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Coping related variables, cardiac vagal activity and working memory performance under pressure

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ABSTRACT

The aim of this study was to assess the predictive role of coping related variables (trait emotional intelligence and reinvestment, challenge and threat appraisals and cardiac vagal activity) on cardiac vagal activity and working memory under low pressure (LP) and high pressure (HP) conditions. Participants (n = 49) completed trait questionnaires, the Decision Specific Reinvestment Scale, the Movement Specific Reinvestment Scale and Trait Emotional Intelligence Questionnaire. They realized the automated span task, which tests working memory, under counterbalanced LP and HP conditions. Cardiac vagal activity measurements were taken at rest, task and post task for 5 min, along with self-reported ratings of stress. Upon completion of the task, self-report measures of motivation, stress appraisal, attention and perceived pressure were completed. Current findings suggest cardiac vagal activity at rest can predict cardiac vagal activity under pressure, decision reinvestment influences cardiac vagal activity in cognitive tasks under LP and working memory performance is predicted by task cardiac vagal activity in HP only. These results show the importance of combining both subjective and objective psychophysiological variables in performance prediction and strengthen the need for this approach to be adopted across samples.

1. Introduction

Pressure, which is caused by factors that increase the need to perform well on a particular occasion (Baumeister, 1984), can have negative effects on a range of cognitive functions (Laborde, Furley, & Schempp, 2015; Tomaka, Blascovich, Kelsey, & Leitten, 1993). When individuals are faced with pressure, cognitive performance is often impaired and this can lead to performance decrements (Laborde, Furley, & Schempp, 2015, Navarro et al., 2012; Beilock & Carr, 2001). These performance decrements triggered by pressure, such as impaired decision making (Laborde, Raab, & Kinrade, 2014), can subsequently lead to a break down or even failure in skill execution. One cognitive function that has been linked to skill failure under pressure is working memory, an executive function that involves holding information and mentally processing it (Diamond, 2013). In order to understand how an individual reacts to pressure, it is necessary to consider a range of coping related variables located in different domains, such as physiological variables, personality traits and psychological states. The aim of this study was to understand how working memory relates to coping related variables under various pressure conditions.

Working memory has been directly linked to many important cognitive processes such as reasoning and problem solving (Just & Carpenter, 1992). Working memory has been shown to influence multiple aspects important for sports performance including; including choking under pressure, skill acquisition, skill execution and attention (Furley & Memmet, 2010), therefore its investigation within athletic samples is of interest. There are two key theories that are associated with working memory and its influence on performance breakdown under pressure. The first being related to worries and ruminations which "blocks up" the capacity to use working memory (Beilock & Carr, 2001) or the second which supports the notion that consciously controlling a skill loads working memory and prevents smooth executions of skills (Masters & Maxwell, 2008). Both of these theories support the concept that working memory capacity is directly linked to the ability to perform under pressure. When specifically assessing working memory performance, it is important to differentiate the degree of pressure. Greater impairments of working memory performance have been found under high pressure conditions when compared to low

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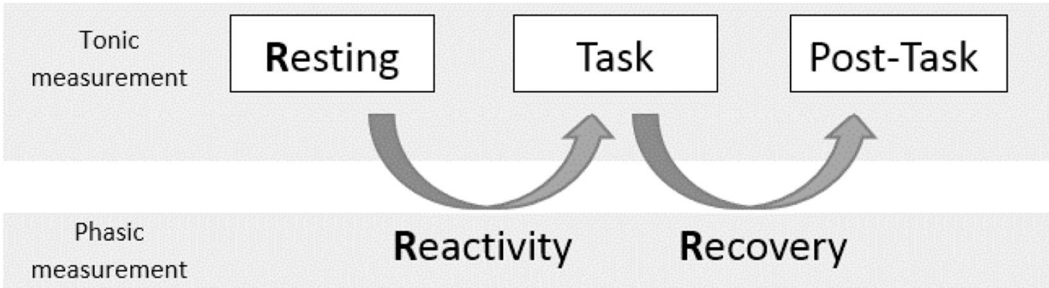

Fig. 1. The three R's adapted from Laborde et al. (2017).

pressure conditions (Laborde, Furley, & Schempp, 2015). Previous research has investigated variables associated with working memory performance under pressure to help understand successful performance, one being the physiological underpinning of working memory.

The physiological underpinning of working memory performance under pressure has been linked to cardiac vagal activity (Thayer, Hansen, Saus-Rose, & Johnsen, 2009). Cardiac vagal activity is a measure derived from heart rate variability, the change in the time interval between successive heart beats (Appelhans & Luecken, 2006). It can be measured at different time points in order to understand how an individual has responded to the environment or a task (Porges, 1995; Thayer et al., 2009). Tonic measurements are taken over a period of time to provide an average cardiac vagal activity measurement (Malik et al., 1996). Recent theoretical (Laborde, Mosley, & Mertgen, in press) and methodological standpoints (Laborde, Mosley, & Thayer, 2017) suggest that this is taken at three stages: rest (or baseline), task and post-task which directly reflects the three R's of cardiac vagal activity: resting, reactivity and recovery (see Fig. 1).

Tonic measures have shown their importance and it is theorised that higher levels of resting cardiac vagal activity is more beneficial for stress management and emotional regulation (Thayer et al., 2009). However, tonic measurements alone are not sufficient to determine the adaptation of the system when demand is placed upon it (Thayer, Ahs, Fredrikson, Sollers, & Wager, 2012). Therefore, it is also important to consider the change between tonic measurements, which is known as phasic cardiac vagal activity (Park, Vasey, Van Bavel, & Thayer, 2014). Phasic cardiac vagal activity comprises cardiac vagal reactivity (the difference between resting cardiac vagal activity and task cardiac vagal activity), and cardiac vagal recovery (the difference between task cardiac vagal activity and post-task cardiac vagal activity) (Laborde et al., 2017). By assessing phasic cardiac vagal activity, we can understand how the individual is regulating themselves under pressure. Importantly, higher levels of tonic cardiac vagal activity were found to increase phasic cardiac vagal activity under load (Park et al., 2014). This can be explained because tonic cardiac vagal activity allows for better self regulation in stressful situations (Thayer et al., 2009). Thus, it is predicted that tonic cardiac vagal activity may predict phasic cardiac vagal activity. Therefore, both tonic and phasic cardiac vagal activity will be measured to understand interactions occurring at the physiological level that may influence both behaviours and performance (Laborde et al., 2017).

