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The effect of psychological stress and relaxation on interoceptive accuracy: Implications for symptom perception☆

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Abstract

Objectives: The goals of the current study were to investigate: (i) how the manipulation of psychophysiological state (stress vs. relaxation) would influence heartbeat detection performance in a laboratory environment and (ii) whether interoceptive accuracy had a relationship with symptom reporting. **Method:** Forty participants (20 males) performed a stressor (a demanding mental arithmetic task) and a relaxation exercise during two counterbalanced sessions, both of which included baseline (control) conditions. Performance of both tasks was interspersed with a heartbeat detection task, i.e., a two-choice Whitehead paradigm. Data were collected from subjective mood scales as well as the electrocardiogram. **Results:** Both stress and relaxation conditions had the anticipated influence on subjective mood. There was no effect of stress or relaxation on heartbeat detection accuracy for male participants. However, the heartbeat detection accuracy of female participants showed a significant decline during the stressor condition. There was evidence that lower mean heart rate tended to improve heartbeat detection performance. A regression analysis revealed that two traits from the Body Perception Questionnaire (autonomic reactivity and body awareness) predicted heartbeat detection accuracy but not in the expected direction. **Conclusions:** The study provided evidence of a gender-specific decrement of heartbeat detection accuracy due to a laboratory stressor. However, the relevance of this finding for health psychology may be limited, as interoceptive accuracy had no significant relationship with symptom reporting.

Keywords: Stress; Interoception; Heartbeat detection; Symptom perception

Introduction

Interoception describes the perception of symptoms and sensations that originate within the body [1,2]. Interoceptive perception of internal change functions as the first stage in the process of symptom detection [3,4]. Interoceptive accuracy (IA) is also relevant for specific clinical conditions, i.e., there is evidence that IA is higher for sufferers of anxiety disorders and panic attacks [5,6].

Laboratory-based assessment of IA typically involves the subjective appraisal of ongoing physiological activity, e.g., sensitivity to temporal characteristics of heart rate [7]. A number of standard protocols have been developed and refined for the measurement of heartbeat detection accuracy [8–10], e.g., the Whitehead procedure [7], which requires participants to discriminate between synchronous ("true") and asynchronous ("false") feedback of the heartbeat, presented aurally as a series of tones [11,12].

With respect to symptom perception within a health context, it has been argued that high IA is associated with hypersensitivity to bodily sensations and a tendency to overreport physical symptoms [13,14]. The evidence to support this hypothesis is mixed. A study by Aronson et al [15] found no association between IA using the Whitehead procedure and scores on the Somatosensory Amplification Scale (SSAS) [16], i.e., the SSAS is associated with hypochondrias and increased symptom reporting. A recent neuropsychological study conducted by Critchley et al [17]

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reported a positive association between: (a) activity in the right anterior insula and IA on the Whitehead task, (b) IA and the size of the right anterior insula (i.e., local gray matter volume) and (c) local gray matter volume in the right anterior insula and a subjective measure of body awareness [18]. This study pointed to a degree of convergence between neurological and subjective traits associated with interoception but provided no evidence for any direct association between subjective body awareness and IA.

If IA is indirectly associated with symptom overreporting via a personality trait or neurological substrate, this relationship may be complicated by the influence of transient changes at the autonomic level. Increased sympathetic activation due to physical manipulation or psychological variables may moderate interoceptive perception by acting directly on the autonomic system. For example, increased stroke volume due to a physical manipulation (a tilt-table) tends to increase the accuracy of heartbeat perception [19,20]. The influence of transient psychological factors such as anxiety and emotional activation has been explored via a number of correlational studies [17,21–24], which demonstrated that increased emotional activation and subjective changes in negative affect/anxiety may improve IA.

It is postulated that physiological reactivity to everyday anxiety or stress may influence the process of symptom perception by acting directly on interoceptive awareness. Anxiety and negative affect have distinct autonomic concomitants [25], which may raise IA and provoke the tendency towards overreporting or symptom amplification previously noted by Barsky and Borus [26] and Pennebaker [14]. If proven, this causal chain could potentially beget a vicious spiral wherein anxiety provokes increased IA, which amplifies symptom detection and severity, and subsequently raises the level of anxiety experienced by the individual.

