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Attenuated beta-adrenergic response to stress and increased anticipation and perception of social threat in women high on perceived criticism

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ABSTRACT

A large amount of literature has demonstrated that Perceived Criticism (PC)—that is, how critical a person believes a given relative is of him or her—is associated with negative clinical outcomes in a broad range of psychiatric disorders (e.g., relapse or recurrence of symptoms). A possible mechanism behind the predictive value of PC might be its association with the stress regulation process. This is the first study to investigate differences in the psychophysiological response to a social stress task in young women (mean age = 21.66, SD = 4.33) with high (n = 40) and low (n = 39) PC. The physiological response was investigated by measuring two markers of sympathetic activity mediated by acetylcholine (skin conductance levels; SCL) and adrenaline (pre-ejection period; PEP) levels, respectively, and one marker of the vagally-mediated parasympathetic system (heart rate variability; HRV). Moreover, we investigated the anticipation and perception of social threat, in the form of criticism, during the stressor. No differences in HRV and SCL were observed. However, individuals high in PC mobilized fewer cardiovascular resources to deal with the stressor, reflected in an attenuated beta-adrenergic response (i.e., lower PEP response). Women high in PC also expected and perceived more criticism during the stress task. Together, our results indicate that women high in PC make heightened social threat anticipation and interpretations, and they tend to engage in less active coping when exposed to socially evaluated stressful events. Our findings indicate that PC is associated with underlying stress-related psychobiological vulnerabilities that may contribute to its association with negative clinical outcomes.

1. Introduction

Perceived Criticism (PC) is a construct that reflects how critical a person believes a given relative is of them (Hooley and Teasdale, 1989). A large body of literature has shown that PC (measured with the single question "*How critical do you think your relative or person who is currently the most emotionally important to you is of you?*", using a 1–10 scale) is a reliable predictor of clinical outcomes (e.g., relapse or recurrence of symptoms) in several psychiatric disorders. These include depression, anxiety, substance abuse, schizophrenia, obsessive–compulsive disorder, and eating disorders (for reviews, see Masland and Hooley, 2015; Renshaw, 2008). Recently, Masland et al. (2019) demonstrated that PC is unrelated to a wide range of measures of personality, psychopathology, early experiences with parents, sensitivity to criticism, cognitive emotion regulation processes (e.g., rumination), as well as other affective variables (see also Renshaw, 2008). Moreover, PC tends to be stable over time and is not associated with age, gender, or education (Hooley and Teasdale, 1989; Masland and Hooley, 2015). These findings suggest that individualś psychological or demographic characteristics do not explain the predictive value of PC. Given growing evidence that PC is a key construct for understanding clinical outcomes in a broad range of psychiatric disorders, identifying the processes associated with PC may facilitate the development of more effective clinical interventions.

Being criticized is a negative experience that is considered a source of stress. A possible explanation for the clinical predictive validity of PC could be PC's association with the stress regulation process. The autonomic nervous system is one of the most important biological systems that participate in the stress response. Once the individual perceives the stressor (including the perception of social-evaluative threat), the autonomic system reduces parasympathetic control to facilitate the physiological changes commanded by the sympathetic nervous system to initiate the fight-or-flight response (Sapolsky et al., 2001). A

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dysregulated autonomic response to stress (reflected in either a diminished or exaggerated sympathetic and parasympathetic response) is related to the course of several psychiatric disorders associated with PC (e.g., Carroll et al., 2017; Duffing et al., 2014; Sinha, 2001; Weintraub et al., 2019). In this context, an exaggerated stress-induced autonomic response has been associated with a larger cortisol increase (e.g., Bosch et al., 2009; Pulopulos et al., 2018b; Pulopulos et al., 2020), leading to a decrease in dorsolateral prefrontal cortex (DLPFC) activity and prolonged amygdala activation (Arnsten et al., 2015; De Raedt and Koster, 2010). These changes in frontolimbic activity would be expected to lead to reduced emotion regulation when facing future stressful events, which would further increase vulnerability to recurrent psychiatric disorders (De Raedt and Koster, 2010). In line with the studies linking lower DLPFC activity and worse stress regulation, Hooley et al. (2009) observed decreased reactivity in the DLPFC when individuals who had fully recovered from depression were exposed to criticism. Hooley et al. (2012) further demonstrated that healthy and depressed individuals with high (vs low) PC showed decreased DLPFC reactions *and* increased amygdala activity when they heard criticism. Importantly, decreased prefrontal cortex (including DLPFC) and increased amygdala activation have also been associated with lower parasympathetic control (Thayer et al., 2009). These results suggest that high PC may be related to high levels of stress reactivity or poor regulatory control when facing affective challenges.

Healthy individuals with high PC also appear to have difficulties with the cognitive control of emotional information (Masland et al., 2015). Given that the successful regulation of stress and negative emotions requires the activation of DLPFC-related cognitive control mechanisms (De Raedt and Hooley, 2016; Ochsner et al., 2012), deficits in cognitive control of emotional information among individuals with high PC may lead to worse physiological stress regulation. Together, the current evidence suggests that high PC is associated with heightened emotional reactivity and greater difficulty controlling attentional resources when facing interpersonal affective challenges. However, research has not yet examined whether individuals with high PC also show heightened psychophysiological responses to socially stressful situations.

