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Altered psychophysiological correlates of risk-taking in borderline personality disorder

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Abstract

Elevated levels of risk-taking behavior as well as affective instability are both cardinal features of Borderline Personality Disorder (BPD). To our knowledge, there are no studies which directly investigate underlying affective processes of risk-taking behavior in BPD, despite the centrality of affect in BPD symptomatology, and indications of affective dysregulation contributing to increased risk-taking behavior in BPD. Here, we examined risk-taking behavior in BPD and its underlying affective processes, using skin conductance responses (SCRs) as a proxy. Twenty-three individuals with BPD and 24 healthy controls performed a modified version of the Balloon Analogue Risk Task, where decisions take place over a time scale of several seconds, enabling us to investigate a continuous integral of SCRs in anticipation of decisions. We used trial-by-trial mixed model analyses to account for within- and between-participant effects, as well as large variability that are often observed in SCRs. In contrast to healthy controls, who showed elevated SCRs in response to high risk, individuals with BPD did not show differential physiological sensitivity towards different risk levels. In addition, increased SCRs—under low risk—were related to more cautious risk-taking behavior in HCs. However, increased SCRs under low risk in BPD were related to greater risk-taking behavior. Alterations in the processing of affective signals, such as SCRs in the context of risk, may impair adaptation to environmental demands and may lead to increased risk-taking behavior in BPD.

KEYWORDS

arousal, borderline personality disorder, psychophysiology, risk-taking, skin conductance

1 | INTRODUCTION

Borderline personality disorder (BPD) is a mental disorder marked by a persistent pattern of instability in interpersonal relationships, self-image, and affect, as well as markedly impulsive behavior (American Psychiatric Association, 2013). These symptoms, particularly behavioral impulsivity, may all lead to excessive levels of risk-taking behavior. BPD patients show suicidal tendencies, have an increased likelihood to engage in substance use, and appear to be at greater risk for reckless driving (Lieb, Zanarini, Schmahl, Linehan, & Bohus, 2004).

Risk-taking can be defined as a decision to engage in a behavior for which there is uncertainty about its outcome

and potential benefits or costs (Figner & Weber, 2011). Compelling scientific evidence has emphasized the role of affect in decision-making, showing that affective processes can shape decisions via multiple pathways, such as through incidental or integral arousal (Figner & Weber, 2011; Lerner, Li, Valdesolo, & Kassam, 2015; Phelps, Lempert, & Sokol-Hessner, 2014). Incidental arousal is unrelated to the decision at hand and may carry over from one situation to the next (e.g., stress at work may influence economic choices). Integral arousal, moreover, arises from the decision itself (e.g., feeling excited when betting all money on black in French roulette, feeling happy after winning, or feeling angry after losing).

In experimental assessments of risk-taking, integral arousal is often measured by skin conductance responses (SCRs), which serve as indices of sympathetic nervous system activity. Increases in SCRs are related to affective arousal (Bradley, Codispoti, Sabatinelli, & Lang, 2001), which has been proposed to guide subsequent decision-making behavior, especially in uncertain and complex situations (Bechara & Damasio, 2005). Increased anticipatory SCRs prior to risky choices have been observed in experimental tasks simulating real-life risk-taking behaviors (Bechara, 1997; Bechara, Damasio, Damasio, & Lee, 1999; Dunn, Dalgleish, & Lawrence, 2006). Moreover, anticipatory SCRs have been shown to be indicative of task performance and risk-taking. For example, increased SCRs were found prior to disadvantageous decisions only in good task performers but not in bad ones (Crone, Somsen, Beek, & Van Der Molena, 2004) and were observed to be decreased in risk-takers compared to nonrisk-takers (Agren, Millroth, Andersson, Ridzén, & Björkstrand, 2019).

Patients with BPD show altered abilities in effectively regulating affect and using affective information during the performance on tasks that simulate real-life risk-taking. For instance, they draw more cards from risky compared to safe decks on experimental gambling tasks (Haaland & Landro, 2007; Paret, Jennen-Steinmetz, & Schmahl, 2017; Schuermann, Kathmann, Stiglmayr, Renneberg, & Endrass, 2011) and continue to draw cards from these decks even after losses, failing to adjust their behavior based on past experiences (Sánchez-Navarro, Weller, López-Navarro, Martínez-Selva, & Bechara, 2014; Schuermann et al., 2011; Svaldi, Philipsen, & Matthies, 2012). Psychophysiological evidence also points to a reduced ability of patients with BPD to learn from feedback. Specifically, studies reported altered feedback-processing as evidenced by an EEG event-related potential, called the feedback-related negativity (FRN), accompanying increased risk-taking in patients with BPD (Endrass, Schuermann, Roepke, Kessler-Scheil, & Kathmann, 2016; Schuermann et al., 2011). Since the FRN has been found to be involved in reinforcement learning (Walsh & Anderson, 2012), reduced FRN amplitudes seen in individuals with BPD may be associated with dysfunctional responses to affective stimuli and a reduced ability to learn from feedback. Altered affective processing in individuals with BPD is also reflected in attenuated signals to gains and losses in the ventral striatum (Herbort et al., 2016; Völlm et al., 2007). Thus, the propensity to show risk-taking behavior may be related to the dysfunctional processing of affective information. However, the current understanding of risk-taking in BPD is limited. Despite the centrality of affect in BPD symptomatology and indications of affective dysregulation contributing to increased risk-taking behavior in BPD, there are no studies which directly investigate the underlying affective processes of risk-taking behavior in BPD. Assessing affective responses during or in anticipation of risk-taking behavior may reveal further insights into dysfunctional processes that contribute to risk-taking behavior in BPD. Therefore, laboratory studies investigating affective processes in BPD which also consider contextual specificity of problematic behaviors in this population are needed (Matusiewicz, McCauley, McCarthy, Bounoua, & Lejuez, 2018).

