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Examining the theory of challenge and threat states in athletes: do predictions extend to academic performance?

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ABSTRACT

Challenge and threat responses have been seen to predict success in meaningful performance environments, however, it is not as clear whether challenge and threat states predict academic outcomes. We tested if predictions from the Theory of Challenge and Threat in Athletes (TCTSA) can be extended to an academic context, by considering antecedents and outcomes of challenge and threat states as well as whether cardiovascular markers predicted academic performance. Thirty-six undergraduate students were asked to give speeches on an academic topic, and their cardiovascular responses, overall annual marks, and marks in a specific presentation assessment were recorded. Challenge and threat indexes failed to predict either of the performance measures. Limited support was found for other hypothesised relationships of the TCTSA, with challenge states predicting greater reinvestment, which was opposite to that hypothesised. Results suggest that predictions of the TCTSA may not be as pertinent in understanding goal pursuit in academic settings.

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Assessment; motivation; presentation; stress; cognitive appraisal

Introduction

Performing tasks in meaningful situations is an important part of succeeding in many domains, including education. Literature investigating the psychophysiology that underpins such performance has often characterised individual responses as a challenge or threat-related (e.g. Moore et al., 2012, 2013, 2018). These are psychological states that occur in response to such meaningful performance situations and produce different physiological and behavioural responses (Blascovich et al., 2004). Researchers have found evidence that people in a challenge or threat state experience a range of

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positive or negative outcomes, for example, optimal attention and decision-making, that influence levels of performance (e.g. Blascovich et al., 2004; Moore et al., 2013; Turner et al., 2012). This relationship has been investigated in a variety of domains, such as sport (Turner et al., 2013), aviation (Vine et al., 2015), and surgery (Vine et al., 2013). However, performance in educational assessments remains broadly under-investigated. While a recent systematic review synthesised the association between challenge and threat and performance (Hase et al., 2019), and a meta-analysis from Behnke and Kaczmarek (2018) identified small-to-moderate performance effects of challenge and threat states, only a single paper from this literature (i.e. Seery et al., 2010) had a predominant focus on academic performance.

Several theoretical approaches to challenge and threat states have been proposed in the literature. These accounts stem from the Blascovich and Tomaka (1996) original biopsychosocial model (BPSM) of challenge and threat. The model posits that in motivated performance situations (a situation whereby an individual engages in active goal-pursuit, where there is evaluation, and can be stressful), challenge states are experienced when an individual perceives that they have sufficient, or nearly sufficient resources to meet the demands of a situation. Alternatively, threat states occur when one perceives they have insufficient resources (Jones et al., 2009). The BPSM contends that demand and resource evaluations are thought to be dynamic, occur at a predominately subconscious (and automatic) level and that demand and resource evaluations are influenced by several interrelated factors (e.g. skill, familiarity, etc.). In addition, the BPSM views challenge and threat states as anchors of a unidimensional continuum although some recent literature has contested this consideration. For example, the Evaluative Space Approach to Challenge and Threat implies that individuals can be both challenged and threatened (c.f. Uphill et al., 2019).

Challenge states are proposed to result in specific neuroendocrine and cardiovascular responses, such as heightened sympathetic adrenomedullary (SAM) activation causing the release of epinephrine. SAM activation leads to a specific pattern of cardiovascular responses, such as vasodilation of blood vessels, reducing total peripheral resistance (TPR: constriction *vs.* dilation in the arterial system), and increased cardiac output (CO: amount of blood in litres pumped by heart in minute). In a threat state, although an individual will experience similar SAM activation, hypothalamic–pituitary–adrenal (HPA) systems are also activated, resulting in the release of cortisol and inhibiting the release of epinephrine which causes increases in vascular resistance and reduced CO. Importantly, one cannot be challenged or threatened without task engagement. Heart rate is an accepted means to assess this engagement (Seery, 2011), and therefore an increased heart rate is a pre-requisite for the assessment of challenge and threat states. For validation of these markers of challenge and threat, see work by Tomaka et al. (1993, 1997) and for a fuller overview of this theorising, see work by Seery et al. (e.g. Seery, 2011, 2013, Seery & Quinton, 2016).

In the sports psychology literature, the BPS model served as a basis for Jones et al. (2009) Theory of Challenge and Threat in States in Athletes (TCTSA). The central prediction of the TCTSA is that challenge states are expected to result in higher performance in competitive sports situations, whereas threat states are expected to result in lower performance, although negative performance effects of a threat state might be avoided if additional compensatory strategies (e.g. extra effort) are employed (Vine et al., 2016). The TCTSA proposes that the interaction between high levels of self-efficacy, perceived control, and focussing on approach goals are antecedents of challenge states, and low self-efficacy, perceived control, and focuses on avoidance goals are antecedents of threat states. The TCTSA also predicts a range of positive outcomes as a result of challenge states, including positive emotional responses, improved cognitive functioning, decreased likelihood of reinvestment, and more efficient self-regulation (with the opposite outcomes predicted as a result of being in a threat state).