The link between working memory and cardiac vagal activity can be explained from a theoretical perspective by the neurovisceral integration model. The model suggests that higher cardiac vagal activity is associated to better executive functioning (Thayer et al., 2009), in this study working memory, as cardiac vagal activity can reflect the integrity of the functioning of the pre-frontal cortex (Thayer et al., 2009). Previous research has found positive associations between executive function and cardiac vagal activity both resting and task (Laborde and Raab, 2013; Laborde et al., 2014; Laborde, Furley, & Schempp, 2015). Therefore, the current research predicts that higher levels of resting and task cardiac vagal activity will be positively associated to working memory performance. Interestingly Laborde, Furley, and Schempp (2015) found a relationship between resting cardiac vagal activity and working memory performance, but not task cardiac vagal activity. However, they only accounted for tonic cardiac vagal activity measurements and not phasic measures (the change in cardiac vagal activity across tonic time points). Measuring phasic cardiac vagal activity is important to consider in order to understand adaptation processes. If the task involves executive functioning, a smaller decrease in cardiac vagal reactivity (reduction form resting to task) is seen to be adaptive (Thayer et al., 2012). Therefore, it is predicted that a smaller cardiac vagal reactivity (less of a reduction from resting to task) will be positively associated to working memory performance. Although there is good evidence to suggest a link between the physiological functioning of an individual and working memory performance, there have been limited endeavours to explore this physiological model in relation to other subjective coping related variables, in particular to personality variables.

Personality-trait-like individual differences (PTLID) is a term used to describe individual differences at the trait level going beyond the Big Five personality factors (Openness, Conscientiousness, Extraversion, Agreeableness, Neuroticism) (Laborde & Allen, 2016). PTLIDs have been found to influence cognitive performance under pressure and specifically this relationship has been explored between working memory and reinvestment (Laborde, Furley, & Schempp, 2015). Reinvestment is an overarching term that triggers individuals to consciously control performance under pressure through cognitive effort, which can result in decreased performance (i.e. Kinrade, Jackson, & Ashford, 2010; Laborde et al., 2014; Poolton, Siu, & Masters, 2011). Reinvestment can be split into movement and decision dimensions. Movement reinvestment is “the manipulation of conscious, explicit, rule based knowledge, by working memory, to control the mechanics of one's movements during motor output” (Masters & Maxwell, 2004 p. 208). Those higher in movement reinvestment perform worse under pressure (Chell, Graydon, Crowley, & Child, 2003; Hardy, Martin, & Mullen, 2001; Mullen, Hardy, & Oldham, 2007; Mullen, Hardy, & Tattersall, 2005) and score lower on working memory tasks, for example in highly complex modular arithmetic tasks (Kinrade, Jackson, & Ashford, 2010). Decision reinvestment is defined as overthinking, through consciously controlling thoughts and/or ruminative thoughts, which is caused by investigating high levels of cognitive effort that negatively affects performance (Kinrade, Jackson, & Ashford, 2010). It has been shown that those individuals higher in this type of reinvestment tend to perform worse in working memory tasks such as the automated version of the operation span task (Laborde, Furley, & Schempp, 2015). Only two studies have examined the link between the reinvestment traits and cardiac vagal activity (Laborde, Furley, & Schempp, 2015; Laborde, Lautenbach, & Allen, 2015). The first examined decision reinvestment, cardiac vagal activity and decision making under pressure (Laborde et al., 2014). Results showed that those higher in decision reinvestment took longer to make a decision in high pressure condition, which may be linked to the conscious monitoring of thoughts slowing the decision process (Kinrade, Jackson,

Table 1
List of hypothesis.

Hypothesis	Supporting literature
H1) We predict that resting and task cardiac vagal activity will be positively predicted by trait emotional intelligence, specifically emotionality, across pressure conditions.	(Laborde, Lautenbach, & Allen, 2015)
H2) We predict that tonic task and post-task cardiac vagal activity variables will be positively related to resting cardiac vagal activity and tonic post-task cardiac vagal activity will be positively related to task cardiac vagal activity.	(Park et al., 2014; Thayer et al., 2009)
H3) We expect that resting tonic cardiac vagal activity may predict phasic cardiac vagal activity across pressure conditions.	(Park et al., 2014)
H4) Higher resting cardiac vagal activity and lower scores in decision reinvestment will have a positive influence on working memory performance in the high pressure condition.	(Kinrade, Jackson, & Ashford, 2010; Laborde, Furley, & Schempp, 2015)
H5) Higher resting cardiac vagal activity and a smaller decrease in cardiac vagal reactivity will be positively associated to working memory performance in the high pressure condition.	(Laborde, Lautenbach, & Allen, 2015; Thayer et al., 2009)
H6) Threat appraisals will decrease cardiac vagal reactivity in the high pressure condition.	(Laborde, Lautenbach, & Allen, 2015)

Ashford, & Bishop, 2010). In addition, cardiac vagal reactivity was higher (a larger decrease from resting to task) in the high pressure condition for high reinvestors (Laborde et al., 2014), which may have led to a less effective cognitive functioning during the task (Thayer et al., 2009). The second study examined both decision and movement reinvestment together with cardiac vagal activity regarding their relationship with working memory performance (Laborde, Furley, & Schempp, 2015). They found that high levels of decision reinvestment and lower resting cardiac vagal activity were negatively related to working memory performance. Moreover, cardiac vagal activity predicted working memory performance over and above reinvestment (Laborde, Furley, & Schempp, 2015). Therefore, the prediction for the current study is that decision reinvestment will be negatively related to working memory performance under pressure.

Another PTLID of interest is Trait Emotional Intelligence (EI) which is defined as a constellation of emotional self-perceptions situated at the lower levels of personality hierarchies (Petrides, Pita, & Kokkinaki, 2007). Although trait EI has yet to be explored within working memory performance, it has been shown to benefit cognitive performance (Laborde, Dosseville, & Scelles, 2010; Sanchez-Ruiz, Mavroveli, & Poullis, 2013), through its positive role on emotion regulation. A recent review of EI and cognitive processing highlighted the fact that more work should be done to understand the role of EI in specific cognitive tasks (Gutierrez- Cobo, Cabello, & Fernandez-Berrocal, 2016). Previous studies have shown that trait EI positively influences levels of cardiac vagal activity under stress (Laborde, Brull, Weber, & Anders, 2011; Laborde, Lautenbach, & Allen, 2015). Specifically, higher trait EI has been associated to higher levels of tonic cardiac vagal activity both at rest (Laborde, Lautenbach, & Allen, 2015) and during stress (Laborde et al., 2011). This may suggest that trait EI may have indirect effects on working memory performance through its influence on cardiac vagal activity. Therefore, it is predicted that trait EI is associated to higher levels of resting and task cardiac vagal activity.