In the present study, we investigated whether anticipatory SCRs are related to risk-taking behavior in individuals with BPD. To this end, we used a modified version of the Balloon Analogue Risk Task (Hüpen, Habel, Schneider, Kable, & Wagels, 2019). The BART has been shown to induce arousal in a similar manner as in naturalistic risk-taking behavior. In contrast to the original BART where participants sequentially inflate a series of visual representations of a balloon by button presses, in the modified version, the balloon automatically inflates and participants only press a response button to cash out. Therefore, in the modified version, decisions take place over a continuous time scale, allowing us to investigate psychophysiological correlates of choice preceding decisions. The modified BART enables us to measure SCRs continuously for different levels of risk and reward. Relative risk and reward contingencies of this task are known by the participants and do not have to be learned. A previous study using the original BART could not reveal any alterations regarding risk-taking behavior in BPD (Coffey, Schumacher, Baschnagel, Hawk, & Holloman, 2011). In the novel version, we aim to investigate risk-taking behavior in BPD under explicit risk and reward contingencies. Based on evidence from previous research showing increased risk-taking and reduced affective processing in BPD, we hypothesize (a) that patients with BPD show reduced psychophysiological arousal indexed by decreased SCRs compared to healthy controls and (b) that these patients show greater risk-taking behavior under high risk.

2 | METHOD

2.1 | Participants

In total, 23 women with BPD and 24 female healthy controls without BPD (HCs) were included in the current study.

Participants with BPD were recruited through the Department of Psychiatry, Psychotherapy and Psychosomatics of the RWTH Aachen University Hospital. HCs were recruited via public flyers and the RWTH Aachen University community.

All participants met the following inclusion criteria: female gender, aged between 18, and 50 years, high proficiency of the German language, no current substance use or addiction and no neurological diseases. A further inclusion criterion for the clinical group was the presence of BPD as the primary psychiatric diagnosis. HCs were excluded if they had any history of psychiatric disorders.

Participants were first asked to complete an online screening survey before being invited to the testing session. This online survey consisted of demographic questions, and two screening questionnaires of the Structured Clinical Interview for DSM-IV Axis I and Axis II Disorders (SCID-I and SCID-II). Eligible participants were invited to a diagnostic session. In this session, both HCs and individuals with BPD underwent the SCID-I (First, Spitzer, Gibbon, & Williams, 1997) and SCID-II (First, Gibbon, Spitzer, & Williams, 1997), or parts of it, as determined by the online screening results. All but one patient were on psychotropic medications, which were taken as usual. The most used psychotropic drugs among the BPD group were atypical antidepressants ($n = 14$), followed by antipsychotic medication ($n = 11$), selective serotonin reuptake inhibitors ($n = 9$), and benzodiazepines ($n = 4$). Most patients had one or more current comorbid diagnoses, including depression ($n = 13$), anxiety disorder ($n = 1$), panic disorder ($n = 4$), posttraumatic stress disorder ($n = 4$), and eating disorder ($n = 1$).

The study was approved by the Ethics Committee of the Medical Faculty of the RWTH Aachen University. All participants gave oral and written informed consent, and no adverse events occurred. Participants were paid 20 Euros as financial reimbursement for study participation.

2.2 | Materials

2.2.1 | Decision-making task: modified BART

In the modified BART, participants are presented with a dynamically growing balloon. The increase in balloon size confers greater risk of an explosion, but also greater potential reward. The goal of the task is to earn as much money as possible without allowing the balloons explode. In order to cash out, the participant must press a response button. Importantly, the balloon inflates for 6,000 ms on every trial, regardless of the participants' behavior. The balloon explosion is not visually presented to participants online. Following the decision phase, individuals are presented with a fixation cross and feedback phase. If participants succeeded in cashing-out prior to the explosion, positive feedback is given with the image of a moneybag showing the amount of money won in that trial and the total account balance (sum of the trials up to that point). In unsuccessful trials, negative feedback is given with an image of an explosion sign. Risk-taking is measured by response times (RT), with longer RTs indicating higher levels of risk-taking. The modified BART is comprised of two levels of risk (high and low) and two levels of reward (high and low). The explosion probability increases linearly with increases in balloon size. In the high-risk condition, compared to the low-risk condition, the explosion probability is 1.5 times greater. Reward also increases linearly, with the profit distribution of the high reward condition being five times higher compared to the low reward condition at each time point (see Hüpen et al., 2019 for more details). At the beginning of each trial, the present condition is displayed. Participants complete 40 trials per condition in a pseudorandom order (160 trials total). See Figure 1 for an overview of the task sequence.

2.2.2 | Neuropsychological assessment

Neuropsychological tests included the Trail Making Test (TMT) A and B. In the TMT-A, a measure of psychomotor speed, participants are required to connect 25 numbers in ascending order. In the TMT-B, participants have to alternatively connect numbers and letters. This task measures cognitive flexibility and working memory, while the ratio of part B to part A provides a measure of executive control (Arbuthnott & Frank, 2000).

