Journal of Sports Sciences

ISSN: 0264-0414 (Print) 1466-447X (Online) Journal homepage: www.tandfonline.com/journals/rjsp20

Affect mediates the relationship between physiological and motivational responses to exercise

Izzy G. Wellings, Richard A. Ferguson & Ian M. Taylor

To cite this article: Izzy G. Wellings, Richard A. Ferguson & Ian M. Taylor (16 Aug 2025): Affect mediates the relationship between physiological and motivational responses to exercise, Journal of Sports Sciences, DOI: 10.1080/02640414.2025.2540216

To link to this article: https://doi.org/10.1080/02640414.2025.2540216

Published online: 16 Aug 2025.

JOURNAL OF SPORTS SCIENCES
https://doi.org/10.1080/02640414.2025.2540216

Routledge
Taylor & Francis Group

SPORT AND EXERCISE PSYCHOLOGY

Affect mediates the relationship between physiological and motivational responses to exercise

Izzy G. Wellings, Richard A. Ferguson and Ian M. Taylor

School of Sport, Exercise & Health Sciences, Loughborough University, Leicestershire, UK

ABSTRACT

How the interaction between physiological and motivational responses to exercise contribute to explaining endurance performance is poorly understood. This study investigated whether within-person changes in blood lactate concentration, heart rate (HR), volume of oxygen uptake (VO_2) and body temperature underlie desire to reduce effort and performance goal value during incremental exercise. Furthermore, the role of core affect in explaining these relationships was explored. Fifty participants (28 males, 22 females, M_{age} = 23.52 years; SD = 6.95 years) completed an incremental cycling step test. Work rate increased 25 watts every 4 min until voluntary exhaustion. The three psychological and four physiological measurements were taken at every stage, then analysed using multilevel modelling. Within-person variation in blood lactate concentration predicted desire to reduce effort (b = 2.19, p < .001) and performance goal (b = -0.85, p = .002). $\dot{V}O_2$ and HR predicted desire to reduce effort (b = 2.64, p < .001; b = 1.59, p = .01), whereas body temperature predicted performance goal (b = 0.58, p = .03). Affect mediated relationships involving blood lactate concentration and $\dot{V}O_2$, an important mediating variable when applying desire-goal conflicts to exercise. The four physiological responses to exercise have different but significant motivational implications.

ARTICLE HISTORY
Received 11 May 2025
Revised 21 May 2025

KEYWORDS
Motivation; endurance; psychophysiology; exercise

Introduction

The human capability to sustain uncomfortable physical activity is evolutionally important and remains key to success in various life domains, such as sport and the military. Understanding the ability to endure is, therefore, an essential research endeavour. Despite efforts to understand the relationship between physiological responses to exercise and psychological antecedents of endurance performance (e.g., Marcora & Staiano, 2010), it remains poorly understood. In particular, the role of affective responses is not universally agreed upon (Taylor et al., 2022). Hence, the aim of this study was to examine the mediating properties of affect on the relationships among important physiological responses to exercise and motivational components that influence endurance performance.

Endurance performance is associated with uncomfortable sensations as the body is under strain from the metabolic and physiological responses associated with exercise (Coyle, 1999). These sensations are integrated into a unidimensional evaluation of whole-body homeostatic disturbance (Hartman et al., 2019). As exercise intensity increases, avoiding these sensations and returning to homeostasis manifests into a motivational state, becoming a tempting and potentially satisfying proximal desire (Ramirez & Pleasure, 2003). This hedonic desire to reduce effort conflicts against the relatively distal approach-oriented and reflective performance goal (Taylor, 2021). Performance goals are often idiographic (e.g., self-referenced goals, such as personal improvement, versus normative-referenced goals, such as demonstrating superiority to competitors (Duda, 2004)). Irrespective of the features of the goal, it is the motivational value of the goal which contrasts with the desire to reduce effort. This antagonism between desire and goal is often termed the desire-goal conflict (Taylor et al., 2020, 2022). During endurance exercise, distinct motivatinal signatures can be seen in the desire and goal values that can explain endurance performance. Relatively poor performances are characterised by a higher initial desire to reduce effort and more rapid decline in goal importance during exercise, compared to better performances (Taylor et al., 2020). Therefore, it is important to understand the factors that determine the motivational strength and trajectories of desire and goal during endurance tasks.

The desire to reduce effort and performance goal value during endurance performance are related to

CONTACT Izzy G. Wellings i.g.wellings@lboro.ac.uk School of Sport, Exercise & Health Sciences, Loughborough University, Leicestershire LE11 3TU, UK

increases in blood lactate concentration, a common biomarker of muscle metabolism during fatiguing exercise (Wan et al., 2017). Specifically, within-person variation in blood lactate concentration positively correlates with desire to reduce effort and negatively correlates with performance goal value (Ramirez & Pleasure, 2003). These data suggest that the desire to reduce effort and the performance goal share underlying physiological concomitants, albeit blood lactate concentration is more strongly correlated with the hedonic desire to reduce effort than the reflective performance goal. Heart rate (HR) also positively correlates with desire to reduce effort, but not the performance goal, suggesting a less influential motivational role, compared to blood lactate concentration (Taylor et al., 2022). This relative lower contribution of HR to motivation makes sense, given that interoceptive signals from HR can be easily suppressed in favour of alternative stimuli (Salomon et al., 2016).

