

**Associations of Emotional Arousal, Dissociation and Symptom Severity with
Operant Conditioning in Borderline Personality Disorder**

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Abstract

Those with borderline personality disorder (BPD) display altered evaluations regarding reward and punishment compared to others. The processing of rewards is basal for operant conditioning. However, studies addressing operant conditioning in BPD patients are rare. In the current study, an operant conditioning task combining learning acquisition and reversal was used. BPD patients and matched healthy controls (HCs) were exposed to aversive and neutral stimuli to assess the influence of emotion on learning. Picture content, dissociation, aversive tension and symptom severity were rated. Error rates were measured. Results showed no group interactions between aversive versus neutral scenes. The higher emotional arousal, dissociation and tension, the worse the acquisition, but not reversal, scores were for BPD patients. Scores from the Borderline Symptom List were associated with more errors in the reversal, but not the acquisition phase. The results are preliminary evidence for impaired acquisition learning due to increased emotional arousal, dissociation and tension in BPD patients. A failure to process punishment in the reversal phase was associated with symptom severity and may be related to neuropsychological dysfunctioning involving the ventromedial prefrontal cortex. Conclusions are limited due to the correlational study design and the small sample size.

Key words:

reversal learning, borderline personality disorder, emotion, impulsivity, psychopathology

1 Introduction

Increased emotional reactivity (Ebner-Priemer et al., 2007, 2005; Kuo and Linehan, 2009; Reitz et al., 2012) and deficits in emotion and behavior regulation (Schmahl et al., 2014) are core features of borderline personality disorder (BPD). BPD is a disabling condition involving frequent self-injurious and suicidal behavior, with prevalence rates around 3% (Tomko et al., 2014) and results in large costs for health care systems. Psychotherapy may be improved by better understanding of learning mechanisms underlying behavioral adaptation and regulation in BPD.

By reversing stimulus-outcome associations in operant conditioning, one's malleable response to reward and punishment can be assessed. In reversal learning tasks, participants are presented with two stimuli, one of which is rewarded upon selection while the other is punished. Learning acquisition of the stimulus-outcome associations is followed by their reversal, and the stimulus which was earlier associated with a reward is now punished when selected. Impairments when processing rewards and punishments were repeatedly shown in several neuropsychological tasks with BPD patients (e.g. (Andreou et al., 2015; Barker et al., 2015; LeGris et al., 2014; Schuermann et al., 2011; Vega et al., 2013)). However, studies addressing reversal learning in BPD patients and healthy controls (HCs) have not shown group differences (Barker et al., 2014; Berlin et al., 2005; Dinn et al., 2004). It is surprising that despite consistent evidence of a deficit in reward processing, previous studies did not reveal affected reversal learning in BPD, although the support for this is sparse.

Learning can be affected by dissociative symptoms (Winter et al., 2014), which are often reported by BPD patients (Stiglmayr et al., 2001; Zanarini et al., 2000). Dissociation can impair classical conditioning processes in BPD patients (Ebner-Priemer et al., 2009) and is a predictor for unfavorable treatment outcomes in BPD (Arntz et al., 2015; Kleindienst et al., 2011). Krause-Utz et al. (2012) showed that dissociation increases in experimental settings when emotional stimuli are involved. This emphasizes the importance of better understanding the influence of dissociation on learning mechanisms. Besides dissociation, symptom severity (Völker et al., 2009) and impulsivity (Berlin et al., 2005; Dowson et al., 2004; Lawrence et al., 2010) affect reward processing in BPD and, hence, may affect operant conditioning. Taken together, increased dissociation and high BPD symptom severity may impair operant conditioning. Unfortunately, previous studies investigating operant conditioning did not report dissociation ratings. Thus, the main

question we addressed was whether the presence of emotional stimuli had detrimental effects on operant conditioning in BPD patients. First, we hypothesized that the presentation of task-irrelevant aversive (versus neutral) stimuli would impair the instrumental learning of stimulus-outcome associations in BPD patients. We further explored associations of emotional intensity ratings and learning to assess whether group differences in emotional intensity might indirectly affect learning. Thirdly, we expected that higher states of dissociation would be associated with worse acquisition learning. Fourth, we wanted to further explore the influence of borderline symptom severity and impulsivity on learning.