The Wortschatz-Intelligenztest (WST) consists of 42 items designed to measure verbal intelligence, where participants have to identify German words. This assessment consists of lists with 42 items, with each list containing four nonsense words and one existing word. A total of 31 correctly identified words correspond to the mean verbal IQ of 101 (Schmidt & Metzler, 1992).

Short-term memory and working memory were assessed with the forward and backward digit span recall tasks, respectively. The forward digit span task requires participants to repeat back a sequence of numbers read to them by the experimenter, in the order that they were read. The first sequence consists of three digits. This version of the task has six trials, each containing one more digit than the previous trial. The backward digit span task requires participants to repeat the sequences back in reverse order.

Depressive symptoms were assessed by the Beck Depression Inventory-II (BDI-II; Steer & Clark, 1997; German version: Hautzinger, Keller, & Kühner, 2010). Internal consistency of the BDI-II in a German validation sample was high with an alpha of 0.84 for depressive patients (Kühner, Bürger, Keller, & Hautzinger, 2007). For our sample of BPD patients, we found an alpha of 0.86.

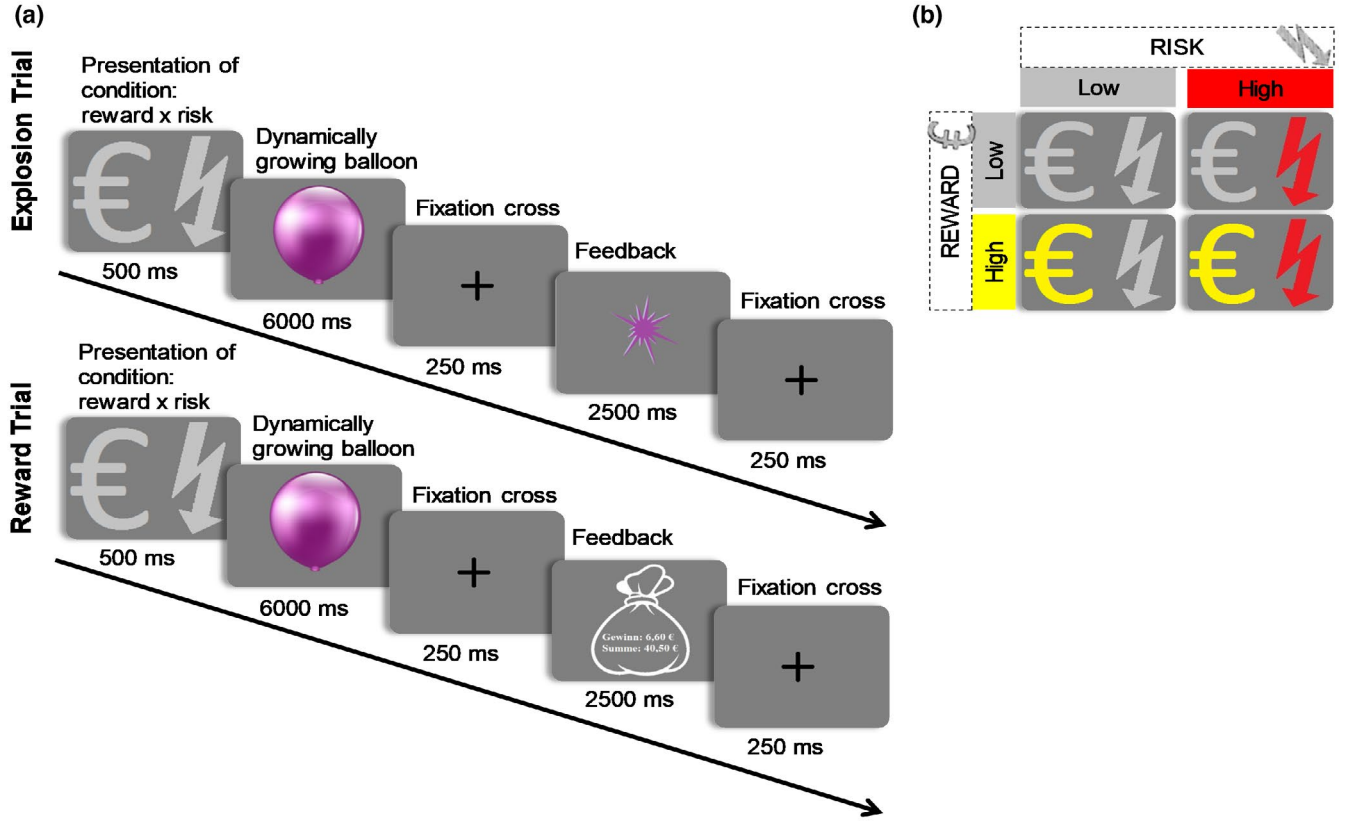

FIGURE 1 (a) Schematic of the modified BART. Participants were presented with a computerized balloon which is dynamically growing large. The increase in balloon size confers to greater risk of explosion, but also to greater potential reward. Via a button press, participants are required to determine the point of time at which the balloon should stop inflating. They are informed about the outcome (explosion or reward) after a temporal delay. A potential explosion of the balloon is saved in the computer program but is not visually presented to participants online. (b) Importantly, the modified BART employs a 2 × 2 design with two levels of risk (high vs. low) and two levels of reward (high vs. low). At the beginning of each trial, these conditions are presented to participants such that they know which condition they play

Self-reported trait impulsivity was assessed by the Barratt Impulsiveness Scale (BIS-11; Patton, Stanford, & Barratt, 1995; Stanford et al., 2009). It comprises 30 items, which are to be rated on a 4-point Likert scale reflecting the frequency of occurrence. We took the total score over all 30 items (after reversing scores for appropriate items) as a participant's impulsivity score, which is recommended for the German version (Preuss et al., 2008).

