

## Challenge and threat states:

Trotman, Gavin; Williams, Sarah; Quinton, Mary; Veldhuijzen van Zanten, Joachimina

DOI:

[10.1016/j.ijpsycho.2018.02.004](https://doi.org/10.1016/j.ijpsycho.2018.02.004)

License:

Creative Commons: Attribution (CC BY)

*Document Version*

Publisher's PDF, also known as Version of record

*Citation for published version (Harvard):*

Trotman, G, Williams, S, Quinton, M & Veldhuijzen van Zanten, J 2018, 'Challenge and threat states: examining cardiovascular, cognitive, and affective responses to two distinct laboratory stress tasks', *International journal of psychophysiology : official journal of the International Organization of Psychophysiology*, vol. 126, pp. 42-51.  
<https://doi.org/10.1016/j.ijpsycho.2018.02.004>

[Link to publication on Research at Birmingham portal](#)

### **Publisher Rights Statement:**

Published in International Journal of Psychophysiology on 02/03/2018

DOI: 10.1016/j.ijpsycho.2018.02.004

### **General rights**

Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

- Users may freely distribute the URL that is used to identify this publication.
- Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.
- User may use extracts from the document in line with the concept of 'fair dealing' under the Copyright, Designs and Patents Act 1988 (?)
- Users may not further distribute the material nor use it for the purposes of commercial gain.

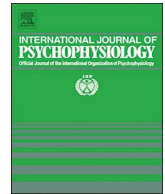
Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

### **Take down policy**

While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact [UBIRA@lists.bham.ac.uk](mailto:UBIRA@lists.bham.ac.uk) providing details and we will remove access to the work immediately and investigate.



# Challenge and threat states: examining cardiovascular, cognitive and affective responses to two distinct laboratory stress tasks

Gavin P. Trotman\*, Sarah E. Williams, Mary L. Quinton, Jet J.C.S. Veldhuijzen van Zanten

School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK

## ARTICLE INFO

### Keywords:

Cardiovascular reactivity  
Challenge and threat  
TCTSA  
Biopsychosocial  
Cognitive appraisals  
Psychological stress

## ABSTRACT

**Background:** The theory of challenge and threat states in athletes (TCTSA) proposes psychological antecedents will predict psychological and cardiovascular responses to stress. The present study investigated this theory in two contextually different stress tasks.

**Method:** 78 males completed a computerised competition and a public speaking task. Cardiovascular activity was measured with impedance cardiography and a blood pressure monitor. Challenge and threat antecedents, indicators of challenge and threat and emotions were assessed pre- and post-tasks.

**Results:** Both tasks induced significant perturbations in cardiovascular activity and were perceived as highly challenging. Reported perceived threat was higher in the public speaking task compared to the competition task. Associations between the proposed antecedents, self-report and cardiovascular indices of challenge and threat and emotions support the TCTSA for the competition task, but less so for the public speaking task.

**Conclusion:** The TCTSA is supported during competitive stress, however during social stress there is dissociation between self-report appraisals and cardiovascular reactivity.

## 1. Introduction

Stress can induce cardiovascular perturbations and the magnitude of cardiovascular reactivity (CVR) has been related to health outcomes such as cardiovascular disease and depression (Chida and Steptoe, 2010; Kamarck and Lovallo, 2003; Phillips et al., 2011). There are individual differences in CVR, and given the association between CVR and health, it is important to explore factors contributing to these individual differences. One such factor is the psychological appraisal of stress. The current study aims to explore how cognitive appraisals associate with CVR to different stress tasks.

The biopsychosocial (BPS) model of challenge and threat provides a framework which relates task appraisals with physiological responses (Blascovich, 2008; Blascovich and Tomaka, 1996). According to this theory, challenge and threat appraisals are conceptualised as multi-dimensional responses to a stressful situation, where environmental demands and personal resources to cope are evaluated either consciously or unconsciously (Blascovich, 2008). A challenge state occurs when the situation is appraised as self-relevant and the individual perceives to have sufficient (or nearly sufficient) personal resources to meet or exceed the demands of the task. In a threat state, the situation is also appraised as self-relevant, but the individual perceives to have insufficient personal resources to meet the demands of the task

(Blascovich, 2008; Seery, 2011). The theory further suggests that these cognitive evaluations precede the physiological responses to a stressful situation (Blascovich, 2008; Blascovich and Tomaka, 1996). Evidence from socially evaluative stress tasks supports the distinction between challenge and threat states based on demand and resource evaluations (e.g., Tomaka et al., 1993; Tomaka et al., 1997).

The theory of challenge and threat states in athletes (TCTSA; Jones et al., 2009) has extended the BPS model by suggesting challenge and threat states are more nuanced than a balance of coping resources and task demands. Specifically, the TCTSA proposes that three antecedents (self-efficacy, perceived control, approach goals) likely influence whether individuals feel they have the resources to cope with a stressful situation. In turn, this is thought to determine a challenge or threat state, and the subsequent physiological and psychological responses associated with a challenge or threat state (Jones et al., 2009). It is proposed that greater levels of self-efficacy, perceived control, and a focus on approach goals lead to a challenge appraisal and lower levels of self-efficacy, perceived control, and a focus on avoidance goals evoke a threat appraisal (Jones et al., 2009). The subsequent appraisal is thought to influence cardiovascular responses to stress (see below) and the emotions experienced during the situation, with a challenge appraisal typically associated with more positive emotions, and a threat state associated with more negative emotions (Jones et al., 2009). The

\* Corresponding author.

E-mail address: [GPT156@bham.ac.uk](mailto:GPT156@bham.ac.uk) (G.P. Trotman).

intensity and interpretations of these emotions are thought to influence performance, with greater challenge and more positive affect leading to improved performance (Skinner and Brewer, 2004).

One emotion explored extensively with regard to performance is anxiety, with greater anxiety proposed to be associated with perceptions of threat (Moore et al., 2012; Skinner and Brewer, 2002; Williams et al., 2010). While anxiety is often seen as negative, the TCTSA proposes that emotions such as anxiety may still be experienced during a challenge state, but will be perceived as more facilitative towards performance. By contrast, similar levels of anxiety are proposed to be seen as more debilitating to performance during a threat state (Jones et al., 2009). In support of the notion that anxiety can be seen as either facilitative or debilitating, research has demonstrated that anxiety can have a facilitative/positive impact on performance during stressful situations in sport (Chamberlain and Hale, 2007; Jones and Swain, 1995; Moore et al., 2013), as well as academic settings (Carrier et al., 1984). Specifically supporting the anxiety predictions of the TCTSA, research demonstrates that anxiety is present in both challenge and threat states, but a threat state has been related to anxiety being perceived as more debilitating towards performance, compared to a challenge state (Jones et al., 2009; Moore et al., 2012; Williams et al., 2010). Despite these findings, the majority of challenge and threat studies investigating anxiety only examine its intensity, even though the extent an individual perceives their anxiety as facilitative/debilitative (i.e., directional perception) is proposed to be a more important predictor of performance than the anxiety intensity (Chamberlain and Hale, 2007).

According to the BPS model and TCTSA, there are two distinct CVR patterns reflecting alterations in the activity of the sympathetic-adrenomedullary (SAM) and hypothalamic-pituitary-adrenal (HPA) axes (Seery, 2011). A challenge state is associated with increased SAM activity, which leads to an increase in heart rate (HR) and cardiac output (CO), alongside a reduction in pre-ejection period (PEP) and total peripheral resistance (TPR). This pattern of physiological response is thought to be indicative of efficient energy mobilisation where increased cardiac performance, coupled with decreased vascular resistance, provides more efficient provision of blood flow to the muscles and the brain (Dienstbier, 1989; Seery, 2011). In contrast, a threat state is associated with increased SAM activity as well as HPA activity. Compared to a challenge state, this is proposed to result in relatively less efficient energy mobilisation through vasoconstriction of the vascular system, reflected in higher TPR and relatively lower CO (Seery, 2011). Thus, it is proposed that while both challenge and threat states are characterised by an increase in HR and a decrease in PEP, the two major CVR constructs thought to distinguish a challenge and a threat state are CO and TPR reactivity.