2 Methods

2.1 Sample

Out of 22 female BPD patients who participated in the study, one was excluded from the analysis due to a technical error in the experimental procedure. This reduced the final sample to $n=21$ (age: 27 ± 6.7 [mean \pm standard deviation]). Patients were recruited via advertisements in print media or websites. Eligible patients were invited for diagnostic interviews conducted with the International Personality Disorder Examination (IPDE; (Loranger, 1999)) and the Structured Clinical Interview for DSM-IV (SCID; (First et al., 1997)) by trained interviewers. Patients were included if they met 5 or more DSM-criteria for BPD and if they were free of psychotropic medication for at least two weeks prior to participation. They were excluded from participation if they met criteria for lifetime bipolar-I, lifetime schizophrenia, current substance use disorder, current major depressive episode, or if they reported any lifetime or current neurological conditions. Comorbidities found in the sample were posttraumatic stress disorder (current=4, lifetime=6), major depression (lifetime=17), dysthymia (current=1), social phobia (current=3), specific phobia (current=1), panic disorder (current=4), bulimia nervosa (current=2). All participants were tested negative for drug ingestion using a urine test before participation. HCs ($n=15$, age: 25.1 ± 3.7) were all female and were included if they did not report any current or lifetime DSM-IV diagnosis. They fulfilled none of the DSM BPD criteria. Both groups did not differ in age ($t(34)=0.99$, $p=.33$). The study was conducted according to the declaration of Helsinki and approved by the Ethics Committee of the Medical Faculty Mannheim of the University of Heidelberg. All subjects provided written informed consent before participation and were financially compensated for participation.

2.2 Procedure

2.2.1 Ratings and psychometric measures

Before the experiment, participants completed the Borderline Symptom List (BSL-23 (Wolf et al., 2009), Cronbach's $\alpha=0.83$, $n=19$; we report Cronbach's alpha of scales for

the BPD group), the Barratt Impulsiveness Scale (BIS-11; (Patton et al., 1995; Preuss et al., 2008), Cronbach's $\alpha=0.46-0.58$, $n=19$) and the UPPS Impulsive Behavior Scale (Cronbach's $\alpha=0.76-0.84$, $n=21$, (Schmidt, 2008; Whiteside and Lynam, 2001)). The items of the dissociation tension scale short version (DSS-4, (Stiglmayr et al., 2009), Cronbach's $\alpha=0.91-0.96$, $n=21$) were presented on the computer screen after each experimental run. The DSS-4 is a four item self-assessment scale asking for the level of current psychological and somatoform dissociative experiences. Additionally, it includes a fifth item to assess aversive tension. Ratings were assessed on a 10 point Likert type scale (0=not at all to 9=extremely high).

After the experiment, each picture was presented again and was rated for emotional arousal and valence on the Self-Assessment Manikin (SAM) scale (5 levels, 1=relaxed/very positive to 5=highly arousing/very negative).

2.2.2 Instruction and set-up

Participants were instructed to choose one of the two pictures presented on a 17'' computer screen by pressing the left or right button on a computer keyboard. If the response was correct, they received 100 credits, otherwise 100 credits were taken off their account. They were instructed to choose the picture that was most often rewarded. Reversals would randomly occur, in which the opposing picture would be associated with a reward. Additionally, participants were told that they would receive one cent per 100 credits earned, in addition to the compensation for participating in the experiment. Stimuli were presented with Presentation software (Neurobehavioral Systems, Berkeley, CA).

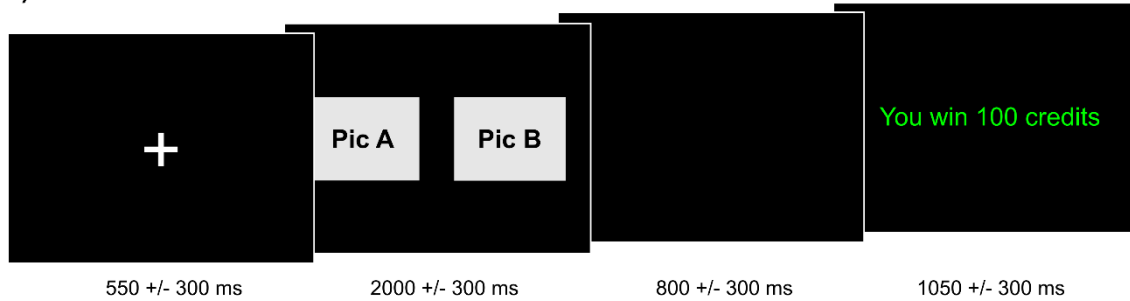
2.2.3 Experimental design

The stimuli in the experimental runs either consisted of images depicting aversive scenes involving human beings (aversive condition) or images of animals (neutral condition). The pictures were selected from the IAPS (Lang et al., 2008) and EmoPics (Wessa et al., 2010) picture sets.