BPD-related psychopathology was quantified by the Borderline Symptom List-95 (BSL; Bohus et al., 2001). The BSL-95 consists of 95 items subdivided into 7 subscales, which are to be rated by on a 5-point Likert scale (0 = not at all, 4 = very strong). For our analysis, we used the total score across subscales.

2.3 | SCR data acquisition

Skin conductance (SC) was recorded with the Brain Vision Recorder (Brain Products GmbH, Gilching, Germany). Measures were taken at the index and middle fingers of participants' non-dominant hand with direct current using two grounded flat silver/silver chloride (Ag-AgCl) electrodes (10 mm diameter), prepared with a 0.5% saline paste in a neutral base (Med Associates TD-246). SC data were recorded at 5,000 Hz and a direct current excitation voltage of 0.5 V. The recording was synchronized with the modified BART task sequence via triggers sent by the Presentation® software (www.neurobs.com).

2.4 | SCR data preprocessing and analysis

Data were preprocessed with BrainVision Analyzer and included downsampling the data to 20 Hz and segmenting it according to the four conditions (i.e., risk × reward). Further preprocessing was performed using the Ledalab toolbox (V.3.4.8) based on standardized procedures as recommended, including smoothing using the Gauss-method and data filtering applying a low-pass Butterworth filter with a cutoff frequency of 5 Hz (Benedek & Kaernbach, 2010). Afterward, a continuous decomposition analysis (CDA) was performed in

order to separate phasic and overlying tonic SCR from each other (Benedek & Kaernbach, 2010). This analysis method follows four steps: estimation of a parameter describing tonic activity (a), non-negative deconvolution of phasic SC data resulting in a driver function and a non-negative remainder (b), segmentation of driver and remainder identifying single impulses by peak detection (c), and reconstruction of SC data (d).

Since our aim was to investigate SCRs related to ongoing risk-taking behavior, we extracted the time integral of the phasic driver over an entire response window. The phasic driver time integral reflects the cumulative phasic activity, within a specified response window (Benedek & Kaernbach, 2010). The response window was defined to range from 1–6 s after condition presentation (i.e., risk × reward). For peak detection, a minimum amplitude criterion of 0.05 μS was used.

2.5 | Statistical analysis

In order to investigate whether individuals with BPD differ from HCs in their SCRs during risk-taking, we fitted a linear mixed-effects trial-by-trial model (model 1) with random intercepts for participants. We did not exclude any "non-responders", since a lack of SCRs to stimuli or only small variations of SCR may be the product of biological processes that underlie individual differences in SCR (Marin et al., 2019). We fitted the model applying restricted maximum likelihood for the estimation of variance components using the R (R Core Team, 2015) package *lme4* (Bates, Mächler, Bolker, & Walker, 2015). Fixed effects parameters were the repeated factors risk and reward, and the between-subjects variable group (BPD vs. HCs). Corresponding p values from t tests were obtained using the *lmerTest* package with Satterthwaite's method of calculating the degrees of freedom (Kuznetsova, Brockhoff, & Christensen, 2017) and the significance level was set at an alpha level of 5%. For follow-up comparisons of significant interactions, the estimated marginal means and corrected p values were computed using the *emmeans* package (Lenth, 2016).

In order to investigate whether SCRs were related to risk-taking behavior, we fitted a final model containing interaction terms with the predictor SCRs and variables which significantly predicted SCRs in model 1. We again included a random intercept for participants and a random slope for participants for the effect of SCR to account for high inter-subject SCR variability and habituation. Follow-up procedures were conducted in the same way as for model 1. Significant three-way interactions containing both, continuous and factor variables were followed-up by estimating marginal slopes, also with the *emmeans* package.

3 | RESULTS

3.1 | Demographic characteristics

There were no significant differences between HCs and individuals with BPD with regard to age, years of education, verbal intelligence as assessed by the WST, psychomotor processing (TMT-A), cognitive flexibility (TMT-B), and short-term memory (digit span). Individuals with BPD had significantly greater levels of self-reported depression and greater levels of self-reported impulsivity (BIS-11). See Table 1 for demographic characteristics per group and BSL scores in BPD. Descriptive statistics ($M \pm SD$) for the dependent variables SCRs and RT for each level of risk and reward, stratified by the group are also presented in Table 1.

3.2 | SCRs to risk and reward as a function of group membership (model 1)

A linear mixed-effects model, with a participant-specific random intercept, risk (high vs. low), and reward (high vs. low) as within-subjects fixed effects, and group (BPD vs. HCs) revealed a significant interaction effect of group and risk ($\beta = 0.15$, $SE = 0.06$, $t = -2.56$, $p = <.05$). No other predictors of this model were found to be significant (see Table 2). Follow-up post hoc analysis of the interaction effect revealed that HCs had significantly greater SCRs for high compared to low risk ($M_{\text{difference}} = 0.06$, $SE = 0.03$, $p < .05$, Figure 2). Individuals with BPD did not differ in their SCRs for differing risk levels ($M_{\text{difference}} = -0.05$, $SE = 0.03$, $p = .08$).