Evidence suggests that PC reflects objective levels of criticism to some extent. However, part of its variance may also be explained by a tendency to overperceive criticism (i.e., the person high in PC perceives more criticism than the intended criticism by the relative or than the observed criticism by coders of an interaction; see Smith and Peterson, 2008). Thus, PC may be understood as a measure of how much criticism gets through to a person (Hooley and Teasdale, 1989). This is especially important in the context of stress because criticism is considered a form of social threat, and the perception of social-evaluative threat is a key psychological element of the autonomic and endocrine response provoked by social stressors (e.g., Bosch et al., 2009). Along these lines, when listening to recorded sets of acoustically combined word pairs (e.g., sad-sand), healthy participants with high (versus low) PC made more depressotypic interpretations (e.g., hearing "sad" rather than "sand"), and social-threat interpretations (e.g., hated-heated, although the difference in social-threat interpretations was not statistically significant) (Masland et al., 2015). These results suggest that individuals high in PC may be predisposed to perceive negative content in ambiguous social interactions. Given that social threat occurs predominantly in social situations, it is important to further investigate whether individuals with high PC perceive increased social threat in the form of criticism when in social stressful situations. Notably, the continuous perception of criticism in a close interpersonal context may affect not only the way individuals perceive criticism when it occurs, but also the way individuals high in PC anticipate future social interactions. Thus, based on their experience in previous social situations, individuals with high PC may expect more criticism from others when anticipating a social exchange. By investigating whether individuals high in PC expect and perceive more criticism when exposed to social stress, we can gain a more comprehensive understanding of how PC is related to the way people anticipate and confront socially stressful situations.

In the present study, we examined the psychophysiological response to a social stressor and the anticipation and perception of criticism in women with high and low PC. Participants performed a stress task that requires motivated performance during a social-evaluative condition. Given the association between a dysregulated autonomic response to stress and some of the psychiatric disorders associated with PC (e.g., Carroll et al., 2017; Duffing et al., 2014; Sinha, 2001; Weintraub et al., 2019), we investigated whether participants with high and low PC show a different sympathetic and parasympathetic response. The sympathetic stress response was assessed by measuring skin conductance levels (SCL) and the pre-ejection period (PEP), two markers of sympathetic activity mediated by acetylcholine and the adrenaline hormone, respectively (See Dawson et al., 2007; Newlin and Levenson, 1979 for a detailed description of SCL and PEP, respectively). The activity of the parasympathetic system was evaluated using a vagally-mediated index of heart rate variability (HRV), a marker of emotion regulation and mental health resilience (Perna et al., 2020; see Laborde et al., 2017 for a detailed description of this marker). Based on previous studies indicating that people with high PC have heightened emotional reactivity and reduced regulatory control (Hooley et al., 2012; Masland et al., 2015), we hypothesized that participants high in PC would show a heightened sympathetic response and lower parasympathetic control. Moreover, we hypothesized that individuals high in PC, compared with those low in PC, would both expect and perceive more criticism during the stress task.

2. Methods

2.1. Participants

Eighty women living in the Boston area and aged between 18 and 35 years old were recruited from the Harvard Psychology study pool. Exclusion criteria included a history of major head trauma, cardiovascular disorder, neurologic and psychiatric disorder or cognitive impairment, antidepressant use, use of medication that could affect cardiovascular activity, and smoking more than ten cigarettes per day. Moreover, students from Harvard University were also excluded if they had attended Harvard's "Science of Stress" course (this was because this course included information about the stress induction procedure used in the current study). To control for sex differences in the physiological response to stress (Pulopulos et al., 2018a), only women were recruited.

PC was assessed using the measure developed by Hooley and Teasdale (1989). Participants were asked to answer the question "*How critical do you think your relative or person who is currently the most emotionally important to you —the person with whom you share the closest relationship— is of you?*", using a scale ranging from 1 (not at all critical) to 10 (very critical). Moreover, participants were asked to indicate whom they were thinking about when answering the question, and whether they were living with this person. In a study of relapse of depression, Hooley and Teasdale (1989) observed that every individual with a score of 6 or higher on PC relapsed. Thus, in line with the cut-off scores proposed by Hooley and Teasdale (1989) and following previous studies (e.g., Hooley et al., 2012; Masland et al., 2015), scores ranging from 1 to 5 were categorized as low PC, and scores ranging from 6 to 10 were categorized as high PC. We recruited 40 participants with high PC (high-PC group) and 40 participants with low PC (low-PC group).

2.1.1. Stress task

Participants performed an adapted version of the Trier Social Stress Test (TSST; Kirschbaum et al., 1993), a valid and reliable experimental paradigm designed to induce a psychophysiological stress response. In the TSST, participants are informed that they have to give a 5-min speech explaining why they believe they are the best candidate for a job position of their choice, and that after the speech they will perform an arithmetic task. They are also informed that they will perform the task in front of two evaluators, and that the task will be recorded by a camera and a microphone for subsequent voice and behavioral analysis (though participants were not actually recorded in the present study). The second part is the anticipatory phase, in which participants have time to prepare their speech. In the current study, the anticipation phase lasted 15 min. Finally, in the last part, the participants are asked to perform the 5-min free speech task and a 5-min arithmetic task (Participants in the current study were asked to subtract the number 13 from 2083 as fast and accurately as possible).

For the present study, the habituation phase, the TSST, and the recovery phase all took place in the same room. Moreover, to avoid the influence of the evaluators' body posture and facial expressions on the participants' perception of criticism, the TSST was performed in a room with a one-way mirror, and the two evaluators were located behind the mirror. As in the standard version of the TSST, to create an ambiguous social situation, the evaluators were trained to provide neutral and standardized feedback in response to the participant's speech and arithmetic accuracy. The mirror was covered with blinds and not visible to the participants until the introduction to the TSST, and it was covered again at the end of the task. The evaluators entered the room behind the mirror immediately before the speech. Moreover, to increase the perception of social evaluation, the experimenter remained in the room with the participant. However, the participants were always located in a place where they were unable to see the experimenter's face. During the tasks, the participants only communicated with the evaluators via an intercom system. Previous studies using a similar version of the TSST have shown a significant psychophysiological response to stress (e.g., Pulopulos et al., 2020a).

