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DOI:
10.1080/10615806.2019.1648794

Anxiety, Stress, & Coping
An International Journal

ISSN: 1061-5806 (Print) 1477-2205 (Online) Journal homepage: https://www.tandfonline.com/loi/gasc20

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To cite this article: Gavin P. Trotman, Jet J. C. S. Veldhuijzen van Zanten, Jack Davies, Clara Möller, Annie T. Ginty & Sarah E. Williams (2019): Associations between heart rate, perceived heart rate, and anxiety during acute psychological stress, Anxiety, Stress, & Coping, DOI: 10.1080/10615806.2019.1648794

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ANXIETY, STRESS, & COPING
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Associations between heart rate, perceived heart rate, and anxiety during acute psychological stress

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ABSTRACT

Background: Acute psychological stress elicits increases in heart rate (HR) and anxiety. Theories propose associations between HR, perceived HR, and anxiety during stress. However, anxiety is often measured as a unidimensional construct which limits a comprehensive understanding of these relationships.
Objectives: This research explored whether HR reactivity or perceived HR change was more closely associated with cognitive and somatic anxiety during acute psychological stress.
Design: Two laboratory-based studies were conducted.
Methods: In a single laboratory session, healthy male ($N = 71$; study 1) and female ($N = 70$; study 2) university students completed three laboratory psychological stress tasks (counterbalanced), each with a preceding baseline. Heart rate, perceived HR change, and cognitive and somatic anxiety intensity and interpretation of anxiety symptoms were assessed immediately following each task. Data were aggregated across tasks.
Results: Actual HR change was unrelated to anxiety intensity, but was associated with more debilitative interpretations of anxiety (study 2). Perceptions of HR change were consistently associated with greater intensity of cognitive (study 1) and somatic (study 1 and 2) anxiety.
Conclusions: Perceived HR rather than actual HR is more closely associated with anxiety intensity during psychological stress. The findings have implications for stress management and the clinical treatment of anxiety symptoms.

ARTICLE HISTORY
Received 31 December 2018
Revised 27 May 2019
Accepted 28 May 2019

KEYWORDS
Acute psychological stress; heart rate; perceived heart rate; cognitive anxiety; somatic anxiety; anxiety interpretation

Introduction

Anxiety is a common psychological disorder with lifetime prevalence as high as 28.8% in the United States (Bandelow & Michaelis, 2015; Kessler et al., 2005). Psychological stress plays a substantial role in anxiety. Stressful life events are known to precede anxiety disorders (Faravelli & Pallanti, 1989) and individuals with anxiety disorders report feeling more psychological stress and are impacted more by events that are considered stressful (Grossman, Wilhelm, Kawachi, & Sparrow, 2001; Mauss, Wilhelm, & Gross, 2004). It has been proposed that appraising a situation as threatening or stressful, combined with the alterations in cardiovascular activity, such as increases in HR (heart rate), may consequently lead to greater feelings of anxiety intensity (Jones, Meijen, McCarthy, & Sheffield, 2009; Mallorqui-Bague, Bulbena, Pailhez, Garfinkel, & Critchley, 2016).

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Supplemental data for this article can be accessed at https://doi.org/10.1080/10.1080/10615806.2019.1648794.

Whilst influential theories propose a relationship between the mind and body (Damasio, 1996; James, 1884; Schachter & Singer, 1962), extensive experimental research has demonstrated limited associations between physiological and psychological responses to stress (Campbell & Ehlert, 2012). Rather, it has been proposed that the perception of the physiological changes (i.e., perceptions of HR change) may contribute to anxiety symptoms (Mallorqui-Bague et al., 2016). Evidence from clinical populations supports this (Mauss et al., 2004; Schmitz, Blechert, Kramer, Asbrand, & Tuschen-Caffier, 2012). For example, Mauss et al. (2004) found that anxiety reported during a speech task was associated with perceptions of physiological responses (e.g., greater HR, sweaty palms), while being unrelated to all actual physiological responses (Mauss et al., 2004). Another study showed that individuals who were led to believe their HR had increased, reported greater anxiety and physical cues of anxiety measured with the autonomic perception questionnaire (Wild, Clark, Ehlers, & McManus, 2008). This result was consistent across both high and low anxiety groups, showing that individuals who perceive greater HR activity likely experience increased anxiety levels (Wild et al., 2008). As such, it could be suggested that perceived rather than actual HR is likely to be more strongly associated with anxiety responses to stress, however, this is yet to be examined in a non-clinical population. Understanding which factors strongly contribute to the experience of anxiety symptoms, particularly in a healthy population, will inform interventions to minimize anxiety experienced during stress.

A limitation of the previous work examining the relationship between actual and perceived HR and anxiety is the anxiety assessment. When examining anxiety comprehensively, it is important to consider its multidimensional components, including cognitive and somatic anxiety (Degood & Tait, 1987; Schwartz, Davidson, & Goleman, 1978; Steptoe & Kearsley, 1990). Cognitive anxiety refers to the mental symptoms of anxiety such as negative thoughts, whereas somatic anxiety is specific to the physical symptoms of anxiety such as increased HR (Martens, Vealey, & Burton, 1990). Previous work has typically assessed anxiety as a unidimensional construct (Anderson & Hope, 2009; Mauss et al., 2004; Wild et al., 2008) and often used scales specifically designed for the study (Grossman et al., 2001). Consequently, the lack of a relationship between HR and anxiety responses described in previous studies could be due to the lack of detailed and comprehensive anxiety measures used which separately tease out the distinction between cognitive anxiety and somatic anxiety.

When exploring the associations between anxiety and physiological responses to stress, it is logical to propose that compared to cognitive anxiety, somatic anxiety is more closely associated with HR responses given that its definition encompasses increases in HR (Martens, Vealey, et al., 1990). Central to anxiety disorders is the concept that individuals experience heightened physiological symptoms (i.e., palpitations) and focus their attention on bodily responses in stressful situations (American Psychiatric Association, 1994; Siess, Blechert, & Schmitz, 2014). It would be of interest to explore the variance of cognitive and somatic anxiety during stress accounted for by actual physiological responses (HR) and perceived changes in HR in healthy individuals. Given the fundamental physiological components of somatic anxiety, it may be that HR and/or perceived HR responses will be associated with somatic anxiety during stress. In contrast, cognitive anxiety may be unrelated to perceptions of HR, and this discrepancy between anxiety constructs could underlie the equivocal findings in previous work. As such, understanding the relationship between HR, perceptions of HR, and cognitive and somatic anxiety in healthy individuals may highlight mechanisms contributing to the development of anxiety which can be used to develop appropriate preventative treatments.