3.3 | Relationship between SCRs and risk-taking behavior

In order to estimate RTs on the modified BART, we fitted a linear mixed-effects model (model 2), again with the within-subjects fixed effects of risk (high vs. low) and reward (high vs. low) and the between-subjects effect group (BPD vs. HCs) as predictors. In addition, based on the results from model 1, SCR was added as a covariate to the interaction effect of risk and group. This model revealed a main effect of risk ($\beta = 1176.40$, $SE = 27.80$, $t = 42.32$, $p = <.001$) and a main effect of reward ($\beta = 73.53$, $SE = 25.39$, $t = 2.89$, $p = <.01$). Both high levels of risk and of reward were each associated with smaller RTs compared to low levels. The model also revealed a significant three-way interaction effect of SCRs, group and risk ($\beta = -117.72$, $SE = 41.55$, $t = -2.83$, $p < .05$; Figure 3). The marginal R^2 for mixed models (i.e., proportion of variance explained by the

TABLE 1 Demographic and clinical characteristics of healthy controls (HCs) and patients with borderline personality disorder

	HCs ($n = 24$)	BPD ($n = 23$)	t	p
SCR (μS) for high risk	0.43 ± 0.89	0.44 ± 1.01		
SCR (μS) for low risk	0.37 ± 0.76	0.49 ± 1.12		
SCR (μS) for high reward	0.39 ± 0.81	0.47 ± 1.07		
SCR (μS) for low reward	0.41 ± 0.85	0.47 ± 1.06		
RT for high risk	998.60 ± 670.96	945.95 ± 742.96		
RT for low risk	2107.94 ± 1021.84	2134.41 ± 1003.82		
RT for high reward	1528.04 ± 973.73	1502.87 ± 1029.59		
RT for low reward	1578.47 ± 1077.25	1577.79 ± 1097.03		
Age (years)	26.50 ± 7.12	27.70 ± 8.20	−0.53	.60
Education (years)	16.35 ± 2.36	14.93 ± 2.88	1.81	.08
BDI	3.29 ± 3.47	35.30 ± 19.91	−14.54	<.001*
TMT-A (s)	18.15 ± 4.71	19.17 ± 3.84	−0.81	.42
TMT-B (s)	36.37 ± 10.56	49.30 ± 55.27	−1.13	.27
B/A	2.07 ± 0.64	3.18 ± 9.73	−0.89	.36
Verbal IQ (WST)	104.46 ± 9.32	99.00 ± 11.85	1.74	.09
Digit span forward	15.63 ± 3.55	14.91 ± 3.54	0.68	.50
BSL 95 sum	–	186.30 ± 66.36	–	–
Range	–	52.00–336.00	–	–

Abbreviations: BDI = Beck depression inventory; BPD = borderline personality disorder; BSL = borderline symptom list; HC = healthy controls; TMT = trail making test; WST = Wortschatztest.

*$p < .05$.

fixed factors alone) was found to be $R^2 = 0.30$, whereas the conditional R^2 (i.e., proportion of variance explained by the fixed and random factors) was found to be $R^2 = 0.50$ for this model. Post hoc analyses on estimated marginal slopes revealed significantly different slopes for high and low risk on RT for HCs ($M_{\text{difference}} = 93.7$, $SE = 32.9$, $p < .05$). Moreover, under low risk, the impact of SCRs on RT was significantly different for BPD participants compared to HCs. While the relationship between SCRs on RT was positive for BPD participants ($\beta = 90.0$, 90% CI: 6.82–173.0), it was negative, albeit not statistically significant, for HCs ($\beta = -41.6$, 90% CI: −125.14–42.0). Please see Table 2 for all other parameter estimates.

3.4 | Relationship between SCRs and psychiatric symptoms

Since most BPD patients exhibited high levels of comorbid depressive symptoms, we calculated Pearson correlations between BDI-II scores and SCRs under both high-risk conditions combined within the BPD group. The results, however, did not reveal a significant correlation $r(21) = -0.21$, $p = .35$. SCRs were also not correlated with borderline symptomatology, as assessed by the global BSL score, $r(21) = -0.06$, $p = .79$.

3.5 | Exploratory supplemental analysis of impulsivity

Descriptively, the variance of RTs under high risk was greater in the patient group than it was in HCs (cf. Table 1). This finding possibly reflects greater heterogeneity among our patient sample. Since impulsivity is one of the core diagnostic symptoms in BPD and known to be related to risk-taking behavior, we conducted an exploratory analysis to estimate RTs on the BART in the BPD sample only (see supplementary material). Results show that higher levels of trait impulsivity were significantly related to greater risk-taking behavior (greater RTs) under both high and low risk ($\beta = -5.48$, $SE = 2.63$, $t = -2.09$, $p = < .05$). However, this relationship was more pronounced under high risk ($M_{\text{difference}} = 5.29$, $SE = 2.39$, $p < .05$).