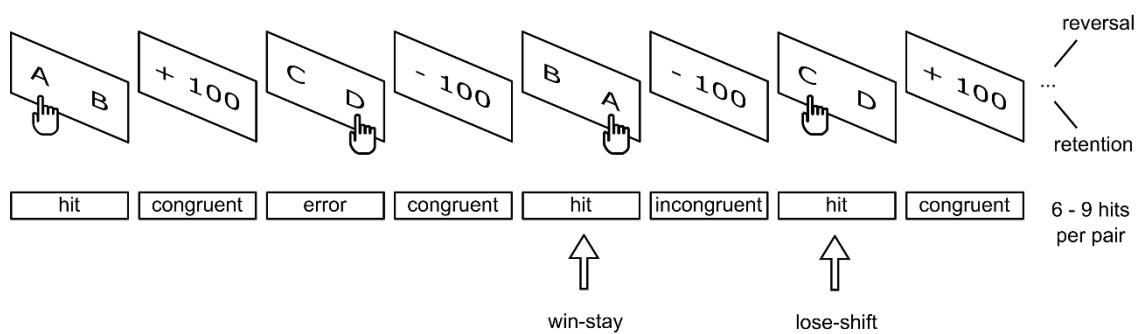
To test our hypotheses, an operant conditioning task was developed implementing both acquisition and reversal conditions, while controlling for aversive versus neutral stimulus content. Four experimental runs were administered, either starting with the aversive condition or the neutral condition; the conditions alternated in the remaining runs. Each trial started with the presentation of a fixation cross on a black screen (550 ± 300 ms),

followed by the presentation of the picture pair (2000 ± 300 ms), then a black screen (800 ± 300 ms) and then finally a feedback presentation (1050 ± 300 ms) stating either “you win 100 credits“ in green or “you lose 100 credits“ in red letters in German language (

a) Trial



b) Acquisition



c) Reversal (pair AB) & Retention (pair CD)

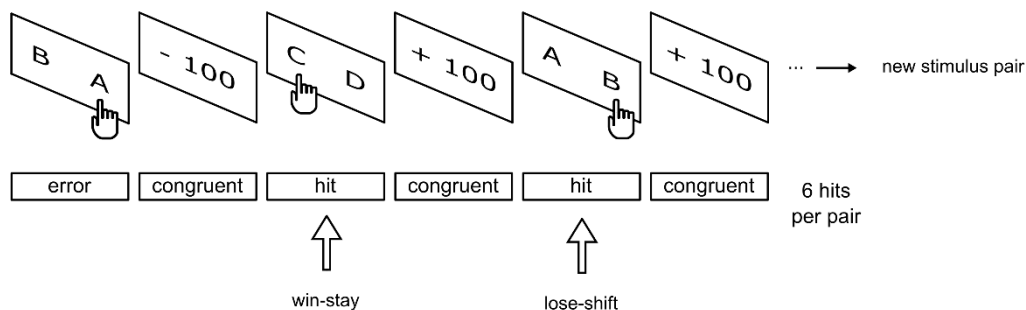
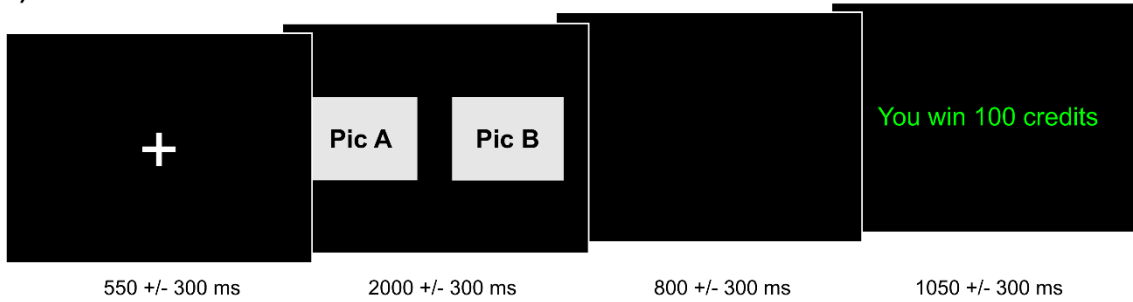


Figure 1a). Participants were advised to press a button every time a picture pair was presented before it disappeared. There were 100 trials per run, resulting in a total of 200 runs per condition. At the end of the run, participants received a message stating the number of credits they had won during the run.