In addition to its intensity, anxiety can also vary in whether it is interpreted as being facilitative or debilitative (Chamberlain & Hale, 2007; Jones, 1995; Jones, Hanton, & Swain, 1994; Thomas, Hanton, & Jones, 2002). Theories support the notion that anxiety is not always negative, and increases in anxiety do not always mean the anxiety will be more debilitative (Hanin, 2000; Neil, Wilson, Mellalieu, Hanton, & Taylor, 2012; Yerkes & Dodson, 1908). For example, the inverted-U hypothesis suggests a non-linear relationship between anxiety and perceived interpretation of these symptoms, in particular for somatic anxiety whereby elevated levels to an extent are thought to be beneficial (Martens, Burton, Vealey, Bump, & Smith, 1990; Yerkes & Dodson, 1908). Similarly, updated theories such as the individual zones of optimal functioning (IZOF) propose anxiety is not always detrimental and that there are inter-individual differences in how anxiety symptoms are interpreted (Hanin, 2000). As such, it would be of interest to explore whether actual HR or perceptions of HR change relate to the both anxiety intensity but also the perceived interpretation of anxiety symptoms during psychological stress. Given that individuals with greater anxiety sensitivity report greater somatic and panic symptoms (Eley, Stirling, Ehlers, Gregory, & Clark, 2004) it might be expected that individuals who perceive greater somatic symptoms (reflected in greater perceived HR changes during stress), report more debilitative anxiety symptoms, however this is yet to be examined. Understanding the factors contributing to the interpretation of anxiety symptoms will help develop targeted interventions which will reduce an individual's focus on negative cues, resulting in anxiety being interpreted as less debilitative and stress having a less maladaptive effect.

Research investigating psychological and physiological responses during stress typically use a single task, focussing on the social evaluative speech task (Cohen et al., 2000; Fox, Cahill, & Zougkou, 2010; Jansen, Gispen-de Wied, & Kahn, 2000; Mauss et al., 2004). An individual's cardiovascular and psychological responses vary depending on the type of stress (Kamarck & Lovallo, 2003). Even within the lab, cardiovascular and anxiety responses vary based on the nature and demands of the stress task (Richter, Friedrich, & Gendolla, 2008; Veldhuijzen Van Zanten et al., 2004; Wright, Killebrew, & Pimpalapure, 2002). For example, reaction time tasks and mental arithmetic tasks typically induce β-adrenergic driven cardiovascular responses, mirror tracing and cold pressor tasks typically produce α-adrenergic driven cardiovascular responses, and video games a mixed pattern of α-adrenergic and β-adrenergic cardiovascular responses (Allen, 2008; Kamarck & Lovallo, 2003; Turner, 1994). Differences in cognitive and somatic anxiety and stress appraisals are also evident between speech, mental arithmetic and competitive stress tasks (AlAbsi et al., 1997; Trotman, Williams, Quinton, & Veldhuijzen Van Zanten, 2018). Consequently, previous relationships or lack of relationships between anxiety and actual and perceived HR changes may have been dictated by the type of stress task utilized in the study.

To provide a more valid and reliable measure of cardiovascular reactivity (including HR change), Kamarck et al. (1992) exposed individuals to several psychological stress tasks with different demands, and aggregated data resulting in a "trait" cardiovascular reactivity score. Literature has since called for studies to implement a variety of individual tasks and aggregate data to reduce idiosyncratic measurement variability resulting in a more reliable "trait" overall score, thus increasing the generalisability of studies to general life stress (Kamarck & Lovallo, 2003; Kamarck, Jennings, Stewart, & Eddy, 1993). We are unaware of any literature calculating aggregated stressor-evoked anxiety and perceptions of HR change scores. However, it is likely that calculating aggregated psychological responses to several stress tasks will also provide a more reliable reflection of an individual's psychological response to acute psychological stress.

Literature has demonstrated gender differences in anxiety disorders, with increased severity and prevalence reported in females (McLean, Asnaani, Litz, & Hofmann, 2011). Furthermore, anxiety sensitivity (i.e., the fear of anxiety-related sensations) is also much more prevalent in females compared with males (Armstrong & Khawaja, 2002; Norr, Albanese, Allan, & Schmidt, 2015; Stewart, Taylor, & Baker, 1997). Even though there have been mixed findings regarding gender differences in reactivity, a meta-analysis revealed stressor-evoked HR reactivity does not differ across genders (Brindle, Ginty, Phillips, & Carroll, 2014). However, literature has demonstrated females report greater anxiety, somatic complaints and cardiac associated complaints during psychological stress (Grossman et al., 2001). Given trait and state gender differences, it is likely that gender also influences the associations between our independent and dependent variables. Consequently, the present body of research first explored in a male sample whether relationships were apparent between perceived HR, actual HR and multidimensional anxiety outcomes. We then looked to replicate study 1 with a secondary study (study 2) to explore if the observed relationships could be extended and reproduced in an independent female sample.

The purpose of this two-study paper is to rigorously explore the associations between actual HR reactivity and perceived HR changes with cognitive and somatic anxiety intensity and symptoms interpretation in healthy male and female individuals. Three different stress tasks with a range of psychological demands and diverse stress responses were used. Aggregated HR reactivity, perceived HR change, cognitive and somatic anxiety intensity and symptom interpretation scores score were derived.

Study 1

Aims and hypotheses

The aim of study 1 was to examine whether objectively measured HR reactivity or perceived HR changes to three aggregated stress tasks are predictors of (1) cognitive anxiety intensity, (2) somatic anxiety intensity, (3) cognitive anxiety symptom interpretation, (4) somatic anxiety symptom interpretation, experienced during acute psychological stress. It was hypothesized that perceptions of HR change would be more strongly associated with anxiety intensity than actual HR reactivity. Second, it was hypothesized perceptions of HR would be associated with more debilitative anxiety.