Accumulating research testing the BPS model and the TCTSA have found support for challenge and threat patterns of CVR being associated with performance in a variety of tasks, such as mental arithmetic and public speaking tasks (Kelsey et al., 2000; Rith-Najarian et al., 2014; Tomaka et al., 1993) as well as golf putting, netball shooting, cricket batting and climbing tasks (Moore et al., 2012; Moore et al., 2013; Turner et al., 2014; Turner et al., 2012; Turner et al., 2013). However, there is less evidence to support the proposed relationships between the challenge and threat antecedents, the psychological and cardiovascular indices of challenge and threat and resulting emotions. Studies employing both psychological and physiological measures have found weak or no associations between the BPS/TCTSA antecedents, appraisal, and CVR from non-sport settings (Rith-Najarian et al., 2014), as well as sport specific settings (Turner et al., 2012; Turner et al., 2013). Furthermore, associations opposing the model's predictions have been reported (e.g., self-efficacy being positively associated with a greater cardiovascular threat response during a non-competitive speech task; Meijnen et al. (2014)).

It is important to note that CVR in the studies previously mentioned

has been assessed in anticipation of the stress task. Research is yet to assess cardiovascular activity while experiencing the stress tasks. Although CVR assessment in anticipation of the task minimises the influence of movement related to the task on CVR (Kamarck and Lovallo, 2003), it does not provide any information on how possible antecedents might relate to psychological or cardiovascular indices of challenge and threat during stress. It should also be noted that studies exploring challenge and threat frequently employ either the cardiovascular indices (CO and TPR; Seery et al., 2010; Turner et al., 2012; Turner et al., 2013) or self-report indices (Meijnen et al., 2013; Moore et al., 2013) to group subjects as challenged or threatened, which is surprising given that the TCTSA proposes that individuals will experience both the physiological and psychological indices. To comprehensively examine how the TCTSA antecedents and outcomes are associated with challenge and threat, both the physiological and psychological indices of challenge and threat should be measured. It is also important to take the cardiovascular measurements during the stress task and the psychological measurements immediately prior to and following completion of the tasks to measure the entire appraisal process (Hellhammer and Schubert, 2012; Quigley et al., 2002).

Within the psychophysiology literature the very nature of different stress tasks can elicit different psychological and cardiovascular responses (AlAbsi et al., 1997; Kamarck and Lovallo, 2003; Kelsey et al., 2007). These differences may mean the relationship between challenge and threat indices with the antecedents and outcomes may vary depending on the stress-evoking situation (i.e., the stress task). The majority of studies examining the TCTSA have used tasks which tend to be more of a sporting and/or competitive nature (e.g., netball shooting, golf-putting, cricket performance, rock climbing; Moore et al., 2013; Turner et al., 2014; Turner et al., 2012; Turner et al., 2013). Some studies have employed non-competitive tasks, but have found a lack support for the TCTSA (Meijnen et al., 2014). To our knowledge research is yet to directly compare how the indices of challenge and threat are associated with the antecedents and the outcomes of challenge and threat across different tasks. Such information would examine the extent to which the TCTSA can be generalised to other less competitive or sport specific stressful situations.

The present study aimed to examine whether the antecedents of challenge and threat are associated with self-reported and cardiovascular indices of challenge and threat, emotional outcomes as well as performance. All participants completed two distinct tasks, i.e., a competitive performance task and a social evaluative public speaking task, which are both known to induce changes in cardiovascular activity (AlAbsi et al., 1997; Bosch et al., 2009; Veldhuijzen van Zanten et al., 2002). The two tasks were chosen to examine if the TCTSA theory is specific to competitive context or whether it can be generalised to other tasks with different, non-competitive, demands. Implementing a within-subject design allowed for the examination that the context of the stress task has on the relationships between challenge and threat antecedents, indices and outcomes.

It was hypothesised that irrespective of task, lower perceived task demand, and greater self-efficacy, perceived control, and coping resources would be associated with increases in CO and decreases in TPR during the tasks (i.e., CVR suggestive of a challenge state). Further, these antecedents would be associated with greater challenge appraisals and lower threat appraisals, as well as more facilitative anxiety and greater positive affect. During the competition task it was hypothesised that greater increases in CO and decreases in TPR would be associated with a faster race time. It was also hypothesised that the results from the competition task would more robustly support the TCTSA's proposed relationships, compared to the public speaking task. This is due to the TCTSA being devised specifically for a sport setting which is likely to be more closely aligned with a competition task rather than a public speaking task due to its competitive nature.

## 2. Method

### 2.1. Participants

Seventy-eight healthy male students from the University of Birmingham participated in the study (Mean [SD] age = 20.0 [1.3] years, Mean [SD] body mass index = 23.9 [2.9] kg/m<sup>2</sup>). None of the participants were smokers, had a history of immune, cardiovascular, metabolic, or kidney disease or had taken any prescribed medication in the previous 4 weeks. Participants were asked to abstain from taking part in vigorous exercise and consuming alcohol 24 h prior to testing. All participants were asked to refrain from eating up to 1 h before testing, as well as avoiding caffeine on the day of testing. Ethical approval was obtained from the university ethics committee. All participants gave written informed consent prior to testing and upon completion were given a course credit for an undergraduate module.

### 2.2. Cardiovascular measures

Systolic (SBP) and diastolic blood pressure (DBP) were obtained using a blood pressure monitor (Omron HEM-705CP), with a cuff attached to the participant's non-dominant upper arm. Mean arterial pressure was calculated with the formula:  $((2 \times \text{DBP}) + \text{SBP}) / 3$ . The Ambulatory Monitoring System, VU-AMS5fs<sup>1</sup> (TD-FPP, Vrije Universiteit, Amsterdam, the Netherlands; de Geus et al., 1995) was used to measure the electrocardiogram (ECG) and impedance cardiogram (ICG) following published guidelines (Sherwood et al., 1990). Following automated inter-beat interval (IBI) time series detection in the VU-DAMS software, artefacts were removed and all ECG data was manually inspected and corrected where necessary. Sixty-second ensemble averaged ICG complexes were derived, and scored in the VU-DAMS program. Specifically, 4 key points were detected by the VU-DAMS automatic scoring algorithm; the onset of the Q-point in the ECG, the B-point, the  $dz/dt_{\min}$  and the X-point in the ICG. The Q-point represents the start of the electromechanical heart cycle. The B-point signifies the commencement of left-ventricular ejection time where the aortic valves open and was scored as the inflexion point at the start of the greatest slope before the  $dz/dt_{\min}$ . The  $dz/dt_{\min}$  characterizes the maximal velocity of blood during systole (minimum impedance) and the X-point marks the closing of the aortic valves and end of left-ventricular ejection (Sherwood et al., 1990). To ensure reliability, the 4 key points of each 60-second ensemble average were individually inspected and artefacts were removed. Furthermore, a secondary impedance trained marker independently scored any spurious sample data. The following measures were derived from these analyses:

R-R interbeat interval (IBI, ms), was used to calculate heart rate (HR, bpm) using the formula,  $\text{HR} = 60,000 / \text{IBI}$ . Pre-ejection period (PEP, ms), an index of sympathetic activity was calculated as the time between Q-wave onset and the B-point. Heart rate variability (HRV) measured as the square root of mean squared differences of successive cardiac R-R intervals (RMSSD), was used as an index of parasympathetic activity. Stroke volume (SV, ml), was calculated with Kubicek's equation (Kubicek et al., 1974), cardiac output (l/min) was calculated as  $(\text{HR} \times \text{SV}) / 1000$ , and total peripheral resistance (dyne-s/cm<sup>-5</sup>) was calculated using the formula,  $\text{TPR} = (\text{MAP}/\text{CO}) \times 80$ .

### 2.3. Questionnaires

Participants completed a pre-task and post-task questionnaire pack via pen and paper. The questionnaires were the same in both packs, however, the phrasing was adjusted to either reflect the upcoming task

(pre-task questionnaire pack) or the task that was just completed (post-task questionnaire pack). The questionnaire packs contained the following measures:

#### 2.3.1. Challenge and threat appraisal measures

Perceptions of challenge and threat were assessed with 6-items used in previous research (Williams et al., 2010), adapted from McGregor and Elliot (2002). Example questions are "I view the task as a threat" and "I feel threatened by the situation". All questions are scored on a 7-point Likert scale ranging from 1 (not at all true) to 7 (very true). Previous research has demonstrated the subscales to generate acceptable reliability (Williams et al., 2010) and in the present study Cronbach's alphas were  $\geq .84$  and  $\geq .96$  for challenge and threat appraisals.