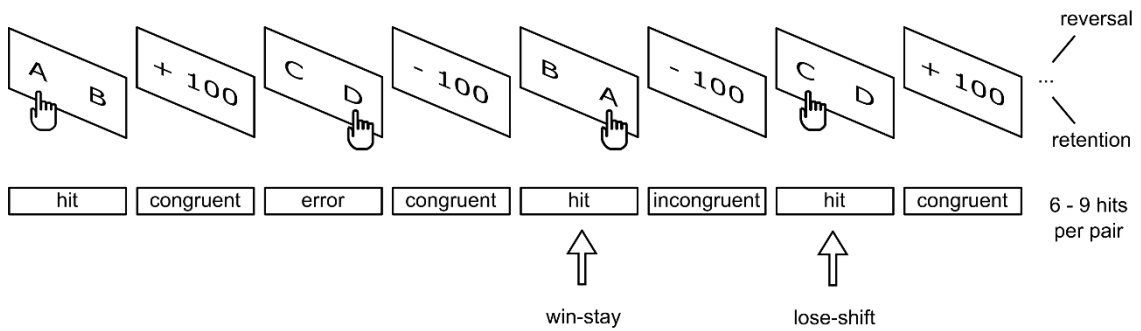
We assessed the performance in three separate phases: an early phase (‘acquisition’) and two late phases (‘reversal’ and ‘retention’). Trials of a picture pair were presented repeatedly until the pair passed the ‘acquisition’ phase and entered one of the late phases. During the ‘acquisition’ phase, one of the paired images was rewarded (the ‘rewarded stimulus’) when selected (i.e., in case of a ‘hit’ response). The other stimulus (the ‘non-

rewarded stimulus’) was always punished when selected (i.e., in case of an ‘error’ response,

a) Trial



b) Acquisition



c) Reversal (pair AB) & Retention (pair CD)

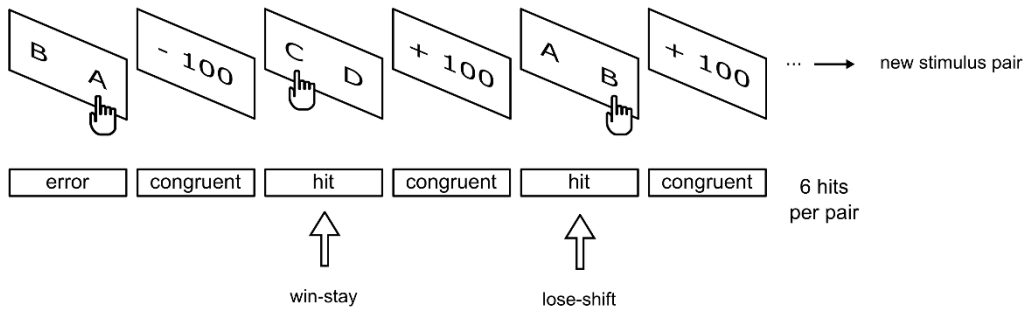
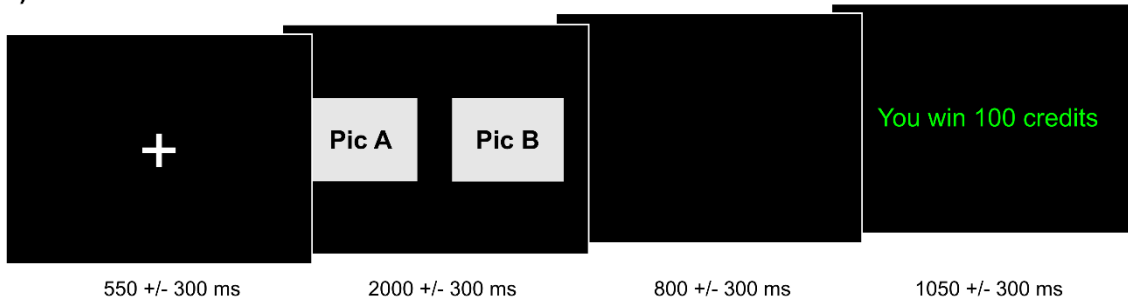