In addition to trait variables, it is also important to understand the subjective state psychological components involved with coping related variables. Specifically, we focus here on challenge and threat appraisals, which have been shown to play a role within cognitive performance under pressure. Challenge and threat appraisals allow for an understanding of demand and resource evaluations within a pressurised environment (Tomaka et al., 1993). The cardiovascular states associated with these appraisals have been sown to predict cognitive performance under pressure, as challenge states enhanced Stroop task performance whereas threat states decreased performance (Turner, Jones, Sheffield, & Cross, 2012). These appraisals have also been shown to influence cardiac vagal activity, as those who displayed threatened patterns were found to have a decrease in cardiac vagal activity under pressure (Laborde, Lautenbach, & Allen, 2015). Given the predictions of the neurovisceral integration model, this drop in cardiac vagal activity may negatively affect cognitive performance that involves executive functioning (Thayer et al., 2009). As it is known that lower levels of cardiac vagal activity negatively influence working memory performance (Laborde, Furley, & Schempp, 2015) and threat appraisal can lower cardiac vagal activity (Laborde, Lautenbach, & Allen, 2015); it is of interest to examine whether these interactions will exist when tested together. Therefore, we predict that threat appraisals will have a negative influence on cardiac vagal activity.

It has been illustrated that cardiac vagal activity is influenced by coping related variables under pressure (Laborde, Furley, & Schempp, 2015; Laborde, Lautenbach, & Allen, 2015; Laborde et al., 2014). In addition, working memory performance may be influenced directly by cardiac vagal activity (Laborde, Furley, & Schempp, 2015; Thayer et al., 2009) or indirectly through coping related variables under pressure (Laborde, Furley, & Schempp, 2015; Laborde, Lautenbach, & Allen, 2015). However, the coping related variables of interest have mainly been studied in isolation and this hinders the comprehension of the psychophysiological components needed to cognitively perform under pressure. By systematically assessing these variables new knowledge can be developed around which variables hold the most influence over psychophysiological reactions and which help or hinder cognitive performance. This paper aims to firstly investigate the influence of coping related variables on the cardiac vagal activity throughout a pressurised event; secondly assess the role of coping related variables (including cardiac vagal activity) on working memory performance. In the present study working memory will be assessed under low and high pressure conditions and examined in conjunction with cardiac vagal activity, reinvestment, trait EI and challenge and threat appraisals. Based on the reviewed literature we make the following broad predictions: cardiac vagal activity will be influenced by coping related variables throughout the pressurised task and working memory performance will be influence by both cardiac vagal activity and coping related variables. A specific breakdown of hypothesis and supporting literature is listed in Table 1.

2. Methodology

2.1. Participants

Forty-nine participants (Female = 28, Male = 21, M_{age} = 24.1, SD = 6.5) took part in the experiment. All participants were athletes currently competing in a variety of sports (team = 40, individual = 9) some examples include netball, rugby, football, cricket, tennis and badminton. Participants had an average of 10.7 years' experience (SD = 7). Participants were asked if they had a history of cardiac disease or if they were taking any medication which could affect the heart, none reported so.

2.2. Research design

The study used a within subject design. Within subject designs are recommended in heart rate variability research as it allows for optimal experimental control, reduces individual differences in respiratory rate, requires fewer participants and reduces the impact of external variables such as sleep (Quintana and Heathers, 2014). Within subject design can promote learning effects of a task and habituation of conditions may occur (Laborde et al., 2017), however, these confounding effects were reduced through by implementing counterbalanced conditions (Laborde et al., 2014). Participants performed the same task across two different pressure conditions, low and high, approximately within one week of each other which were counterbalanced.

2.3. Measures

2.3.1. Personality measures

The Trait Emotional Intelligence Questionnaire (TEIQue) (Petrides & Furnham, 2003) measures emotional intelligence as a trait. It measures four main factors: well-being, self-control, emotionality and sociability and has 15 subscales. It has 153 items which are scored on a seven-point Likert-scale from 1 (completely disagree) to 7 (completely agree) (Petrides & Furnham, 2003). Some samples of items include "I would describe myself as a calm person" and "I often find it difficult to recognise what emotions I'm feeling". It was deemed a reliable scale in the current study (global score $\alpha = 0.74$, wellbeing $\alpha = 0.87$, self-control $\alpha = 0.91$, emotionality $\alpha = 0.89$, sociability $\alpha = 0.86$).

The Movement-Specific Reinvestment Scale (MSRS) was used (Masters & Maxwell, 2008). The MSRS is a nine item scale which has two internal sub-scales, conscious motor processing and movement self-consciousness. Items are rated on a five point Likert scale which ranges from 1 strongly agree to 6 strongly agree and some sample items include "I am always trying to think about my movements when I carry them out". The MSRS was deemed reliable in the current study ($\alpha = 0.83$).

The Decision-Specific Reinvestment Scale (DSRS) by Kinrade, Jackson, Ashford, and Bishop (2010) consists of 13 item measure, which was reliable in the current study ($\alpha = 0.84$). The DSRS has two subscales the first being decision reinvestment (the propensity to consciously monitor the decision making process), and decision rumination (the propensity to reflect on previous poor decisions). It is rated on a 5 point Likert scale ranging from 0 not characteristic to 4 very characteristic. An example items includes "When I am reminded about poor decisions I have made in the past, I feel as if they are happening all over again".

2.3.2. Cardiac vagal activity

Heart rate variability, from which cardiac vagal activity is derived, was measured using the eMotion Faros 180° (Mega Electronics Ltd., Pioneerinkatu, Finland) which collects electrocardiogram (ECG) data from two electrodes. Sampling rate was set to 500 hz as this is deemed to be a conservative sampling rate (Laborde et al., 2017). The first electrode was placed in the right infraclavicular fossa and the second electrode was aligned with the left 12th rib. Disposable ECG pre-gelled electrodes were used (Ambu VLC-00-S/25, Ambu GmbH, Bad Nauheim, Germany).

2.3.3. Perceived stress intensity

A visual analogue scale (VAS) was used to in order to rate stress intensity. Participants were asked how stressed they felt at the present moment and placed a cross on a 100 mm line, anchored from "not at all stressed" to "extremely stressed" (Lesage, Berjot, & Deschamps, 2012).

2.3.4. Perceived pressure

The pressure/tension subscales were utilised from the intrinsic motivation inventory (Ryan, 1982). This consisted of four items including statements like "I felt tense while doing the task" and "I was anxious while doing the task" which were subsequently rated on a Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree).

2.3.5. Attention

A VAS was also used to measure the direction of attention during the task. Participants were asked to place a cross on the line to determine where their attention was focused during the task. Two VAS scales were used, the first was anchored by the phrases "towards the task" and "away from the task", the second was anchored by the phrases "towards self" and "away from self", which was based on a suggestion from previous research (Laborde, Lautenbach, & Allen, 2015).