In addition to blood lactate concentration and HR, there is potential for other physiological responses to influence the desire to reduce effort and performance goal. It is suggested, for example, that body temperature influences endurance performance with sensory input from rises in body temperature during high-intensity exercise being associated with perception of effort (Flouris & Schlader, 2015). Ventilatory responses are also a crucial sensory cue and significantly contribute to unpleasant sensations and perceptions of effort at high exercise intensities (Robertson, 1982). Specifically, increased volume of oxygen uptake ($\dot{V}O_2$) can lead to more negative psychological responses to exercise (e.g., Ekkekakis et al., 2004) . As such, it is plausible that core temperature and $\dot{V}O_2$ also impact on the desire to reduce effort and performance goal, over and above the more established correlates of blood lactate concentration and HR.

As well as examining potential physiological correlates of the desire-goal conflict during exercise, the present research addresses a theoretical limitation of previous work. It has been assumed that the relationship between underpinning physiological responses and desire to reduce effort, and to a lesser extent goal value, is mediated by affective responses to exercise (Taylor et al., 2022). Affect can be described as a positive or negatively valanced feeling in response to a stimulus (Lindquist et al., 2016). Opinions on the role of affective responses during exercise vary from negligible (Marcora, 2008) to essential (Taylor, 2021). In line with the latter perspective, physiological responses to exercise are detected by receptors in the skin, muscles and organs (McArdle et al., 2010). These receptors inform afferents which send affective signals to the brain, entering consciousness and giving the physiological responses salience (St Clair Gibson et al., 2018). Affective responses become less positive at higher intensities and during longer durations of exercise, indicating that metabolic strain negatively correlates with affect (Ekkekakis & Petruzzello, 1999). Hence, blood lactate concentration, $\dot{V}O_2$, HR and core temperature are correlated with affect (Ekkekakis et al., 2004; Taylor et al., 2022). In turn, these affective cues become more salient as the threat to homeostasis increases and contribute to the (dis)continuation of exercise behaviour (Greenhouse-Tucknott et al., 2020; Venhorst et al., 2018).

Moreover, classic and contemporary psychological theory on the 'primacy of affect' proposes that affective reactions influence ensuing reflective, cognitive processes (Ekkekakis & Brand, 2021; Zajonc, 1984). Thus, any affective disturbance based on physiological responses to exercise are likely to influence the cognitive-oriented performance goal value alongside the desire to reduce effort. Despite this indirect evidence, the mediating role of affect in the relationship among physiological responses to exercise and desire and goal value has yet to be established. Doing so will aid understanding of psychophysiological processes that explain endurance exercise capability. Hence, the aim of this study was to examine the mediating properties of affect on the relationships among important physiological responses to exercise and motivational components that influence endurance performance.

Based on the above review, the present study tested the hypothesis that within-person changes in blood lactate concentration, HR, $\dot{V}O_2$ and body temperature during increasingly difficult exercise would predict the desire to reduce effort and, to a lesser extent, the performance goal value. In addition, it was hypothesized that affect would mediate the relationship between the physiological responses to exercise, the desire to reduce effort and the performance goal value.

Materials & methods

Participants

All experimental procedures were approved by a university ethics approvals committee and conformed with the Declaration of Helsinki (ID: 16344). Inclusion criteria required participants to be 18–50 years old, physically active (defined as participating in ≥30 min of moderate-intensity activity 3 days a week for 3 months), and free of pre-existing medical conditions or family history that made high-intensity exercise potentially dangerous. Fifty participants were recruited through word of mouth and social media (28 males and 22 females, M_{age} = 23.52 years; SD = 6.95 years). This sample size was based on a minimum of 50 level-2 units (i.e., participants in the present study) required for minimal bias in multilevel modelling statistical parameters, when combined with at least three level-1 units (i.e., measurement points in the present study) (Maas & Hox, 2005).

Procedure

Participants were fully informed of study details and the risks and discomforts associated with the experimental trial. It was clarified that participation was voluntary, data would be stored anonymously, and they had a right to withdraw at any point during the study without consequences. Participants provided written informed consent and completed questionnaires to establish they met the inclusion criteria.

Previous goal-based research has shown self-selected motives are likely to hold more personal value than externally imposed motives (Smith et al., 2007) so therefore, participants were given a list of goals (i.e., to beat other participants; to prove my fitness; to do the best I possibly can; to learn about my mental and physical abilities; to be respected by the experimenters; to demonstrate my cycling ability; to be admired for my performance) and asked to choose one to focus on during the trial. This was then placed on the wall in front of them for the duration of the trial.