Consistent evidence has supported the predictive relationship between challenge and threat and performance (e.g. Blascovich et al., 2004; Moore et al., 2012). For example, Hase et al. (2019) conducted a systematic review and found that 74% of studies (28 out of 38) evidenced that a challenging state had a positive impact on performance. However, support for the antecedents proposed by the TCTSA is mixed, and some of the suggested mechanisms have received little attention. For example, Meijen et al. (2013) manipulated task demands that in turn influenced perceptions of self-efficacy and control but failed to influence challenge and threat states. Wood et al. (2018) found challenge and threat states did not influence anaerobic power. Furthermore, performance consequences, such as threat states causing an increased likelihood to reinvest (to consciously control actions using declarative memory structures) have shown mixed findings. Moore et al. (2013) found that the challenge group reported less conscious processing than the threat group, however, Wood et al. (2018) found that challenge and threat states failed to explain variance in self-focussed attention. Many of the antecedents and outcomes of the TCTSA have not been tested in performance scenarios outside the sporting arena. In education, for example, a threat response could lead to reinvestment and conscious control of presentation style could take up considerable working memory resources resulting in a decrement in the student's ability to convey understanding. Importantly, no current domain specific model exists for performance outside of a sporting context, including in education environments.

While no model and limited evidence exists in education settings, researchers have found evidence to support the predictions made by Blascovich and Mendes (2000) and Jones et al. (2009) concerning the link between challenge states and enhanced subsequent sporting performance (Behnke & Kaczmarek, 2018; Hase et al., 2019). For example, empirical work by Blascovich et al. (2004) asked college-level athletes to give two speeches, including one concerning playing in a critical game situation, to record cardiovascular markers of challenge and threat, and examined the consequences for athletic performance over an entire season. Results showed that athletes who exhibited cardiovascular reactivity associated with a challenge state during the speech had significantly higher levels of performance in the following season compared to those who exhibited a threat state. Moore et al. (2012) found that participants who exhibited a challenge state performed better compared to those in a threat state in a golf-putting task, which was completed immediately after cardiovascular measures of challenge and threat had been taken. Further work in netball (Turner et al., 2012) and cricket (Turner et al., 2013) have provided evidence indicating that cardiovascular markers of challenge states (in comparison to a threat state) have positive implications for performance. The work of Turner et al. in a sporting context used a variety of the presentation-based and sport-specific tasks to induce challenge and threat response. For educational environments, the presentation tasks used to induce stress responses are in fact meaningful performance situations in the form of assessments.

While research has displayed consistent findings concerning the link between challenge states and enhanced performance in more active tasks, limited research has examined this link in an educational context. Challenge and threat patterns have been seen to predict performance in word search tasks (Mendes et al., 2008) and arithmetic tasks (Tomaka et al., 1997). Ringeisen et al. (2019) found that greater threat appraisals were associated with higher pre-exam anxiety. This then led to steeper anxiety decreases on the exam day which was then related to better performance. However, the work of Ringeisen et al. used self-reported threat appraisals and cortisol as an indicator of stress. Seery et al. (2010) were the first to examine whether challenge and threat states (using cardiac output and TPR as objective markers of challenge and threat) were associated with enhanced performance in a formal academic setting. Seery et al. instructed university students to give a speech about an academic topic, with cardiovascular markers taken to illustrate the challenge and threat states when preparing for and delivering the speech. The findings revealed that those in a challenge state performed significantly better on their subsequent course scores, compared to those in a threat state. However, this finding only occurred when students were asked to give a speech about academic interests. When students were asked to speak about an upcoming exam, the cardiovascular measures of challenge and threat did not predict academic performance.

Much of the literature investigating challenge and threat responses have utilised speech-giving tasks to assess challenge and threat tendency. However, these are often non-specific, artificial tasks, used to induce and measure an individual's tendency to produce a challenge or threat response. Challenge and threat responses have been shown to be situation or task-specific (Moore et al., 2019), and thus, in assessment-driven education environments, delivering speeches or presentations are often performance scenarios themselves. Findings indicated that experiencing challenge and threat states may have the potential to explain why some students perform better academically than others, but this relationship is currently unclear.