The purpose of the current study is to test this hypothesis by prospectively manipulating levels of anxiety in a laboratory environment and assessing any subsequent effects on heartbeat perception accuracy. The study will also investigate any possible correlational relationships between IA, individual traits and symptom reporting.

Methods

Participants

Forty participants completed the experiment: 20 males (mean age=25.3 years, S.D.=6.3) and 20 females (mean age=25.8 years, S.D.=4.9). Participants were excluded from the study if they were taking any medication at the time of the experiment or if there was any evidence for (a) stress-related illness (e.g., peptic ulcer, hypertension), (b) psychological illness (e.g., depression, high anxiety), or (c) cardiovascular illness (e.g., cardiac arrhythmia). All participants received a financial reward for taking part in the study.

Independent variables

A laboratory stressor based upon the mental arithmetic task used by Brod [27] was used during the stress condition. Initially, participants received a three-digit number presented on a computer screen (e.g., 517), which they were instructed to summate (e.g., 5+1+7=13) and then add this sum to the original number (e.g., 13+517=530) and verbally report the answer when the "Answer Now" screen appeared 6 s later. The three digits of the new total must then be added together (e.g., 5+3+0=8) and added to the total (e.g., 530+8=538). This cycle was repeated for a duration of 3 min.

For the relaxation condition, participants were taught a simple Yogic breathing technique. Participants were instructed to mentally count during inhalation and exhalation and to progressively extend the duration of inhalation and exhalation over the 3-min duration of the task, i.e., from a count of three during the first minute to a count of five during the final minute.

Apparatus

The electrocardiogram (ECG) was monitored via three electrodes connected to a MP150 BIOPAC system running AcKnowledge 3.8 (BIOPAC Systems, Goleta, CA, USA) at a sample rate of 1000 Hz, with high and low bandpass filters were set at 0.5–35 Hz, respectively. Vinyl electrodes were positioned on the seventh intercostal space on the right and left side of the body to measure heart activity. A common ground electrode was placed on the hip on the right side of the body. Participants received aural feedback of each R peak in the ECG trace via a triggering algorithm in the AcKnowledge software, which produced a tone that was presented binaurally via headphones. A time delay facility within the AcKnowledge software allowed tones to be presented at delays of either 200 and 500 ms from actual R peak. A second computer was used during the stressor condition that ran a slideshow (using Microsoft PowerPoint; Microsoft Corporation, Redmond, WA, USA) to prompt the participant to provide answers during the mental arithmetic task.

Heartbeat detection task

Participants listened to 10 consecutive tones (i.e., heart beats) during each heartbeat detection trial. At the end of each series of 10 tones, they were prompted to indicate in writing whether they believed the series represented their actual heart rate or not. Half of the series were presented as synchronous tones (200-ms delay) and the other half were presented as asynchronous tones (500-ms delay) [12], providing a 1:1 ratio of "targets" and "non-targets."

Dependent variables

Performance on the heartbeat detection task was assessed using a parametric measure of sensitivity (d') based on signal detection theory [28].

The mean interbeat interval (IBI) during the heartbeat detection task was derived from the ECG and the standard deviation of IBI used to represent heart rate variability. ECG data were collected continuously during all experimental sessions and during the heartbeat detection trials that accompanied each condition. However, ECG data during the stress/relaxation tasks were not analysed as differences in respiratory activity due to verbalisation during the stressor, and performance of the breathing exercise would confound statistical comparison with the baseline sessions.

Changes in mood due to the independent variables were measured using the University of Wales Mood Adjective Checklist (UMACL [29]). The UMACL yields three bipolar components of mood: energetical arousal (EA: alert-tired), tense arousal (TA: tense-relaxed) and hedonic tone (HT: happy-sad). The scale was administered following each experimental condition (baseline, stressor, relaxation).