Next, participants performed an incremental step test to voluntary exhaustion on an electronically braked cycle ergometer (LodeExcalibur Sport, Lode B.V. Groningen, The Netherlands). Experimental trials were undertaken between 9 am and 5pm, the average temperature of the lab was 18.06 degrees Celsius, and the humidity was 761.06 mmHg. Ergometer saddle and handlebar dimensions were set up to suit individual specifications. Depending on experience and personal preference individuals started from 25 to 150 watts (W). Flexible starting workloads were used because we were interested in changes in psychological and physiological variables, rather than performance (i.e., time to exhaustion). A warmup was not included due to the low starting load, this was considered a sufficient warmup for the participants. Work rate was increased by 25 W every 4 min. Participants' cadence was maintained above 70 rpm with the test continuing until the participant stopped, or cadence dropped below 70 rpm for more than 5 s. Visual information regarding workload and time was obscured to avoid participants using this information to regulate their performance. After 90 s of each stage, participants were presented with the measures to establish desire to reduce effort, performance goal value, and affect. At 120 s, body temperature of the participant was recorded. HR was recorded 140 s into each stage. During the last 90 s of each stage, $\dot{V}O_2$ was measured. Within the last 30 s of each stage, capillary blood samples were obtained from the ear to measure blood lactate concentration.

Measures

Affect

Affect was measured using The Feeling Scale (Hardy & Rejeski, 1989) an 11-point scale ranging from +5 (very good) to −5 (very bad). Participants were asked 'How do you currently feel?' before responding with a number corresponding to the scale. The validity of the scale and its suitability as a measure of exercise-related affect has been established in previous studies (Hardy & Rejeski, 1989).

Desire to reduce effort and performance goal

The desire to reduce effort was measured by verbal responses to the instruction 'Please rate to what extent do you want to reduce your effort' on a scale, ranging from 0 (not wanting to reduce effort at all) to 20 (definitely want to reduce effort immediately). The value of the performance goal was measured by responding to the instruction 'Please rate how important is it to achieve your goal' on a scale, ranging from 0 (not important at all) to 20 (extremely important). These scales have previously demonstrated predictive and nomological validity (Taylor et al., 2022).

Blood lactate concentration

Capillary blood samples were taken from the earlobe and analysed within 1 hour using a Biosen C-line glucose and lactate analyzer (EKF Diagnostics, Barleben, Germany). The Biosen gives reliable measurements of blood lactate concentration across a whole range of values (Davison et al., 2003).

HR

HR was monitored continuously using a T31 transmitter and FT1 watch (Polar Electro Oy, Kempele, Finland). The reliability of this device has been demonstrated in numerous settings (Montes & Navalta, 2019).

Temperature

A Tympanic thermometer (Braun ThermoScan Pro6000 Ear Thermometer) was used to measure core temperature. Data obtained using this method has been found to correlate with data obtained using the core temperature pill, with values reported lying between the two gold standard measurements of core temperature (i.e., rectal and oesophageal thermocouples (Fenemor et al., 2020).

$\dot{V}O_2$

Hans Rudolph breathing value (2700; Hans Rudolph, Inc., Kansas City, MO) and Douglas bags (Plysu Industrial, Ltd., Milton Keynes, UK) were used to collect 60 s of expired air. Douglas bags are regarded as the gold standard for assessing changes in pulmonary gas exchange with high reliability (Hopker et al., 2012). The participants were given a mouthpiece and nose clip then breathed into the mouthpiece for 30 s without collection to allow them to regulate their breathing. Air was collected during the last 60 s of each stage. O_2 and CO_2 content of participants' expired air was measured with a high-accuracy gas analyzer (Servomex, West Sussex, UK), calibrated with gasses of known concentrations. Volume of expired air collected in the Douglas bags were analysed with a dry gas metre (Harvard Apparatus, Kent, UK).

Planned data analysis

The analysis plan was published on the Open Science Framework prior to data collection (https://osf.io/np6ed). MLwiN software (version 3.05) (Rasbash et al., 2015) was used to construct multilevel models. Two direct effects multilevel models were created with blood lactate, heart rate, core temperature and $\dot{V}O_2$ included as independent variables predicting desire and goal value, respectively. The independent variables were centred around each participant's unique mean (i.e., group mean centred) to estimate if within-person variation in the independent variables predicted desire to reduce effort and performance goal value. To test multilevel mediation, established guidelines were followed (Krull & MacKinnon, 2001). In step 1, a multilevel model was created to investigate the relationship between the physiological responses and the mediating variable (i.e., affect). In step 2, two multilevel models were created including the significant physiological variables from step 1 and affect as independent variables predicting desire and goal value, respectively. These models tested the relationship between affect and the outcome variables (desire to reduce effort and performance goal value) whilst controlling for the physiological responses. Following this, Sobel tests (Sobel, 1982) were performed to statistically confirm whether affect significantly mediated between the independent variables (physiological responses) and dependent variables (desire and goal).

Ad hoc data analysis

After data collection was completed, we realised that the methods used for measuring $\dot{V}O_2$ provided an opportunity to calculate other ventilatory responses to exercise without additional measurements being taken. Hence, the ventilatory equivalent (VE; the ventilation rate divided by the rate of oxygen intake) (Robergs et al., 2004) and volume of CO_2 uptake ($\dot{V}CO_2$) was also calculated and their relationships with affect explored. This ad hoc analysis was not part of our original data analysis plan, but the findings are described in the Results section.