Here we expand on the current educational literature by considering the underpinnings of performance in an academic performance measure, an assessed presentation, that has the potential to induce significant stress responses in students. Understanding of psychological underpinnings of performance in such assessments is the first step toward developing interventions that allow students to display their full potential in these stress-inducing scenarios. Further, we extend the evaluation of the key propositions of the TCTSA (Jones et al., 2009) by moving into a new domain. Based on this theory, we first hypothesised that both self-efficacy and perceived control would predict challenge and threat response. More specifically, we first hypothesise that higher self-efficacy and perceived control will be antecedents of a challenge state. Second, we predict that challenge and threat states would be associated with overall academic performance and presentation performance, with challenge predicting higher performance and threat states predicting lower performance. Third, we hypothesised that engagement (student involvement in preparing a group presentation) and reinvestment (consciously focussing on controlling the execution of the task)

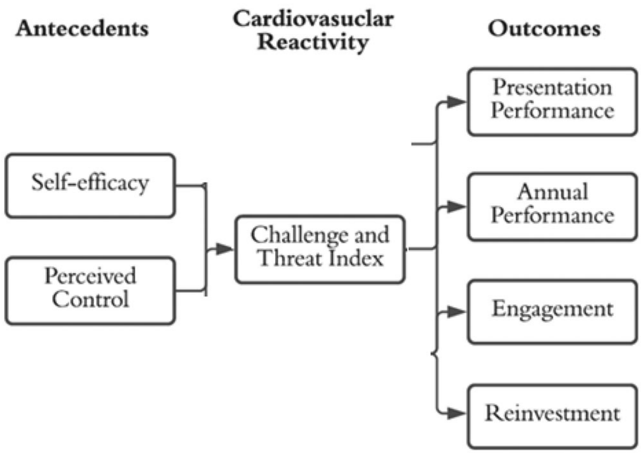

Figure 1. Adapted from TCTSA (Jones et al., 2009). A framework to show the antecedents of cardiovascular reactivity measures and the subsequent outcomes, where the arrows represent the hypothesised relationships (i.e. hypothesis 1—arrows between antecedents and cardiovascular reactivity; hypothesis 2/3—arrows between cardiovascular reactivity and outcomes).

would be associated with challenge and threat states with challenge states predicting greater engagement and reduced reinvestment. Such predictions are based on the predictions of the TCTSA and are exploratory in nature, as previous research examining challenge and threat states has not investigated these outcome variables. A summary of these predictions can be seen in Figure 1.

Method

Participants

Thirty-six undergraduate students enrolled in psychology courses at a higher education institution in the south of England ($n = 19$ females and $n = 17$ males; $M_{age} = 20.24$, $SD = 2.86$ years) volunteered to participate. To determine an adequate sample size, we conducted an *a-priori* power analysis using G*power (Faul et al., 2007). The calculation was based on the variance explained ($R^2 = 0.225$) by Seery et al. (2010) who also investigated challenges and threats in an educational context. We set the power at 0.8 and the total sample size required was $n = 30$. Participants were informed of the purpose of the study, which was to explore performance in a higher education setting, and that the research could help shape future interventions aimed at improving an individual's academic work. Participants were not offered any inducement or incentive to take part. All participants reported being in good health with no cardiovascular concerns and completed informed consent before taking part in the study. Ethical approval was granted from the local institutional ethics committee.

Materials and measures

Antecedents

Self-efficacy. Participants were asked to respond to two items adapted from Turner et al. (2013) which measured self-efficacy; 'to what extent do you feel confident that you can score highly' and 'to what extent do you feel confident that you can deliver a clear, fluent presentation?' This second item was re-worded to refer to the presentation element in our study. The participants responded on a 5-point Likert scale ranging from 1 (not at all) to 5 (completely), with the scores averaged to create a single measure of self-efficacy. Cronbach's alpha was 0.89 for the self-efficacy scale.

Perceived control. Like Turner et al. (2013), we adapted item 2 from the 8-item Academic Control Scale (Perry et al., 2001). Participants rated how much they agreed to the statement 'The more effort I put into this presentation, the better I will do', on a 5-point Likert scale from 1 (strongly disagree) to 5 (strongly agree).

Challenge and threat data. CV data was recorded using the Finometer PRO (Finometer 230 V by Finapres Medical System; Netherlands). The Finometer uses plethysmography via the volume clamp method (e.g. Penaz, 1992) and physical criteria (Wesseling, 1995), methods that have been widely used (e.g. James et al., 2012; Moore et al., 2018; Zanstra et al., 2010) to measure cardiac and vascular measures pertinent to the assessment of challenge and threat states; CO, TPR, and Heart Rate (HR). The Finometer allows for continuous and non-invasive measurement of the aforementioned cardiovascular indices, via the use of a finger cuff, placed on the index or middle finger. The finger cuff itself is connected to the Finapres Medical Systems hardware.