2.3.6. Cognitive appraisal

The cognitive appraisal ratio was adopted to reflect challenge and threat appraisals (Tomaka et al., 1993). The two items are "How demanding did you feel the task was?" which relates to the perceived demand within the situation and "How able were you to cope with the demands of the task?" to assess the perceived resources that are available to the individual in order to cope with the demands faced (Tomaka et al., 1993; Lazarus, 2000). Participants rated the items on a 6 point Likert scale anchored from 1 (not at all) and 6 (extremely).

2.3.7. Motivation and effort

Participants completed a single item indicating "How motivated were you to perform to your best in this task?" on a 6 point Likert scale from 0 (not at all) to 5 (very much so).

2.3.8. Working memory performance

The automated version of the operation span task (AOSPAN), which measures working memory, was used in this study (Turner & Engle, 1989; Unsworth, Heitz, Schrock, & Engle, 2005). This task has been proven to be sensitive to pressure manipulations (Leach & Griffith, 2008) and has been used in conjunction with personality traits, specifically reinvestment and cardiac vagal activity (Laborde, Furley, & Schempp, 2015). The task involved participants solving maths problems and remembering orders of letters. A typical sequence would consist of a maths question such as $(4 * 5) - 5 = ?$, followed by an answer which the participant selected true or false, followed by a single letter such as P. Once the sequence was complete the participant had to recall the letters in the order they appeared. The task consists of 15 separate trials which varied in size of 3 sets of maths and letters to 7 sets, which were randomised. In total there were 75 letters and 75 maths problems presented. If participants took too long over the trial it was counted as an error, the time allowed to answer the question was their average answer time plus 2.5 standard deviations (Unsworth et al., 2005).

2.4. Procedures

2.4.1. Pre-performance procedures

Ethical approval was granted from the University ethics board. Recruitment was conducted through the use of advertisements placed around the university site, which were aimed at individuals actively competing in sport. Once recruited, participants were given an information sheet, provided written informed consent and were emailed the battery of online questionnaires (which include the TEIQue, MSRS, DSRS). After the participants completed the questionnaires they were invited to the first lab session and asked to refrain from heavy exercise 24 h before attending and avoid consuming caffeine and food 2 h before the session. When participants arrived at the laboratory they were prompted to re-read the information sheet, which was followed by the attachment of two electrodes and the Faros 180° device which was then activated to begin recording. Participants were then seated, arms in lap, palms upwards and eyes closed (Laborde et al., 2017) and a resting heart rate variability reading was taken for 5 min, after which the first stress VAS was completed.

2.4.2. Performance

Before beginning the AOSPAN test the participants listened to a pre-recorded high or low pressure script, developed in line with

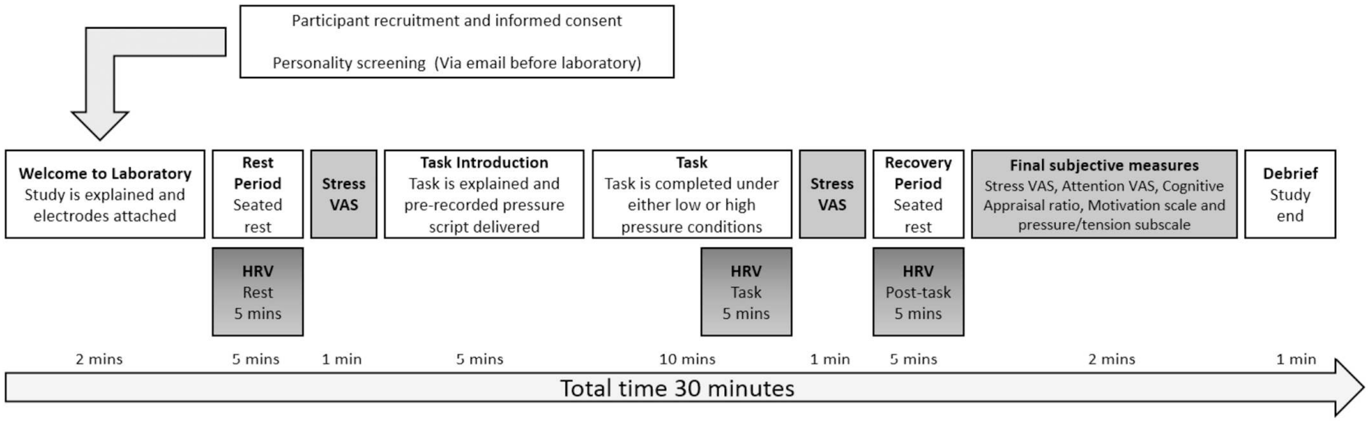

Fig. 2. Study procedure.

Baumeister's (1984) recommendations. In the low pressure condition, the script detailed the stipulations of the task which was coined as a memory competition. The top five performers would receive monetary incentives (£50, £25, £15, £10, £5) and the worst five performers would be interviewed and a public leader board of results emailed to all participants. In addition to the script, the high pressure condition used further pressure manipulations were imposed through the participants being filmed and the implementation of performance comparison with national databases. To further induce pressure a second experimenter actively made notes on “behavioural reactions” throughout the task, ensuring to make noise and move around the participant while doing the task. Furthermore, the percentage of maths success was shown in the corner of the screen. Participants were told that their current score was below the mean generally achieved by a similar population, which mirrored the procedure used in Laborde, Furley, and Schempp (2015).

The participant then commenced the AOSPAN task and followed the on screen instructions for the practice trials. After the practice trials the participant was reminded of the competitive instructions and started the competitive trial. In total the AOSPAN task lasted approximately 15 min from which the last 5 min were used as the heart rate variability recording. The last 5 min of the task were recorded as “task heart rate variability” and mirrors procedures used in previous research to reflect pressure (Laborde, Furley, & Schempp, 2015; Laborde, Lautenbach, & Allen, 2015; Laborde and Raab, 2013).

Directly after the end of the task, the participant completed the second VAS and remained seated for a further 5 min while post task heart rate variability was recorded. Lastly, the final set of subjective measures was taken including the third stress VAS, attention VAS, cognitive appraisal ratio, pressure/tension scale and motivation item. The participants were thanked, debriefed and notified about their second visit to the lab which was within a week of the first visit, which is in accordance with similar research in this area (Laborde, Furley, & Schempp, 2015). A detailed version of the procedural outline can be seen in Fig. 2.