A number of trait scales were also completed by participants before the experiment; these included demographic information (age, gender, weight, height), health screening information (i.e., frequency of health problems including exclusion criteria such as hypertension and heart disease) as well as a number of existing trait variables: the Positive and Negative Affect Schedule (PANAS: [30]), the Body Perception Questionnaire (BPQ [18]), the Trait Anxiety Inventory (STAI [31]), the Marlowe-Crowne Scale of Social Desirability [32] and the Pennebaker Inventory of Limbic Languidness (PILL [33]), which measures the frequency of illness symptoms over the previous 6-month period.

Procedure

Participants attended two counterbalanced sessions (stressor and relaxation) separated by a 7-day interval. Each session contained a baseline session, and all participants were tested at the same time of day for each session.

At the initial session, the participants signed a consent form and completed the trait questionnaires. The ECG electrodes were attached to each participant who was seated in a comfortable chair, who was physically separated from the experimenter via a screen. The participant was instructed to place their hands on the arms of the chair and to maintain this position when performing the heartbeat detection trials, i.e., to prevent the participant checking his or her own pulse. Each participant received a training session of 12 heartbeat detection trials where no data were collected. Half of the trials contained synchronous tone series, and this ratio was maintained throughout all subsequent conditions. The training trials were followed by 24 baseline trials before exposure to the "experimental trials" where heartbeat detection trials were interspersed with the psychological stressor or relaxation exercise. These experimental trials began with exposure to the stressor/relaxation exercise for 3 min, followed by six heartbeat detection trials (which took approximately 2 min to complete). This sequence was repeated over four cycles, yielding 24 heartbeat trials per experimental condition. Post-test mood scales were completed following the final set of heartbeat detection trials. This procedure was duplicated during the second session.

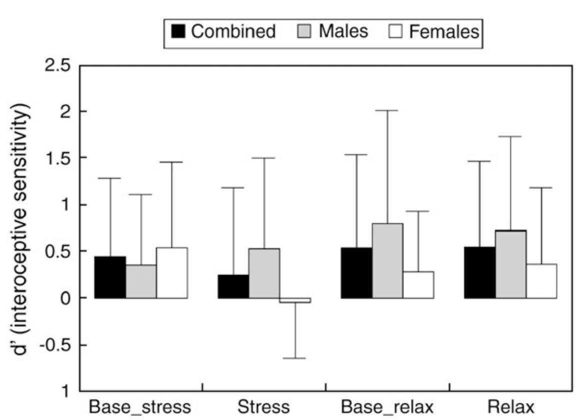

Fig. 1. Sensitivity (d') of heartbeat detection performance *with standard errors* across all four experimental conditions for: (■) all participants (combined) (N=40), (■) males only (n=20) and (□) females only (n=20).

Table 1
Means and standard deviation for the three UMACL mood factors across all four experimental conditions (N=40).

	Baseline stress	Stress	Baseline relaxation	Relaxation
Energetical arousal	22.03	20.98	21.45	18.33
	[3.04]	[4.17]	[3.22]	[4.27]
Tense arousal	14.50	16.10	15.13	12.47
	[3.62]	[4.31]	[3.85]	[3.04]
Hedonic tone	27.25	24.85	26.92	26.68
	[3.68]	[4.44]	[3.83]	[3.61]

Results

Experimental data were analysed using SPSS v12.0.1 (SPSS, Chicago, IL, USA) and Statistica 6 (StatSoft, Tulsa, OK, USA). Analysis of variance (ANOVA) and multivariate ANOVA (MANOVA) procedures were used to investigate both between- and within-participant effects. Violations of sphericity were detected using Mauchly's test and F values corrected using the Greenhouse-Geisser adjustment where necessary. Post hoc testing was performed using the Bonferroni procedure and t tests.