Results

Descriptive statistics

Baseline and final descriptive statistics for all study variables, as well as intraclass correlation coefficients can be found in Table 1. Participants had, on average, a $\dot{V}O_{2max}$ score of 44.0 ($SD = 10.3$) ml/min/kg and completed 8.54 stages ($SD = 4.88$), which corresponds to approximately 34 min of total work.

Predictors of desire to reduce effort

Table 2 shows the regression coefficients and standard errors in the multilevel models with desire to reduce effort as the outcome variable. HR, blood lactate concentration, and $\dot{V}O_2$ positively predicted desire to reduce effort in the direct effects model; however, core temperature did not. In step 1 of the mediation analysis, blood lactate and $\dot{V}O_2$ negatively predicted affect, however, HR and core temperature did not. These latter two variables, therefore, were excluded from the final step. In step 2 when controlling for $\dot{V}O_2$ and blood lactate, affect negatively predicted desire to reduce effort. These

Table 1. Descriptive statistics for all study variables.

Variable	Baseline mean (*SD*)	Final mean (*SD*)	ICC
Desire to reduce effort	0.00 (0.00)	17.02 (3.52)	0.004
Performance goal	16.34 (3.57)	13.78 (5.33)	0.61
Affect	3.08 (1.77)	−2.42 (2.12)	0.16
Blood lactate concentration (mmol)	1.17 (0.37)	8.95 (2.73)	0.06
Heart rate (beats.min^{-1})	81.41 (14.63)	179.00 (14.94)	0.05
Temperature (Degree Celsius)	36.88 (0.28)	38.01 (0.68)	0.45
Volume of oxygen uptake (kg.min.min^{-1})	19.50 (4.33)	44.26 (9.95)	0.20

Note. *SD* = Standard Deviation, ICC = Intraclass Correlation Coefficient.

Table 2. Multilevel models describing the physiological responses > affect > desire to reduce effort mediation process.

Step	Predictor	Outcome	b(SE)
Direct effects	HR	Desire to reduce effort	**1.59 (0.68)**
	[bLa]		**2.19 (0.35)**
	$\dot{V}O_2$		**2.65 (0.56)**
	Temperature		−0.34 (0.38)
Mediation step 1	HR	Affect	−0.02 (0.30)
	[bLa]		**-1.01 (0.15)**
	$\dot{V}O_2$		**-1.08 (0.25)**
	Temperature		0.13 (0.17)
Mediation step 2	$\dot{V}O_2$	Desire to reduce effort	**2.20 (0.30)**
	[bLa]		**1.19 (0.31)**
	Affect		**-3.28 (0.31)**

Note. Bold figures indicate statistical significance ($p \leq .05$). Exact p values can be calculated from the Z scores (b/SE for the fixed effects). SE = Standard Error, HR = Heart rate, [bLa] = blood lactate concentration, $\dot{V}O_2$ = volume of oxygen uptake.

equations imply affect mediated the relationship between blood lactate and desire, as well as $\dot{V}O_2$ and desire, both of which were confirmed in Sobel tests ($z = 5.59$, $p < .001$ and $z = 4.06$, $p < .001$, respectively).

Predictors of performance goal value

Table 3 shows the regression coefficients and standard errors in the multilevel models with performance goal as the outcome variable. Blood lactate negatively predicted performance goal value, and core temperature positively predicted performance goal in the direct effects models. HR and $\dot{V}O_2$ did not predict performance goal value. To examine the unexpected finding that core temperature positively predicted performance goal, we ran a supplementary model with just core temperature included as an independent variable predicting performance goal. The relationship between the two variables was significant and negative ($\beta = -0.44$, $p = .003$), implying that statistical suppression had occurred in the full direct effects model. In the mediation analysis, step 1 was the same as the desire to reduce effort analysis described above, therefore, HR and core temperature were excluded from the next step. In step 2, when controlling for blood lactate and $\dot{V}O_2$, affect positively predicted performance goal. These equations imply that affect mediated the relationship between blood lactate and performance goal, as well as between $\dot{V}O_2$ and performance goal, which were confirmed by Sobel tests ($z = -3.92$, $p < .001$ and $z = -3.26$, $p < .001$, respectively).

Ad hoc analysis

We also examined whether VE and VCO_2 predicted affect over and above $\dot{V}O_2$ and blood lactate. VCO_2 positively predicted affect ($b = 2.90$, $p < .001$), whereas VE ($b = 0.69$, $p < .001$), blood lactate ($b = -.96$, $p < .001$) and VO_2 ($b = -3.59$, $p < .001$) all negatively predicted affect.

Discussion

The psychological conflict between the desire to reduce effort and performance goal value can be employed to better understand human endurance performance (Taylor, 2021). The present study expanded this idea by

Table 3. Multilevel models describing the physiological responses > affect > performance goal value mediation process.