Method

Participants

Participants were 71 healthy male university students (*M* [SD] age = 20.13 [1.12] years, *M* [SD] BMI = 22.78 [2.57] kg/m^2) who were non-smokers, had no history of cardiovascular disease, and had not taken any prescribed medication in the 4 weeks prior to testing. Participants were asked to abstain from consuming caffeine and eating up to 2 h before testing as well as consuming alcohol and participating in vigorous exercise 12 h before testing. All participants provided written informed consent and were given undergraduate module credit upon study completion. The study was approved by the University of Birmingham ethics committee and data was collected September 2015–March 2016.

Cardiovascular measures

Heart rate was recorded continuously using the ambulatory monitoring system, VU-AMS5fs (TD-FPP, Vrije Universiteit, Amsterdam, the Netherlands; de Geus, Willemsen, Klaver, & Vandoornen, 1995; Willemsen, DeGeus, Klaver, VanDoornen, & Carroll, 1996) to measure the electrocardiogram. Following automated inter-beat interval (IBI) time series detection, ectopic beats were removed and the ECG was manually inspected.

Questionnaires

Cognitive and somatic anxiety intensity and interpretation

The Immediate Anxiety Measures Scale (IAMS; Thomas et al., 2002) assessed cognitive and somatic anxiety intensity as well as perceived interpretation of cognitive and somatic anxiety symptoms. Single items assessed cognitive and somatic anxiety intensity from 1 (not at all) to 7 (extremely), as well as the perceived interpretation from −3 (very debilitative/negative) to +3 (very facilitative/positive). The IAMS provides valid and reliable cognitive and somatic anxiety scores which have been validated against multi-item anxiety questionnaire (CSAI-2) (Thomas et al., 2002). In particular, validation has emphasized the measurement accuracy in close proximity to a stressful event, and the IAMS is used frequently in stress research to assess task-specific anxiety (Moore, Vine, Wilson,

& Freeman, 2012; Trotman et al., 2018; Williams, Veldhuijzen van Zanten, Trotman, Quinton, & Ginty, 2017).

Perceived heart rate change

Perceived HR change was assessed with a single item developed for the purpose of this study. Participants were asked to rate how much they perceived their HR to change during the acute psychological stress tasks from 0 (not at all) to 6 (very much so). A 7-point Likert-type scale was developed in line with commonly reported stress-related psychological variables in the psychophysiology literature (Bibbey, Carroll, Roseboom, Phillips, & de Rooij, 2013; Ginty, Carroll, & Williams, 2014). Given validation literature supporting the use of single-item measures to assess psychological states in close proximity to a stressful event (Thomas et al., 2002) and that recovery of HR occurs transiently the following stress, a visual analogue scale was implemented to limit any temporal effects which could bias the reporting.

Manipulation checks

Following the completion of each task, participants rated how difficult and stressful they found the task, as well as the extent they were trying to perform well as a measure of engagement. Each question was assessed using a 7-point Likert scale from 1 (not at all) to 7 (extremely).

Acute stress tasks

Three standardized acute psychological stress tasks were implemented which have been shown to elicit a diverse set of cardiovascular and anxiety responses (AlAbsi et al., 1997; Allen, 2008; Turner, 1994). The chosen tasks were selected to represent various stressors that individuals encounter on a daily basis which vary in the demands required to be able to cope to enhance lab-to-life generalisability. The selected validated stressors include social evaluative negative feedback (e.g., work presentations), competitive pressure (e.g., competition for job applications), and perseverance (e.g., problem-solving). Task responses were aggregated across these three domains to generate a "trait" response per individual, increasing reliability and generalisability of results (Kamarck et al., 1992; Kamarck et al., 1993; Kamarck & Lovallo, 2003). The following psychological tasks were used:

Mental arithmetic stress

Participants completed a 6-minute version of the *Paced Auditory Serial Addition Test* (PASAT; Gronwall, 1977) whereby a series of single-digit numbers were presented through audio speakers. Participants add consecutive numbers together and verbalize their answers, whilst remembering the most recent number to add it to the next presented number. The presentation frequency of the numbers decreased from 2.0 to 1.6 and 1.2 s every 2 min. The PASAT involves social evaluation; participants were videotaped, which was displayed on a monitor, a mirror was presented directly in front of the participant in which they were instructed to watch themselves, and they were informed that "body language experts" would assess their anxiety levels. Furthermore, a prominent leader board was displayed. Finally, participants were informed they would hear a loud buzzer if they hesitated or answered incorrectly, which has been shown to increase the stress experienced (Veldhuijzen Van Zanten et al., 2004). In reality, no such body language analysis took place and participants were buzzed at standardized intervals. The PASAT reliably perturbs the cardiovascular system (Ring, Burns, & Carroll, 2002; Veldhuijzen Van Zanten et al., 2004) and demonstrates strong test-retest reliability (Ginty, Gianaros, Derbyshire, Phillips, & Carroll, 2013).

Competition task

A computer car racing game (Need for speed: Underground – EA Games), was used as a competitive stress task. Participants controlled the game with their ring, middle and index fingers of their dominant hand, thus minimizing physical exertion. The task involved completing 8-laps of a predetermined race track against 5 computerized opponents. The game manipulations allowed races to be standardized and the computerized opponents' ability to match that of the participants. A prominent leader board with the 5 quickest times in the study was displayed in front of the participants and they were informed that £10 in Amazon vouchers would be provided to the top performance at the completion of the study to emphasize the competitive nature of the task. On average, participants completed the task in 05:32 min. Competition has frequently been utilized in stress psychophysiology research (Turner, 1994), has been recommended for inclusion in a behavioral stress battery (Turner et al., 1997), has previously demonstrated it elicits a cardiovascular stress response and elevates cognitive and somatic anxiety (Trotman et al., 2018).