#### 2.3.2. Antecedents: demand and resource evaluations, self-efficacy and perceived control

Perceptions of task demands ("How demanding do you expect the upcoming task to be?") and individual resources ("How able are you to cope with the demands of the upcoming task?") were each assessed with single item questions from the cognitive appraisal ratio (Tomaka et al., 1993) and were answered on a 6-point Likert scale from 1 (not at all) to 6 (extremely). Self-efficacy was measured with a single item "how well do you think you will perform/have performed at the task". Ratings were made on a 7-point Likert-type scale ranging from 1 (very poorly) to 7 (very well). Perceived control was assessed with the single item "How much control do you think you will have/had over the outcome of the task". Ratings were scored on a Likert scale from 1 (none at all) to 7 (total).

#### 2.3.3. Cognitive and somatic anxiety

The Immediate Anxiety Measures Scale (IAMS; Thomas et al., 2002) assessed cognitive and somatic anxiety symptom intensity as well as the extent to which they perceived these symptoms as being facilitative or debilitative towards performance. Participants were first provided with a written definition of cognitive and somatic anxiety which was verbally explained by the researcher. Cognitive and somatic anxiety intensity were then reported on separate 7-point Likert scales from 1 (not at all) to 7 (extremely). Next, the facilitative/debilitative perceptions of these anxiety symptoms were assessed on a 7-point Likert scale from -3 (very debilitative/negative towards performance) to +3 (very facilitative/positive towards performance). The IAMS has been shown to produce valid and reliable scores of anxiety (Thomas et al., 2002) and has been used when assessing or manipulating perceptions of challenge and threat (Moore et al., 2012; Williams et al., 2010).

#### 2.3.4. Emotions

The Sport Emotion Questionnaire (Jones et al., 2005) is a 22-item questionnaire used to measure emotion. Answers were marked on a 5-point Likert scale ranging from 1 (not at all) to 5 (extremely), which create 5 subscales consisting of anxiety (5 items; not reported due to anxiety measurement with IAMS), dejection (5 items, e.g., disappointed), excitement (4 items, e.g., enthusiastic), anger (4 items, e.g., furious) and happiness (4 items, e.g., cheerful). Scores derived from the SEQ have previously demonstrated validity and reliability in assessing emotion (Jones et al., 2005) and Cronbach's alphas from the current sample were  $\geq .78$  for dejection,  $\geq .86$  for excitement,  $\geq .76$  for anger and  $\geq .88$  for happiness, across the different tasks and time points.

#### 2.3.5. Post-task situational appraisal<sup>2</sup>

After completion of each task, participants answered on a 7-point Likert scale how difficult, competitive, and stressful they perceived the task to be, as well as the extent they were trying to perform well

<sup>1</sup> 9 participants' data were recorded on a previous impedance cardiograph and electrocardiograph system (Vrije Universiteit Ambulatory Monitoring System, VU-AMS); however, data was analysed on both systems and no differences were found.

<sup>2</sup> Perceptions of difficulty, stressfulness, competitiveness and perceived effort were completed post-task only.



(effort). All questions ranged from 1 (not at all) to 7 (extremely).

## 2.4. Tasks

### 2.4.1. Competition task

The competition task was a computer car racing game (*Need for Speed: Underground – EA Games*). Video games and car racing games have been used before in psychophysiological stress research and have been shown to induce psychological and physiological responses (Dembroski et al., 1981; Turner, 1989, 1994; Turner et al., 1997; Veldhuijzen van Zanten et al., 2002). Participants controlled the game using their index, ring, and middle finger of their dominant hand on a computer keypad, thus minimal physical movement was exerted. The competition task involved completing 3 laps on a pre-determined track against 3 computerised opponents. Standardised audio instructions were delivered to the participants with information on how to control the car and that the aim of the race was to win the race in the fastest time possible. Performance was assessed with the time needed to complete the laps. To familiarise themselves with the task, participants first completed 2 practice laps. Game setting manipulations allowed all races to be standardised and computer opponents were matched to the ability of the participant. To induce the competitive element, all participants were instructed immediately prior to the competition, that whoever completed the race with the quickest time at the end of the study would receive £10 in reward vouchers. A leader board of the current top 5 race times was also displayed prominently on the laboratory wall in front of the participants and they were informed they should attempt to beat the current scores. On average, participants took 03:51 (SD = 00:25) min to complete the competition task.

### 2.4.2. Public speaking task

The public speaking task consisted of a 2-minute preparation phase and a 4-minute speech phase as used in previous research (see Bosch et al., 2009). Standardised audio instructions were delivered to participants through speakers. Participants were informed that they had been falsely accused of shoplifting a belt and they had 4 minutes to defend themselves. To add an element of social evaluation, participants were instructed they were being evaluated (in reality no such evaluations occurred) and were observed by 3 experimenters who maintained a serious and stoic facial expression throughout preparation period and the speech presentation. Further, speeches were recorded by video camera which was connected to a TV and participants were asked to watch themselves as they prepared and presented the speech. It was emphasised that participants must speak for the entire 4 minutes of the task period, and if they hesitated they would be prompted to continue speaking.

## 2.5. Procedure

Upon arrival at the temperature regulated (21 °C) psychophysiology laboratory, participants were briefed on the general protocol and any questions were answered, after which the participants provided informed consent. Height and weight measurements were obtained and they were instrumented with the equipment to record cardiovascular activity. Participants were then seated in a comfortable chair where they remained throughout the session. Two initial blood pressure readings were taken to familiarise participants with cuff inflation and deflation. Participants then completed a trait questionnaire pack (data not reported), followed by a 15-minute baseline period whereby they watched a nature documentary. Blood pressure readings were collected during minutes 9, 11, 13 and 15 of the baseline rest period and blood pressure, ECG and ICG data were analysed for these minutes. An average of the measurements taken during minutes 9, 11, 13 and 15 of the baseline rest period were used to provide a good overall resting state, in line with previous studies using competition and speech tasks (Bosch et al., 2009; Veldhuijzen van Zanten et al., 2002; Veldhuijzen

van Zanten et al., 2009; Veldhuijzen Van Zanten et al., 2005). Upon completion of the baseline period, participants were provided with standardised audio instructions about the task they would complete and filled in the pre-task questionnaire pack. Blood pressure measurements were collected during minutes 1 and 3 of the tasks, as well as during minute 1 of the preparation period of the public speaking task. ICG and ECG data were analysed for these minutes. Based on pilot testing, minutes 1 and 3 were chosen so that cardiovascular measurements encompassed the first and final minutes during the tasks that all participants had complete data for. Immediately following the task, participants completed the post-task questionnaire pack. A second 15-minute rest period was conducted following the same procedures as the initial rest period. Following this, participants completed the second task, with associated pre- and post-questionnaires using the same protocol as the first task. The order of the two tasks was counterbalanced between participants. After completion of both tasks, participants were detached from the physiological recording equipment, debriefed and thanked for their participation.

## 2.6. Data reduction and analysis

Measurements taken during each rest period were averaged to yield a pre-task baseline value for each cardiovascular measure. Similarly, cardiovascular measurements taken during competition task, and measurements during public speaking task preparation and speech phase were averaged to calculate separate competition and public speaking task values, respectively. To investigate the cardiovascular activity in response to the tasks, separate 2 Task (Competition, Speech)  $\times$  2 Time (Baseline, Task) Analyses of Variance (ANOVAs) were conducted. Additionally, separate 2 Task (Competition, Speech)  $\times$  2 Time (Pre-Task, Post-Task) ANOVAs investigated participant's challenge and threat appraisals and psychological responses over time and between tasks. Where appropriate, Bonferroni post-hoc analyses were conducted to interrogate the results further. Dependent sample t-tests were run to compare post-task appraisals between the tasks.

Subsequent analyses were completed separately for the competition and public speaking task. Pearson correlation analyses were used to examine the associations between pre- and post-task psychological appraisals with the 4 indices of challenge and threat (i.e., CO reactivity, TPR reactivity, challenge appraisal, threat appraisal) as well as performance in the competition task. No differences in cardiovascular activity were found between the two task baselines and as such the baseline refers to the cardiovascular activity during the initial rest period ( $p$ 's > .05). Therefore, CO and TPR reactivity were calculated as the difference between cardiovascular activity during each task minus baseline cardiovascular activity resulting in a separate competition and public speaking task reactivity score. Where indices of challenge and threat were correlated with multiple TCTSA antecedents, further analyses using multiple regressions were implemented. Antecedents were entered simultaneously as predictor variables to explore which antecedent was the strongest predictor of CO reactivity, TPR reactivity, challenge appraisal or threat appraisal. Multiple regressions were not carried out on data where only one antecedent was associated with the specific index of challenge and threat. The reported degrees of freedom reflect occasional missing cardiovascular data due to technical problems. The alpha level was set at .05 for all analyses.