Step	Predictor	Outcome	b(SE)
Direct effects	HR	Performance goal value	0.38 (0.49)
	[bLa]		**-0.85 (0.25)**
	$\dot{V}O_2$		−0.49 (0.41)
	Temperature		**0.58 (0.27)**
Mediation step 1	HR	Affect	−0.02 (0.30)
	[bLa]		**-1.01 (0.15)**
	$\dot{V}O_2$		**-1.08 (0.25)**
	Temperature		0.13 (0.17)
Mediation step 2	$\dot{V}O_2$	Performance goal value	**0.52 (0.24)**
	[bLa]		−0.32 (0.25)
	Affect		**-1.21 (0.25)**

Note. Bold figures indicate statistical significance ($p \leq .05$). Exact p values can be calculated from the Z scores (b/SE for the fixed effects). SE = Standard Error, HR = Heart rate, [bLa] = blood lactate concentration, $\dot{V}O_2$ = volume of oxygen uptake.

investigating several physiological responses to exercise as predictors of the desire to reduce effort and performance goal during an endurance task. In addition, the present study formally tested a previous held assumption that core affect mediated these relationships. In general, the relationships among $\dot{V}O_2$, blood lactate concentration and motivational responses during endurance performance were mediated by core affect; hence, the study evidences a process portraying the interplay between physiological and psychological factors which impact endurance performance.

The current study examined four different physiological variables which had potential to influence motivational responses to exercise, namely, blood lactate concentration, $\dot{V}O_2$, HR and core temperature (Ekkekakis et al., 2004; Salomon et al., 2016; Taylor et al., 2022). Replicating previous research, the presented study tested whether blood lactate concentration and HR significantly predicted desire to reduce effort and performance goal value (Taylor et al., 2022). Our findings confirm that blood lactate concentration is an important predictor of hedonic motivation (i.e., the desire to reduce effort) and is sufficiently influential to also predict reflective motivational factors (i.e., the value of the performance goal). Also congruent with previous work, increases in HR were associated with the desire to reduce effort, but not the value of the performance goal. Therefore, the sensory information from HR may only impact hedonic motivational appraisals.

Combining these results with those of earlier work implies that blood lactate concentration, a strong indicator of muscle metabolism in fatiguing muscles, is the primary physiological antecedent of the desire-goal conflict during endurance tasks. So far, it is the only physiological response to exercise that consistently predicts desire to reduce effort and performance goal value. Nonetheless, it remains to be seen whether blood lactate concentration and related biomarkers of muscle metabolism *cause* important motivational changes or is simply a concomitant of some other underlying physiological process. If the former, then it is likely achieved through changes in muscle metabolism which leads to changes in blood pH during high-intensity exercise (Robergs et al., 2004). Experimental and mechanistic work will help evaluate this idea.

Extending current understanding, the present study tested whether $\dot{V}O_2$ was an additional physiological response to exercise that influences the desire-goal conflict. This was hypothesized because ventilatory responses are associated with adverse psychological effects, which may impact on performance-related cognition (Ekkekakis et al., 2004; Robertson, 1982). Like HR, the present study demonstrated that within-person increases in $\dot{V}O_2$ were positively associated with the desire to reduce effort, but not the value of the performance goal. Therefore, $\dot{V}O_2$, a marker of metabolic energy expenditure, can be similarly viewed as an influence on the desire to avoid performance-related discomfort and return to homeostasis, but it is not sufficiently potent to impact on rationale, approach-based motivation. It is noteworthy that, despite their associations, within-person increases in blood lactate concentration, HR, and $\dot{V}O_2$ all incrementally predicted the desire to reduce effort in the same multilevel analysis. This finding implies that they each have their own unique role to play in signalling whole-body homeostatic disturbance.

It was also hypothesized that increases in core temperature would be related the desire to reduce effort, but this was not the case. On the one hand, rising core temperature during high-intensity exercises leads to increased effort perception and changes in exercise behaviour (Flouris & Schlader, 2015). In contrast, core temperature is so essential to survival that its regulation does not rely on conscious processing to a great extent (Kurz, 2008). Core temperature did have a direct, positive effect on the performance goal. However, further analysis indicated that this unexpected finding is likely caused by statistical suppression, in which the inclusion of additional variables in regression models causes alterations in the relationship between an independent and dependent variable (Martinez Gutierrez & Cribbie, 2021).

As well as direct effects of physiological responses on the desire to reduce effort and performance goal, the mediating properties of affect were also examined. In the past, this explanatory role of affect was presumed but, until now, had not been investigated. As hypothesized, the relationships between blood lactate concentration, $\dot{V}O_2$ and desire and goal value were mediated by affect. Past research has found affect to become increasingly negative as lactate and ventilatory thresholds are breached (Ekkekakis et al., 2004). The current study extends this work by showing that despite their high correlation (Bentley et al., 2001) within-person increases in blood lactate concentration and $\dot{V}O_2$ independently associated with greater negative affect during endurance performance. In turn, within-person changes in affect predicted the desire to reduce effort and performance goal in the expected direction. This process suggests that signals associated with these physiological responses are integrated into a universal negative feeling indicating homeostatic disturbance and metabolic strain (Ekkekakis & Petruzzello, 1999; St Clair Gibson et al., 2018) which then shape an individual's desire to terminate exercise alongside devaluing of the performance goal (Greenhouse-Tucknott et al., 2020). These mediation effects imply that affect should be included in motivational models that explain endurance and persistence (e.g., Taylor, 2021). However, HR did not predict affect in step 1 of the mediation analysis; therefore, no evidence was found that affect mediated the relationship between HR and desire to reduce effort. At present, therefore, both direct and indirect effects of physiological responses to exercise on the desire-goal conflict should be included in theoretical models, depending on the specific physiological response in question.