Puzzle task

Participants were provided with six-minutes to complete a series of Euler puzzle tracing tasks. Specifically, participants had to trace directly over all the lines of a set puzzle, without removing their pen from the puzzle or tracing over a previously marked line. There were three puzzles to complete during the task, starting with a relatively easy puzzle (average time to complete = 0:28 min), moving to a progressively harder puzzle (2:44 min) and finishing with an impossible puzzle. An experimenter stood next to the participants to ensure that they completed the task correctly and were instructed to complete as many of the puzzles as possible within the 6-minutes. Unsolvable puzzle tasks have the fundamental principles of stress, including novelty, unpredictability and negative feedback are frequently used in stress literature (Perry, Calkins, Nelson, Leerkes, & Marcovitch, 2012; Yang et al., 2019). For a full description including diagrams of puzzles used, see Bibbey (2015).

Procedures

Following informed consent, height and weight measurements were obtained and ECG equipment was attached. Participants began a ten-minute baseline period watching a nature documentary before completing the stress tasks which were presented in a counterbalanced order. Each task was preceded with its own respective 10-minute baseline period and was set-up identically: (1) following basic task instructions participants completed a short practice to become familiar with the task demands, (2) standardized audio instructions were presented to emphasize the relative characteristics and manipulations of each task, and (3) participants completed the task. Immediately following each task participants provided their perceived HR change and completed the IAMS and manipulation checks. Participants were then detached from the physiological recording equipment, debriefed and thanked for their participation.

Data reduction and analyses

HR measurements taken during each rest period were averaged to yield a pre-task baseline value and minute-by-minute HR measurements taken during each task were averaged to calculate separate competition, mental arithmetic and puzzle task values. Subsequently, reactivity for HR (stress task minus baseline) was computed. A 3 task (competition, PASAT, puzzle) by 2 time (baseline, task) repeated measures ANOVA was performed to confirm that each stress task perturbed increases in HR activity. Psychological data was analysed using MANOVAs unless assumptions were violated. As such, a series of 3 task (competition, PASAT, puzzle) repeated measures ANOVAs were run to explore whether the 3 tasks differed regarding manipulation checks and perceived HR change. Two separate MANOVAs were run for anxiety intensity and for anxiety symptom interpretation, meeting MANOVA assumptions (Verma, 2015). Heart rate reactivity scores were standardized for each task, and standardized scores aggregated across the three tasks to create an aggregate HR reactivity score (Kamarck et al., 1992; Kamarck & Lovallo, 2003). Similarly, for perceived HR, cognitive and somatic anxiety intensity and perceived interpretation, scores were standardized and averaged across tasks to create an aggregate score for each separate variable. A Pearson's correlation explored whether actual HR reactivity associated with perceived HR change. Heart rate reactivity scores and anxiety scores were analysed as these represent the values during the actual stress period. To determine associations between HR reactivity, perceived HR change and anxiety scores, separate multiple regressions were run for each anxiety construct. Aggregate HR reactivity and aggregate perceived change in HR were entered simultaneously to predict each anxiety response. For ANOVAs conducted, Greenhouse-Geisser values were reported, Bonferroni post-hoc analyses were run where appropriate, and partial eta-square was implemented as a measure of effect size. All data was analysed in SPSS (version 22) where data was screened and participants with outliers ($n = 4$) greater than 3 standard deviations were removed from all analyses (Trotman, Gianaros, Veldhuijzen van Zanten, Williams, & Ginty, 2019). Therefore, a sample of 67 participants was analysed. No participants dropped out from the study, however missing data due to cardiovascular equipment malfunction ($n = 6$) or failure to complete a questionnaire ($n = 2$) is reflected by variations in degrees of freedom for the respective analyses. The alpha level was set at $p < .05$ for all analyses.

Results

Task comparison manipulation checks

Task ratings

A 3 task (PASAT, competition, puzzle) ANOVA revealed all three tasks were rated as moderately to highly difficult, stressful and engaging. Significant task effects were observed for perceived difficulty ($n = 67$), $F(2,114) = 52.20$, $p < .001$, $\eta^2 = .445$, and perceived stressfulness ($n = 67$), $F(2,125) = 34.59$, $p < .001$, $\eta^2 = .347$. The PASAT was rated as the most difficult, followed by the puzzle, and then the competition. Similarly, the PASAT was rated as the most stressful, however, no differences between the competition and the puzzle were evident. No task effects were observed for task engagement ($n = 67$), $F(2,138) = 0.98$, $p = .377$, $\eta^2 = .014$ (see Table 1).

Heart rate

A 3 task (PASAT, competition, puzzle) by 2 time (baseline, stress) ANOVA ($n = 61$) revealed a significant task effect, $F(2,112) = 26.48$, $p < .001$, $\eta^2 = .306$, a significant time effect, $F(1,60) = 139.97$, $p < .001$, $\eta^2 = .700$, and a significant task by time interaction, $F(2,109) = 48.13$, $p < .001$, $\eta^2 = .445$ (see Table 1). Post-hoc analyses revealed that HR increased from baseline during each task. No task differences were evident during baseline, but HR was significantly greater during the competition and the PASAT compared to the puzzle task.

Table 1. Study 1 – Mean (SD) heart rate, perceived heart rate change, anxiety and post-task appraisal scores during the three stress tasks.

	PASAT	Competition	Puzzle
Heart rate during baseline (bpm)	67.10 (10.75)	67.48 (11.37)	67.34 (10.84)
Heart rate during task (bpm)	79.01 (12.65)[#]	80.09 (12.29)[#]	71.56 (10.26)[a,b,#]
Perceived heart rate change (0–6)	4.48 (1.12)	3.58 (1.42)[a]	2.59 (1.30)[a,b]
Cognitive anxiety intensity (1–7)	5.26 (1.51)	3.42 (1.54)[a]	3.81 (1.56)[a]
Somatic anxiety intensity (1–7)	4.24 (1.71)	3.34 (1.56)[a]	2.79 (1.39)[a,b]
Cognitive anxiety interpretation (−3 to +3)	−1.21 (1.44)	0.21 (1.34)[a]	−0.22 (1.43)[a]
Somatic anxiety interpretation (−3 to +3)	−0.80 (1.25)	0.02 (1.32)[a]	−0.28 (1.22)[a]
Perceived stressfulness (1–7)	5.48 (1.39)	3.90 (1.47)[a]	3.98 (1.52)[a]
Task difficulty (1–7)	5.97 (0.99)	3.90 (1.40)[a]	4.95 (1.11)[a,b]
Engagement (1–7)	6.35 (1.04)	6.43 (1.18)	6.26 (1.04)

[a]Significantly different at $p < .05$ from PASAT.
[b]Significantly different at $p < .05$ from competition.
[#]Significantly different from baseline.