Interoceptive accuracy

The frequency of "hits" (correct identification of 200-ms series as own heart rate) and "false alarms" (incorrect identification of 500 ms series as own heart rate) were calculated for each of the four experimental conditions (baseline stressor, stressor, baseline relaxation, relaxation). Pretesting revealed that distributions of "hits" and "false alarms" conformed with parametric assumptions, and there-

Table 2
Means and standard errors for ECG variables in all three experimental conditions expressed in milliseconds (*N*=40)

ECG variable	Baseline stress	Stress	Baseline relaxation	Relaxation
Mean IBI	892.25	909.19	891.75	888.68
HRV	144.22	146.92	145.10	148.41

fore, sensitivity (d') was calculated using a software program [34] working on the following formulae:

$d' = z(\text{HITS}) - (\text{FA})$ [28].

The resulting data were subjected to mixed 2×4 repeated-measures ANOVA procedure (gender×experimental condition). The analysis of sensitivity (d') revealed no significant main effects between baseline (stressor), stressor, baseline (relaxation) and relaxation manipulation; however, there was an interaction effect between gender and experimental condition [$F_{3,36}$=2.87, $P<.05$]. Post hoc t tests revealed that interoceptive sensitivity was reduced during the stressor condition for female participants, compared to baseline stress (t=2.50, df=19, P=.02), baseline relaxation (t=2.15, df=19, P=.04) and relaxation conditions (t=2.10, df=19, P=.05); in addition, interoceptive sensitivity was lower for female participants compared to males during the stressor condition (t=1.99, df =38, P=.05). This significant interaction and the main effect are illustrated in Fig. 1.

Mood

The UMACL scale was administered following each baseline condition and both experimental conditions. These data were subjected to a 2×4×3 MANOVA (gender×experimental condition×UMACL component). This analysis revealed a significant interaction between experimental condition and mood component [Wilks $\text{Lambda}_{6,33}$=.42, $P<.01$]. Post hoc Bonferroni tests revealed that (1) EA was significantly reduced following the relaxation condition compared to all other conditions ($P<.01$); (2) TA was significantly higher after the stress condition compared to either baseline stress or relaxation condition ($P<.01$); in addition, TA was significantly reduced after the relaxation condition compared to all other conditions ($P<.05$), and (3) HT decreased following the stress manipulation compared to all other conditions ($P<.05$). The direction of change for all mood constructs was as expected, and descriptive statistics for these data are presented in Table 1.

Cardiovascular variables

Heart rate (mean IBI) and heart rate variability were calculated during the heartbeat detection tasks for each experimental manipulation. A 2×3×2 MANOVA (gender×experimental condition×cardiovascular variable) revealed no significant differences in heart rate or heart rate variability during the heartbeat detection trials in both conditions. The descriptive statistics for cardiovascular variables are presented in Table 2.

Correlation between heartbeat detection, mood and cardiovascular variables

Correlation coefficients were calculated for interoceptive sensitivity, mood and cardiovascular variables during each condition. The correlation matrix between cardiovascular variables and interoceptive sensitivity revealed only one significant coefficient between sensitivity (d') and mean IBI (r=0.463) in the stressor condition ($P<.05$), i.e., sensitivity was highest for those with the slowest heart rate.

Multiple regression analysis

A baseline value of d' was calculated using data obtained from both baseline sessions only (i.e., 48 trials in total), and this baseline d' was used as a dependent variable. A number of trait variables were selected as independent variables; these were: (i) age, (ii) body mass index (BMI) calculated

Table 3
Zero-order correlation coefficients between all dependent variables (*N*=40)

	1	2	3	4	5	6	7	8	9	10
1. d'										
2. Age	−.15									
3. BMI	−.18	.43**								
4. BA	−.03	−.01	.07							
5. AR	.45**	−.19	−.19	.45**						
6. MC	−.20	.05	−.03	−.29	−.35*					
7. PILL	.05	−.18	.02	.23	.28	−.41**				
8. NA	.02	.02	−.07	.16	.06	−.25	.13			
9. TA	−.11	.17	.15	.22	.12	.10	.15	−.24**		
10. Mean IBI	.33	−.07	.12	.12	.26	−.13	.26	−.03	−.04	
11. Mean HRV	.14	−.09	.04	.41**	.27	−.25	.09	−.09	−.1	.35**

d', interoceptive accuracy; AR, autonomic reactivity; MC, Marlowe-Crowne Social Desirability; PILL, Pennebaker Inventory of Limbic Languidness; NA, negative affectivity; TA, trait anxiety. *$P<.05$, **$P<.01$.