Reactivity values for both CO and TPR were calculated by subtracting raw CO and TPR responses for the final minute of baseline, with raw CO and TPR responses for the task instruction (1 min) and preparation phase (2 min). Next, CO and TPR reactivity were combined into a single challenge and threat index (Blascovich et al., 2004; Turner et al., 2012, 2013). To do so, CO and TPR reactivity values were standardised and multiplied by $+1$ or -1, respectively. These values were combined to create a single challenge and threat index value with a positive value reflecting challenge and a negative value reflecting threat. The extent of challenge or threat is determined by the value itself, such that a value of 3.50 indicates relatively more challenge than a value of 1.50, and a value of -3.50 reflects relatively more threat than a value of -1.50.

Outcomes

Presentation performance. Four independent markers (who were all lecturers at higher education institutions), with an average of six years ($SD = 1.58$ years) experience in marking presentations in an academic setting assessed performance in the presentation task. The assessors used two scales from a validated and standardised rubric, a comprehensive measure that incorporated a range of presentation skills ($\alpha = .97$; Peeters et al., 2010), designed to evaluate student presentations. Specifically, nonverbal skills were categorised by the following behaviours; eye contact, note reading, facial expressions, composure, gesticulating, and posture. Verbal skills were assessed using the following classifications; enthusiasm, clear articulation, speed of speech, and volume. Each category was rated on a 4-point scale, with a higher value indicating greater competence. The mean score for each category across four assessors was taken as the final mark. Inter-rater reliability between the four independent assessors was taken by comparing rubric scores for all individuals for both verbal and non-verbal communication. This resulted in 93% of all skills being scored within one mark across the four assessors. A variety of kappa calculations are available when three or more coders are involved (Hallgren, 2012). As the raters here were free to assign any number of students to a given mark we calculated a free marginal kappa (Brennan & Prediger, 1981; Randolph, 2005; Warrens 2010) resulting in moderate to good agreement between four raters for marks on both non-verbal ($k = 0.42$) and verbal ($k = 0.50$) communication (Cicchetti, 1994; Landis & Koch, 1977). Content scores were omitted to explicitly focus on the student's ability to *deliver* the presentation in a separate measure to overall academic performance (below).

Annual performance. A more general long-term measure of academic performance was also collected. This involved accessing all eight module scores in their first academic year in higher education to produce an average module score (out of 100%). The scores ranged from 41.9 to 78.3%.

Reinvestment and rumination. The Decision-Specific Reinvestment Scale (DRES; Kinrade et al., 2010) was used to assess the propensity to reinvest and ruminate. The DRES consists of 13 items designed to measure one's propensity to reinvest (dysfunctional use of conscious thought in pressure situations). Participants indicated, on a 5-point Likert scale, how characteristic a statement is when applied to themselves, from 0 (not characteristic) to 4 (very characteristic). Of the 13 items, seven represent the decision rumination factor (e.g. 'I remember poor decisions I make for a long time afterwards') and six represent the decision reinvestment factor (e.g. 'I'm always trying to figure out how I make decisions'). Total reinvestment and sub-scale scores for reinvestment and rumination were calculated. Cronbach's alpha for reinvestment was 0.85, rumination was 0.91), and total reinvestment was 0.92.

Engagement. Participants were asked to assess their own levels of engagement in relation to their preparation for the presentation assessment by responding to four questions, which included 'to what extent did you attend and contribute fully in [group] planning meetings', with participants responding on a 5-point Likert scale from 1 (not at all) to 5 (fully involved). Cronbach's alpha was 0.68 for the engagement measure.

Procedure

All participants were encouraged to refrain from vigorous physical activity in the 24 h preceding their testing and were asked to avoid consuming caffeine or alcohol2 h before the testing session, as these aspects can impact cardiovascular markers. All participants were tested individually and completed a Health History Questionnaire on arrival, which was screened by a researcher to ensure no evidence of cardiovascular concerns. All participants were prepared for the collection of cardiovascular measures in the same manner as literature that has employed plethysmography (e.g. Hodgson & Choate, 2012). Individually, each participant was connected to the Finometer PRO. All relevant demographic information (e.g. age, height, weight) was entered to facilitate calibration, and the finger cuff was placed correctly (taking into account finger size to ensure the two infra-red sensors were opposite each other) around the index finger of the non-dominant hand. A Rica-Rocci blood pressure cuff was placed around the upper arm on which the finger cuff is measured, and participants were told the 10-min baseline period would begin. Two minutes into this period, participants were informed the Finometer would perform a return-to-flow calibration, by inflating the Rica-Rocci cuff. All participant's calibration values were within 10MMHG of each other which is in line with the suggestions of the manufacturer.