Perceived heart rate change

A 3 task (PASAT, competition, puzzle) ANOVA ($n = 66$) revealed a significant task effect for perceived HR, $F(2,127) = 45.04$, $p < .001$, $\eta^2 = .409$. The greatest perceived change in HR was during the PASAT, followed by the competition which was in turn greater than the puzzle task.

Anxiety

Two separate MANOVAs (anxiety intensity and anxiety interpretation; $n = 66$) revealed a significant multivariate task effect, for cognitive and somatic anxiety intensity, Pillai's trace = .700, $F(4,62) = 36.08$, $p < .001$, $\eta_p^2 = .700$, and cognitive and somatic anxiety interpretation, Pillai's trace = .377, $F(4,62) = 9.39$, $p < .001$, $\eta_p^2 = .377$. Inspection of univariate results revealed significant task effects for cognitive intensity, $F(2,117) = 42.48$, $p < .001$, $\eta^2 = .395$, somatic intensity, $F(2,127) = 29.46$, $p < .001$, $\eta^2 = .312$, cognitive symptom interpretation, $F(2,125) = 21.63$, $p < .001$, $\eta^2 = .250$, and somatic symptom interpretation, $F(2,117) = 10.28$, $p < .001$, $\eta^2 = .137$. Post-hoc analyses revealed that cognitive and somatic anxiety intensity were significantly greater during the PASAT compared to the competition and puzzle tasks (see Table 1). Lower somatic anxiety was reported during the puzzle task compared to the competition task. More debilitative interpretations of cognitive and somatic anxiety symptoms were reported during the PASAT compared to the competition and puzzle tasks.

Main analyses

The following analyses are computed with the three stress task aggregated scores, with an individual value for each psychological and physiological variable.

Association between heart rate reactivity and perceived heart rate change

A Pearson's correlation revealed that perceived HR change and objectively measured HR reactivity were associated with each other, $r(58) = .276$, $p = .033$.

Regression analyses predicting anxiety

Significant regression models for cognitive, $F(2,56) = 11.12$, $p < .001$, and somatic, $F(2,56) = 9.77$, $p < .001$, anxiety intensity were evident, with perceived HR change being an independent predictor of these outcome measures, and actual HR reactivity being unrelated (see Table 2.). Greater perceived increases in HR change, predicted greater cognitive and somatic intensity. Cognitive, $F(2,56) = 2.03$, $p = .141$, and somatic, $F(2,56) = 1.39$, $p = .256$, anxiety interpretations were not significantly predicted by objective HR reactivity or perceived HR change.

Table 2. Study 1 – Multiple regressions with aggregate perceived heart rate change and aggregate heart rate reactivity predicting anxiety.

Criterion	Predictors	R^2	β	p
Cognitive anxiety intensity		.284***		
	Perceived heart rate change		.542***	<.001
	Heart rate reactivity		−.037	.752
Somatic anxiety intensity		.259***		
	Perceived heart rate change		.503***	<.001
	Heart rate reactivity		.018	.879
Cognitive anxiety interpretation		.068		
	Perceived heart rate change		−.185	.173
	Heart rate reactivity		.239	.080
Somatic anxiety interpretation		.048		
	Perceived heart rate change		−.199	.147
	Heart rate reactivity		.157	.252

***$p < .001$.

Summary of study 1 findings

Objectively measured HR reactivity and perceived change in HR reactivity were significantly associated. As hypothesized, subjective perceptions of HR change, and not HR reactivity, was associated with cognitive and somatic anxiety intensity during acute psychological stress. Individuals who perceived a greater change in their HR experienced greater levels of cognitive and somatic anxiety intensity. It therefore appears that both somatic and cognitive components of anxiety are related to the perception of cardiac sensations rather than actual HR reactivity. Neither HR reactivity nor perceptions of HR change were associated with anxiety interpretation.

A limitation of study 1 is that the subjective perceived changes in HR were assessed in terms of a general change in HR without inferring any direction in this change. A growing body of literature supports *the blunted reactivity* hypothesis (Phillips, Ginty, & Hughes, 2013) where some individuals may experience a lower HR reactivity during stress. Indeed, the current study's data demonstrate HR reactivity ranged from −6.9 bpm to +36 bpm. As such, it is unknown whether a participant's reported perceived HR change represented a perceived increase or perceived decrease in HR. Accordingly, study 2 addressed these limitations by refining the measure of perceived HR change by adding a directional component (i.e., the extent to which the heart is perceived to be increasing or decreasing during stress) to examine if the associations change based on this alteration. Second, study 1 investigated the research question in males only, and is therefore limited in its generalisability. Several lines of research report gender differences in anxiety responses and perceived physiological changes during psychological stress (Grossman et al., 2001; Quigley, Barrett, & Weinstein, 2002). Consequently, this study aimed to extend the findings to a female sample, to explore if results were similar across genders.

Study 2

Aims and hypotheses

Study 2 aimed to extend the findings of study 1 by investigating whether HR reactivity and/or perceived change in HR predicted cognitive or somatic anxiety responses during acute psychological stress in a separate sample consisting of female participants. It was hypothesized that HR reactivity would not be associated with cognitive or somatic anxiety, whereas perceiving greater increases in HR change would be positively associated with somatic anxiety intensity during acute psychological stress. Although not hypothesized in study 1, perceived HR changes were associated with cognitive anxiety intensity. As such, study 2 re-examined this relationship. It was hypothesized that whilst HR reactivity would not, perceptions of HR change would be associated with somatic anxiety symptom interpretation, but not with cognitive symptom interpretation.