4 | DISCUSSION

The primary aim of the present study was to investigate risk-taking behavior in individuals with BPD using a modified version of the BART. Simultaneous SCR recordings were assessed to inspect affective processes underlying risky behavior. Results of the current study present empirical evidence for altered affective processes underlying risk-taking in

TABLE 2 Parameter estimates from the linear mixed model analyses

	b	SE	*t*	95% CI
SCR model				
Intercept	0.426	0.079	5.357	0.267 to 0.584
Group	0.006	0.115	0.057	−0.21 to 0.228
Risk	0.069	0.042	1.636	−0.01 to 0.152
Reward	0.021	0.042	0.520	−0.06 to 0.105
Group × Risk	−0.154	0.059	−2.576	−0.27 to −0.036*
Group × Reward	−0.031	0.059	−0.523	−0.148 to 0.085
Risk × Reward	−0.034	0.060	−0.582	−0.153 to 0.082
Group × Risk × Reward	0.085	0.084	1.007	−0.081 to 0.252
RT model				
Intercept	887.19	101.65	8.72	688.890 to 1086.329
SCR	66.02	43.54	1.516	−17.879 to 153.578
Group	69.32	142.37	0.487	−209.566 to 347.06
Risk	1176.40	27.80	42.316	1121.7897 to 1230.762*
Reward	73.53	25.39	2.896	23.929 to 123.459*
SCR × Group	−13.90	60.81	−0.229	−132.555 to 103.121
SCR × Risk	24.01	25.41	0.945	−25.452 to 74.224
Group × Risk	−41.68	39.58	−1.053	−119.299 to 35.869
Group × Reward	−20.48	35.77	−0.572	−90.533 to 49.665
SCR × Group × Risk	−117.72	41.55	−2.833	−198.856 to −35.935*

Note: Linear mixed model fit by restricted maximum likelihood estimation. The SCR model estimated SCRs on a trial-by-trial basis with group, risk, and reward as predictors. The RT model estimated RTs on a trial-by-trial basis with group, risk, reward, and skin conductance response as a covariate.

Abbreviations: CI = confidence interval; SE = standard error.

*$p < .05$ (*t* tests are based on the Satterthwaite's degrees of freedom method).

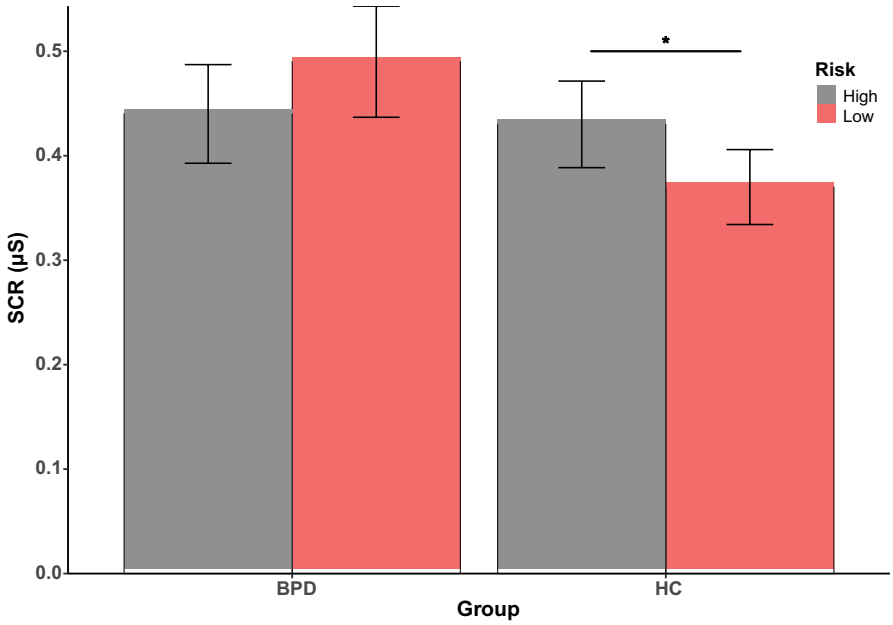

FIGURE 2 SCRs to risk as a function of group (HCs, BPD). Error bars represent *SEM*. The figure displays the interaction effect of group and risk (high and low), and Bonferroni-corrected follow-up *t* tests, *$p < .05$

individuals with BPD compared to HCs. In contrast to HCs, who showed elevated SCRs in response to high risk, differential physiological sensitivity toward different levels of risk was absent in individuals with BPD. Our results of increased SCRs in response to high risk in HCs resemble those reported by previous studies. Namely, prior research has demonstrated that typically, high risk is associated with increases in arousal as indexed by increased SCRs (Bechara, 1997;

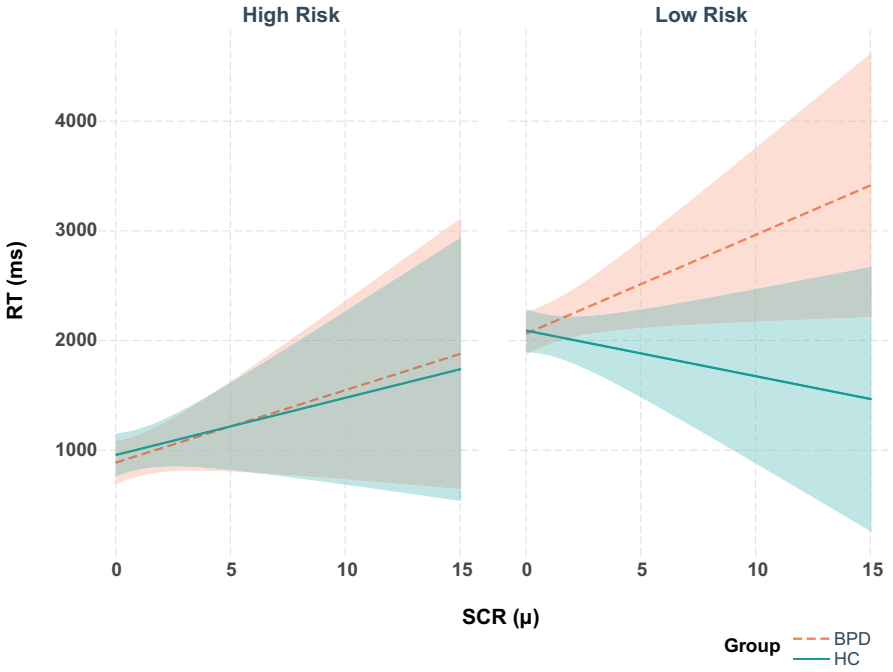

FIGURE 3 Simple slopes for the interaction of skin conductance responses (SCRs) at the factor variables risk (high, low) and group (HC, BPD)