The cardiovascular data were recorded throughout the 10-min baseline period, with the final minute used as a baseline for all cardiovascular values. Following the 10-min of baseline, and in line with previous research using a speech task as a stress-inducing situation (Meijen et al., 2013), participants were instructed to prepare and deliver an academic speech (this speech was not actually delivered, but the instructions used to provoke a challenge or threat response). Specifically, they were told to give a 3-min speech, in line with the timings of Meijen et al. (2014), about a topic of their choice from a named psychology module from their previous semester. Similar to previous literature (e.g. Barker et al., 2010), the instructions given (i.e. a video camera was set up and participants were told their speech would be filmed and used in future teaching sessions as a teaching resource) were designed to create an evaluative environment, in which challenge and threat appraisals would manifest. After this instruction phase, participants were given 2 min of preparation time to plan their speech (again the timings are in line with Meijen et al.) with the average across this time taken to calculate preparation reactivity. Participants were asked to sit still during this period of cardiovascular recording to ensure minimalization of movement artefact.

Before delivering the speech, each participant completed all self-report measures relating to self-efficacy and control. Approximately 2 months after the first testing session, and in line with similar research protocols (e.g. Blascovich et al., 2004), participants delivered an assessed presentation as part of a module on which they were enrolled. This presentation was video recorded and individually assessed by four independent judges. Following the presentation assessment, participants completed self-report measures of reinvestment and engagement in the assessment. The experimental protocol followed is shown in Figure 2.

Analytical strategy

As a manipulation check, a paired samples *t*-test was conducted to compare average HR for the task instruction phase and HR in the final minute of the baseline period of

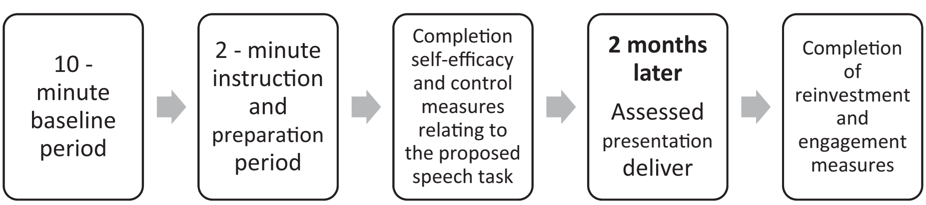

Figure 2. Experimental protocol followed.

Table 1. Means and standard deviations of cardiovascular measures across time.

	Baseline	Instruction/preparation	Reactivity
HR	79.17 (13.10)	92.04 (14.63)	12.88 (8.86)
CO	5.95 (1.68)	7.54 (1.93)	1.59 (1.21)
TPR	1383.58 (450.56)	1247.49 (370.48)	−136.08 (336.18)

Note. HR: Heart rate; CO: Cardiac output; TPR: Total peripheral resistance; Parenthesises denote standard deviations.

cardiovascular data collection (see Table 1). To confirm task engagement (a pre-requisite for the assessment of challenge and threat states), we measured average HR for the task instruction phase and HR in the final minute of the baseline period of cardiovascular data collection (Turner et al., 2012, 2013). Reactivity was calculated by combining instruction and preparation phases and subtracting the final minute of baseline. This determined whether the task was indicative of a motivated performance situation. In the sample, we confirmed HR increased significantly [$t_{(35)} = 9.14$, $p < .001$, $d = 1.01$] between the final minute of baseline ($M = 79.17$ bpm; $SD = 13.10$ bpm) and the task instruction phase ($M = 93.40$ bpm; $SD = 14.93$ bpm). Pearson's correlation analyses were conducted to examine the association between the tested variables. Table 2 displays correlations between all predictor and outcome variables. All multicollinearity (i.e. Durbin-Watson test, Tolerance, Variance Inflation Factor), multivariate normality (i.e. Mahalanobis distance), and outlier checks were seen to meet all relevant analysis assumptions.

A series of two-step hierarchical multiple regression analyses were conducted. Hierarchical multiple regression analyses determine whether independent variables are statistically significant predictors of a dependent variable and provide the respective contribution of independent variables in said prediction. As such, it enables one to determine whether control variables (i.e. age and gender) are significant predictors of the dependent variable in step 1. We included age and gender as control variables as differences in higher educational attainment and coping strategies have been seen between genders and mature students (Cabras & Mondo, 2018; Núñez-Peña et al., 2016). If the hypothesised variables entered in step 2 explain a significant amount of variance above and beyond the control variables, greater confidence can be gleaned from the findings (Tabachnick & Fidell, 2019).

The enter method was used to predict a series of outcome variables; non-verbal presentation performance, verbal presentation performance, yearly academic performance, total reinvestment (including sub-scales of reinvestment and rumination), and engagement, with the CT index. In step 1 age and gender were entered, and in step 2 CT index was entered. The alpha value was set at 0.05 for all analyses.