Table 4
Results of the multiple regression analysis (N=40)

Independent variable	Standard beta	t	Significance
BMI	0.176	1.149	.26
BA	−0.369	−2.081	.04
Autonomic reactivity	0.622	3.588	<.01
Marlowe-Crowne	0.050	0.287	.78
Trait NA	−0.216	−1.387	.18
Trait anxiety	−0.273	−1.672	.11
Mean IBI	0.352	2.266	.03
HRV	−0.003	−0.018	.99
Symptom frequency (PILL)	−0.016	−0.095	.93

on the basis of height and weight (i.e., there is some evidence that high BMI impairs interoceptive accuracy [35]), (iii) mean IBI from the ECG data (averaged across both baseline conditions also), (iv) average heart rate variability (HRV) also averaged across both baseline sessions, (v) negative affectivity from the PANAS, (vi) Body Awareness (BA) subscale from the BPQ, (vii) the Autonomic Nervous System Reactivity (ANS-R) subscale from the BPQ, (viii) trait anxiety (TA) from the STAI, (viv) total number of reported physical symptoms from the PILL and (x) social desirability from the Marlowe-Crowne scale. Zero-order correlation coefficients for all variables are shown in Table 3.

The regression equation was significant [$F_{8,31}$=3.09, P<.01] and achieved an R^2 of 0.45 (adjusted R^2=0.28). Three independent variables achieved statistical significance: BA, autonomic reactivity and mean IBI. Standard beta weights, t values and significance levels for all independent variables are shown in Table 4. Autonomic reactivity and mean interbeat interval from the ECG both had a positive association with IA; however, BA exhibited a negative association with IA (Table 4).

Discussion

Both experimental manipulations produced the expected influence on mood relative to each respective baseline, i.e., psychological stress increased anxiety (TA) and negative affect (reduced HT), whilst the relaxation exercise reduced levels of alertness (EA) and anxiety (Table 1). However, both manipulations failed to significantly influence the accuracy of heartbeat perception, except for female participants whose performance significantly declined during the stressor condition (Fig. 1).

Based on previous research [17,21–24], it was anticipated that IA would improve when the participant experienced high emotional activation and/or negative affect. The stressor induced both anxiety and negative affect (Table 1) but failed to significantly improve IA; in fact, heartbeat detection performance significantly declined for female participants (Fig. 1). There was no evidence of any corresponding interaction between gender and condition with respect to either self-reported mood or cardiovascular activity; therefore, this finding cannot be accounted for with recourse to autonomic traits or mood differences between males and females. It is possible that reduced IA for female participants was caused by fatigue due to the intense cognitive demand during the previous period, i.e., the Whitehead task requires concentration, and exposure to the mathematical stressor may have diminished participants' ability to focus on the heartbeat detection task. However, it is not clear why this factor would specifically degrade the performance of females. There is some evidence in the heartbeat detection literature that males tend to perform at a superior level to females for laboratory tests of IA [35], which raises the possibility that females' heartbeat perception performance may have been more susceptible to cognitive demand/fatigue, but this explanation is pure conjecture. An alternative explanation is suggested by the "competition of cues" hypothesis [14], where the decline of IA observed for females represented an attentional strategy, i.e., to focus on the external environment at the expense of internal cues during a period of stress. This explanation is speculative, but there is evidence for this type of gender bias with respect to attentional strategies and interoception [36].