2.2. Demographics and questionnaires

At the beginning of the session, participants reported a number of demographic variables, including age, socioeconomic status (assessed using the subjective socioeconomic status scale; Adler et al., 2000), and use of hormonal contraceptives. Moreover, to check for differences in trait and state factors that may affect the physiological response to stress, participants were asked to complete a series of questionnaires to assess depression symptoms (Beck Depression Inventory-II; Beck et al., 1996; Cronbach's alpha=0.84), self-esteem (Rosenberg Self-Esteem Scale; Rosenberg, 1965; Cronbach's alpha=0.75), narcissistic grandiosity (Narcissistic Grandiosity Scale; Rosenthal et al., 2020; Cronbach's alpha=0.94), and trait cognitive emotion regulation strategies (Cognitive Emotion Regulation Scale; Garnefski and Kraaij, 2007; Cronbach's alphas for each subscale were: Self-blame=0.77, Acceptance=0.72, Rumination=0.77, Positive refocusing=0.87, Refocus planning=0.77, Positive reappraisal=0.87, Putting into perspective=0.80, Catastrophizing=0.45, and Blaming others=0.77). Given the low internal consistency of Catastrophizing, this subscale was not included in the analyses.

2.3. Anticipated and perceived criticism during the stress task

To measure how much criticism the participants anticipated during the stress task, they were asked the question "*How critical do you think the evaluators will be of you?*" at the beginning of the anticipation period. To measure how much criticism the participants perceived during the stress task, they were asked the question "*How critical do you think the evaluators were of you?*" immediately and 20 min after the end of the stress task. Participant answered the questions on a scale ranging from 1 (not at all critical) to 10 (very critical).

2.4. Anticipatory cognitive appraisal

Anticipatory cognitive stress appraisal was measured at the beginning of the anticipatory phase using the Primary Appraisal Secondary Appraisal scale (PASA: Gaab et al., 2005). The PASA is a 16-item questionnaire rated on a 6-point Likert scale (ranging from 1 = Strongly disagree, to 6 = Strongly agree). This scale is used to assess "Primary appraisal" (i.e., how threatening and challenging the situation is perceived as being), "Secondary appraisal" (i.e., self-concept of one's competence and control expectancy), and a global index of "Anticipatory stress appraisal" (calculated as the difference score between Primary appraisal and Secondary appraisal), which relates the two appraisals to each other. Gaab and colleagues (2005) provide a detailed description of the questionnaire. Cronbach's alphas for primary and secondary appraisal were 0.76 and 0.72, respectively.

2.5. Physiological response to stress

Cardiovascular activity and skin conductance were continuously recorded throughout the session using the Vrije Universiteit Ambulatory Monitoring System (VU-AMS; De Geus et al., 1995), an ambulatory device that records skin conductance levels (SCL), electrocardiogram (ECG), and thorax impedance cardiography (ICG). SCL was recorded from two electrodes (GSR Electrodes SA2659) attached to the medial phalanges of the index and middle fingers of the non-dominant hand using a 10 Hz sampling rate. SCL was measured by passing a small current through the surface of the skin between the two electrodes at a constant voltage of 0.5 V. The measurement ranged between 1 and 100 μS, with a resolution of 0.0125 μS. Higher SCL values indicate higher sympathetic activation. ECG and ICG were recorded from five electrodes (Covidien Kendall H135SG) placed on the participant's chest and two on the participant's back. A 1000 Hz sampling rate was used for the ECG and ICG recordings. To compute the PEP, HRV, and SCL, the data were imported to the VU-DAMS software (http://www.psy.vu.nl/vu-ams) for visual inspection, artefact correction, and R-to-R interval interpolation. Inter-beat-interval time series were computed from the R-to-R distances after being manually corrected. The PEP was computed as the time interval in milliseconds between the beginning of the ventricular depolarization (Q-wave onset in the ECG) and the beginning of the ventricular ejection (B-point of the dZ/dt waveform from the ICG). The Q-wave onset and the B-point were manually corrected when necessary. Lower PEP values indicate higher sympathetic activation. Kelsey (2012) proposed that the PEP can also be calculated as the interval between the peak of the R-wave (in the ECG) and the B-point (in the ICG). The statistical conclusions of this study are the same if the index proposed by Kelsey (2012) is used in the analyses. As an index of vagally-mediated HRV, we used the root mean square successive difference (RMSSD), an index of parasympathetic control that is relatively free of respiratory influences (Laborde et al., 2017). Higher RMSSD values indicate higher parasympathetic activation.

The VU-AMS also records the motility signal (from an inbuilt vertical accelerometer) and respiration rate. Importantly, differences in motility and the respiration rate may affect HRV, PEP, and SCL levels. In this study, no differences between groups (low-PC vs high-PC) were observed in motility and respiration rate in each phase of the study protocol.

2.6. Procedure

The study was approved by the Harvard University Institutional Review Board and carried out in accordance with the Declaration of Helsinki. Participants provided written informed consent at the beginning of the experiment.

The participants were recruited to participate in an experiment they were told was about emotion regulation. Before the session, they were asked to sleep as long as usual; abstain from alcohol and heavy physical exercise for 12 h before the session; drink only water; and not eat, smoke, or take any stimulants (such as coffee, cola, caffeine, tea, or chocolate) for two hours before the session. At the beginning of the session, the experimenter confirmed with the participants that they had followed these instructions. Then, the electrodes were attached to record the physiological data, and participants were asked to complete the demographic and baseline questionnaires. After completing the questionnaires, they were asked to stay quiet in the room for 15 min for baseline recording of the physiological data. After the habituation period, participants were introduced to the TSST task, and asked to prepare for the task for 15 min (i.e., anticipation phase). At the beginning of the anticipation phase, they completed the PASA to assess cognitive stress appraisal, and they answered the question about anticipation of criticism during the stress task. After 15 min of anticipation, participants gave their speech (5 min) and completed the arithmetic task (5 min) of the TSST. After the stress task, the participants were asked to stay quiet for 20 min to recover from the stressor. Immediately after the stress task, and at the end of the recovery phase, they answered the questions measuring perceived criticism during the stress task. Finally, the participants were debriefed on the purpose of the study and received either $30 or course credit for their participation. The session lasted approximately 1 h 45 min.