Method

Participants

Seventy healthy female university students participated in study 2 (*M* [SD] age = 19.71[0.95] years, *M* [SD] BMI = 22.28 [3.10] kg/m^2), with data collected September 2016–March 2017. All participant exclusion criteria were identical to the study 1, except all participants in this sample were taking the contraceptive pill.

Cardiovascular measures

The measures were identical to those of study 1.

Questionnaires

All questionnaires were identical to study 1, except perceived HR which was altered as described below.

Perceived heart rate change

Perceived HR was assessed with a single item asking individuals to rate their perceived change in HR on a 7-point Likert scale. Ratings ranged from −3 (Large decrease in HR), 0 (No change in HR), to +3 (Large increase in HR). This item was refined to acknowledge both increases as well as decreases in perceived HR during the acute psychological stress tasks.

Acute stress tasks

Participants completed identical versions of the PASAT, competition and puzzle tasks. The average time to complete the competition task in this sample was 05:53 min. The average time to complete puzzle 1 was 0:27 min and puzzle 2 was 1:57 min.

Procedures and data analysis

The procedures and data analysis were identical to study 1. No participants dropped out from the study however three individuals were removed from all analyses due to being identified as outliers. Therefore, a sample of 67 participants was analysed. Missing data due to cardiovascular equipment malfunction ($n = 9$) is reflected by variations in degrees of freedom for the respective analyses.

Results

Task comparison manipulation checks

Task ratings

All three tasks were rated as moderately to highly difficult, stressful and engaging (see Table 3). A 3 task (PASAT, competition, puzzle) ANOVA revealed significant task effects for difficulty ($n = 67$), $F(2,110) = 37.720$, $p < .001$, $\eta^2 = .364$, and stressfulness ($n = 67$), $F(2,107) = 41.72$, $p < .001$, $\eta^2 = .387$. The PASAT was rated the most difficult, followed by the puzzle and then the competition. The PASAT was rated as the most stressful, with no differences reported between the competition and the puzzle. No differences in engagement were reported ($n = 67$), $F(2,113) = 0.79$, $p = .43$, $\eta^2 = .01$.

Heart rate

A 3 task (PASAT, competition, puzzle) by 2 time (baseline, stress) ANOVA ($n = 58$) revealed a significant task, $F(2,112) = 11.04$, $p < .001$, $\eta^2 = .162$, time, $F(1,657) = 99.19$, $p < .001$, $\eta^2 = .162$, and a significant task by time interaction, $F(2,108) = 32.65$, $p < .001$, $\eta^2 = .364$. Post-hoc analyses revealed for all tasks HR increased from baseline to stress. No task differences were evident during baseline but HR was greater during the competition and the PASAT compared to the puzzle task (see Table 3).

Table 3. Study 2 – Mean (SD) heart rate activity, perceived heart rate change, anxiety and post-task appraisal scores during the three stress tasks.

	PASAT	Competition	Puzzle
Heart rate during baseline (bpm)	69.03 (10.84)	69.61 (11.65)	69.97 (12.32)
Heart rate during task (bpm)	79.03 (13.33)[#]	79.08 (13.47)[#]	73.35 (11.16)[a,b,#]
Perceived heart rate change (−3 to +3)	1.85 (0.68)	1.57 (0.87)[a]	1.04 (0.84)[a,b]
Cognitive anxiety intensity (1–7)	5.33 (1.18)	3.60 (1.50)[a]	3.78 (1.62)[a]
Somatic anxiety intensity (1–7)	4.51 (1.62)	3.70 (1.61)[a]	2.85 (1.41)[a,b]
Cognitive anxiety interpretation (−3 to +3)	−1.12 (1.50)	−0.21 (1.31)[a]	−0.19 (1.28)[a]
Somatic anxiety interpretation (−3 to +3)	−0.96 (1.41)	−0.04 (1.29)[a]	−0.13 (1.16)[a]
Perceived stressfulness (1–7)	5.58 (0.97)	4.01 (1.37)[a]	4.18 (1.53)[a]
Task difficulty (1–7)	6.04 (0.84)	4.64 (1.26)[a]	5.18 (0.95)[a,b]
Engagement (1–7)	5.74 (1.00)	5.72 (1.10)	5.93 (0.89)

[a]Significantly different at $p < .05$ from PASAT.
[b]Significantly different at $p < .05$ from competition.
[#]Significantly different from baseline.

Perceived heart rate change

A 3 task (PASAT, competition, puzzle) ANOVA ($n = 67$) revealed significant task effects for perceived HR change, $F(2,120) = 21.87$, $p < .001$, $\eta^2 = .249$. The greatest perceived change in HR was during the PASAT, followed by the competition with the puzzle task significantly lower than both tasks (see Table 3).

Anxiety

Two separate MANOVAs ($n = 67$) revealed a significant multivariate task effect, for cognitive and somatic anxiety intensity, Pillai's trace = .747, $F(4,63) = 46.56$, $p < .001$, $\eta_p^2 = .747$, and cognitive and somatic anxiety interpretation, Pillai's trace = .376, $F(4,63) = 9.50$, $p < .001$, $\eta_p^2 = .376$. Inspection of univariate results revealed significant task effects for cognitive intensity, $F(2,124) = 62.37$, $p < .001$, $\eta^2 = .486$, somatic intensity, $F(2,131) = 29.65$, $p < .001$, $\eta^2 = .310$, cognitive symptom interpretation, $F(2,130) = 19.97$, $p < .001$, $\eta^2 = .25$, and somatic symptom interpretation, $F(2,131) = 14.13$, $p < .001$, $\eta^2 = .176$, were observed. Cognitive and somatic anxiety intensity were greater during the PASAT compared to the competition and puzzle tasks, with greater somatic anxiety intensity reported during the competition compared to the puzzle task. More debilitative perceptions of cognitive and somatic anxiety were reported during the PASAT compared to the competition and puzzle tasks (see Table 3).

Main analyses

The following analyses are computed with the three stress task aggregated scores, with an individual value for each psychological and physiological variable.