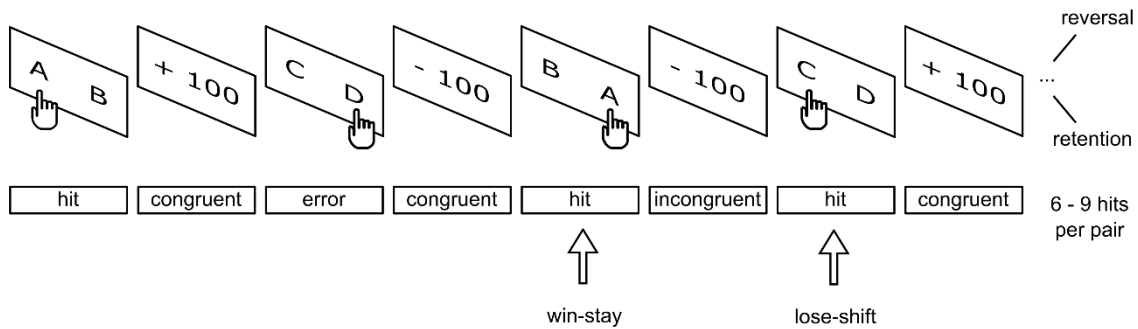
Figure 1b). As soon as the rewarded stimulus was selected in a certain number of subsequent trials (probabilistic learning criterion: 6-9 hits), stimulus-outcome associations in half of the pairs swapped and the pair entered the ‘reversal’ phase. For the other half of the pairs, stimulus-outcome associations stayed the same, i.e., the

participants needed to produce the correct responses from memory (the ‘retention’ phase,

a) Trial



b) Acquisition



c) Reversal (pair AB) & Retention (pair CD)

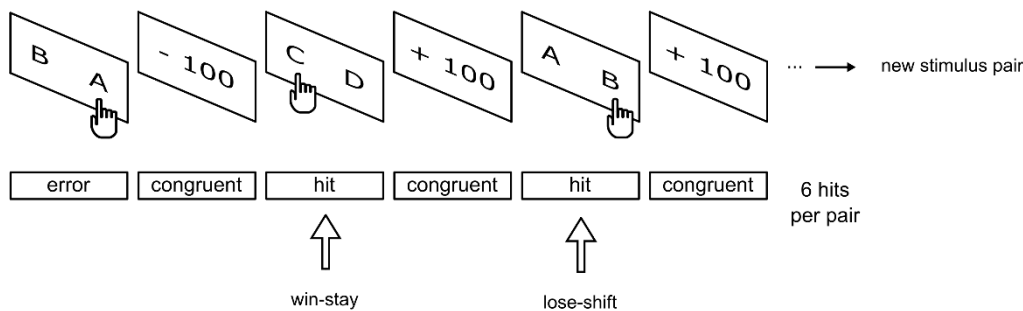


Figure 1c). Again, after 6 subsequent hits, the learning criterion was passed and the picture pair was replaced by a new pair of images, starting with the acquisition phase. To aid in ones learning stability, 90% hits were rewarded with congruent feedback and 10% of hits were punished with incongruent feedback. Congruent feedback was always given on the first hit at the beginning of each phase. Additionally, congruent feedback was always given on the last hit in the ‘acquisition’ phase. To aid in one’s motivation, a hit was followed by congruent feedback when participants had chosen the wrong picture in the preceding trial.