The participants were asked to fill in four 10-centimeter Visual Analogue Scales (VAS) to assess stress perception, tiredness, happiness, and tension. These were completed: (i) at the end of the habituation phase, (ii) at the end of the anticipation phase, (iii) after the speech task, (iv) immediately after the arithmetic task, and (v) 20 min after the stress task ended.

Participants also completed questionnaires assessing trait and state measures of regret and rumination before and after the TSST, as well as state measures of emotion regulation during the last 10 min of the recovery phase. These measures were not a focus of interest in the current study and are not included in the analyses.

2.7. Data management and statistical analyses

VAS measures of happiness, stress, tension, and worry at each sampling point were averaged to get a composite negative affect score. Higher scores indicate higher levels of negative affect (happiness scales were reversed). For HRV, PEP, and SCL, the last 5 min of the habituation and anticipation phases were used for the analyses. HRV, PEP, and SCL levels during the speech and arithmetic tasks were averaged to compute the physiological response during the stress task. The first 10 min of the recovery phase were separated into 5 min epochs and averaged to compute the HRV, PEP, and SCL levels during recovery.

All data were analyzed in R 3.5.0 (R Core Team, 2013) in conjunction with Rstudio 1.2.1335. *T*-tests and X^2 were used to investigate group differences (low-PC vs. high-PC) in demographics, the person who was identified as being the most emotionally important to the participants, whether they were living with that person, depression symptoms, self-esteem, and narcissistic grandiosity. A MANOVA was used to investigate between-group differences (low-PC vs. high-PC) in trait cognitive emotion regulation strategies, with the eight subscales of the CERQ (i.e., Self-blame, Acceptance, Rumination, Positive refocusing, Refocus planning, Positive reappraisal, Putting into perspective, and Blaming others) as the dependent variables. A linear regression model (LM) was used to investigate between-group differences (low-PC vs. high-PC) in primary appraisal, secondary appraisal, and anticipatory stress appraisal. Linear mixed effects regressions (LMER) were used to investigate group differences in negative affect, anticipated and perceived criticism from the evaluators during the stress task, HRV, PEP, and SCL. For negative affect, a 2 (Group: low-PC vs. high-PC) X 5 (Time: Habituation, Anticipation, Speech, Math, Recovery) LMER was fitted. For anticipated and perceived criticism during the stress task, a 2 (Group: low-PC vs. high-PC) X 3 (Time: Anticipated criticism before stress, perceived criticism immediately after stress, and perceived criticism 20 min after stress) LMER was used. Finally, a 2 (Group: low-PC vs. high-PC) X 4 (Time: Habituation, Anticipation, Stress, Recovery) LMER was used for HRV, PEP, and SCL. In all the LMER, we included random intercepts for subjects. For the LM and LMER, *p*-values are provided using the Kenward-Roger degrees of freedom approximation, 95% confidence intervals (CI). To decompose interaction effects, Tukey adjusted pairwise comparisons were carried out using the 'emmeans' package (Lenth and Lenth, 2018). The p-values of main effects and interactions from the hypothesis-driven LM and LMER were not adjusted. LM and LMER were computed using the '*lmerTest*' package (Kuznetsova et al., 2017). For LMER, we computed the marginal r squared (r_m^2) values, a measure of the proportion of variance explained by the fixed effects using the '*MuMIn*' package (Nakagawa et al., 2017). Although we dichotomized PC ratings (low-PC vs. high-PC), all statistical conclusions remain the same if PC is considered as a continuous variable.

No previous study has investigated the role of PC in the physiological response to stress. At a psychological level, in a recent unpublished study focused on a different research question, we observed a significant effect size $f = 0.34$ of PC on cognitive stress appraisal (measured using the PASA). A G*Power analysis for a between-subject design (alpha=0.05 and power=0.80) indicates that a sample of 70 participants is needed to observe the same difference in the current study. Considering possible missing data in physiological measures, we recruited 80 participants. One participant was subsequently excluded because she did not follow the instructions during the stress task. Due to problems with the recording of the physiological data, the HRV and PEP data from four participants and the SCL data from two other participants were excluded from the analyses. Moreover, three participants were outliers (±3 SD) for HRV, PEP, and SCL, and so were excluded from analyses. Thus, the final sample included in the analyses consisted of 79 participants for the questionnaires (high-PC: $n = 40$; low-PC: $n = 39$), 72 for HRV and PEP data (high-PC: n = 37; low-PC: n = 35), and 74 for SCL data (high-PC: $n = 38$; low-PC: $n = 36$). Considering the final sample, the current study has a power > 0.90 to detect small to medium (f=0.175) effect sizes for the physiological response to stress, and the anticipation and perception of criticism. Notably, we use LMER with fixed and random effects to test our hypothesis, a statistical approach with larger statistical power than the one estimated by G*Power for ANOVA.

3. Results

3.1. Demographics and baseline questionnaires

Table 1 shows the characteristics of the study sample. No significant differences between groups (low-PC vs high-PC) were observed in age, subjective socioeconomic status, use of hormonal contraceptives, and measures of depression symptoms, self-esteem, and narcissistic grandiosity (all $ps > 0.097$). Participants in the low-PC group had a higher body mass index ($p < 0.001$). No differences were observed with regard to the person who was identified by participants as being the most emotionally important to them, or in the number of participants who were currently living with that person ($p > 0.101$). We also observed that there were no between-group differences in the cognitive emotion regulation strategies participants reported using (via the Cognitive Emotion Regulation Scale) (Pillai's Trace = 0.11, $F(8,70) = 1.15$, $p = 0.341$).

Importantly, although the high-PC group had a significantly greater body mass index, when this variable is included in the statistical models testing group differences in the psychophysiological stress response and the anticipation and perception of criticism, it is not associated with the dependent variables (*results not shown*).

3.2. Psychological response to stress

The LMER model assessing changes in negative affect indicated a significant effect of Time ($F(1,4) = 51.05$, $p < 0.001$). Post-hoc analyses indicated that negative affect was higher during stress anticipation (95% CI [−24.56,−16.87], $p < 0.001$) and after the speech (95%CI [−21.73,−14.04], $p < 0.001$) and arithmetic tasks (95%CI [−20.11,−12.42], $p < 0.001$) than during habituation. No differences

Table 1
Characteristics of the study sample and between-group differences in demographics and baseline questionnaires.