In addition to the hypothesized relationships discussed above, the methods employed in the study presented an opportunity to explore a variety of ventilatory responses and their relationship with affect. This extra analysis demonstrated that VE and VCO_2 predicted affect, even when blood lactate concentration and $\dot{V}O_2$ were controlled for. This is somewhat unsurprising as feelings becoming more negative as breathing rate increases during exercise (Hartman et al., 2019). Moreover, $\dot{V}CO_2$. is indicative of anaerobic metabolism which is associated with negative affect (Ekkekakis et al., 2004). Nonetheless, it is interesting that three highly correlated ventilatory responses uniquely predicted affect during exercise. This exploratory finding implies that the collective ventilatory system holds significant influence over motivational responses to endurance exercise and encourages further confirmatory investigation.

Future directions & limitations

This study highlighted several psychophysiological processes that can help explain human endurance capability; nonetheless, it also raises further questions. The current study recruited participants who were physically fitter than the general population. Differences in the relationships between physiological and psychological factors may be observed in typically sedentary individuals, for example, who do not have much experience of exercise. Second, it is important to experimentally manipulate physiological responses (e.g., by digesting sodium bicarbonate, which impacts on muscle metabolism by causing metabolic alkalosis and delaying exhaustion (Ferreira et al., 2019) to establish the causal impact of changing physiological responses to exercise, such as blood lactate concentration, on affect, desire to reduce effort and performance goal.

Third, our measure of affect only examined valence, but not arousal, which refers to how physiologically activated individual feels (Lindquist et al., 2016). This decision was made because it is often difficult for participants to understand arousal and to distinguish it from valence in an experimental setting (Lindquist et al., 2016). Nonetheless, some researchers may view the lack of an arousal measure as an incomplete view of core affect (e.g., Barrett & Russell, 1999). The measurement of respiratory frequency should be investigated in the future as this likely plays an important part in the ventilatory to affective response relationship with individuals being largely aware of their increase in respiratory frequency. Furthermore, measuring rate of perceived exertion (RPE) would give us a better picture of how these motivational constructs relate to each other and the physiological responses. Future research should also examine the construct validity of the measure of desire to reduce effort. For example, to what extent is the desire to reduce effort different from a desire to reduce discomfort? The desire to reduce effort may arise from several different psychological and physiological factors. In contrast, the desire to reduce discomfort may primarily stem from underpinning physiological responses (Taylor et al., 2022). As a result, these two related desires may have different motivational consequences for endurance performance.

The current study employed exercise with an open-ended finish point. This type of exercise is often simpler for participants as it only requires a decision to either continue or stop. However, most athletic competitions consist of exercise in which individuals are aware of the distance of the race. In this type of exercise, more decisional factors come into play such as pacing and performance of competitors (Smirmaul et al., 2013). Future research could focus on different types of exercise and competitive settings to investigate how desire and performance goal value are influenced. Blood lactate concentration and $\dot{V}O_2$ remained significant predictors of desire to reduce effort and performance goal value, despite including the mediator, affect, in the multilevel models. Moreover, affect did not mediate the relationship between HR and desire to reduce effort. These findings imply that other mediators or direct effects might exist that further research could investigate. Finally, the present study examined the desire and goal as separate constructs, as is typical in previous research (e.g., Taylor et al., 2022). However, the desire-goal conflict may arise because the temptation to reduce effort is a direct disturbance of the performance goal (Kotabe &

Hofmann, 2015). Hence, more research is needed to decipher whether the desire-goal *conflict*, rather than the individual components is important in explaining human endurance.

Conclusion

Embedded within the desire-goal conflict framework, this study identifies possible psychophysiological processes that underpin endurance exercise. It is the first study to test the mediating impact of affect on the relationships among physiological responses observed during endurance efforts and important motivational factors. Moreover, the physiological responses have different motivational signatures with important ramifications. This cross-disciplinary approach to explain endurance behaviour will help to improve performance in many aspects of human behaviour.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author(s) reported there is no funding associated with the work featured in this article.