## 3. Results

### 3.1. Cardiovascular responses

Figure 1 displays the cardiovascular activity at baseline and during the tasks. Separate 2 Task (Competition, Speech)  $\times$  2 Time (Baseline, Task) ANOVAs revealed significant time effects for HR,  $F(1, 69) = 209.59, p < .001, \eta^2 = .75$ , HRV,  $F(1, 59) = 27.43, p < .001$ ,

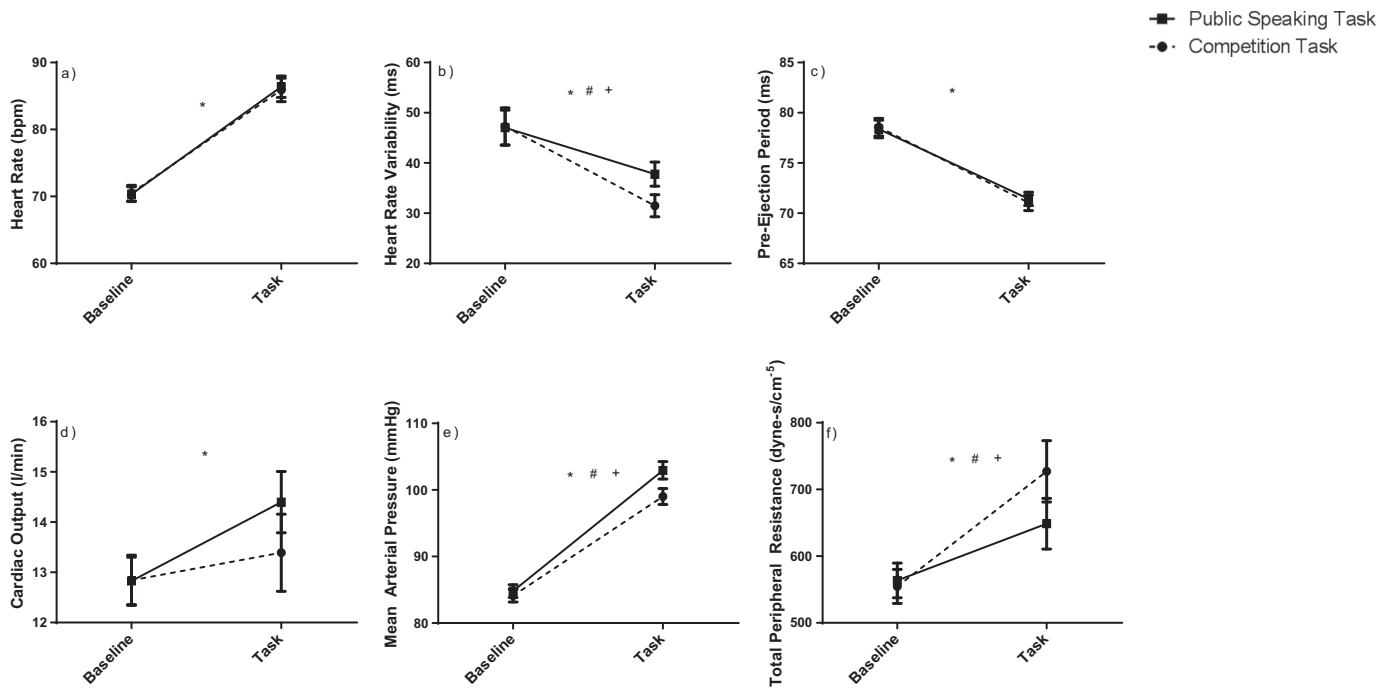


Fig. 1. Mean (SE) heart rate (a), heart rate variability (b), pre-ejection period (c), cardiac output (d), mean arterial pressure (e), total peripheral resistance (f), during baseline, competition and speech. \*Significant time effect,  $p < .05$ ; #significant task effect,  $p < .05$ ; + significant interaction  $p < .05$ .

$\eta^2 = .32$ , PEP,  $F(1,67) = 165.05$ ,  $p < .001$ ,  $\eta^2 = .71$ , CO,  $F(1, 63) = 6.02$ ,  $p = .02$ ,  $\eta^2 = .09$ , TPR(1, 40) = 21.21,  $p < .001$ ,  $\eta^2 = .34$ , and MAP,  $F(1, 50) = 293.85$ ,  $p < .001$ ,  $\eta^2 = .85$ . Task effects were found for HRV,  $F(1,59) = 10.61$ ,  $p = .002$ ,  $\eta^2 = .15$ , TPR,  $F(1,40) = 4.69$ ,  $p = .04$ ,  $\eta^2 = .10$ , and MAP,  $F(1,50) = 11.94$ ,  $p = .001$ ,  $\eta^2 = .19$ , as well as interaction effects for HRV,  $F(1,59) = 9.94$ ,  $p = .003$ ,  $\eta^2 = .14$ , TPR,  $F(1,40) = 6.54$ ,  $p = .01$ ,  $\eta^2 = .14$ , and MAP,  $F(1,50) = 8.62$ ,  $p = .005$ ,  $\eta^2 = .15$ . As can be seen from Fig. 1, post-hoc analyses revealed HR, MAP and TPR were significantly increased, whereas PEP and HRV were lower during the tasks compared to baseline. There was a significantly greater decrease in HRV and increase in TPR during the competition compared to the public speaking task whereas the MAP increase was greater during the speech. CO significantly increased during the public speaking task, however no perturbations were observed during the competition task.

### 3.2. Challenge and threat appraisals

Self-report data is presented in Table 1. A 2 Condition (Competition, Speech)  $\times$  2 Time (Pre-Task, Post-Task) ANOVA for challenge and threat appraisals yielded only a significant main task effect for threat appraisal,  $F(1,75) = 84.422$ ,  $p < .001$ ,  $\eta^2 = .53$ . Participant's perceived the public speaking task to be significantly more threatening than the competition task, both pre- and post-task.

### 3.3. Emotional responses

The 2 Condition  $\times$  2 Time ANOVAs revealed that compared to the competition task, participants experienced greater cognitive and somatic anxiety and perceived their anxiety as more debilitating, in the public speaking task (see Table 1). Anxiety increased during both tasks, whereas perceptions of cognitive anxiety increased during the speech and decreased during the competition. Participants reported greater negative emotions before the public speaking task (dejection, anger) as well as less positive emotions (excitement, happiness) compared to the competition task. Dejection and anger increased in both tasks, with greater increases during the competition. Excitement decreased during both tasks, whereas happiness increased during the speech but

decreased during the competition (see Table 1).

Immediately prior to completing the competition task, participants perceived themselves to be more efficacious, reported more control, perceived the task as less demanding and had greater perceptions of their ability to cope with the task, compared to the public speaking task. During both tasks perceived task demands increased, with self-efficacy increasing during the speech, and decreasing along with perceived coping resources during the competition.

Finally,  $t$ -tests showed that the public speaking task was perceived as significantly more stressful, more difficult and less competitive than the competition task. During the competition task, participants perceived they used more effort compared to the public speaking task.

### 3.4. Competition task

#### 3.4.1. Cardiovascular indices of challenge and threat

As presented in Tables 2 and 3, CO reactivity was positively correlated with pre-task challenge appraisal, facilitative perceptions of cognitive anxiety, self-efficacy, perceived control, and coping, as well as post-task challenge appraisal, somatic anxiety intensity, and perceptions of coping. In addition, greater increase in CO reactivity was associated with a faster race time.

TPR reactivity was negatively associated with pre-task challenge appraisal, more facilitative perceptions of cognitive anxiety, somatic anxiety intensity, self-efficacy, and task demand, as well as post-task challenge appraisal, perceptions of cognitive anxiety and coping (see Tables 2 and 3). Furthermore, an increase in TPR reactivity was associated with a slower race time.