2.4.3. Data preparation

Firstly, the challenge and threat ratio was determined by dividing demands from resources (Tomaka et al., 1993) and all personality questionnaires were coded and scored accordingly. Secondly, heart rate variability data were processed for artefacts, which was done through Kubios (Tarvainen, Niskanen, Lipponen, Ranta-Aho, & Karjalainen, 2014). The artefact correction function of Kubios was used, the low threshold was applied and this was visually inspected to ensure artefacts were correctly being identified (1%). Next, indicators of cardiac vagal activity were extracted, in this study high frequency absolute power derived from the Fast Fourier Transform was used, which is between 0.15–0.4 Hz (Camm et al., 1996; Berntson et al., 1997), and is deemed a reliable measure for cardiac vagal activity (Malliani, Lombardi, & Pagani, 1994). Thirdly, in order to calculate phasic cardiac vagal activity variables tonic variables were subtracted from each other as follows: reactivity = task-baseline and recovery = recovery-task. Next, data were first checked visually for normality via histograms and boxplots. If any outliers existed, they were winsorized (mean + 2x standard deviations). Heart rate variability variables were not normally distributed, therefore a log10 transform was applied, in line with procedures used in other research of this nature (Park et al., 2014). After data transformation data were checked again for normality and it was ensured they had a z score of between ± 2.58 (Field, 2009), all variables were considered to be normally distributed.

2.4.4. Data analysis

To ascertain whether the pressure conditions were successful, a repeated-measures (RM) MANOVA was used with condition (low pressure vs. high pressure) set as the within subject factor and the subjective stress variables (Stress VAS after the task, pressure and tension subscales) as dependent variables. A pressure effect would be noted by higher ratings of stress after the task, higher ratings of pressure and lower ratings of relaxation in the high pressure condition when compared to the low pressure condition. To explore the contribution of coping related variables to cardiac vagal activity (resting, task, post task, reactivity and recovery) bivariate correlations were run followed by hierarchical stepwise linear regression analyses. Using a hierarchical regression the predictors for cardiac vagal activity 1) resting, task, post task, reactivity, and recovery and 2) working memory performance were entered as dependent variables. The first block included age and gender, which allowed the researchers to control covariates that may affect heart rate variability data. The second block contained the predictors for each of the cardiac vagal activity variables and working memory performance. For the prediction of resting cardiac vagal activity trait emotional intelligence (global score, emotionality, sociability, wellbeing, self control) and reinvestment (movement and decision) were entered as predictors. For task cardiac vagal activity the addition of resting cardiac vagal activity, challenge and threat appraisal and attention were added. For post task cardiac vagal activity the addition of task cardiac vagal activity was added. For reactivity and recovery, task and recovery were removed as the variables were derived from them. For working memory performance all variables were entered. When assessing any phasic variables, or when phasic variables were used as a predictor resting cardiac vagal activity was also controlled for in the first block of the hierarchical regression.

2.4.5. Preliminary checks

In order to ensure all participants were motivated to compete in both conditions, a one item measure asked “How motivated were you to perform to your best in this task?” on a 6 point Likert scale from 0 (not at all) to 5 (very much so). The participants appeared to be motivated in both the low pressure condition ($M = 4.11$, $SD = 0.79$) and the high pressure condition ($M = 4.15$, $SD = 0.94$). A paired sample *t*-test confirmed there was no difference between motivation in both conditions $t(47) = -1.550$, $p = .128$, $d = -0.22$. Breathing rate was also checked across conditions, this was to ensure participants did not change their breathing patterns across conditions. There should be no differences in respiratory frequency between experimental tasks when drawing conclusions from cardiac vagal activity (Laborde et al., 2017). To do this a measure of estimated respiratory frequency, derived from the electrocardiogram derived respiration variable obtained post-hoc from Kubios (Tarvainen et al., 2014), was compared across both low and high pressure conditions. A paired sample *t*-test confirmed there was no difference between breathing rate in both conditions $t(48) = 0.497$, $p = .622$, $d = 0.070$.

3. Results

Firstly, descriptive data are reported in Table 2, secondly pressure manipulation checks are discussed, thirdly the correlation matrices featuring all study variables can be found in Tables 3. As study variables were intercorrelated a series of stepwise regressions were performed to identify salient predictors for cardiac vagal activity variables and working memory performance (Tables 5 and 6). Each regression utilised different predictors, which is specified in the data analysis section.

3.1. Pressure manipulation checks

The RM MANOVA showed a significant main effect for condition, Wilks' Lambda = 0.66, $F(3, 46) = 7.69$, $p < .001$, $\eta^2 = 0.33$. The univariate analyses from the RM MANOVA showed a main effect for stress rating after the task with a significant increase in stress following the high pressure condition when compared to low pressure condition $F(3,46) = 19.77$, $p < .001$, $\eta^2 = 0.29$, this was also found for pressure ratings $F(3,46) = 15.7$, $p < .001$, $\eta^2 = 0.24$. A significant main effect for relaxation was also found with a decrease in relaxation when competing in the high pressure condition when compared to the low pressure condition $F(3,46) = 13.57$, $p = .001$, $\eta^2 = 0.22$. Results indicate that the pressure manipulations were successful in creating low and high pressure conditions at the subjective level. In order to check the objective manipulation of pressure through differences in working memory performance, a paired samples *t*-test was conducted. This revealed that the working memory performance was significantly worse in the high pressure condition ($M = 37.06$, $SD = 13.78$) when compared to the low pressure condition ($M = 44.51$, $SD = 18.13$), $t(48) = -4.202$, $p < .001$, $d = -0.60$.

3.2. Correlation matrices

Correlations between all variables are reported in Tables 3 and 4. Key significant correlations of interest in low pressure were between decision reinvestment and task ($r = 0.36$, $p < .01$) and recovery ($r = -0.35$, $p < .05$) cardiac vagal activity. Trait emotional intelligence emotionality and cardiac vagal recovery ($r = 0.30$, $p < .05$) and trait emotional intelligence emotionality and task cardiac vagal activity ($r = -0.33$, $p < .05$). Key significant correlations of interest in the high pressure condition were working memory score and task cardiac vagal activity ($r = -0.40$, $p < .01$). Positive correlations between resting cardiac vagal and task ($r = 0.59$, $p < .01$), post task ($r = 0.57$, $p < .01$), and recovery ($r = 0.31$, $p < .05$).

Table 2
Descriptive statistics.