Results

Antecedents

Self-efficacy predicting cardiovascular reactivity

In step 1, a significant proportion of variance in the dependent variable of CT Index was not accounted for, $R^2 = .075$, $p = .30$. The addition of the independent variable of self-efficacy in step 2 made a non-significant contribution to the proportion of variance accounted for in the dependent variable of CT index, $R^2 = .126$, $p = .20$. Higher

Table 2. Correlation analyses for tested variables.

Variable	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1. Module performance	–										
2. Year performance	.53**	–									
3. Presentation performance—non-verbal	.30	.18	–								
4. Presentation performance—verbal	.34	.38	.83**	–							
5. C/T index	−.09	.02	−.28	−.43*	–						
6. Self-efficacy	.17	.06	−.18	−.16	.37*	–					
7. Perceived control	0	.21	−.17	.10	.17	.47**	–				
8. Engagement	.18	.17	−.03	−.10	.27	.05	.10	–			
9. Total reinvestment	−.12	−.07	−.19	−.05	.41*	−.16	.04	−.03	–		
10. Rumination	−.06	−.02	.04	.07	.31	−.17	.04	.05	.95**	–	
11. Reinvestment	−.18	−.12	−.19	−.21	.47**	−.12	.04	−.13	.89**	.69**	–

Note. *$p < .05$; **$p < .01$.

self-efficacy was not significantly associated with higher CT Index ($b = .214$, $\beta = .266$). Therefore, the hypothesis that self-efficacy would predict challenge and threat responses was rejected.

Perceived control predicting cardiovascular reactivity

In step 1, a significant proportion of variance in the dependent variable of CT Index was not accounted for, $R^2 = .075$, $p = .30$. The addition of the independent variable of perceived control in step 2 made a non-significant contribution to the proportion of variance accounted for in the dependent variable of CT index, $R^2 = .107$, $p = .31$. Higher perceived control was not significantly associated with higher CT Index ($b = .337$, $\beta = .178$). Therefore, the hypothesis that perceived control would predict challenge and threat responses was rejected.

Outcomes

Cardiovascular reactivity predicting non-verbal presentation performance

In step 1, a significant proportion of variance of the dependent variable of non-verbal presentation performance was not accounted for, $R^2 = .066$, $p = .372$. When the independent variable of the CT Index was added in step 2, this did not make a significant contribution to the proportion of variance accounted for in the dependent variable of non-verbal presentation performance, $R^2 = .088$, $p = .42$. A higher CT Index was not a significant predictor of a higher non-verbal presentation score ($b = -.024$, $\beta = -.156$). Therefore, the hypothesis that challenge and threat responses would predict non-verbal presentation performance was rejected.

Cardiovascular reactivity predicting verbal presentation performance

In step 1, a significant proportion of variance of the dependent variable of verbal presentation performance was not accounted for, $R^2 = .071$, $p = .43$. When the independent variable of the CT Index was added in step 2, this did not make a significant contribution to the proportion of variance accounted for in the dependent variable of verbal presentation performance, $R^2 = .202$, $p = .07$. A higher CT Index was not a significant predictor of a higher verbal presentation score ($b = -.068$, $\beta = -.386$). Therefore, the hypothesis that challenge and threat responses would predict verbal presentation performance was rejected.

Cardiovascular reactivity predicting annual performance

In step 1, a significant proportion of variance in the dependent variable of annual performance was not accounted for, $R^2 = .041$, $p = .55$. When the independent variable of the CT Index was added in step 2, this did not make a significant contribution to the proportion of variance accounted for in the dependent variable of annual performance, $R^2 = .047$, $p = .66$. A higher CT Index was not a significant predictor of a higher annual performance score ($b = .673$, $\beta = .086$). Therefore, the hypothesis that challenge and threat responses would predict annual performance was rejected.

Cardiovascular reactivity predicting module performance

In step 1, a significant proportion of variance in the dependent variable of module performance was not accounted for, $R^2 = .037$, $p = .58$. When the independent variable of the CT Index was added in step 2, this did not make a significant contribution to the proportion of variance accounted for in the dependent variable of module performance, $R^2 = .038$, $p = .87$. A higher CT Index was not a significant predictor of a higher module performance score ($b = .108$, $\beta = .031$). Therefore, the hypothesis that challenge and threat responses would predict module performance was rejected.

Cardiovascular reactivity predicting engagement

Engagement scores out of a possible total of 25 were high across the sample ($M = 21.5$, $SD = 2.4$). In step 1, a significant proportion of variance in the dependent variable of engagement was not accounted for, $R^2 = .010$, $p = .86$. The addition of the independent variable of the CT Index in step 2 did not make a significant contribution to the proportion of variance accounted for in the dependent variable of engagement, $R^2 = .081$, $p = .14$. A higher CT Index was not a significant predictor of a higher engagement score ($b = 0.906$, $\beta = .277$). Therefore, the hypothesis that challenge and threat responses would predict engagement was rejected.