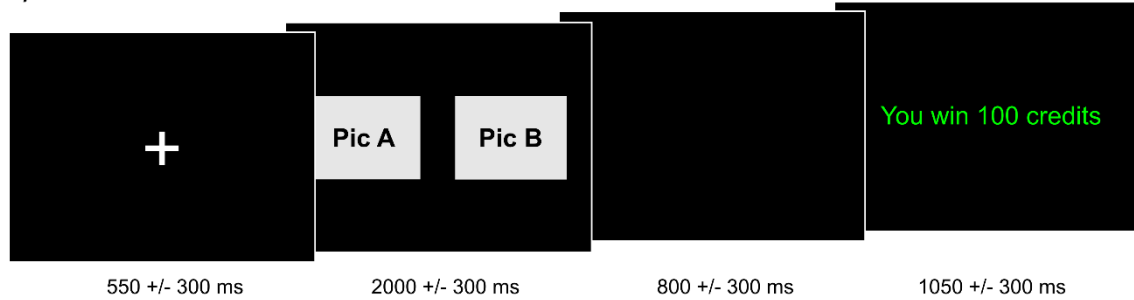
Figure 1 around here

Presentation of paired images on the left or the right side of the computer screen was semi-randomized, with the restriction of no more than two presentations of a picture on

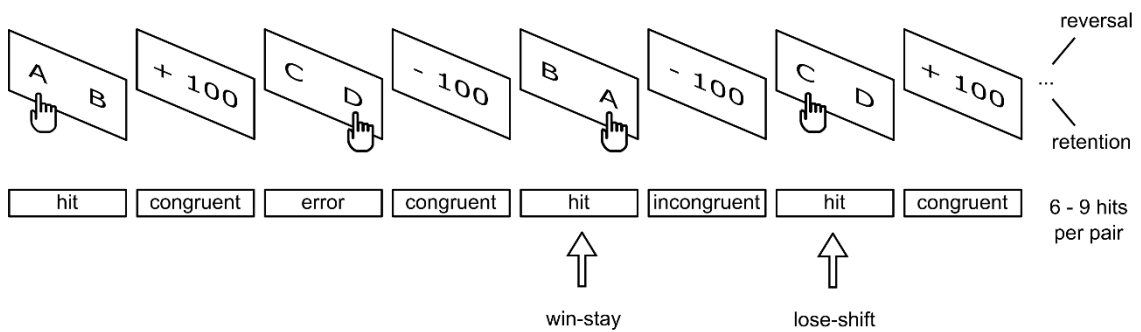
the same side during subsequent trials. To exclude systematic effects, pictures were paired randomly for each participant.

To further increase unpredictability of stimulus reversals, two different picture pairs were presented in semi-randomized order (with the restriction of no more than two presentations of the same pair in two subsequent trials; see

a) Trial



b) Acquisition



c) Reversal (pair AB) & Retention (pair CD)

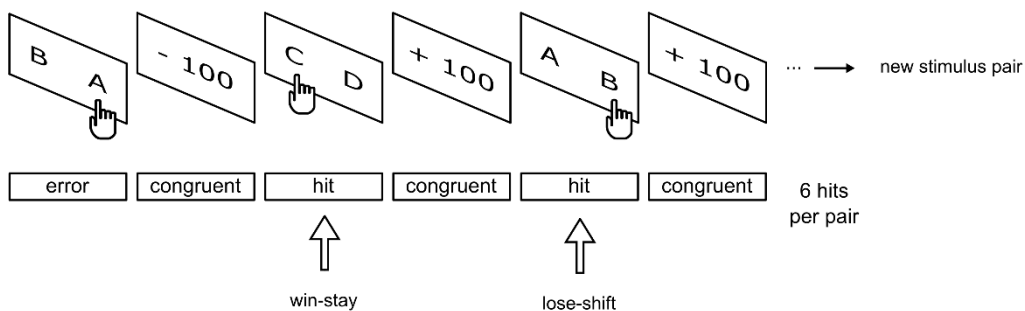


Figure 1b and c for illustrations). If one of the pairs was in the ‘reversal’ phase, the other pair was either in the ‘acquisition’ phase or entered the ‘retention’ phase. This restriction was implemented to limit task difficulty, as reversal of two different picture pairs at the same time was assumed to considerably impair performance. Descriptive statistics on the number of fulfilled learning criteria can be obtained from Table 1.