	M	SD
Age	24.12	6.57
Trait variables		
DSRS	26.89	9.74
MSRS	24.06	9.74
Trait EI - Well-Being	5.23	0.88
Trait EI - Self-Control	4.44	0.88
Trait EI - Emotionality	4.81	0.82
Trait EI - Sociability	4.84	0.73
Trait EI - Global Score	4.8	0.61

Performance variables	High pressure condition		Low pressure condition	
	M	SD	M	SD
Working Memory Score	37.06	13.78	44.51	18.13
Attention Towards Task	12.75	19.57	10.93	15.28
Attention Towards Self	59.79	31.48	48.55	36.22
Perceived Demands	4.55	1.24	4.36	1.16
Perceived Resources	4.02	1.01	4.40	0.88
Demand/Resource Ratio	−0.53	1.89	0.12	1.82
Resting CVA	2.94	0.42	2.89	0.30
Task CVA	2.66	0.34	2.69	0.39
Post Task CVA	2.96	0.41	2.95	0.36
Reactivity CVA	−0.15	0.28	−0.19	0.32
Recovery CVA	0.29	0.43	0.25	0.38
Perceived Stress Post Rest	12.81	11.94	9.87	8.82
Perceived Stress Post Task	48.12	25.59	32.36	23.17
Perceived Stress Post Recovery	23.14	17.68	16.18	15.80
Perceived Tension Post Task	5.22	1.61	4.20	1.81
Perceived Pressure Post Task	5.20	1.80	4.04	1.95
Perceived Anxiety Post Task	4.46	1.65	3.57	1.67
Perceived Relaxation Post Task	2.69	1.58	3.79	1.80
Motivation to Compete	4.34	0.77	4.47	0.61

Note: DSRS = decision reinvestment total score; MSRS = movement reinvestment total score; Trait EI = Trait Emotional Intelligence; CVA = Cardiac Vagal Activity (indexed by high frequency HRV absolute power – log transformed).

Table 3
Correlation matrix for all variables (low pressure condition).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. DSRS	–														
2. MSRS	0.61**	–													
3. Trait EI - Well-Being	−0.37**	−0.42**	–												
4. Trait EI - Self-Control	−0.21	−0.57**	0.48**	–											
5. Trait EI - Emotionality	−0.52**	−0.48**	0.69**	0.45**	–										
6. Trait EI - Sociability	−0.27	−0.19	0.51**	0.18	0.54**	–									
7. Trait EI - Global Score	−0.46**	−0.56**	0.85**	0.70**	0.87**	0.65**	–								
8. Attention Towards Task	0.24	0.21	0.03	−0.08	−0.03	0.01	−0.04	–							
9. Attention Towards Self	0.16	0.15	−0.18	−0.32*	−0.12	−0.06	−0.24	−0.17	–						
10. Demand/Resource Ratio	−0.04	−0.41**	0.16	0.54**	0.23	0.13	0.37**	−0.06	−0.14	–					
11. Resting CVA	0.21	0.12	−0.08	−0.05	−0.17	−0.12	−0.15	0.06	0.01	−0.04	–				
12. Task CVA	0.36**	0.22	−0.18	−0.00	−0.33*	−0.13	−0.21	−0.03	0.02	0.04	0.61**	–			
13. Post Task CVA	0.02	0.09	−0.04	−0.05	−0.03	−0.09	−0.07	0.14	−0.12	−0.08	0.55**	0.47**	–		
14. Reactivity CVA	0.25	0.16	−0.14	0.04	−0.25	−0.05	−0.12	−0.10	0.01	0.10	−0.21	0.64**	0.05	–	
15. Recovery CVA	−0.35*	−0.13	0.14	−0.05	0.30*	0.05	0.15	0.16	−0.14	−0.12	−0.09	−0.56**	−0.45**	−0.60**	–
16. Working Memory Score	0.14	0.22	−0.06	−0.06	−0.24	−0.03	−0.16	0.02	0.10	−0.06	0.01	0.11	−0.06	0.13	−0.18

Note: DSRS = decision reinvestment total score; MSRS = movement reinvestment total score; Trait EI = trait emotional intelligence; CVA = cardiac vagal activity.
* $p < .05$.
** $p < .01$.

Table 4
Correlation matrix for all variables (high pressure condition).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. DSRS	–														
2. MSRS	0.61**	–													
3. Trait EI - Well-Being	−0.37**	−0.42**	–												
4. Trait EI - Self-Control	−0.21	−0.57**	0.48**	–											
5. Trait EI - Emotionality	−0.52**	−0.48**	0.69**	0.45**	–										
6. Trait EI - Sociability	−0.27	−0.19	0.51**	0.18	0.54**	–									
7. Trait EI - Global Score	−0.46**	−0.56**	0.85**	0.70**	0.87**	0.65**	–								
8. Attention Towards Task	0.01	0.04	0.09	−0.02	0.00	−0.02	0.02	–							
9. Attention Towards Self	0.12	0.04	−0.17	−0.19	−0.01	0.05	−0.12	0.05	–						
10. Demand/Resource Ratio	0.11	−0.18	0.19	0.52**	0.12	0.01	0.27	−0.08	−0.18	–					
11. Resting CVA	−0.24	−0.00	−0.11	−0.22	−0.00	0.01	−0.11	0.07	0.08	−0.15	–				
12. Task CVA	−0.09	0.04	−0.03	−0.17	0.10	0.07	−0.02	−0.27	0.00	−0.12	0.59**	–			
13. Post Task CVA	−0.08	0.06	0.07	−0.19	0.06	0.19	0.03	0.03	0.02	0.04	0.57**	0.37**	–		
14. Reactivity CVA	0.19	0.02	0.06	−0.19	0.00	0.27	−0.27	−0.10	0.11	0.03	−0.24	0.21	−0.12	–	
15. Recovery CVA	−0.11	0.06	0.54	−0.10	0.05	0.15	0.04	0.16	0.09	−0.00	0.31*	−0.07	0.80**	−0.37**	–
16. Working Memory Score	−0.04	0.13	−0.03	−0.08	−0.03	−0.01	−0.06	0.18	−0.15	0.04	−0.17	−0.40**	−0.07	−0.08	0.05

Note: DSRS = decision reinvestment total score; MSRS = movement reinvestment total score; Trait EI = trait emotional intelligence; CVA = cardiac vagal activity.
* $p < .05$.
** $p < .01$.

3.3. The contribution of coping-related variables to cardiac vagal activity in low pressure condition

There were no predictors for resting cardiac vagal activity. For task cardiac vagal activity the first predictor extracted was the level of resting cardiac vagal activity (adjusted $R^2 = 0.37$, $p < .001$). The second predictor extracted was DSRS (adjusted $R^2 = 0.06$, $p < .001$). The two predictors together accounted for 43% of the variance in task vagal activity. For post task the first and only predictor extracted was the level of resting cardiac vagal activity (adjusted $R^2 = 0.29$, $p < .001$). For cardiac vagal reactivity, there were no predictors. For cardiac vagal recovery, the first and only predictor extracted was decision reinvestment (adjusted $R^2 = 0.10$, $p = .014$).

3.4. The contribution of coping-related variables to cardiac vagal activity in the high pressure condition

For resting cardiac vagal activity no predictors were found. For task cardiac vagal the first and only predictor extracted was the level of resting cardiac vagal activity (adjusted $R^2 = 0.34$, $p < .001$). For post

Table 5
Multiple (stepwise) regressions for cardiac vagal activity in low pressure condition.