Cardiovascular reactivity predicting total reinvestment

In step 1, a significant proportion of variance in the dependent variable of total reinvestment was accounted for, $R^2 = .240$, $p = .02$. When the independent variable of the CT Index was added in step 2, this contributed significantly to the proportion of variance accounted for in the dependent variable of total reinvestment, $R^2 = .501$, $p = .00$. A higher CT Index was significantly associated with a higher total reinvestment score ($b = 3.008$, $\beta = .532$). Therefore, the hypothesis that challenge and threat responses would predict total reinvestment was accepted.

Cardiovascular reactivity predicting reinvestment (subscale)

In step 1, a significant proportion of variance in the dependent variable of reinvestment was not accounted for, $R^2 = .087$, $p = .27$. The addition of the independent variable of the CT Index in step 2 made a significant contribution to the proportion of variance accounted for in the dependent variable of reinvestment (subscale), $R^2 = .375$, $p = 0.00$. A higher CT Index was significantly associated with a higher reinvestment score ($b = 1.453$, $\beta = .559$). Therefore, the hypothesis that challenge and threat responses would predict total reinvestment (subscale) was accepted.

Cardiovascular reactivity predicting rumination (subscale)

In step 1, a significant proportion of variance in the dependent variable of rumination was accounted for, $R^2 = .330$, $p = .00$. The addition of the independent variable of the CT Index in step 2 made a significant contribution to the proportion of variance accounted for in the dependent variable of rumination (subscale), $R^2 = .509$, $p = .00$. A higher CT Index was significantly associated with a higher rumination score ($b = 1.555$, $\beta = .439$). Therefore, the hypothesis that challenge and threat responses would predict rumination (subscale) was accepted.

Discussion

The current study extends the challenge and threat literature by examining the predictions of the TCTSA in an education domain. We used an academic presentation task in a higher education context and task-specific measures of cardiovascular reactivity to investigate specific predictions of the TCTSA. Firstly, the large increase in mean heart rate from baseline illustrated that the speech task manipulation was effective in engaging participants in the task. Contrary to our hypotheses and the theoretical predictions, self-efficacy and perceived control were not antecedents of a challenge state, and challenge and threat states did not predict performance outcomes either over the academic year or in the presentation assessment. There was partial support for the third hypothesis, we did not find a significant relationship between cardiovascular response and engagement, but we did find that challenge and threat predicted total reinvestment and both reinvestment and rumination subscales.

Contrary to theoretical approaches that have considered a challenge and threat states (e.g. BPSM; TCTSA), we found no support for the notion that self-efficacy and perceived control act as antecedents to the cardiovascular measures which created indexes of psychological states of challenge or threat. Despite the TCTSA proposing the importance of the interplay between self-efficacy, control, and goal orientation, empirical evidence has provided mixed findings relating to each of the three constructs. Meijen et al. (2013) found support for the role of self-efficacy in predicting cardiovascular responses to a speech-giving task, in that individuals that reported higher levels of self-efficacy appraised a motivating situation as a challenge. However, a second study by Meijen et al. (2013), found that self-efficacy and perceived control both failed to predict challenge or threat appraisals. Similarly, our findings in an education setting add to mixed conclusions regarding the sources of challenge and threat and do not support predictions of the TCTSA.

Furthermore, contrary to theoretical predictions, we found that challenge and threat states did not predict certain performance outcomes either over the academic year or in the presentation assessment. However, the correlation analyses, while not offering any predictive value, showed a relationship where a more challenging cardiovascular reactivity was associated with poorer verbal presentation performance. Although the findings in this present study are inconsistent with some previous research assessing performance in other domains (e.g. Behnke & Kaczmarek, 2018; Hase et al., 2019), our findings align more closely with indifferent findings in the education literature. For example, Seery et al. (2010) asked students to give two different speeches, the first concerning academic interests, of which challenge and threat states significantly predicted performance. The second speech concerned an upcoming exam, and challenge and threat was not a predictor of academic performance. It is possible that the variety of assessments and tasks used to induce challenge and threat responses throughout the literature base may contribute to the mixed conclusions that have been made.

Research that has examined the impact of challenge and threat states in performance situations has generally provided evidence using performance tasks that were completed a short period after cardiovascular measures were taken (e.g. Moore et al., 2012; Turner et al., 2013). In our study, the subsequent assessed presentation occurred ∼2 months after the cardiovascular measures were taken so it is possible that those in the threat state were aware of their maladaptive responses. Indeed, researchers (e.g. Vine et al., 2016) have recently suggested that a threat state may be advantageous in certain situations. In their integrative framework of stress, attention, and performance, Vine et al. posit that the negative influence of a threat state on performance could be nullified if an individual engages in compensatory strategies, such as increasing effort. Thus, students may have found this process facilitative, responding by increasing their longer-term work output, to perform better both in the specific presentation assessment and indeed, in assessed tasks overall. If this occurred for some participants, this might offset the positive link between challenge states and performance, and explain the lack of a predictive link between challenge and threat and performance. This suggestion is supported by the fact that the engagement scores for the presentation task were high throughout the sample, so overall, the sample was engaged to put work into the presentation assessment regardless of whether they experienced challenge or threat states.