2.2.4 Outcome measures

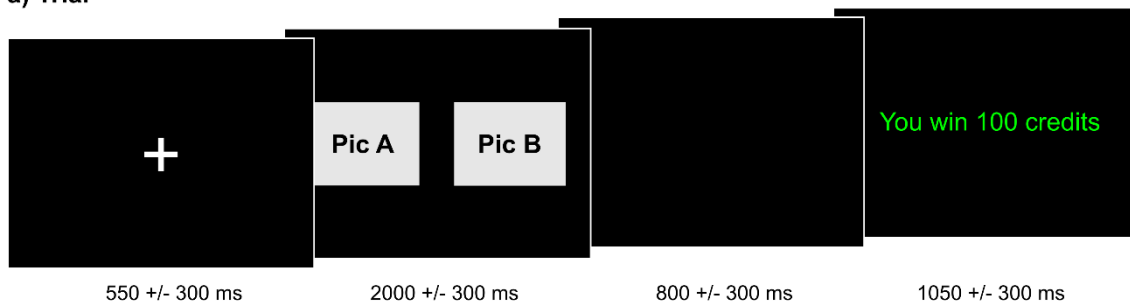
The error rate (i.e., percentage of errors) was received by dividing the number of errors multiplied by 100 by the sum of all responses (Formula 1).

Formula 1: Error rate

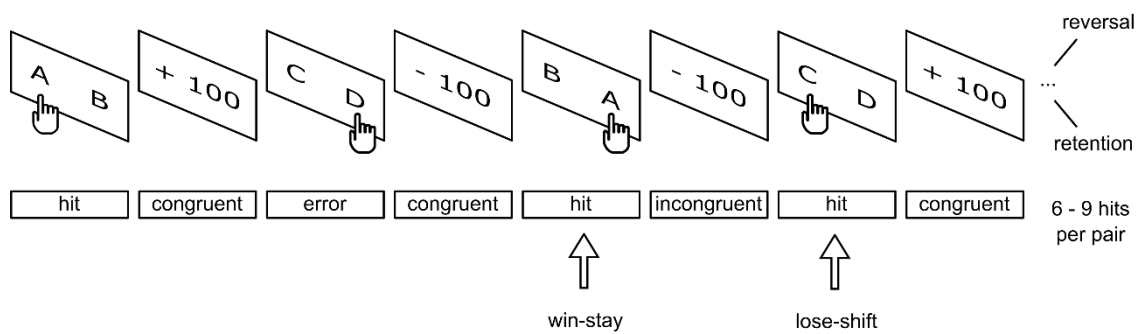
$$\text{error rate} = \frac{\text{errors} \times 100}{\text{errors} + \text{hits}}$$

To assess adaptive responding to punishment, we calculated the proportion of responses where participants switched from the selection of the non-rewarded to the rewarded image after being punished for their previous error response (i.e., ‘lose-shift’ responses; see

a) Trial



b) Acquisition



c) Reversal (pair AB) & Retention (pair CD)