#### 3.4.2. Self-report indices of challenge and threat

Correlation analyses revealed that challenge appraisal was positively associated with pre-task facilitative perceptions of cognitive anxiety, somatic anxiety intensity, self-efficacy, perceived control, task demands and excitement (see Table 3). Post-task challenge appraisal was positively associated with cognitive and somatic anxiety intensity, perceived task demands, dejection, and excitement, but negatively associated with competition race time.

Finally, pre-task threat appraisal was positively associated with

**Table 1**  
Mean (SD) pre-task and post-task appraisals for the competition and public speaking task.

	Pre-task		Post-task		Task effect	Time effect	Interaction
	Competition	Speech	Competition	Speech			
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD			
Appraisals							
Challenge appraisal	5.19 (1.15)	5.29 (1.01)	5.28 (1.15)	5.51 (1.26)	.18	.06	.38
Threat appraisal	2.08 (1.10)	3.58 (1.63)	2.18 (1.27)	3.62 (1.82)	< .001	.29	.87
Antecedents							
Efficacy	4.27 (1.15)	2.78 (1.08)	3.34 (1.37)	3.27 (1.50)	< .001	.05	< .001
Control	5.44 (1.11)	4.47 (1.54)	5.32 (1.20)	4.57 (1.58)	< .001	1.0	.23
Demand	3.39 (0.92)	4.23 (0.99)	3.55 (1.03)	4.55 (1.06)	< .001	.01	.01
Coping	4.35 (0.87)	3.36 (0.96)	3.78 (1.07)	3.40 (1.18)	< .001	.01	.01
Emotions							
Anxiety							
Cognitive anxiety intensity	2.99 (1.33)	4.26 (1.54)	3.17 (1.42)	4.62 (1.70)	< .001	.01	.44
Cognitive anxiety perception	0.10 (1.53)	−1.06 (1.26)	−0.05 (1.41)	−0.79 (1.59)	< .001	.53	.01
Somatic anxiety intensity	2.90 (1.29)	3.73 (1.53)	3.32 (1.57)	4.23 (1.59)	< .001	< .001	.06
Somatic anxiety perception	0.12 (1.50)	−0.79 (1.12)	0.00 (1.34)	−0.73 (1.45)	< .001	.89	.90
SEQ							
Dejection	1.09 (0.26)	1.26 (0.51)	1.57 (0.56)	1.46 (0.62)	.45	< .001	.01
Excitement	2.72 (0.83)	1.89 (0.68)	2.30 (0.91)	1.76 (0.73)	< .001	< .001	.01
Anger	1.10 (0.28)	1.27 (0.52)	1.64 (0.75)	1.44 (0.64)	.89	< .001	< .001
Happiness	2.45 (0.83)	1.76 (0.73)	2.24 (0.86)	1.94 (0.89)	< .001	.90	< .001
Task ratings							
Difficulty	–	–	3.91 (1.26)	5.16 (1.28)	< .001	–	–
Stressful	–	–	3.47 (1.35)	4.65 (1.34)	< .001	–	–
Competitive	–	–	4.86 (1.49)	2.61 (1.62)	< .001	–	–
Effort	–	–	6.04 (1.20)	5.56 (1.27)	.01	–	–

Note: Challenge and Threat Appraisals (1–7); Cognitive and Somatic Anxiety Intensity (1–7); Cognitive and Somatic Anxiety Perception (−3 to +3); SEQ: Sports Emotion Questionnaire (1–5). Efficacy & Control (1–7); Demand and Coping (1–6) Difficulty, Stressful, Competitive & Effort (1–7).

**Table 2**  
Correlations between psychological and cardiovascular indices of challenge and threat during the competition task.

	ΔCO	ΔTPR
Pre-task		
Challenge appraisal	.32**	−.28*
Threat appraisal	−.09	−.21
Post-task		
Challenge appraisal	.26*	−.29*
Threat appraisal	.14	−.18

\*  $p < .05$ .

\*\*  $p < .01$ .

cognitive and somatic anxiety intensity, perceived task demands, dejection, and anger, with similar associations evident for post-task appraisals (see Table 3). No associations between threat appraisal and performance were evident.

### 3.4.3. Multiple regressions

The regression analysis indicated that the 3 pre-task predictor variables (i.e., self-efficacy, perceived control and coping) significantly predicted CO reactivity during the competition task,  $F(3,63) = 2.97$ ,  $p = .04$ , accounting for 12% of its variance. Although self-efficacy appeared the strongest predictor, no variable was an independent predictor of CO reactivity when accounting for the other variables (see Supplementary Table 1). A model containing pre-task self-efficacy and perceived demands significantly predicted TPR reactivity,  $F(2,61) = 6.87$ ,  $p = .002$ , accounting for 18% of its variance. Beta weights indicated that both self-efficacy and perceived demands individually predicted TPR reactivity (with self-efficacy being the strongest predictor). Challenge appraisal was significantly predicted by self-efficacy, perceived control, and task demand,  $F(3,73) = 6.33$ ,  $p = .001$ , accounting for 21% of the variance. However, beta weights indicated that task demands and perceived control were the only significant

predictors with task demands being the strongest predictor. Multiple regression analysis for threat appraisal was not run due to task demand being the only significant predictor. Furthermore, no post-task regression analyses were conducted due to each index of challenge and threat being associated with only one TCTSA antecedent (see Table 3).

### 3.5. Public speaking task

#### 3.5.1. Cardiovascular indices of challenge and threat

As can be seen in Tables 4 and 5, correlation analyses revealed that CO reactivity was positively associated with pre-task challenge appraisal and perceptions of control and CO reactivity was positively associated with post-task cognitive anxiety intensity and perceived control. TPR reactivity was also negatively associated with pre-task perceived control. Similar negative associations were found between TPR reactivity and post-task appraisals of perceived control and perceived coping resources.

#### 3.5.2. Self-report indices of challenge and threat

Challenge appraisal was positively associated with pre-task cognitive and somatic anxiety intensity, and perceived task demands (see Table 5). Post-task, challenge appraisal was positively associated with cognitive and somatic anxiety intensity, perceived demands and dejection, and associated with less facilitative perceptions of cognitive and somatic anxiety, as well as lower perceived coping resources.

As reported in Table 5, threat appraisal was positively associated with cognitive and somatic anxiety intensity, dejection, anger, and perceived task demand, and negatively associated with self-efficacy, perceived control, and coping resources, both pre- and post-task.

#### 3.5.3. Multiple regressions

Regressions for pre-speech CO reactivity, TPR reactivity and challenge appraisal were not carried out as there was only one significant predictor. The regression analysis including self-efficacy, perceived task demands, perceived control, and coping, significantly predicted pre-speech threat

**Table 3**

Correlations between pre- and post-competition task psychological responses and psychophysiology indices of challenge and threat.

	Pre-psychological variables				Post-psychological variables			
	$\Delta$ CO	$\Delta$ TPR	Challenge appraisal	Threat appraisal	$\Delta$ CO	$\Delta$ TPR	Challenge appraisal	Threat appraisal
Antecedents								
Self-efficacy	.32**	-.33**	.25*	.07	.18	-.16	.20	.02
Perceived control	.24*	-.17	.27*	-.12	.24	-.14	.20	.11
Demand	.16	-.29*	.32**	.25*	.12	-.24	.49**	.41**
Coping	.26*	-.16	.19	-.21	.28*	-.38**	.07	-.18
Emotions								
Anxiety								
Cognitive anxiety intensity	.08	-.14	.16	.27*	.21	-.20	.44**	.46**
Cognitive anxiety perception	.27*	-.30*	.23*	.09	.19	-.25*	.21	-.04
Somatic anxiety intensity	.24	-.35**	.32**	.34**	.30*	-.24	.43**	.34**
Somatic anxiety perception	.15	-.12	.19	.07	.19	-.14	.19	-.09
SEQ								
Dejection	.01	.00	.11	.39*	-.01	-.17	.26*	.44**
Excitement	.14	-.16	.38**	.08	.03	-.03	.25*	-.03
Anger	-.07	.05	.07	.38**	.04	-.14	.22	.45**
Happiness	-.06	.02	.10	-.01	.12	-.11	.09	-.18
Race time	–	–	–	–	-.30*	.28*	-.24*	.10

Note:  $\Delta$ CO: cardiac output reactivity;  $\Delta$ TPR: total peripheral resistance reactivity; SEQ: Sports Emotion Questionnaire.\*  $p < .05$ \*\*  $p < .01$ **Table 4**

Correlations between psychological and cardiovascular indices of challenge and threat during the speech task.