Model	Unstandardized coefficients		Standardized coefficients	t
	B	Std error	β	
Task CVA				
1 Resting CVA	0.78	0.14	0.61	5.27**
2 Resting CVA	0.71	0.14	0.55	4.90**
DSRS	0.01	0.00	0.25	2.20**
Post Task CVA				
1 Resting CVA	0.65	0.14	0.55	4.57**
Recovery CVA				
1 DSRS	−0.01	0.00	−0.35	2.56*

Note: CVA = cardiac vagal activity, DSRS = decision reinvestment score.
If regressions had no predictors they were excluded from the table.
* $p < .05$.
** $p < .01$.

Table 6
Multiple (stepwise) regressions for cardiac vagal activity in high pressure condition.

Model	Unstandardized coefficients		Standardized coefficients	t
	B	Std error	β	
Task CVA				
1 Resting CVA	0.49	0.09	0.59	5.11**
Post Task CVA				
1 Resting CVA	0.56	0.11	0.57	4.82**
Recovery CVA				
1 Resting CVA	0.36	0.15	0.31	2.27*
Working Memory				
1 Task CVA	−15.84	5.28	−0.40	−2.99*

Note: CVA = cardiac vagal activity.
If regressions had no predictors they were excluded from the table.
* $p < .05$.
** $p < .01$.

task cardiac vagal activity trait the first and only predictor extracted was resting cardiac vagal activity (adjusted $R^2 = 0.34$, $p < .001$). For cardiac vagal reactivity, no predictors were found. For cardiac vagal recovery the first (and only) predictor extracted for cardiac vagal recovery was resting cardiac vagal activity (adjusted $R^2 = 0.08$, $p = .028$).

3.5. The contribution of coping-related variables and cardiac vagal activity on working memory performance in low and high pressure conditions

For performance prediction all trait, state psychological variables and cardiac vagal activity variables were entered at this stage. There were no predictors found for working memory performance for the low pressure condition. In the high pressure condition working memory performance was predicted by task cardiac vagal activity (adjusted $R^2 = 0.14$, $p = .004$).

4. Discussion

The aim of this study was to assess the predictive role of coping related variables (trait emotional intelligence, reinvestment, challenge and threat appraisals, and cardiac vagal activity) on levels of cardiac vagal activity and working memory performance under low and high pressure conditions. Firstly, the predictors of cardiac vagal activity will be discussed and secondly the predictors for working memory performance.

4.1. Resting cardiac vagal activity

Hypothesis 1 predicted that trait emotional intelligence would be positively associated with resting cardiac vagal activity was not supported. In both low pressure and high pressure conditions trait EI global score and factors did not emerge as predictors for resting cardiac vagal activity. This prediction was based on previous research where trait EI predicted resting cardiac vagal activity, in particular the subscale of wellbeing (Laborde, Lautenbach, & Allen, 2015). In contrast other research exploring similar aims found no association with trait EI and resting cardiac vagal activity (Laborde et al., 2011). Given the inconsistent findings in the prediction of resting cardiac vagal activity with trait EI, it may be linked to the fact that studies have only taken a snap shot of cardiac vagal activity over 5 min. As cardiac vagal activity can be influenced by many transient variables (Laborde et al., 2017), it may be that stable predictors such as traits should be matched to more longitudinal measures of cardiac vagal activity to draw sound conclusions. Notwithstanding, this warrants further investigation into the relationship between trait EI and resting cardiac vagal activity.

4.2. Task cardiac vagal activity

Hypothesis 2 suggested resting cardiac vagal activity would predict task cardiac vagal activity was supported. In the high pressure condition resting cardiac vagal activity was the sole predictor of task cardiac vagal activity. Those who had higher levels of cardiac vagal activity at rest had higher levels of cardiac vagal activity during the task, which is supported by previous research (Park et al., 2014). Higher levels of resting cardiac vagal activity have been shown to positively influence adaptive emotional responding (Ruiz-Padial, Sollers Iii, Vila, & Thayer, 2003; Thayer et al., 2009) and facilitative behavioural responses during tasks (Hansen, Johnsen, & Thayer, 2003). This suggests that individuals with higher resting cardiac vagal activity are better able to meet the demands of the task by regulating themselves in stressful situations. This could be seen to be a benefit for working memory performance, as higher levels of cardiac vagal activity are required in order to produce better performance on tasks relying on executive functioning (Thayer et al., 2009).

In the low pressure condition, the first predictor of task cardiac vagal activity was resting cardiac vagal activity, which replicates the findings from the high pressure condition. Therefore, hypothesis 2 is further supported, as we found that higher levels of resting cardiac vagal activity positively influences task cardiac vagal activity across pressure conditions. A second predictor for task cardiac vagal activity was decision reinvestment. Findings suggested that higher levels of decision reinvestment positively influenced cardiac vagal activity during the task. This contradicts hypothesis 4 and previous findings from Laborde et al. (2014) and Laborde, Furley, and Schempp (2015) that showed higher levels of decision reinvestment to be associated to reduced levels of task cardiac vagal activity, potentially due to the role of revisiting decisions made within a task (Kinrade, Jackson, & Ashford, 2010). One important point to note is that this finding was only present within the low pressure condition in the present study and the effects of reinvestment are usually only present within high pressure conditions (Jackson, Ashford, & Norsworthy, 2006). This may be linked to the principle of trait activation, where individual differences in personality will have a differing impact across different pressure situations (Geukes, Mesagno, Hanrahan, & Kellmann, 2013). For example, it may be that decision reinvestment may have reverse effects in low pressure conditions. This may be linked to the concept that rumination can consist of contemplative and adaptive repetitive thoughts, when the valence associated to those thoughts is positive (Watkins, 2008). This can lead to better problem solving, planning and reduces negative moods (Watkins, 2008), which may then be associated with an increase in cardiac vagal activity. Although the current finding is unexpected, it may be that more research needs to be conducted into the role of decision reinvestment and cardiac vagal activity in differing pressure conditions.

With regards to hypothesis 6, threat appraisals would reduce task levels of cardiac vagal activity, no relationships were found and consequently the hypothesis was rejected. This hypothesis was based on previous research, where threat appraisals were found to be associated to reduced cardiac vagal activity (Laborde, Lautenbach, & Allen, 2015). In the current study, it may be that null findings were discovered as a result of the number of predictors and the shared variance within the analysis.