	Low PC (n = 39)	High PC (n = 40)	
	Mean/n (SD)	*Mean/n (SD)*	*p*
PC	2.79 (1.34)	8.23 (1.51)	< 0.001
Person who is the most emotionally important			0.173
Parent	15	24	
Sibling	2	3	
Partner	13	8	
Friend	9	4	
Daughter	0	1	
Do you live with this person? (Yes/No)	8/31	16/24	0.101
Age (years)	21.36 (4.02)	21.95 (4.69)	0.550
Body mass index (kg/cm^2)	20.94 (2.37)	25.42 (7.19)	< 0.001
Subjective Socioeconomic Status	6.78 (1.09)	6.59 (0.95)	0.401
Hormonal contraceptives (Yes/No)	17/22	20/20	0.730
Rosenberg Self-Esteem Questionnaire	20.15 (2.56)	20.6 (2.58)	0.443
Narcissistic Grandiosity Scale	40.82 (16.27)	46.95 (16.16)	0.097
Beck Depression Inventory II	6.74 (5.28)	7.68 (5.65)	0.451
CERQ (MANOVA) - Pillai			0.341
CERQ Self blame	10.28 (2.71)	9.65 (2.43)	0.280
CERQ Acceptance	11.59 (2.19)	12.08 (3.54)	0.467
CERQ Rumination	14.05 (3.10)	12.83 (3.90)	0.127
CERQ Positive refocusing	9.59 (3.07)	10.28 (4.00)	0.396
CERQ Refocus planning	14.38 (2.83)	13.98 (3.21)	0.550
CERQ Positive reappraisal	14.69 (3.43)	13.63 (4.19)	0.220
CERQ Putting into perspective	13.56 (3.64)	12.33 (3.74)	0.140
CERQ Blaming others	7.38 (1.52)	7.95 (2.02)	0.165

Note: PC = Perceived criticism; CERQ = Cognitive Emotion Regulation Questionnaire.

were observed in negative affect between the habituation period and the end of the recovery period (95%CI [−4.88,2.81], $p = 0.597$). Neither Group nor the interaction between Group and Time showed significant effects (Group: $F(1,1) = 1.34$, 95%CI [−9.03,2.39], $p = 0.251$; Group*Time: $F(1.4) = 0.87$, $p = 0.483$). These results indicate that the stress task provoked a similar increase in negative affect in both groups. The r_m^2 of this model was 0.23. See Fig. 1A for the VAS scores.

3.3. Anticipatory cognitive appraisal

Between-group comparisons examining differences in the PASA scale (Fig. 1B) indicated that there were no significant differences between the high- and low-PC groups in primary (95%CI [−0.27,0.33], $p = 0.840$) and anticipatory stress appraisal (95%CI [−0.12,0.77], $p = 0.152$). However, the high-PC group reported lower secondary appraisal than the low-PC group (95%CI [−0.55,−0.03], $p = 0.028$). In other words, although there were no differences in how stressful the participants perceived the task as being, individuals high in PC reported less control and fewer resources to deal with the stress task.

3.4. Anticipated and perceived criticism during the stress task

The LMER model indicated that the high-PC group both anticipated and perceived more criticism during the stress task than did the low-PC group ($F(1,77) = 8.71$, 95%CI [−1.84, −0.35], $p = 0.004$). Time was statistically significant, though the interaction between Group and Time was not (Time: $F(2154) = 6.91$, $p = 0.001$; Time*Group: $F(2154) = 0.07$, $p = 0.928$). The r_m^2 of this model was 0.10. Post-hoc analyses indicated that, overall, there were no differences in the anticipated criticism during stress anticipation and in perceived criticism reported immediately after the stress task (95%CI [−0.27,0.47], $p = 0.588$). However, across groups perceived criticism reported at the end of the recovery phase was lower than the expected criticism during stress