ORCID

Izzy G. Wellings http://orcid.org/0009-0001-7820-1350

References

Barrett, L. F., & Russell, J. A. (1999). The structure of current affect: Controversies and emerging consensus. *Current Directions in Psychological Science*, *8*(1), 10–14. https://doi.org/10.1111/1467-8721.00003

Bentley, D. J., McNaughton, L. R., Thompson, D., Vleck, V. E., & Batterham, A. M. (2001). Peak power output, the lactate threshold, and time trial performance in cyclists. *Medicine & Science in Sports and Exercise*, *33*(12), 2077–2081. https://doi.org/10.1097/00005768-200112000-00016

Coyle, E. F. (1999). Physiological determinants of endurance exercise performance. *Journal of Science & Medicine in Sport / Sports Medicine Australia*, *2*(3), 181–189. https://doi.org/10.1016/s1440-2440(99)80172-8

Davison, R. R., Coleman, D., Balmer, J., Nunn, M., Theakston, S., Burrows, M., & Bird, S. (2003). Assessment of blood lactate: Practical evaluation of the Biosen 5030 lactate analyzer. *Medicine & Science in Sports and Exercise*, *2*(1), 243–247. https://doi.org/10.1097/00005768-200001000-00036 ·.

Duda, J. L. (2004). Goal setting and achievement motivation in sport. *Applied Psychology*, *2*, 109–119. https://doi.org/10.1016/B0-12-657410-3/00804-7

Ekkekakis, P., & Brand, R. (2021). Exercise motivation from a post-cognitivist perspective: Affective-reflective theory. In C. Englert & I. Taylor (Eds.), *Motivation & self-regulation in sport and exercise* (pp. 87–101). Routledge.

Ekkekakis, P., Hall, E. E., & Petruzzello, S. J. (2004). Practical markers of the transition from aerobic to anaerobic metabolism during exercise: Rationale and a case for affect-based exercise prescription. *Preventive Medicine*, *38*(2), 149–159. https://doi.org/10.1016/j.ypmed.2003.09.038

Ekkekakis, P., & Petruzzello, S. J. (1999). Acute aerobic exercise and affect. *Sports Medicine*, *28*(5), 337–347. https://doi.org/10.2165/00007256-199928050-00005

Fenemor, S. P., Gill, N. D., Sims, S. T., Beaven, C. M., & Driller, M. W. (2020). Validity of a tympanic thermometer and thermal imaging camera for measuring core and skin temperature during exercise in the heat. *Meas Phys Edu Exerc Science*, *24*(1), 49–55. https://doi.org/10.1080/1091367X.2019.1667361

Ferreira, L. H. B., Smolarek, A. C., Chilibeck, P. D., Barros, M. P., McAnulty, S. R., Schoenfeld, B. J., Zandona, B. A., & Souza-Junior, T. P. (2019). High doses of sodium bicarbonate increase lactate levels and delay exhaustion in a cycling performance test. *Nutrition Journal*, *60*, 94–99. https://doi.org/10.1016/j.nut.2018.09.018

Flouris, A. D., & Schlader, Z. (2015). Human behavioral thermoregulation during exercise in the heat. *Scandinavian Journal of Medicine and Science in Sports*, *25*(S1), 52–64. https://doi.org/10.1111/sms.12349

Greenhouse-Tucknott, A., Wrightson, J. G., Raynsford, M., Harrison, N. A., & Dekerle, J. (2020). Interactions between perceptions of fatigue, effort, and affect decrease knee extensor endurance performance following upper body motor activity, independent of changes in neuromuscular function. *Journal of Psychophysiology*, *57*, e13602. https://doi.org/10.1111/psyp.13602

Hardy, C. J., & Rejeski, W. J. (1989). Not what, but how one feels: The measurement of affect during exercise. *Journal of Sport & Exercise Psychology*, *11*(3), 304–317. https://doi.org/10.1123/jsep.11.3.304

Hartman, M. E., Ekkekakis, P., Dicks, N. D., & Pettitt, R. W. (2019). Dynamics of pleasure-displeasure at the limit of exercise tolerance: Conceptualizing the sense of exertional physical fatigue as an affective response. *Journal of Experimental Biology*, *222*(Pt 3), jeb186585. https://doi.org/10.1242/jeb.186585

Hopker, J. G., Jobson, S. A., Gregson, H. C., Coleman, D., & Passfield, L. (2012). Reliability of cycling gross efficiency using the Douglas bag method. *Medicine & Science in Sports and Exercise*, *44*(2), 290–296. https://doi.org/10.1249/MSS.0b013e31822cb0d2

Kotabe, H. P., & Hofmann, W. (2015). On integrating the components of self-control. *Perspect Psycholl Science*, *10*(5), 618–638. https://doi.org/10.1177/1745691615593382

Krull, J. L., & MacKinnon, D. P. (2001). Multilevel modeling of individual and group level mediated effects. *Multivariate Behavioral Research*, *36*(2), 249–277. https://doi.org/10.1207/S15327906MBR3602_06

Kurz, A. (2008). Physiology of thermoregulation. *Best Practice & Research Clinical Anaesthesiology*, *22*(4), 627–644. https://doi.org/10.1016/j.bpa.2008.06.004

Lindquist, K. A., Satpute, A. B., Wager, T. D., Weber, J., & Barrett, L. F. (2016). The brain basis of positive and negative affect: Evidence from a meta-analysis of the human neuroimaging literature. *Cerebral Cortex*, *26*, 1910–1922. https://doi.org/10.1093/cercor/bhv001