Similar to research investigating TCTSA predictions of antecedents of challenge and threat responses, few studies have investigated predicted outcomes other than task performance. Here, contrary to the theory's prediction, we did not find a significant relationship between cardiovascular response and engagement in the regression analysis. We did, however, find that challenge and threat scores offered a significant predictive value of total reinvestment and both reinvestment and rumination subscales. However, this relationship was opposite than hypothesised, with challenge responses being associated with higher reinvestment, a state purported as disadvantageous for performing under pressure in cognitive or motor tasks (Kinrade et al., 2010; Masters & Maxwell, 2008). The increase in reinvestment and rumination in older and challenged participants (generally detrimental to performance) could underpin the lack of impact of challenge and threat on presentation and overall academic performance. It is possible that the reinvestment scale findings link to engagement and that the older and more challenged students were more consciously reflective of their decisions during the presentation. Future work should assess other outcome factors alongside performance to examine these possible interactions.

The findings of the current study have implications for both the development of theory in the challenge and threat literature and for applied practice in education. We found that predictions of the TCTSA may not be robust when tested in domains outside of sport. We also tested predictions beyond the relationship between challenge and threat and performance that have lacked a strong empirical foundation and have found no support for these. Future research should endeavour to test all predictions of the TCTSA, not just performance outcomes, and to continue to clarify the complex relationship between cardiovascular responses and numerous psychological factors. Specifically, in the context of education, the findings presented here build on the work of Seery et al. (2010) and question the assertion that the challenge and threat literature can be applied in an educational context (Hase et al., 2019). We suggest that specific protocols are developed to use context-specific scenarios in the testing challenge and threat responses. It is clear that a complex combination of factors will affect academic performance and while we used a highly specific measure of challenge and threat and a robust specific performance measure for a presentation performance, the predictors of academic attainment may be challenging to identify.

We conducted a sample size calculation based on the findings of Seery et al. (2010) and collected an appropriate sample. In the time since our data-collection period, which was constrained by the academic timetable, the Behnke and Kaczmarek (2018) meta-analysis has suggested far smaller effect sizes may be the norm in the challenge and threat literature. Therefore, our negative findings should be consumed in the light of a lack of power that would be required to detect such small effects. As previously stated, however, the study by Seery et al. is the only other example to address these questions in the education domain. Further issues surface when undertaking research using a meaningful assessment in a higher-education environment. It was not possible to take measures directly before the presentation performance and presentations were required to follow strict formats agreed upon in module development, taking some control away from the researchers. A further limitation is that our study did not control for potential confounding variables (e.g. entrance exam scores). Finally, our research expanded on the education literature by examining various antecedents and outcomes of challenges and threats in this context. Further research might consider examining other predictions of the TCTSA, such as whether approach or avoidance motivation occurs in a challenging state.

This study used a robust and validated performance measure with multiple experienced markers but could have benefitted from more in-depth measures of the nature of engagement between the challenge and threat measurement and final presentation performance. We used a two-item measure of self-efficacy and a single-item measure of perceived control, which had been developed and used in previous research (Turner et al., 2013). Items with limited scales may lack sensitivity to detect small changes and detract from the predictive power of the regression models. Therefore, future research might use extended measures of such variables to test predictions more fully. In addition, future work in the area should adopt a similar longitudinal approach that takes detailed measures over time, such as motivations towards work and behaviours in the performance context to investigate all the predictions proposed in the TCTSA. For example, it is possible in the current study that students who would be threatened when considering academic pursuits either participated in our study because they were motivated to try things to improve their performance, or were threatened so simply avoided participating in the task.

In summary, the current study extends the challenge and threat literature by moving into the educational domain to test both under-investigated predictions of the

TCTSA and the well-established link between challenge and threat states and performance. We used an academic presentation task in a higher education context and task-specific measures of cardiovascular reactivity to investigate several predictions of the TCTSA. We found limited evidence that predictions of the TCTSA will be upheld in an education performance setting. In addition, we expanded the extremely limited literature in this area by using a task-specific test to measure challenge and threat responses and showing that this did not predict performance in either short-term specific assessments or longer-term academic achievement. We have raised further questions around the limited empirical basis for predictions of the TCTSA that go beyond the relationship between cardiovascular responses and performance.

Disclosure statement

No potential conflict of interest was reported by the authors.

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