Guillaume et al., 2009; Holper, Wolf, & Tobler, 2014). In individuals with BPD, however, these SCR modulations by risk level were absent. BPD patients exhibited similar SCRs for low and high risk, failing to exhibit differential responses to different risk levels. SCRs in the context of risk-taking are used as an index of psychophysiological arousal. The anticipation phase especially has been suggested to be a major contributor to arousal during risk-taking (Agren et al., 2019). Furthermore, it has been suggested that the differential response to high relative to low risk is the essential variable associated with favorable performance on risk-taking tasks (Guillaume et al., 2009). A lack of differential responding to different risk levels in BPD may impair behavioral adaptation and may lead to unfavorable task performance. Indeed, imaging studies also point to evidence of altered affective processes, here indexed by altered electrophysiological responses to feedback, to be related to reduced behavioral adaptation (Endrass et al., 2016; Schuermann et al., 2011). In these studies, EEG amplitudes in BPD patients did not differentiate between positive and negative feedback information and BPD patients selected high- and low-risk options with equal probability. Another study reported an insensitivity to explicit reinforcement signals in BPD leading to more negative outcomes (Saunders, Goodwin, & Rogers, 2015). Specifically, when the probability of winning and losing was known, BPD was associated with a greater tendency to choose outcomes with a negative, instead of a positive expected value. Clinically, reduced differential responding of reinforcement signals, especially in the context of risk, may partly explain self-destructive and sensation-seeking behavior in affected patients. A lack of physiological responses to different risk environments may lead to an underestimation and misperception of dangerous situations. Risk misperception and diminished learning have also been noted in other psychiatric disorders, such as in individuals with posttraumatic stress disorder (PTSD). In PTSD, emotion dysregulation often underlies poor risk perception (Walsh, DiLillo, & Messman-Moore, 2012). In this line, it has been suggested that individuals who have problems distinguishing between emotional states may also have problems identifying feelings that signal a need to leave the situation. Future studies should investigate risk-related SCRs in different psychiatric patient groups. If comparable SCRs across risk are specific to patients with BPD, they may serve as a potential biomarker, which is easily assessable and economically viable.

In addition to the finding of reduced psychophysiological discrimination between low and high risk in BPD patients, we found that under low risk, greater SCRs were associated with greater risk-taking behavior in BPD patients. In contrast, increased SCRs in HCs were related to more cautious behavior on the modified BART. Elevated levels of SCRs in the BPD group show that these patients are easily aroused, even under low risk. In these situations, patients with BPD seem to take more risks. Elevated levels of arousal in BPD patients have been associated with reduced learning (Paret, Hoesterey, Kleindienst, & Schmahl, 2016). Alternatively, greater arousal in association with increased risk-taking behavior may mirror the increased exposure to a risky situation.

Surprisingly, we could not find any evidence for an association between SCRs and risk-taking behavior under the high-risk condition, which presents an interesting condition concerning BPD. This may be due to the fact that the range of RTs in this condition was very narrow, with both groups

responding quickly. Moreover, descriptively, the variance of RTs in this condition was greater in the patient group than it was in HCs (c.f. Table 1). This possibly reflects greater heterogeneity among the BPD sample. Some patients acted cautiously, whereas others took more risks. A difference in variance might have obscured finding significant group differences.