4.3. Post task cardiac vagal activity

Hypothesis 3, predicting that resting cardiac vagal activity would positively influence post task cardiac vagal activity was supported. Resting cardiac vagal activity positively influenced the level of post task cardiac vagal activity in both the low and high pressure conditions. Consistent with previous findings resting cardiac vagal activity has shown to have many benefits across health, emotional regulation and stress management (Hansen et al., 2003; Ruiz-Padial et al., 2003; Thayer et al., 2009), the higher the levels of cardiac vagal activity at rest, the better able individuals can successfully regulate and adapt during stress. Post task recovery is a crucial indicator of the adaptability of an organism as it determines the ability to effectively return to resting level after facing a stressful event (Stanley, Peake, & Buchheit, 2013). Conversely, lower levels of post task cardiac vagal activity reflects the result of poor self-regulation, as a return to resting level is achieved slower or not at all (Berna, Ott, & Nandrino, 2014). More efficient return to resting levels enables the individual to face another potential stressor. In demanding environments where multiple stressors are presented in rapid succession with changing intensity this would be crucial. Such a finding has application not only to athletes in sporting situations but further to other occupations who function under situations of pressure such as air traffic control officers, accident and emergency doctors. These findings suggest a higher level of resting cardiac vagal activity fosters more effective cardiac vagal recovery, because a larger cardiac vagal activity is available in the first instance, which allows for a greater uptake of self-regulation resources.

4.4. Cardiac vagal recovery

In the low pressure condition decision reinvestment was negatively associated with cardiac vagal recovery. Individuals who were higher in decision reinvestment, had decreased cardiac vagal recovery after the stressful task. This may suggest that the high reinvestors were thinking back to their previous performance even after the task had finished and therefore this prompted a decrease in cardiac vagal recovery. It is not uncommon for those high in this trait to ruminate about past decisions (Kinrade, Jackson, & Ashford, 2010). Previous research found that high levels of decision reinvestment caused a larger decrease in cardiac vagal activity during a task (Laborde et al., 2014). However, this is a new finding when compared to previous research, as decision reinvestment has not been assessed with cardiac vagal recovery. A point of interest is that the opposing pattern was discovered for task cardiac vagal activity, where those higher in decision reinvestment had higher levels of cardiac vagal activity. It may be that during the task, participants used adaptive repetitive thoughts to solve the task, and after the task the participants then thought back to their performance perhaps in a negative light, which caused a decrease in cardiac vagal activity. This may be an interesting avenue for future research and interventions to help athletes recover more effectively, particularly if the sport contains multiple time points of breaks in play such as tennis.

In the high pressure condition, hypothesis 3, assuming that resting cardiac vagal activity would predict phasic cardiac vagal activity, was supported. It was found that higher levels of resting cardiac vagal activity positively influenced the recovery process from task to recovery. This is in line with the notion that higher levels of resting cardiac vagal activity promote cardiac vagal activity enhancement under stress due to an enhanced ability to effectively uptake self-regulatory resources (Park et al., 2014; Segerstrom & Nes, 2007).

4.5. Working memory performance

Hypothesis 4, predicting that lower decision reinvestment and higher resting and task cardiac vagal activity would positively influence working memory performance, was not supported. It was also predicted that a smaller decrease in cardiac vagal reactivity would positively influence working memory performance (hypothesis 5). Findings related to cardiac vagal activity and working memory performance were only present in the high pressure condition, which reflect previous findings (Laborde, Furley, & Schempp, 2015). In the current study there was a negative relationship between working memory performance and levels of task cardiac vagal activity, which would partially support hypothesis 4 and reject hypothesis 5. Lower levels of task cardiac vagal activity positively affected working memory performance. Theoretically this is not supported by the neurovisceral integration model, as higher executive functioning performance is associated to high levels of cardiac vagal activity, and that a decrease from resting to task will negatively affect executive performance (Thayer & Lane, 2000). In previous work higher levels of resting cardiac vagal activity were positively associated to working memory performance (Hansen et al., 2003; Laborde, Furley, & Schempp, 2015). However, Hansen et al. (2003) found a suppression in RMSSD over the course of the working memory task. This was suggested to be linked to sustained attention, as the duration and intensity of the task increases, and so does the demand on the organism (Porges, 1992). Considering the working memory task was 15 min in length and the task cardiac vagal activity measure was derived from the final 5 min, it could be that the negative relationship demonstrates successful adaptation across the time. This may suggest that those who performed better used up their self-regulation resources across the task, resulting in a reduction in cardiac vagal activity at the end of the task. More explorations of the different tonic and phasic measurement points for cardiac vagal activity in combination to different types of working memory tasks and environmental demands are needed to further understand the role of cardiac vagal activity and working memory performance.

4.6. Limitations

To reflect on the findings, the limitations of the current study must be acknowledged. Firstly, the nature of the study was laboratory based on a computer task, which can be considered to be quite removed from the sporting environment. However, working memory can play an important role in cognitive sporting functions such as reasoning and problem solving (Just & Carpenter, 1992). Although where possible the time of day for testing was accounted for in some cases it was not logistically possible for the participant to be tested at the same exact time of day. As HRV has a circadian rhythm this may influence the readings taken (Laborde et al., 2017), this is therefore acknowledged as a limitation regarding the measurement of HRV in this particular study. Sample size could have been increased, given other studies of a similar nature had slightly more participants (Laborde, Furley, & Schempp, 2015). Another issues in regards to sample is the fact that the sample was heavily biased towards team sports (40) and only had 9 individual sport athletes. This may affect the personality results, as team sports showed differences in personality when compared to those who competed in individual sports (Laborde, Guillén, & Mosley, 2016). Future research should explore the findings either with purely individual athletes or achieve an equal split between the sporting disciplines, or with non-sporting samples that also face the need to have effective working memory performance, such as air traffic control officers.

5. Conclusion

To conclude, the current study has developed knowledge around how coping related variables and cardiac vagal activity may be associated to working memory performance under pressure. At the theoretical level, we further supported the importance of resting cardiac vagal activity as an enduring resource for self-regulation under differing pressure demands, maintaining the need for its inclusion in pressure research. Decision reinvestment was the only trait that directly influenced cardiac vagal activity during and after the working memory task. We found that decision reinvestment may influence cardiac vagal activity differently across points in experimental tasks. In particular, the role of valence in rumination should be examined (Watkins, 2008), in order to determine adaptive and maladaptive patterns associated with decision reinvestment. On this occasion, there was evidence to suggest that higher levels of task cardiac vagal activity were negatively associated with working memory performance. This contradicts previous theory and potentially requires further investigation, or multiple measures of working memory performance should be addressed across the task, given sustained attention tends to reduce cardiac vagal activity over time (Hansen et al., 2003). At the applied level, practitioners should monitor cardiac vagal activity to reap the benefits of understanding psychophysiological reactions. A further consideration is how decision reinvestment may directly affect athlete's psychophysiological functioning, and how to potentially enhance this through understanding adaptive and maladaptive rumination patterns in pressurised events.

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