo players. *Journal of Sports Sciences, 24*(8), 807-815.
- Sammy, N., Anstiss, P. A., Moore, L. J., Freeman, P., Wilson, M. R., & Vine, S. J. (2017). The effects of arousal reappraisal on stress responses, performance and attention. *Anxiety, Stress, & Coping, 30*(6), 619-629.
- Seery, M. D. (2011). Challenge or threat? Cardiovascular indexes of resilience and vulnerability to potential stress in humans. *Neuroscience & Biobehavioral Reviews, 35*(7), 1603-1610.

- Seery, M. D., Blascovich, J., Weisbuch, M., & Vick, S. B. (2004). The relationship between self-esteem level, self-esteem stability, and cardiovascular reactions to performance feedback. *Journal of Personality and Social Psychology, 87*(1), 133.
- Seery, M. D., Weisbuch, M., & Blascovich, J. (2009). Something to gain, something to lose: The cardiovascular consequences of outcome framing. *International Journal of Psychophysiology, 73*(3), 308-312.
- Siebenmann, C., Rasmussen, P., Sørensen, H., Zaar, M., Hvidtfeldt, M., Pichon, A., ... & Lundby, C. (2015). Cardiac output during exercise: A comparison of four methods. *Scandinavian Journal of Medicine & Science in Sports, 1*(25), e20-e27.
- Sherwood, A., Allen, M. T., Fahrenberg, J., Kelsey, R. M., Lovallo, W. R., & van Doornen, L. J. (1990). Methodological guidelines for impedance cardiography. *Psychophysiology, 27*(1), 1-23.
- Smirmaul, B. P. C., Dantas, J. L., Nakamura, F. Y., & Pereira, G. (2013). The psychobiological model: a new explanation to intensity regulation and (in) tolerance in endurance exercise. *Revista Brasileira de Educação Física e Esporte, 27*(2), 333-340.
- Snyder, A. C., Jeukendrup, A. E., Hesselink, M. K. C., Kuipers, H., & Foster, C. (1993). A physiological/psychological indicator of over-reaching during intensive training. *International Journal of Sports Medicine, 14*(1), 29-32.
- Tucker, R., & Noakes, T. D. (2009). The physiological regulation of pacing strategy during exercise: a critical review. *British Journal of Sports Medicine, 43*(6), e1-e1.
- Turner, M. J., Jones, M. V., Sheffield, D., Slater, M. J., Barker, J. B., & Bell, J. J. (2013). Who thrives under pressure? Predicting the performance of elite academy cricketers using the cardiovascular indicators of challenge and threat states. *Journal of Sport and Exercise Psychology, 35*(4), 387-397.
- Turner, M. J., Jones, M. V., Sheffield, D., Barker, J. B., & Coffee, P. (2014). Manipulating cardiovascular indices of challenge and threat using resource appraisals. *International Journal of Psychophysiology, 94*(1), 9-18.
- Vine, S. J., Freeman, P., Moore, L. J., Chandra-Ramanan, R., & Wilson, M. R. (2013). Evaluating stress as a challenge is associated with superior attentional control and motor skill performance: testing the predictions of the biopsychosocial model of challenge and threat. *Journal of Experimental Psychology: Applied, 19*(3), 185.
- Vine, S. J., Moore, L. J., & Wilson, M. R. (2016). An integrative framework of stress, attention, and visuomotor performance. *Frontiers in Psychology, 7*, 1671.

Table 1: Results from hierarchal regression analyses performed on data in study one.

Footnotes

1. Supplementary demand and resource evaluation scores (e.g., as used in Feinberg and Aiello, 2010; Moore et al., 2012) were not utilised in the study, after pilot data ($n = 5$) showed insufficient variance in self-reported situational demands (mean = 6; SD = 0). This effect was attributed to the uniformly-high (i.e., exhaustive) demands of the exercise test, and limitations in the sensitivity of self-report measures for detecting subconscious evaluations (discussed in Blascovich, 2008), as reflected in maximal reported values in all participants.

Table 2. Group descriptive statistics (mean \pm SD) for demographic, body size, and familiarisation data in study two.