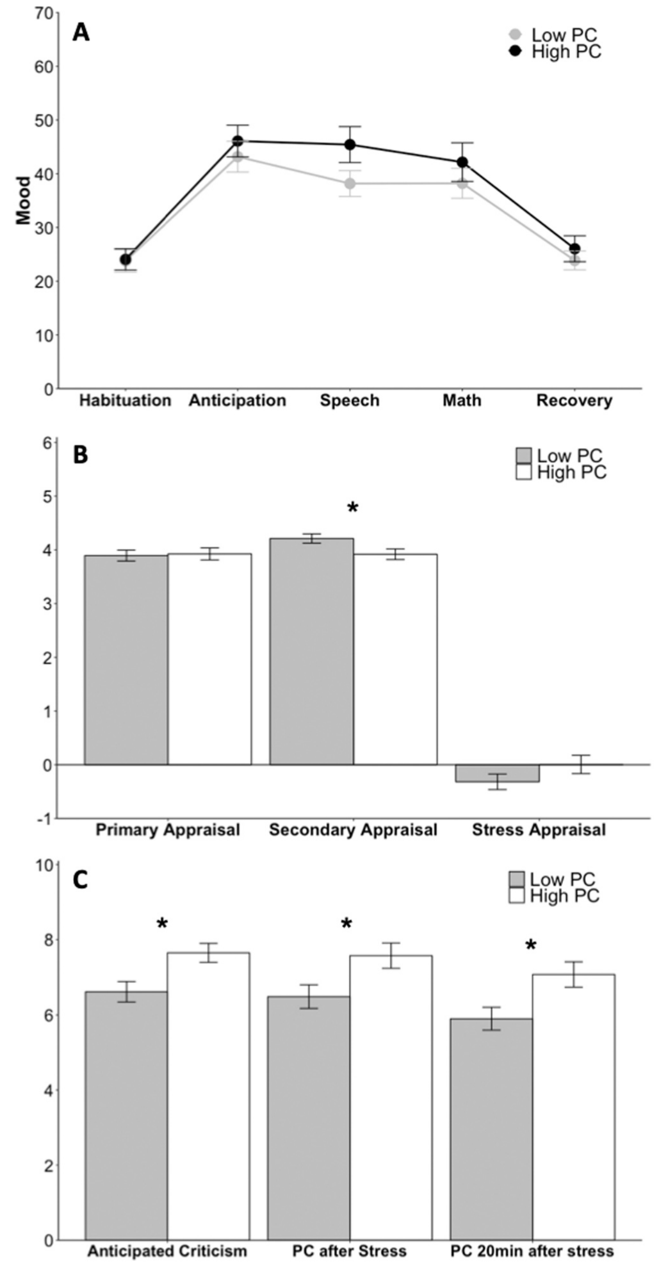

Fig. 1. (A) Changes in mood during the session for the high- (black) and low-PC (grey) groups. No significant differences between groups were observed. (B) Primary appraisal, secondary appraisal, and anticipatory stress appraisal for the high- (white) and low-PC (grey) groups. (C) Anticipated and perceived criticism during the stress task for the high- (white) and low-PC (grey) groups. Means and standard errors. *$p < 0.050$.

anticipation and the perceived criticism immediately after the stress task (95%CI [0.18,0.91], $p < 0.004$) (See Fig. 1 C).

3.5. HRV

Fig. 2 shows the HRV values during habituation, anticipation, the stress task, and the recovery phase for the high- and low-PC groups. The LMER model indicated a significant effect of Time ($F(3210) = 56.22$, $p < 0.001$). HRV showed a significant decrease from the habituation phase to the anticipation of the stress task (95%CI [0.92,7.41], $p = 0.012$), and from the anticipation phase to the stress task (95%CI [11.14,17.63], $p < 0.001$). These results indicate a decrease in parasympathetic activation during the anticipation phase and the stress task.

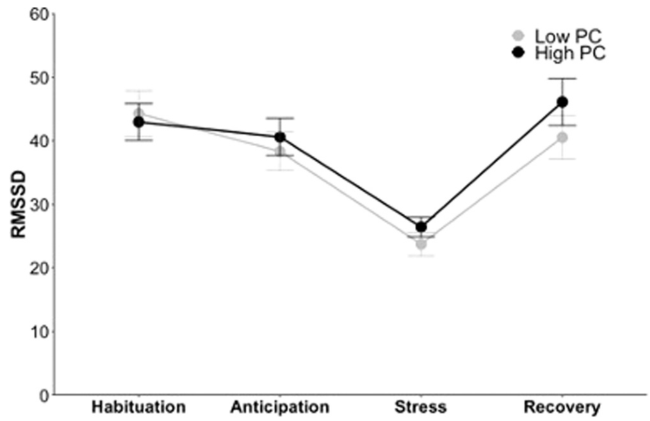

Fig. 2. Heart rate variability (RMSSD) during the session for the high- (black) and low-PC (grey) groups. Means and standard errors. No significant between-group differences were observed.

Finally, HRV increased from the stress task to the recovery phase (95%CI [−21.49,−14.99], $p < 0.001$), and there were no significant differences in HRV levels during habituation and the recovery phase (95%CI [−2.94,3.56], $p = 0.852$). Neither Group (low-PC vs high-PC) ($F(1,70) = 0.40$, 95%CI [−9.62,5.00], $p = 0.530$) nor the interaction between Time and Group were statistically significant ($F(3210) = 1.49$, $p = 0.218$). The r_m^2 of this model was 0.16.

3.6. PEP

Fig. 3 shows the PEP values during habituation, anticipation, the stress task, and the recovery phase for the high- and low-PC groups. The LMER model indicated no significant differences between the high and low-PC groups in the overall group averages ($F(1,70) = 1.38$, 95%CI [−9.30,2.41], $p = 0.244$). Time was statistically significant ($F(3210) = 45.22$, $p < 0.001$). PEP significantly decreased from the habituation phase to the anticipation of the stress task (95%CI [11.28,18.39], $p < 0.001$), and no differences were observed between anticipation and the stress task (95%CI [−1.17,5.95], $p = 0.187$). PEP values increased from the stress task to the recovery phase (95%CI [−18.00,−10.88], $p < 0.001$), reaching similar levels to those observed during the habituation phase (95%CI [−0.77,6.35], $p = 0.124$). Importantly, the LMER model indicated a significant interaction between Time and Group ($F(3210) = 3.30$, $p = 0.021$). No differences between the high- and low-PC groups were observed in PEP values during the habituation (95%CI [−5.18,9.33], $p = 0.572$) and recovery phases (95%CI [−8.60,5.91], $p = 0.715$). However, the PEP was slower in the high-PC group than it was in the low-PC group during the stress task (95%CI [−14.95,−0.44], $p = 0.038$), indicating a lower sympathetic activity in the high-PC group. This difference was also observed during the anticipation phase, although the difference was not statistically significant (95%CI [−14.06,0.44], $p = 0.065$). The r_m^2 of this model was 0.20.

3.7. SCL

Fig. 4 shows the SCL during habituation, anticipation, the stress task, and the recovery phase for the high- and low-PC groups. The LMER model indicated a significant effect of Time ($F(3216) = 85.77$, $p < 0.001$). SCL increased from the habituation phase to the anticipation of the stress task (95%CI [−3.82,−2.75], $p < 0.001$), and from the anticipation phase to the stress task (95%CI [−1.27,−0.21], $p = 0.006$). This increased SCL indicates an increase in sympathetic activation. SCL decreased from the stress task to the recovery phase (95%CI [1.48,2.54], $p < 0.001$), but values did not reach the SCL during the habituation phase (95%CI [−2.55,−1.49], $p < 0.001$). Neither Group (low-PC vs high-PC) ($F(1,72) = 0.33$, 95%CI [−1.16,2.09], $p = 0.567$) nor the interaction between Time and Group were statistically significant ($F(3216) = 0.42$, $p = 0.742$). The r_m^2 of this model was 0.14.