It was striking that neither heart rate nor heart rate variability was significantly affected by the experimental manipulations during the heartbeat detection trials (Table 2). However, increased IBI (i.e., decreased heart rate) was significantly correlated with increased sensitivity on the heartbeat detection task during the stress condition, and higher average IBI at baseline was a significant and positive predictor of IA during the multiple regression analysis (Tables 3 and 4). This finding replicated earlier work [37] and suggests that those with slower heart rates have an advantage during the Whitehead task due to increased information processing time.

The final section of the analysis dealt with a multiple regression analysis that used a range of dependent variables to predict IA using an aggregated data set based on both baseline sessions (i.e., 48 trials in total). The absence of any statistically significant relationship between IA and the PILL (Tables 3 and 4) failed to directly support the hypersensitivity hypothesis (i.e., high levels of IA are associated with increased frequency of self-reported symptoms) [13,14]. This finding weakens the relevance of the hypothesis underlying the stress/relaxation manipulation used in the study, i.e., if IA has no relationship to symptom-reporting, then any variation of interoceptive sensitivity due to stress/anxiety is irrelevant in this respect.

Two traits from the Body Perception Questionnaire [18] achieved significance as predictors of IA during the multiple regression: ANS-R and BA (Tables 3 and 4). The positive relationship between interoceptive sensitivity and ANS-R was expected, but the negative association between BA and IA (Table 4) was counterintuitive. The distinction between both subscales is subtle: BA is concerned with awareness (never–always) of general bodily signs (e.g., goose bumps, urge to urinate) and symptoms (e.g., muscle pain, stomach pain), whereas the ANS-R focuses on specific signs (e.g., overproduction of saliva) and symptoms (e.g., shortness of breath) associated with high activation of the autonomic nervous system. Whilst the positive link between IA and ANS-R is broadly supportive of a hypervigilance hypothesis (albeit acausally), this relationship is undermined by the negative association between BA and IA. Regardless of this issue, the precise relationship of autonomic reactivity to IA is difficult to discern as the ANS-R scale mixes symptoms of ill health (e.g., vomiting, diarrhea, constipation, chest pains) with awareness of nonclinical signs of autonomic reactivity. Therefore, the significant links between IA and traits associated with body perception reported in the current experiment are inconclusive but merit further investigation as these traits have a positive association with symptom-reporting (Table 3) and could play a mediating or moderating role in the relationship between IA and symptom reporting. In addition, the origins of body perception traits remain relatively unexplored; these traits could represent psychophysiological substrates [17,38] or a learned characteristic based upon previous conditioning [39], or an attentional strategy [40] that incorporates both physiological and psychological elements; further research is warranted in this respect.

The current study could have been improved by increasing the number of heartbeat detection trials (to achieve greater levels of reliability) and, possibly, by extending the range of interoceptive tasks, i.e., to incorporate sensitivity to respiratory resistance as well as heartbeat detection performance [41]. The influence of cognitive demand or fatigue on heartbeat detection during the stressor condition represented a possible confound, and the protocol would be improved by using a psychosocial stressor with low cognitive demands (e.g., public speaking) or conducting a longitudinal "diary" to study the link between stress and interoceptive accuracy, i.e., testing heartbeat detection performance on several occasions during high and low periods of naturalistic "life" stress. The measurement of cardiovascular activity used in the current study was also rudimentary. Use of cardiovascular impedance measurement would have permitted a distinction between sympathetic (e.g., pre-ejection period) and parasympathetic (e.g., vagal tone) inputs to control of the heart rate [42,43], as the former has been positively related to interoceptive accuracy [19]. There is also evidence that blood pressure reactivity may enhance performance on the heartbeat detection task [44], and this variable would be a useful addition to future studies.

To summarize, the study provided evidence that transient states of stress may degrade interoceptive accuracy for female participants during laboratory testing. This effect was not created by any change of cardiovascular rate or rhythm or any gender-based differences in subjective mood. However, the relevance of this finding for symptom-reporting and health psychology may be limited. A regression analysis found no evidence to support any relationship between IA and symptom reporting. There was a positive association between subjective awareness of autonomic reactivity and performance of the heartbeat detection task, which merits future investigation.

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