	$\Delta$ CO	$\Delta$ TPR
Pre-task		
Challenge appraisal	.31*	-.14
Threat appraisal	.10	-.03
Post-task		
Challenge appraisal	.18	-.06
Threat appraisal	.01	.12

\*  $p < .05$ 

appraisal,  $F(4,72) = 6.47$ ,  $p < .001$ , accounting for 10% of the variance (see Supplementary Table 2). Findings revealed that perceived task demand was the strongest and only significant predictor. A model using post-task perceived control and coping did not significantly predict TPR reactivity,  $F(2,41) = 2.36$ ,  $p = .11$ , however perceived control individually predicted TPR reactivity. Post-task efficacy, perceived task demands and coping significantly predicted post-task challenge appraisal,  $F(3,73) = 18.59$ ,  $p < .001$ , accounting for 43% of the variance, with perceived demand being the strongest and only significant predictor. A significant overall model was found for self-efficacy, perceived control, task demands, and coping predicting post-task threat appraisal,  $F(4,72) = 4.08$ ,  $p = .005$ , accounting for 14% of the variance. However, perceived demand was the strongest and only significant predictor.

**Table 5**

Correlations between pre- and post-public speaking psychological responses and psychophysiology indices of challenge and threat.

	Pre-psychological variables				Post-psychological variables			
	$\Delta$ CO	$\Delta$ TPR	Challenge appraisal	Threat appraisal	$\Delta$ CO	$\Delta$ TPR	Challenge appraisal	Threat appraisal
Antecedents								
Self-efficacy	.02	-.11	-.13	-.36*	-.02	-.02	-.27*	-.27*
Perceived Control	.30*	-.31*	.14	-.31**	.38**	-.32*	-.02	-.29*
Demand	.18	-.27	.67**	.31**	.13	.03	.65**	.34**
Coping	-.06	.01	-.15	-.42**	.03	-.07*	.27*	-.29*
Emotions								
Anxiety								
Cognitive anxiety intensity	.24	-.14	.52**	.47**	.26*	-.07	.65**	.54**
Cognitive anxiety perception	.09	-.09	-.08	-.21	.09	-.03	-.25*	-.22
Somatic anxiety intensity	.04	.06	.48**	.35**	.15	.03	.55**	.53**
Somatic anxiety perception	.11	.01	.02	-.04	.10	.05	-.24*	-.21
SEQ								
Dejection	-.11	.04	.003	.33**	-.01	.09	.33**	.38**
Excitement	.11	-.14	.11	-.03	.03	.02	-.07	-.01
Anger	-.15	.29	.01	.36*	-.14	.17	.15	.45**
Happiness	-.05	-.07	-.06	-.16	.01	-.07	-.05	-.20

Note:  $\Delta$ CO: Cardiac Output Reactivity;  $\Delta$ TPR: Total Peripheral Resistance Reactivity; SEQ: Sports Emotion Questionnaire.\*  $p < .05$ .\*\*  $p < .01$ .



## 4. Discussion

### 4.1. Summary

This is the first study to incorporate two distinct stress tasks to examine the associations between psychological antecedents, psychological and cardiovascular indices of challenge and threat, as well as emotional outcomes, where CVR importantly, was measured during the actual stress tasks. The two tasks induced elevations in HR, TPR, and MAP, as well as decreases in PEP and HRV, with subtle differences between the tasks. The competition and speech did not differ with regard to challenge appraisals, but the public speaking task was more threatening, induced greater levels of anxiety and more debilitating perceptions of anxiety. The public speaking task elicited greater negative and less positive emotions, greater task demand, and lower perceptions of control and coping resources compared to the competition task. The primary finding is that the associations between the proposed antecedents, self-reported and cardiovascular indices of challenge and threat and emotional outcomes, support the BPS model and TCTSA for the competition task, but less so for the public speaking task.

### 4.2. Cardiovascular and psychological indices of challenge and threat

Support for the BPS model and TCTSA was dependent on the nature/context of the task, suggesting that during stress, only challenge appraisal is consistently related to the proposed challenge and threat cardiovascular markers of CO and TPR reactivity. Previous associations between self-reported appraisals of challenge and threat and objective measures of cardiovascular responses have been inconsistent (Meijen et al., 2014; Quigley et al., 2002; Rith-Najarian et al., 2014; Turner et al., 2012; Turner et al., 2013). The difference in the present study could be explained by the difference in timing of self-report measures and cardiovascular recording. The present data show psychological appraisals alter from pre- to post-stress tasks and thus previous research may not have captured the entire stress appraisal process. This methodology is important and supported in the literature where appraisals are constantly fluctuating with feedback from the environment (Hellhammer and Schubert, 2012; Lazarus and Folkman, 1984; Quigley et al., 2002). Thus, measuring cardiovascular activity during the task and obtaining task-appraisals before and after the task, allowed for a thorough psychophysiological examination of responses and appraisals. Consequently, we propose a similar methodology should be employed in future challenge and threat research.

### 4.3. Challenge and threat antecedents

During competition, the TCTSA was supported, however except for the association between perceived control and CVR reactivity, these associations were not evident in the public speaking task. This is in line with previous research investigating cardiovascular challenge and threat indices utilising a speech stress task (Meijen et al., 2014). During both tasks, self-reported challenge and threat appraisals suggest that greater levels of threat is associated with more maladaptive coping, whereas challenge is associated with adaptive coping. Results from the regression analyses suggest that inducing individuals with high self-efficacy before a competition could facilitate a greater challenge appraisal, thus emphasising the importance of providing individuals with appropriate coping mechanisms to utilise during stress to ensure they are able to maintain a challenge state (Turner et al., 2014; Williams et al., 2017).

Perceived demands predicting an increase in threat appraisal is in line with the TCTSA, however the finding that perceived task demand was the single significant predictor of a challenge appraisal is surprising. This posits that an individual can feel challenged even when faced with large task demands, and therefore more research on understanding the role of task demand on an individual's challenge or

threat state is necessary. It is possible that our findings are because the TCTSA is only applicable within a sporting context and the proposed antecedents being derived from the competition literature do not cross over into non-sport scenarios. This supports recent studies employing a public speaking task to examine the BPS and TCTSA where the results were contrary to the proposed relationships (Meijen et al., 2014; Rith-Najarian et al., 2014).

### 4.4. Anxiety, challenge and threat

In support of our hypothesis, and in accordance with prior research (Moore et al., 2013; Williams and Cumming, 2010) our results emphasise the importance of making a distinction between cognitive anxiety intensity and directional perceptions when exploring challenge and threat states (Williams and Cumming, 2010) and behavioural outcomes (Chamberlain and Hale, 2007; Jones and Swain, 1992). Although no relationships were apparent with anxiety intensity, a clear pattern of results shows that perceiving cognitive anxiety as more facilitative is associated with more efficient cardiovascular alterations during the stress, as well as perceiving the task as more challenging. This has important practical applications for stress interventions and relates to literature promoting reappraisal techniques to lead to more efficient CVR (Jamieson et al., 2012; Moore et al., 2015). Against our hypothesis, both challenge and threat appraisals were associated with higher levels of cognitive and somatic anxiety intensity, and a greater challenge appraisal was associated with more debilitating perceptions of cognitive and somatic anxiety post-task. These findings from the public speaking task were unexpected, but it is possible that the increased intensities of anxiety and perceived threat experienced during the public speaking meant participants were not able to interpret their anxiety as facilitative towards their speech, in agreement with previous findings (Williams et al., 2010).

### 4.5. Affect, challenge and threat

With the exception of anxiety and in accordance with previous research, reported emotions were not associated with CO reactivity or TPR reactivity in either task (Turner et al., 2012; Turner et al., 2013). This suggests an incongruence with CVR and affective states during periods of stress (Maier et al., 2003). It is possible that the relatively low levels of positive affect (and low SDs) elicited by the tasks could have underestimated any relationships due to the restricted range in the data (Goodwin and Leech, 2006). However, pre- and post-task perceptions of threat were related to negative emotions of dejection and anger, and challenge appraisals were associated with positive emotions, albeit it only in the competition task. The nature of the public speaking task may have ensured that individuals were unable to experience positive emotions despite feeling challenged. Emotions being associated with appraisals but not CVR replicates previous research (Maier et al., 2003) and suggests a possible re-evaluation of the TCTSA's proposal that CVR and affective states are associated. However, the associations between self-report challenge and threat and emotions support the TCTSA, illustrating that high perceptions of threat will consistently be associated with negative emotions whereas perceptions of challenge will typically be associated with positive emotions (Jones et al., 2009). These results further illustrate, that high perceptions of threat can lead to more negative emotions and highlights the importance of lowering threat perceptions for interventions (Williams et al., 2017).