4. Discussion

We investigated the psychophysiological response to a socially stressful task in women who scored high and low on PC, as well as anticipated and perceived criticism before and during social evaluation of the participants' performance. The high-PC group anticipated and perceived more criticism from the evaluators before and during the stress task. They also reported feeling that they had fewer resources to deal with the stressor and less control over the stressful situation on the PASA. No group differences were observed in the psychological (i.e., mood) and parasympathetic responses (i.e., HRV) to stress. Regarding the sympathetic system, no group differences were observed in SCL. However, the high-PC group showed a lower stress-induced decrease in PEP.

The stress task provoked a robust psychophysiological response in both groups, reflected in increased negative mood, parasympathetic withdrawal (HRV), and sympathetic activation (SCL and PEP). However, our results do not support the hypothesis of a generally heightened psychophysiological response to social stress in individuals with high PC. Regarding the parasympathetic system, our results with HRV indicate a similar stress-induced parasympathetic withdrawal in both groups. Given that HRV is considered a marker of emotion regulation (Perna et al., 2020), this result suggests that individuals with high and

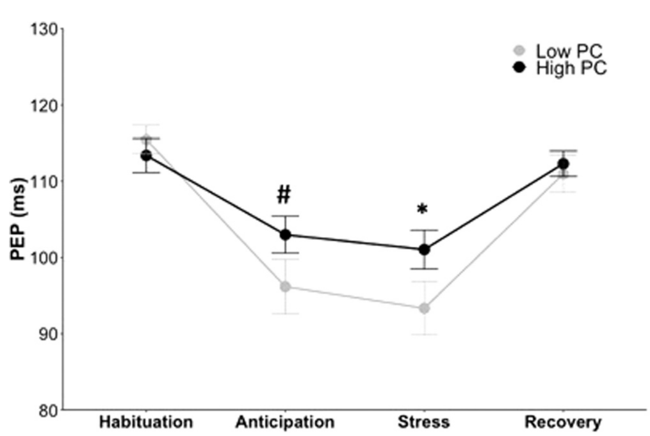

Fig. 3. Pre-Ejection period (PEP) during the session for the high- (black) and low-PC (grey) groups. Means and standard errors. The high-PC group showed slower PEP during the stress task. *$p < 0.050$; # $p = 0.065$.

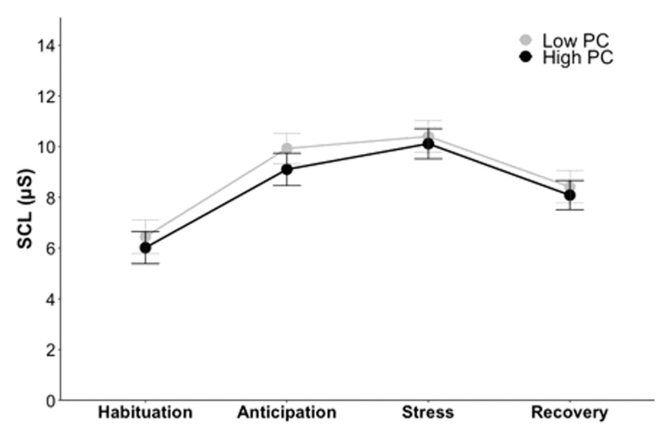

Fig. 4. Skin conductance levels (SCL) during the session for the high- (black) and low-PC (grey) groups. Means and standard errors. No significant between-group differences were observed.

low PC alike show similar emotion regulation abilities when facing interpersonal stressors. This idea is also supported by the lack of group differences in the stress-induced changes in mood and in the trait measure of cognitive emotion regulation strategies (assessed using the Cognitive Emotion Regulation Questionnaire).

Regarding the sympathetic nervous system, we did not observe differences in SCL. However, contrary to our hypothesis, the high-PC group showed a lower PEP response. Importantly, this finding cannot be attributed to the perception of stress, given that no group differences were observed in primary and anticipatory stress appraisal (i.e., PASA scale). In contrast to SCL, which is mediated by acetylcholine levels, the PEP reflects sympathetic activity mediated by beta-adrenergic receptors (e.g., Newlin and Levenson, 1979; Wolfram, 2012). Whereas SCL is considered a marker of general sympathetic arousal (Critchley, 2002), beta-adrenergic sympathetic influence on the heart (i.e., reflected in PEP values) occurs during conditions that involve active efforts to cope with environmental demands (Kelsey, 2012; Sherwood et al., 1986). Along this line, a large body of research has shown that PEP is a marker of effort mobilization in motivated actions, and that faster PEP (i.e., larger PEP reactivity, as observed in the low-PC group) would occur primarily when individuals engage in active coping during challenging and stressful situations (e.g., Gendolla et al., 2012; Kelsey et al., 2004; Seery, 2011; see Kelsey, 2012 for a review). Researchers propose that active coping occurs when individuals perceive that they have some possibility of escaping from the stressor or have the resources to cope with or control the stressful event (Kelsey, 2012). In our study, the high-PC group reported lower secondary appraisal, although this measure was not related to the stress-induced PEP response (*results not shown*). Together, our results indicate that stressful situations provoke a similar level of arousal in individuals with high and low PC (as reflected in SCL), but individuals higher in PC mobilize fewer cardiovascular resources to actively cope with socially stressful situations (reflected in PEP).