Association between heart rate reactivity and perceived heart rate change

A Pearson's correlation revealed perceived HR change and objectively measured HR reactivity were not associated with each other, $r(58) = .109$, $p = .417$.

Regression analyses

A significant regression model for somatic anxiety intensity, $F(2,55) = 4.16$, $p = .021$, revealed perceived HR change was an independent predictor of somatic intensity, and actual HR reactivity was unrelated. Greater perceived increases in HR were predictive of greater somatic anxiety intensity. The model for cognitive anxiety intensity, $F(2,55) = 0.91$, $p = .408$ was non-significant. The model for cognitive anxiety interpretation, $F(2,55) = 2.70$, $p = .076$, was non-significant, however actual HR reactivity individually predicted more debilitative cognitive anxiety interpretations (see Table 4).

Table 4. Study 2 – Multiple regressions with aggregate perceived heart rate change and aggregate heart rate reactivity predicting anxiety.

Criterion	Predictors	R^2	β	p
Cognitive anxiety intensity		.032		
	Perceived heart rate change		.168	.214
	Heart rate reactivity		.047	.729
Somatic anxiety intensity		.131*		
	Perceived heart rate change		.290*	.026
	Heart rate reactivity		.188	.142
Cognitive anxiety interpretation		.090		
	Perceived heart rate change		−.022	.863
	Heart rate reactivity		−.296*	.026
Somatic anxiety interpretation		.118*		
	Perceived heart rate change		−.218	.092
	Heart rate reactivity		−.242	.063

*$p < .05$.

A significant model for somatic anxiety interpretation, $F(2,55) = 3.67$, $p = .032$ was evident, but neither predictors were individually significant.

Summary of study 2 findings

Unlike study 1, there was a dissociation between objectively measured HR reactivity and subjective perceived change in HR. As hypothesized, perceptions of HR change were associated with somatic anxiety intensity and objectively measured HR reactivity was unrelated to anxiety intensity. In contrast to study 1, cognitive anxiety intensity was unrelated to perceived HR change. While the overall model for cognitive anxiety interpretation was non-significant, HR reactivity was individually associated with cognitive anxiety symptom interpretation. In contrast, the overall somatic anxiety model was significant but neither predictor was individually significant (HR reactivity approaching significance, $p = .06$). Thus, greater perceived increases in HR appear to be related to greater levels of somatic anxiety intensity and while greater objectively measured HR reactivity may be related to more debilitative interpretations of cognitive and somatic anxiety symptoms.

General discussion

Despite theories proposing associations between anxiety and physiological responses such as HR during stress (Damasio, 1996; James, 1884; Schachter & Singer, 1962), consistent evidence supporting a relationship between anxiety and HR is lacking (Campbell & Ehlert, 2012; Feldman et al., 1999). The present studies were the first to explore the associations between HR reactivity and comprehensive assessments of anxiety by making a distinction between cognitive and somatic anxiety and examining both anxiety intensity and interpretation. Furthermore, by exposing participants to several psychological stress tasks and creating a "trait" stress response score, this increased the reliability and generalisability of the stress responses. Whilst utilizing this methodology, perceived HR responses during stress appear to be more closely related to anxiety than actual HR reactivity. Notably, the associations were not consistent across the male (study 1) and female sample (study 2), and associations were stronger in the male sample, which raises interesting questions about whether factors contributing to anxiety differ across genders, which should be explored with future research.

Research has found patients with high anxiety compared to low anxiety report greater perceived physiological activation and anxiety, which is independent of objectively measured physiological responses (Edelmann & Baker, 2002; Grossman et al., 2001). However, the current work is the first to specifically model both the actual HR response as well as perceived HR response and compare which of the two independently predicts cognitive and somatic anxiety levels. The results across both studies for somatic anxiety support the literature showing that general anxiety is associated with perceptions of physiological responses (e.g., HR, skin conductance, respiration) during psychological stress (Mauss et al., 2004). However, previous studies have utilized general anxiety measures which do not assess the multidimensional nature of cognitive and somatic anxiety, or the perceived interpretation of these symptoms. This is an important nuance, as understanding whether perceptions of physiological activity during periods of stress contribute to cognitive and somatic anxiety will aid the ability to prevent and treat the development of anxiety disorders. Anxiety theories have suggested augmented perceptions of cardiac sensations during stress can lead to heightened anxiety (Clark et al., 1997; Mallorqui-Bague et al., 2016). It could be that a vicious cycle occurs, where perceiving greater changes in HR increases anxiety levels, consequently leads to greater awareness of heartbeats, exacerbating the somatic anxiety further (Clark et al., 1997; Mallorqui-Bague et al., 2016). Thus, interventions aimed at altering how an individual perceives their HR responses during stress, may reduce the anxiety and emotional distress experienced, and interrupt the negative cascade leading to greater experienced anxiety. However, due to the results being cross-sectional causation cannot be concluded.

Contrary to our hypotheses, perceived HR change positively associated with cognitive anxiety in the male sample. Anxiety is a complex disorder with experiential, behavioral and physiological components (Mallorqui-Bague et al., 2016). The interaction of anxiety antecedents, and specifically the awareness of physiological symptoms, may contribute to exacerbating cognitive components of anxiety. Indeed, it is established from the anxiety sensitivity literature that perceiving arousal sensations (e.g., HR) as negative, can lead to anxiety symptoms more akin to cognitive anxiety such as fear and other negative thoughts (Taylor, Jang, Stewart, & Stein, 2008). Furthermore, evidence has shown that exposing individuals to these arousal sensations in the absence of fear (i.e., exercise) can reduce anxiety levels (McEntee & Halgin, 1999). Thus, perceptions of HR during stress may be related to anxiety manifesting as both somatic and cognitive symptoms. It is important to note that in the male sample only there are moderate to large effect sizes for perceived changes in HR predicting cognitive and somatic anxiety (β's > .50). This supports our hypothesis, that the perceptions of HR are associated with multidimensional symptoms of anxiety intensity. While it is unknown if these participants are misattributing their physiological symptoms, these effects emphasize the importance for clinicians to reduce the focus on physiological signals during stress, which could contribute to the exacerbation of anxiety states (Mallorqui-Bague et al., 2016).