RPE ₀₋₁₀	1	Age	0.05	0.09	0.57
	2	Body Mass	-0.02	0.03	-0.75
	3	CTI	-0.49	0.20	-2.41*
RPE (11 min)	1	Age	-0.08	0.10	-0.84
	2	Body Mass	-0.04	0.04	-1.23
	3	CTI	-0.59	0.22	-2.73*
RPE (50%TTE)	1	Age	0.03	0.05	0.67
	2	Body Mass	-0.01	0.02	-0.52
	3	CTI	-0.17	0.14	-1.23
TTE	1	Age	0.21	0.09	2.20*
	2	Body Mass	0.07	0.03	2.41*
	3	CTI	0.22	0.22	0.98

RPE: ratings of perceived exertion (RPE₀₋₁₀: average ratings during moderate-intensity exercise);
CTI: challenge and threat index; TTE: time to exhaustion; * $p < .05$

	Challenge Group	Threat Group	Neutral Group
Age (years)	21.86 ± 2.10	23.00 ± 2.45	24.29 ± 3.99
Height (cm)	178.36 ± 9.50	176.93 ± 9.38	176.96 ± 10.67
Weight (kg)	71.76 ± 11.76	71.49 ± 15.95	71.56 ± 17.37
Training Experience (years)	4.00 ± 2.00	5.00 ± 3.32	6.43 ± 7.43
Weekly Training Time (min)	505.00 ± 535.33	492.86 ± 253.29	508.57 ± 241.28
TTfam Average $\dot{V}O_2$ (ml.kg/min)	37.86 ± 8.91	35.79 ± 13.09	37.39 ± 8.60
TTfam Average PO (W.kg)	2.46 ± 1.03	2.28 ± 0.84	2.46 ± 0.76
TTfam TTC (min)	34.64 ± 9.41	34.56 ± 6.40	32.59 ± 4.48

TTfam: familiarisation time-trial; $\dot{V}O_2$: pulmonary oxygen uptake; PO: power output; TTC: time to completion; no significant differences between groups ($p > .05$).

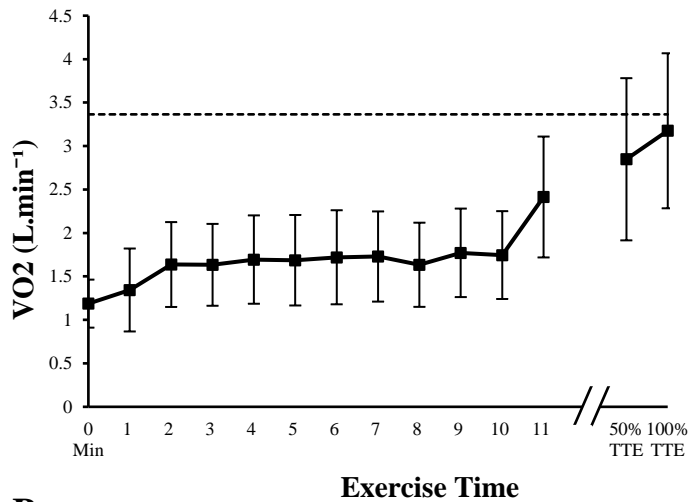
Table 3. Group and trial averages (mean \pm SD) for resting and exercise outcome measures in study two.

	Challenge Group		Threat Group		Neutral Group	
	TTcon	TTexp	TTcon	TTexp	TTcon	TTexp
CTI Score	-0.70 \pm 1.34	1.50 \pm 1.53*	0.77 \pm 1.45	-1.71 \pm 1.42*	0.04 \pm 1.42	-0.06 \pm 0.72
$\dot{V}O_2$ (ml.kg.min)	35.26 \pm 8.53	39.72 \pm 8.55	33.89 \pm 9.48	34.41 \pm 8.72	37.69 \pm 7.28	35.07 \pm 7.14
PO (W.kg)	2.91 \pm 0.49	2.73 \pm 0.84	2.34 \pm 0.69	2.42 \pm 0.68	2.45 \pm 0.84	2.46 \pm 0.83
TTC (min)	33.26 \pm 8.15	33.03 \pm 7.48	32.81 \pm 6.18	31.99 \pm 6.43	31.21 \pm 4.29	31.58 \pm 3.63

TTcon: control time-trial; TTexp: experimental time-trial; CTI: challenge and threat index; $\dot{V}O_2$: pulmonary oxygen uptake; PO: power output; TTC: time to completion; *significant difference between visits ($p < .05$).