Our findings shed light on the predictive value of PC in clinical outcomes in psychiatric disorders. A reduced cardiac response to psychological stress has been observed in depression, addiction, and disordered eating and bulimia (Carroll et al., 2017; Salomon et al., 2013). Carroll et al. (2017) proposed that attenuated or blunted reactivity of the stress systems may reflect dysregulation of the motivational systems within the brain. Along this line, research has demonstrated a reduced effort mobilization (reflected in lower PEP reactions) during (social) reward and punishment anticipation in clinical and subclinical depression (Brinkmann and Franzen, 2017; Franzen and Brinkmann, 2015), and depression has been associated with deficits in the motivational approach system that are highly resistant to treatment (Fava et al., 2014; Stahl, 2002). Effort-related motivational deficits have also been observed in bipolar disorder and schizophrenia (Salamone et al., 2016), and girls with loss of control eating show reduced activation in the ventromedial prefrontal cortex and DLPFC during anticipated evaluation from peers (Jarcho et al., 2015). Furthermore, slower PEP has been associated with worse cognitive control (Duschek et al., 2017), and Masland et al. (2015) observed impaired executive control of negative emotional information in individuals high in PC, which may be related to less active coping of emotional information. Together, our results suggest that deficits in emotion regulation or a heightened autonomic response to stress may not explain the link between higher PC and negative clinical outcomes. Rather, higher PC may be a risk factor for relapse and other negative clinical outcomes in several psychiatric conditions because it is associated with deficits in motivational processes when facing challenging interpersonal situations.

In addition to showing lower PEP reactivity, individuals high in PC anticipated and perceived more criticism from the evaluators during the stress task. Importantly, group differences in the perception of criticism during the stress task could not be explained by the evaluators' behavior because they were blind to the participants׳ group, and participants could not see the evaluators during the stress task. Moreover, as in the standard version of the TSST, to create an ambiguous social situation, the evaluators provided neutral feedback to the participants׳ performance and their responses were standardized across participants. Our observations are consistent with a recent study showing that individuals high in PC make more negative interpretations in ambiguous contexts than do individuals low in PC (Masland et al., 2015). Importantly, although Masland and colleagues (2015) observed significant between-group differences for depressotypic interpretations (e.g., they heard "sad" rather than "sand" when presented with a 50–50 acoustic word morph), but not for social-threat interpretations (e.g., hated-heated), we expanded these results by showing that, in social-evaluative situations, individuals high in PC may also make more social-threat interpretations, in the form of perceiving more criticism, during social-evaluative situations. We further demonstrated that, even before the socially evaluative situation occurs, individuals high in PC expected to be criticized more. Perhaps based on what they have learned from previous experiences (i.e., the perception of criticism in close relationships and in socially stressful interactions), those high in PC may be more prone to expect criticism from others. Together, our findings suggest that individuals high in PC may not only show a criticality bias (i.e., the tendency to over-perceive criticism) (Smith and Peterson, 2008), but perhaps also a criticism expectation bias (i.e., the expectation of being criticized).

Heightened anticipation and perception of criticism in threatening social interactions may contribute to more passive coping in individuals high in PC via the influence of heightened anticipation and perception of criticism on stress-related neurocognitive processes. Stress regulation is highly dependent on the activation of prefrontal areas, especially the DLPFC, and the ability to exert cognitive control over negative information, a DLPFC-dependent process (De Raedt and Hooley, 2016; De Raedt and Koster, 2010). Hooley and colleagues (2012) observed that individuals high in PC showed less DLPFC activation when exposed to criticism. Thus, the over-perception of criticism and the anticipation of criticism during stressful situations may contribute to the hypoactivation of the DLPFC, perhaps leading to deficits in cognitive control over negative information (Masland et al., 2015). Importantly, the prefrontal cortex is involved not only in autonomic regulation but also in motivational behaviors (Carroll et al., 2017; Salamone et al., 2016). Moreover, individuals with slower PEP tend to have worse cognitive control (Duschek et al., 2017). Thus, feeling highly criticized may contribute to the hypoactivation of brain areas and cognitive processes associated with motivated action needed to deal with interpersonal challenges. However, because we did not measure DLPFC activity and cognitive control in our participants, future studies are needed to explore this idea fully. Moreover, it is crucial to know how the results of our study apply to clinical samples. Thus, future research should investigate whether similar results are observed in individuals with a current diagnosis or a prior history of stress-related psychological disorders.

Despite these novel findings, some limitations should be considered. We only included young women in this study. Therefore, more research is needed to investigate whether similar results are observed in men and older people. In addition, although we assessed several variables associated with differences in stress regulation and used LMM nested within participants (to control for individual variation), we did not collect information regarding the participants' race/ethnicity and socioeconomic background. Previous research suggests that race/ethnicity may affect how individuals respond to the PC scale. For instance, Allred and Chambless (2014) observed that, compared to white patients, black patients made more positive and negative attributions regarding the motivation of the critical person and that black patients tend to make more extreme ratings when answering the PC scale (but see Allred and Chambless, 2018). However, these differences do not seem to be reflected in differences in the PC score (Allred and Chambless, 2014). Individuals in racial/ethnic minority groups and with low socioeconomic backgrounds are also more exposed to socially stressful situations (e.g., discrimination) and tend to show greater psychophysiological responses to psychosocial stressors (Myers, 2009; Thoits, 2010). Additionally, although there were no group differences in subjective socio-economic status (a measure highly related to education and income), we did not collect objective information regarding the participants' educational level and income. In the future, it would be important to investigate whether these factors may influence the association between PC and stress regulation. Finally, we did not assess hypothalamic-pituitary-adrenal (HPA) axis activity, an important stress system that is thought to be highly dependent on the presence of social-evaluative threats (Dickerson and Kemeny, 2004). Future research may benefit from investigating cortisol responses to stress among individuals high and low in PC.

In conclusion, our findings in women without current or past psychiatric disorders suggest that PC moderates the way individuals confront socially stressful events, with individuals high in PC mobilizing fewer cardiovascular resources to actively cope with socially stressful situations and anticipating and perceiving more social threat in the form of criticism during these stressors. PC has been gaining increasing research interest due to its predictive value in clinical outcomes in a broad range of psychiatric disorders. This study adds to current knowledge in this area by showing that PC may be used to identify individuals who have difficulties in dealing with stressful interpersonal situations and who might benefit from interventions focused on stress management.

Conflict of Interest

The authors state that there are no conflicts of interest associated with the research.

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