It is not clear why the association between perceived HR changes and cognitive anxiety was evident in males only. It has previously been shown that females report greater anxiety sensitivity, in particular relating to physical concerns (Stewart et al., 1997), experience greater severity of anxiety symptoms (McLean et al., 2011), and differ in their self-reported physiological symptoms (Grossman et al., 2001). However, in the current study, males and females reported similar levels of anxiety across studies (see Tables 1 and 3), with analyses confirming no gender differences (see supplementary Table 1). It is plausible that differences across studies were found due to the altered assessment in perceived change in HR, and thus interpretation of the current results must be made with caution across samples. Nonetheless, results suggest that in males, greater perceived HR change contributes not only to greater somatic anxiety, but also to greater cognitive anxiety. Future research should aim to develop a standardized methodology to assess perceptions of HR during stress.

This is the first study to implement measures of anxiety symptom interpretation and examine whether HR and/ or perceived HR relate to how anxiety is interpreted. Whilst no relationships were evident in the male sample, in the female sample actual HR reactivity was related to more debilitative cognitive symptoms, albeit with a small association, and there was a trend for an association with somatic anxiety symptoms. Interestingly, when analysing individual bivariate correlations (not multiple regressions), results demonstrated HR reactivity to be significantly associated with both cognitive ($r(56) = -.30$, $p = .02$) and somatic ($r(56) = -.27$, $p = .04$) anxiety interpretation. These data suggest that bodily signals contribute to the extent to which anxiety symptoms are interpreted as being facilitative or debilitative. That is, with greater HR reactivity during acute psychological stress, cognitive and somatic anxiety symptoms are interpreted as more debilitative. These anxiety interpretation results align with anxiety models that emphasize physiological symptoms as important in anxiety states (Clark et al., 1997; Mallorqui-Bague et al., 2016). This could explain why few studies have found associations between anxiety and physiological responses; relationships with physiological activity may be specific to the anxiety interpretation rather than the intensity.

No such associations were evident in the male sample for anxiety interpretation. This could be due to reported gender differences in anxiety sensitivity (the fear of anxiety sensations) (Stewart et al., 1997). Indeed, females score higher on global anxiety sensitivity scales, specifically factors relating to physical concerns (Stewart et al., 1997). As such, gender differences in the pattern of psychophysiological stress responses may underlie why relationships differed across the two current studies. Analysis of the current studies revealed gender differences in HR reactivity, but only for the competitive stress task (see supplementary Table 1). As such, research is warranted to further explore factors that are associated with these gender differences, and also in individuals with clinical anxiety who consistently interpret their anxiety symptoms as debilitative, compared to healthy individuals.

It must be noted that males reported facilitative cognitive and somatic anxiety interpretations during the competition task compared to debilitative interpretations by females. Several reasons could underlie these gender discrepancies. First, males may have more experiencing playing competitive car racing tasks, and thus have more confidence in their ability. Research using competitive stress has shown whilst performance does not differ across genders, males perceive they performed better (Veldhuijzen Van Zanten et al., 2004). Together with research highlighting confidence as a key moderator of anxiety interpretation, this may explain the facilitative anxiety reported in males (Hanton, Mellalieu, & Hall, 2004). However, it must be noted in the current study, gender differences in anxiety interpretation were not significant.

It is interesting to observe that in study 1, males' actual HR was correlated with perceived HR change, whereas there was dissociation in study 2 in females. One possible explanation is that, whilst in study 2 a negative directionality was added to the scale, across the three tasks only 3 individuals reported a perceived decrease in HR. Given perceived increases in HR could only be reflected on 3 points of the scale, it is possible that individuals were able to detect subtle differences in HR increases, but that the 3 points of the scale were not specific enough to tease out these subtle differences between participants. Therefore, a correlation was not evident due to the spread of scores being too constrained. The current results highlight some interesting covariation between anxiety states and perceived physiological activity, but future work should refine and standardize the perceived HR measurement. We recommended that future studies should use a bi-directional scale but extend the scale to reduce issues regarding score constraint, or use actual heart rate beats per minute as anchors.

A limitation of the present body of work is that the single-item measures of perceived HR change were developed specifically for these two studies, and as such are not a validated questionnaire to assess subjective changes in perceived HR. As such, comparisons across studies must be interpreted with caution due to the altered measurement method. Second, the measures of anxiety are single-item questions which can reduce reliability, however the IAMS questionnaire has been validated for assessing cognitive and somatic anxiety against longer scales which produce valid and reliable measures of cognitive and somatic anxiety intensity and interpretation, particularly when in close proximity to a stressful event (Thomas et al., 2002). Third, utilizing laboratory stressors to evoke psychological stress may induce smaller responses compared to real life-stressors. However, by implementing the current study methodology, aggregating three types of stress tasks to produce an overall stress reactivity score, this creates a more valid and reliable methodology to assess stress responses and improve lab-to-life generalisability (Kamarck, Debski, & Manuck, 2000). Fourth, the current two separate samples were relatively homogenous. While this increases the internal validity of the results, future work should explore the current research question in clinical mixed-gender populations so that results can be generalized, and the influence of gender can be examined.

In conclusion, the present two studies using both healthy male and female samples demonstrated that subjective perceptions of HR change during acute psychological stress are consistently associated with anxiety. The data extend previous literature by demonstrating subtle differences in the contribution of HR perceptions towards experiencing cognitive and somatic anxiety during stress. As hypothesized individuals, who perceived greater increases in HR change, tend to display greater levels of somatic anxiety during acute psychological stress. In addition, the work was the first to demonstrate initial evidence that HR reactivity during stress is associated with perceiving anxiety as more debilitative. The results have important implications for stress and emotional regulation. Altering perceptions of HR responses experienced during stress, may reduce the anxiety and emotional distress experienced. Second, utilizing strategies to cope with the physiological HR symptoms during stress may help individuals to interpret their anxiety as less debilitating.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

The research in this manuscript was supported by a PhD studentship awarded to the first author by the Economic and Social Research Council [grant number ES/J50001X/1].

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