Figures and Captions:

A:



B:

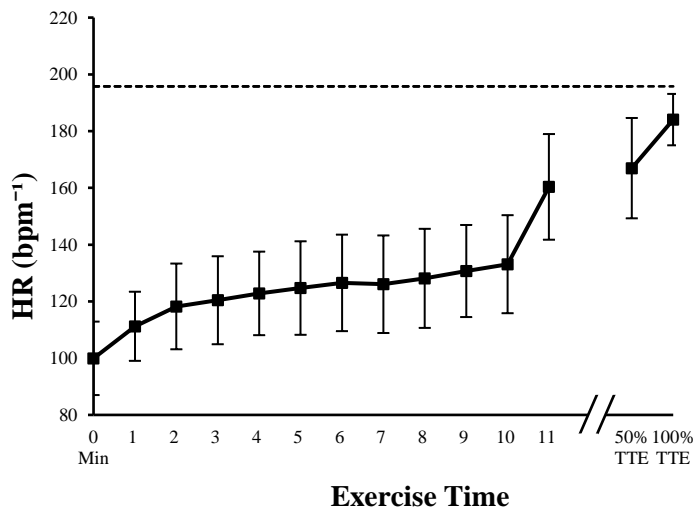


Figure 1. Physiological Responses to Exercise in Study One. Average (\pm SD) $\dot{V}O_2$ (A; L.min) and HR (B; bpm) over time during moderate- (0-10min) and severe-intensity exercise (11min, 50% TTE, 100% TTE). Dotted line: Mean $\dot{V}O_2$ peak at baseline (A), mean age-predicted maximum HR (B).

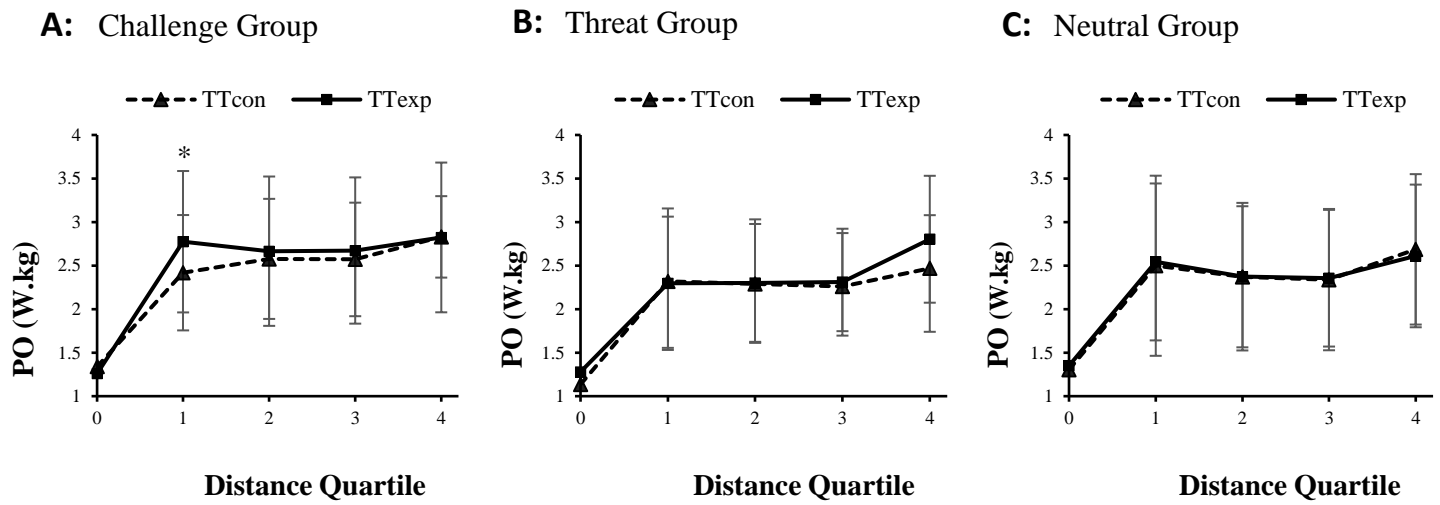


Figure 2. Pacing Profiles during Time-Trials in Study Two. Average power output (PO; W.kg) over 4.025-km race quartiles (0-4 km: Q1, 4-8km: Q2; 8-12km: Q3; 12-16km: Q4) for challenge (A), threat (B) and neutral (C) groups during control (TTcon) and experimental (TTexp) 16.1 km time-trials. *Significant difference between trials ($p < .05$).