The symptom of impulsivity especially was commonly associated with risk-taking in this sample (e.g., Schuermann et al., 2011). However, impulsivity in BPD is a highly heterogeneous symptom and may have contributed to the observed variable responses in the patient group. In order to follow-up on this hypothesis, we conducted an exploratory post hoc analysis on RTs in the BPD group. This analysis indeed revealed that impulsivity in BPD is related to risk-taking behavior, especially under high risk. This finding is in line with the current impetus for studying graded clinical phenotypes (i.e., dimensions) to account for the fact that psychiatric patient groups are highly heterogeneous (Kozak & Cuthbert, 2016). Future studies should address the fact that individuals with BPD differ in their risk-taking behavior and should study risk-taking and its underlying processes in different BPD samples. Additionally, most participants with BPD had clinically significant levels of depression. Therefore, it is, possible that altered SCRs found in this group are modulated by depression. However, we could not find a significant association between BDI-II scores and SCRs. Nevertheless, it is certainly necessary to investigate potential further mechanisms, such as comorbidity, involved in risk-taking and its underlying processes more directly. Larger samples and statistical models including additional predictors, such as depression may be used. Finally, we did not find any associations between SCRs and risk-taking under varying levels of reward. In contrast to this finding, results from studies using paradigms that involve some pursuit of reward in the face of risk do report elevated risk-taking, which is sometimes interpreted as evidence for alterations in reward-processing in BPD. However, previous research on risk-taking and decision-making in BPD could not differentiate between relative contributions of risk and reward-processing regarding risk-taking behavior, which is partly owed to the paradigms used to assess these behaviors. The modified BART enables us to reveal relative contributions of risk- and reward-processing to risk-taking. This finding suggests that in the context of risk-taking, it may be the risk factor as opposed to the reward factor driving the behavior of individuals with BPD. In fact, reports on real-life risk-taking behavior in BPD indicate that individuals with BPD seek risky situations (e.g., reckless driving, substance use, shoplifting) which they find inherently rewarding. Often, they seek this kind of excitement to fill their chronic boredom and emptiness, which induces euphoric feelings. It has been speculated that risk-seeking behavior in BPD may be driven by the desire to stimulate the reward system (Bandelow, Schmahl, Falkai, & Wedekind, 2010). In these situations, additional external rewards may be less relevant—or at least equally relevant compared to HCs. An alternative or complementary explanation would be that individuals with BPD engage in risky behaviors to reduce negative emotions. Indeed, impulsive behavior is likely to occur following the experience of negative emotions accompanied by high levels of arousal (Kemp, Sadeh, & Baskin-Sommers, 2019; Leith & Baumeister, 1996). Therefore, in this case, rewards would play a secondary role. Similar to BPD, PTSD is associated with a range of risky behaviors and emotion regulation deficits. The PTSD literature suggests that risky behavior is related to maladaptive ways of responding to negative emotions as a way to avoid or escape these emotions (James, Strom, & Leskela, 2014; Weiss, Tull, Viana, Anestis, & Gratz, 2012). Building on findings from the PTSD literature, the relationship between emotion dysregulation and risk-taking behaviors should be tested in BPD. It is likely that different underlying psychopathological causes lead to risk-taking behavior as a phenotype in this heterogeneous disorder.

Although the current study adds to the literature on the affective processes of risk-taking behavior in BPD, several limitations must be taken into account. A major limitation of the current study arises from the fact that the BPD sample was on medication during study completion which may have affected behavior and SCRs. However, it is noteworthy that the prescription of the specific medication was stable along the assessment process and might rather induce unspecific noise than a specific effect due to the variability of the prescribed medication. In fact, our study may present ecologically valid findings for patient groups with high pathological symptoms as these often have symptoms that are pervasive, even under medication. Ethically, it is difficult to shortly terminate medication intake for study participation. Regarding SC data, medication effects seem to be negligible (Sarchiapone et al., 2018). For antidepressant medication, reduced SC levels are sometimes reported. While it is important to note a potential influence of medication, the specific effects we observe in SCRs related to risk are unlikely to be the consequence of a general reduction in SCR due to medication.

In order to better integrate our results, future studies should assess baseline SC levels in BPD. Risk dependent alterations in the absence of differences at baseline would support our hypothesis that individuals with BPD process risk differently. Prior work suggests no abnormalities in resting baseline skin conductance levels in BPD. (Bortolla, Cavicchioli, Fossati, & Maffei, 2018).

Moreover, as stated above, there may be several reasons for individuals with BPD to engage in risky behaviors. For example, risky behaviors may occur in the context of sensation-seeking or may be related to negative urgency in which individuals engage in impulsive actions in response to or to

avoid distressing emotions. Another limitation of the current study is that we cannot make inferences about the exact underlying causes of risk-taking. The BART is especially not well-suited to tap into processes such as emotion regulation. Future research should investigate different aspects of risk-taking behavior and should include interpersonal aspects and interpersonal stressors in order to gain a broader understanding of risk-taking in BPD. In addition, self-reports on the subjective emotional state may contribute to making better inferences about the underlying causes of risk-taking. For example, SCRs in the context of risk may signal inhibition in HCs but distress or thrill in BPD. Including self-reports may contribute to uncovering reasons for altered SCRs in BPD.

Finally, we should note that attentional processes involved in completing our task (e.g., participants focus on the balloon expanding) may differ between participants. Individual differences in attentional resources, such as sustained attention have been noted to be related to SCRs (Dawson, Schell, Filion, & Berntson, 2007; Filion, Dawson, Schell, & Hazelett, 1991). In our specific analysis, we included a random slope for participants for the effect of SCRs. Therefore, inter-individual variation regarding SCRs not related to our fixed effects is accounted for in our model. However, since attentional processes are known to influence SCRs, future research may explicitly investigate the effects of attention on SCRs in the context of risk-taking behavior in order to further elucidate factors contributing to risk-taking behavior in BPD.

In conclusion, the present study contributes to and extends evidence suggesting altered affective processing to be involved in risk-taking behavior in BPD. In the present study, we directly assessed continuous psychophysiological correlates underlying risk-taking behavior. BPD patients exhibited attenuated differential physiological sensitivity to varying levels of risk. The present findings further demonstrate an association between increased SCRs and greater risk-taking under low risk in BPD, whereas increased SCRs were related to more cautious behavior in HC, which indicates a dysfunctional mechanism in BPD individuals, in which higher arousal fails to warn individuals of higher risk. Alterations in the processing of affective signals, such as SCRs in the context of risk, may impair adaptation to environmental demands and may lead to increased risk-taking behavior in BPD.

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CONFLICT OF INTEREST

The authors declare that there is no conflict interest regarding the publication of this article.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

Figure S1. Simple slopes for the interaction of risk and self-reported impulsivity as assessed by the Barratt Impulsiveness Scale-11 (BIS-11) on response time (RT) in the Borderline Personality Disorder group

Table S1. Parameter estimates from the linear mixed model analysis in the BPD sample

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