### 4.6. Performance

Previous work has assessed CVR measurements in anticipation of the task (Moore et al., 2012; Moore et al., 2013; Turner et al., 2014; Turner et al., 2012; Turner et al., 2013). To our knowledge, the present study is the first to report associations between performance and CVR indices measured during the task as well as pre- and post-task

appraisals. This has important implications for applied psychological work within sport and health. Indeed, reappraising threat and inducing a greater challenge state has been shown to alter performance during a motor pressurised task (Moore et al., 2015). Further work could explore the effects of altering challenge appraisals in both sport as well as academic performance settings.

#### 4.7. Limitations

This study is not without limitations. Only male participants were included, therefore the data cannot be generalised to women. It has been suggested that males may not disclose feeling threatened by a stress task (Quigley et al., 2002), however, other studies examining challenge and threat appraisals in a similar population to the current study have identified no gender differences in threat appraisals (Williams et al., 2010). Due to the nature of the public speaking task, measuring performance objectively was not achievable; therefore it was not possible to explore the associations between the constructs of the TCTSA and performance during the speech. Given the variation in the associations between the TCTSA between the tasks, it would be interesting to explore associations with performance in a variety of tasks and across different contexts. Furthermore, due to the large number of proposed associations, this inherently increases the probability of false positives occurring; however the consistent pattern of associations in line with the BPS and TCTSA theory suggests our results are not due to error. Another limitation is the possible influence that speech-related respiratory confounds may have had on the interpretation of cardiovascular measures, specifically HR and HRV during the speaking part of the public speaking task. However, we believe that the possible impact of respiration during the speech task will be limited, given that the physiological activity is averaged over both the non-speaking preparation phase and the actual speech task. A final limitation is that we did not measure achievement goals, an antecedent outlined in the TCTSA (Jones et al., 2009). Future research should explore the relationship between achievement goals, and the relationship these have on the psychophysiological response to stress.

#### 4.8. Conclusion

This study's novel results, assessing CVR during the stressor and psychological appraisals both pre- and post-tasks, provide evidence that there are task specific differences in the associations between CVR and psychological appraisals. Associations in the competition task are in agreement with the BPS theory of challenge and threat as well as the TCTSA, yet few associations were evident in the public speaking task. It is possible that the TCTSA is only supported in competitive scenarios, which should be further investigated. During periods of intense social evaluative stress, individuals appear to engage in negative psychological states and perceptions of control are integral to promoting a challenge state. The results support evidence that psychological appraisals are strongly associated with self-report indices of challenge and threat whereas there appears to be dissociation between cardiovascular indices of challenge and threat and psychological states. These results illustrate the complex and multifaceted task of unravelling the secrets of the mind and the heart and the influence that the nature of the stress task has when examining the psychophysiological responses to stress.

#### Acknowledgments

The research in this manuscript was supported by a PhD studentship awarded to the first author by the Economic and Social Research Council (grant no: ES/J50001X/1). We would also like to thank Jack Holder, Andrew Robson, Tom Baird, Grant Neal, Catherine Bedford and Shaun Carroll for their help with data collection.

#### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ijpsycho.2018.02.004>.