Maas, C. J., & Hox, J. J. (2005). Sufficient sample sizes for multilevel modeling. *Methodology*, *1*(3), 86–92. https://doi.org/10.1027/1614-2241.1.3.86

Marcora, S. M. (2008). Do we really need a central governor to explain brain regulation of exercise performance? *European Journal of Applied Physiology*, *104*(5), 929–931. https://doi.org/10.1007/s00421-008-0818-3

Marcora, S. M., & Staiano, W. (2010). The limit to exercise tolerance in humans: Mind over muscle? *European Journal of Applied Physiology*, *109*, 763–770. https://doi.org/10.1007/s00421-010-1418-6

Martinez Gutierrez, N., & Cribbie, R. (2021). Incidence and interpretation of statistical suppression in psychological research. *Canadian Journal of Behavioural Science*, *53*(4), 480–488. https://doi.org/10.1037/cbs0000267

McArdle, W. D., Katch, F. I., & Katch, V. L. (2010). *Exercise physiology: Nutrition, energy, and human performance*. Lippincott Williams & Wilkins.

Montes, J., & Navalta, J. W. (2019). Reliability of the Polar T31 uncoded heart rate monitor in free motion and treadmill activities. *International Journal of Exercise Science*, *12*(4), 69–76. https://doi.org/10.70252/JCQF3272

Ramirez, J. M., & Pleasure, C. M. (2003). The common currency of emotions. *Annals of the New York Academy of Sciences*, *1000*(1), 293–295. https://doi.org/10.1196/annals.1280.028

Rasbash, J., Browne, W. J., Healy, M., Cameron, B., & Charlton, C. (2015). *A* user's guide to MLwiN. 296: *University of Bristol*. https://hdl.handle.net/1983/6f7063c0-1e61-433c-9ad4-825893e05f4f .

Robergs, R. A., Ghiasvand, F., & Parker, D. (2004). Biochemistry of exercise-induced metabolic acidosis. *American Journal of Physiology Regulatory, Integrative and Comparative Physiology*, *287*(3), R502–R516. https://doi.org/10.1152/ajpregu.00114.2004

Robertson, R. J. (1982). Central signals of perceived exertion during dynamic exercise. *Medicine & Science in Sports and Exercise*, *14*(5), 390–396. PMID: 7154895.https://doi.org/10.1249/00005768-198205000-00014

Salomon, R., Ronchi, R., Dönz, J., Bello-Ruiz, J., Herbelin, B., Martet, R., Faivre, N., Schaller, K., & Blanke, O. (2016). The insula mediates access to awareness of visual stimuli presented synchronously to the heartbeat. *Journal of Neuroscience*, *36*(18), 5115–5127. https://doi.org/10.1523/jneurosci.4262-15.201611

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 Ensino de Física*, *27*(2), 333–340. https://doi.org/10.1590/S1807-55092013005000008

Smith, A., Ntoumanis, N., & Duda, J. (2007). Goal striving, goal attainment, and well-being: Adapting and testing the self-concordance model in sport. *Journal of Sport & Exercise Psychology*, *29*(6), 763–782. https://doi.org/10.1123/JSEP.29.6.763

Sobel, M. E. (1982). Asymptotic confidence intervals for indirect effects in structural equation models. *Sociological Methodology*, *13*, 290–312. https://doi.org/10.2307/270723

St Clair Gibson, A., Swart, J., & Tucker, R. (2018). The interaction of psychological and physiological homeostatic drives and role of general control principles in the regulation of physiological systems, exercise and the fatigue process-the integrative Governor theory. *European Journal of Sport Science*, *18*(1), 25–36. https://doi.org/10.1080/17461391.2017.1321688

Taylor, I. M. (2021). A motivational model of endurance and persistence. In C. Englert & I. Taylor (Eds.), *Motivation & self-regulation in sport and exercise* (pp. 87–101). Routledge.

Taylor, I. M., Smith, K., Hunte, R. (2020). Motivational processes during physical endurance tasks. *Scandinavian Journal of Medicine and Science in Sports*, *30*(9), 1769–1776. https://doi.org/10.1111/sms.13739

Taylor, I. M., Whiteley, S., Ferguson, R. A. (2022). Disturbance of desire-goal motivational dynamics during different exercise intensity domains. *Scandinavian Journal of Medicine and Science in Sports*, *32*(4), 798–806. https://doi.org/10.1111/sms.14129

Venhorst, A., Micklewright, D., & Noakes, T. D. (2018). Towards a three-dimensional framework of centrally regulated and goal-directed exercise behaviour: A narrative review. *British Journal of Sports Medicine*, *52*(15), 957–966. https://doi.org/10.1136/bjsports-2016-096907

Wan, J. J., Qin, Z., Wang, P. Y., Sun, Y., & Liu, X. (2017). Muscle fatigue: General understanding and treatment. *Exp Mol Med*. *Experimental & Molecular Medicine*, *49*(10), e384. https://doi.org/10.1038/emm.2017.194

Zajonc, R. B. (1984). On the primacy of affect. *The American Psychologist*, *39*(2), 117–123. https://doi.org/10.1037/0003-066X.39.2.117