#### References

- AlAbsi, M., Bongard, S., Buchanan, T., Pincomb, G.A., Licinio, J., Lovallo, W.R., 1997. Cardiovascular and neuroendocrine adjustment to public speaking and mental arithmetic stressors. *Psychophysiology* 34 (3), 266–275. <http://dx.doi.org/10.1111/j.1469-8986.1997.tb02397.x>.
- Blascovich, J., 2008. Challenge and Threat. In: Elliot, A.J. (Ed.), *Handbook of approach and avoidance motivation*, pp. 431–445 New York.
- Blascovich, J., Tomaka, J., 1996. The biopsychosocial model of arousal regulation. *Adv. Exp. Soc. Psychol.* 28, 1–51. [http://dx.doi.org/10.1016/s0065-2601\(08\)60235-x](http://dx.doi.org/10.1016/s0065-2601(08)60235-x).
- Bosch, J.A., de Geus, E.J.C., Carroll, D., Goedhart, A.D., Anane, L.A., van Zanten, J.J.V., Edwards, K.M., 2009. A general enhancement of autonomic and cortisol responses during social evaluative threat. *Psychosom. Med.* 71 (8), 877–885. <http://dx.doi.org/10.1097/PSY.0b013e3181baef05>.
- Carrier, C., Higson, V., Klimoski, V., Peterson, E., 1984. The effects of facilitative and debilitating achievement anxiety on notetaking. *J. Educ. Res.* 77 (3), 133–138.
- Chamberlain, S.A., Hale, B.D., 2007. Competitive state anxiety and self-confidence: intensity and direction as relative predictors of performance on a golf putting task. *Anxiety, Stress & Coping: An International Journal* 20 (2), 197–207.
- Chida, Y., Steptoe, A., 2010. Greater cardiovascular responses to laboratory mental stress are associated with poor subsequent cardiovascular risk status: a meta-analysis of prospective evidence. *Hypertension* 55 (4), 1026–U1368. <http://dx.doi.org/10.1161/HYPERTENSIONAHA.109.146621>.
- Dembroski, T.M., Macdougall, J.M., Slaats, S., Eliot, R.S., Buell, J.C., 1981. Challenge-induced cardiovascular-response as a predictor of minor illnesses. *J. Hum. Stress.* 7 (4), 2–5.
- Dienstbier, R.A., 1989. Arousal and physiological toughness - implications for mental and physical health. *Psychol. Rev.* 96 (1), 84–100. <http://dx.doi.org/10.1037/0033-295x.96.1.84>.
- de Geus, E.J.C., Willemsen, G.H.M., Klaver, C., Vandoornen, L.J.P., 1995. Ambulatory measurement of respiratory sinus arrhythmia and respiration rate. *Biol. Psychol.* 41 (3), 205–227.
- Goodwin, L.D., Leech, N.L., 2006. Understanding correlation: factors that affect the size of r. *J. Exp. Educ.* 74 (3), 251–266.
- Hellhammer, J., Schubert, M., 2012. The physiological response to Trier Social Stress Test relates to subjective measures of stress during but not before or after the test. *Psychoneuroendocrinology* 37 (1), 119–124. <http://dx.doi.org/10.1016/j.psyneuen.2011.05.012>.
- Jamieson, J.P., Nock, M.K., Mendes, W.B., 2012. Mind over matter: reappraising arousal improves cardiovascular and cognitive responses to stress. *Journal of Experimental Psychology-General* 141 (3), 417–422. <http://dx.doi.org/10.1037/a0025719>.
- Jones, G., Swain, A.B.J., 1992. Intensity and direction dimensions of competitive state anxiety and relationships with competitiveness. *Percept. Mot. Skills* 74, 467–472.
- Jones, G., Swain, A., 1995. Predispositions to experience debilitating and facilitative anxiety in elite and nonelite performers. *Sport Psychologist* 9 (2), 201–211.
- Jones, M., Lane, A.M., Bray, S.R., Uphill, M., Catlin, J., 2005. Development and validation of the sport emotion questionnaire. *Journal of Sport & Exercise Psychology* 27 (4), 407–431.
- Jones, M., Meijen, C., McCarthy, P.J., Sheffield, D., 2009. A theory of challenge and threat states in athletes. *Int. Rev. Sport Exerc. Psychol.* 2 (2), 161–280.
- Kamarck, T.W., Lovallo, W.R., 2003. Cardiovascular reactivity to psychological challenge: conceptual and measurement considerations. *Psychosom. Med.* 65 (1), 9–21. <http://dx.doi.org/10.1097/01.psy.0000030390.34416.3e>.
- Kelsey, R.M., Blascovich, J., Leitten, C.L., Schneider, T.R., Tomaka, J., Wiens, S., 2000. Cardiovascular reactivity and adaptation to recurrent psychological stress: the moderating effects of evaluative observation. *Psychophysiology* 37 (6), 748–756. <http://dx.doi.org/10.1017/s004857720098209x>.
- Kelsey, R.M., Ornduff, S.R., Alpert, B.S., 2007. Reliability of cardiovascular reactivity to stress: internal consistency. *Psychophysiology* 44 (2), 216–225. <http://dx.doi.org/10.1111/j.1469-8986.2007.00499.x>.
- Kubicek, W.G., Kottke, F.J., Ramos, M.U., Patterson, R.P., Witsoe, D.A., Labree, J.W., Garamela, J.T., 1974. Minnesota impedance cardiograph - theory and applications. *Biomed. Eng.* 9 (9), 410–416.
- Lazarus, R.S., Folkman, S., 1984. *Stress, Appraisal, and Coping*. Springer, New York.
- Maier, K.J., Waldstein, S.R., Synowski, S.J., 2003. Relation of cognitive appraisal to cardiovascular reactivity, affect, and task engagement. *Ann. Behav. Med.* 26 (1), 32–41. [http://dx.doi.org/10.1207/s15324796abm2601\\_05](http://dx.doi.org/10.1207/s15324796abm2601_05).
- McGregor, H.A., Elliot, A.J., 2002. Achievement goals as predictors of achievement-relevant processes prior to task engagement. *J. Educ. Psychol.* 94 (2), 381–395.
- Meijen, C., Jones, M., McCarthy, P.J., Sheffield, D., Allen, M.S., 2013. Cognitive and affective components of challenge and threat states. *J. Sports Sci.* 31 (8), 847–855. <http://dx.doi.org/10.1080/02640414.2012.753157>.
- Meijen, C., Jones, M., Sheffield, D., McCarthy, P.J., 2014. Challenge and threat states: cardiovascular, affective, and cognitive responses to a sports-related speech task. *Motiv. Emot.* 38 (2), 252–262. <http://dx.doi.org/10.1007/s11031-013-9370-5>.
- 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. <http://dx.doi.org/10.1111/j.1469-8986.2012.01449.x>.
- 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 & Exercise Psychology* 35 (6), 551–562.
- Moore, L.J., Vine, S.J., Wilson, M.R., Freeman, P., 2015. Reappraising threat: how to optimize performance under pressure. *Journal of Sport & Exercise Psychology* 37 (3), 339–343. <http://dx.doi.org/10.1123/jsep.2014-0186>.
- Phillips, A.C., Hunt, K., Der, G., Carroll, D., 2011. Blunted cardiac reactions to acute psychological stress predict symptoms of depression five years later: evidence from a large community study. *Psychophysiology* 48 (1), 142–148. <http://dx.doi.org/10.1111/j.1469-8986.2010.01045.x>.
- Quigley, K.S., Barrett, L.F., Weinstein, S., 2002. Cardiovascular patterns associated with threat and challenge appraisals: a within-subjects analysis. *Psychophysiology* 39 (3), 292–302. <http://dx.doi.org/10.1017/s0048577201393046>.
- Rith-Najarian, L.R., McLaughlin, K.A., Sheridan, M.A., Nock, M.K., 2014. The biopsychosocial model of stress in adolescence: self-awareness of performance versus stress reactivity. *Stress-The International Journal on the Biology of Stress* 17 (2), 193–203. <http://dx.doi.org/10.3109/10253890.2014.891102>.
- Seery, M.D., 2011. Challenge or threat? Cardiovascular indexes of resilience and vulnerability to potential stress in humans. *Neurosci. Biobehav. Rev.* 35 (7), 1603–1610. <http://dx.doi.org/10.1016/j.neubiorev.2011.03.003>.
- Seery, M.D., Weisbuch, M., Hetenyi, M.A., Blascovich, J., 2010. Cardiovascular measures independently predict performance in a university course. *Psychophysiology* 47 (3), 535–539. <http://dx.doi.org/10.1111/j.1469-8986.2009.00945.x>.
- Sherwood, A., Allen, M.T., Fahrenberg, J., Kelsey, R.M., Lovallo, W.R., Vandoornen, L.J.P., 1990. Methodological guidelines for impedance cardiography. *Psychophysiology* 27 (1), 1–23.
- Skinner, N., Brewer, N., 2002. The dynamics of threat and challenge appraisals prior to stressful achievement events. *J. Pers. Soc. Psychol.* 83 (3), 678–692. <http://dx.doi.org/10.1037/0022-3514.83.3.678>.
- Skinner, N., Brewer, N., 2004. Adaptive approaches to competition: challenge appraisals and positive emotion. *Journal of Sport & Exercise Psychology* 26 (2), 283–305.
- Thomas, O., Hanton, S., Jones, G., 2002. An alternative approach to short-form self-report assessment of competitive anxiety: a research note. *International Journal of Sport Psychology* 33 (3), 325–336.
- Tomaka, J., Blascovich, J., Kelsey, R.M., Leitten, C.L., 1993. Subjective, physiological, and behavioral-effects of threat and challenge appraisal. *J. Pers. Soc. Psychol.* 65 (2), 248–260. <http://dx.doi.org/10.1037/0022-3514.65.2.248>.
- Tomaka, J., Blascovich, J., Kibler, J., Ernst, J.M., 1997. Cognitive and physiological antecedents of threat and challenge appraisal. *J. Pers. Soc. Psychol.* 73 (1), 63–72. <http://dx.doi.org/10.1037/0022-3514.73.1.63>.
- Turner, J.R., 1989. Individual-differences in heart-rate response during behavioral challenge. *Psychophysiology* 26 (5), 497–505. <http://dx.doi.org/10.1111/j.1469-8986.1989.tb00701.x>.
- Turner, J.R., 1994. *Cardiovascular Reactivity and Stress*. Plenum Press, New York.
- Turner, J.R., Treiber, F.A., Davis, H., Rectanwald, J., Pipkin, W., Strong, W.B., 1997. Use of a virtual reality car-driving stressor in cardiovascular reactivity research. *Behav. Res. Methods Instrum. Comput.* 29 (3), 386–389. <http://dx.doi.org/10.3758/bf03200591>.
- Turner, M.J., Jones, M., Sheffield, D., Cross, S.L., 2012. Cardiovascular indices of challenge and threat states predict competitive performance. *Int. J. Psychophysiol.* 86 (1), 48–57. <http://dx.doi.org/10.1016/j.ijpsycho.2012.08.004>.
- Turner, M.J., Jones, M., 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 & Exercise Psychology* 35 (4), 387–397.
- Turner, M.J., Jones, M., Sheffield, D., Barker, J.B., Coffee, P., 2014. Manipulating cardiovascular indices of challenge and threat using resource appraisals. *Int. J. Psychophysiol.* 94 (1), 9–18. <http://dx.doi.org/10.1016/j.ijpsycho.2014.07.004>.
- Veldhuijzen van Zanten, J.J.C.S., De Boer, D., Harrison, L.K., Ring, C., Carroll, D., Willemsen, G., De Geus, E.J.C., 2002. Competitiveness and hemodynamic reactions to competition. *Psychophysiology* 39 (6), 759–766. <http://dx.doi.org/10.1111/1469-8986.3960759>.
- Veldhuijzen Van Zanten, J.J.C.S., Thrall, G., Wasche, D., Carroll, D., Ring, C., 2005. The influence of hydration status on stress-induced hemoconcentration. *Psychophysiology* 42 (1), 98–107. <http://dx.doi.org/10.1111/j.1469-8986.2005.00266.x>.
- Veldhuijzen van Zanten, J.J.C.S., Ring, C., Carroll, D., McIntyre, D., Brown, M.D., 2009. Hemoconcentration during a prolonged stress task: associations with hemodynamic reactivity and microvascular permeability. *Biol. Psychol.* 82 (3), 260–266. <http://dx.doi.org/10.1016/j.biopsycho.2009.08.005>.
- Williams, S.E., Cumming, J., 2010. An investigation of imaged meaning propositions to manipulate athletes' challenge-threat states. *Journal of Sport & Exercise Psychology* 32, S229–S230.
- Williams, S.E., Cumming, J., Balanos, G.M., 2010. The use of imagery to manipulate challenge and threat appraisal states in athletes. *Journal of Sport & Exercise Psychology* 32 (3), 339–358.
- Williams, S.E., Veldhuijzen Van Zanten, J., Trotman, G.P., Quinton, M.L., Ginty, A.T., 2017. Challenge and threat imagery manipulates heart rate and anxiety responses to stress. *Int. J. Psychophysiol.* 117, 111–118.