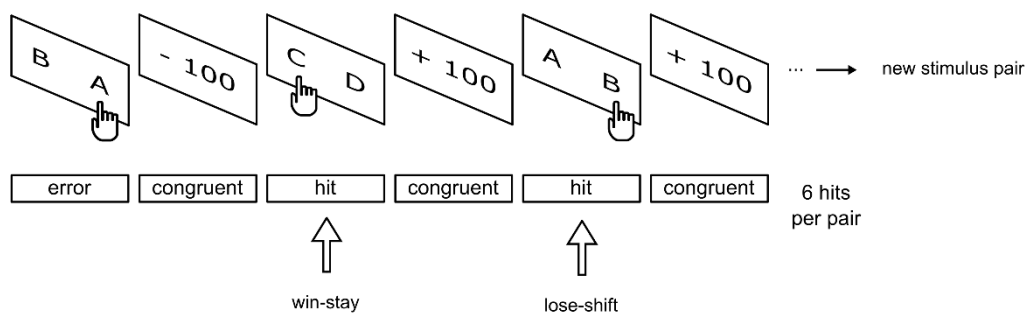


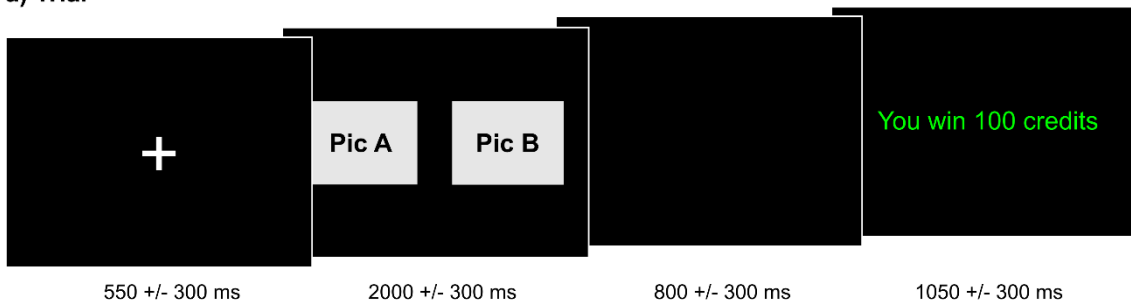
Figure 1b and c for illustrations). The percentage of lose-shift responses was assessed relative to the responses where participants did not shift to the rewarded image (i.e., ‘lose-stay’ responses, Formula 2).

Formula 2: % lose-shift

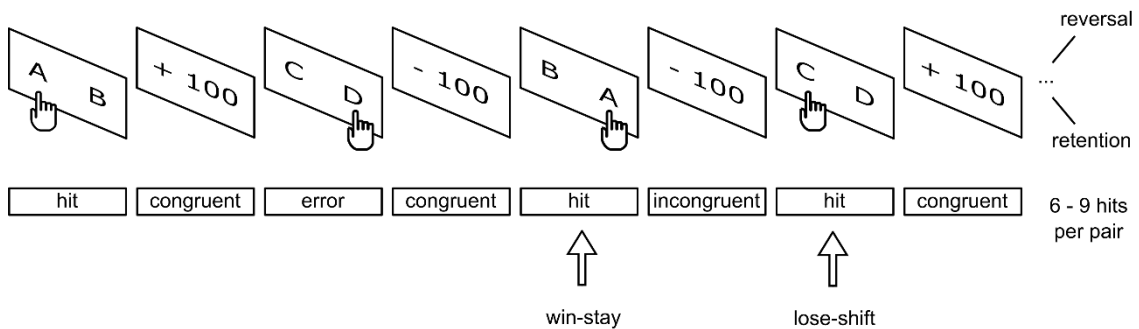
$$\% \text{ lose-shift} = \frac{\text{no-reward-shift} \times 100}{\text{no-reward-shift} + \text{no-reward-stay}}$$

In a similar way, we analyzed adaptive responding to reward by calculating the percentage of ‘win-stay’ responses (see

a) Trial



b) Acquisition



c) Reversal (pair AB) & Retention (pair CD)

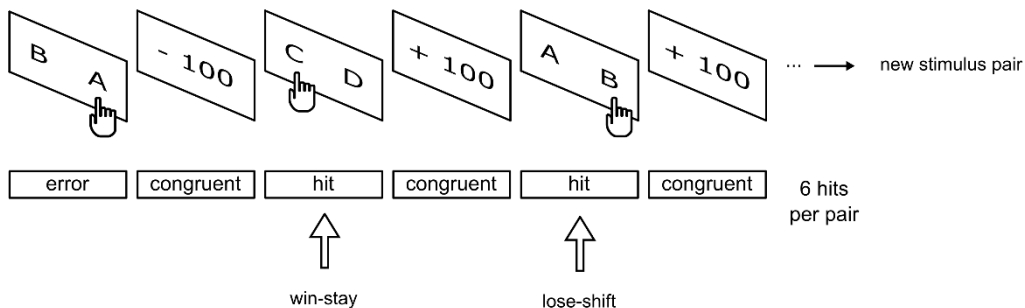


Figure 1b and c for illustrations, Formula 3).

Formula 3: % win-stay

$$\% \text{ win-stay} = \frac{\text{reward-stay} \times 100}{\text{reward-stay} + \text{reward-shift}}$$

2.3 Data analysis

2.3.1 Group interaction analysis

Error rates were analyzed with repeated-measures ANOVAs with one between-subjects factor ('group'; HC and BPD) and the within-subjects factors 'run' (two levels, as there were two runs per condition) and 'condition' (aversive and neutral). Analyses were conducted on the 'acquisition' and 'reversal' phases to test our hypotheses. Results from the 'retention' phase are provided for reasons of completeness.

2.3.2 Analyses on the relationship between ratings and outcome measures

To investigate the association between the emotional intensity of stimuli and learning, correlations of arousal and valence with the outcome measures were assessed. Outcome measures and dissociation DSS-4 ratings were averaged across runs and used for correlation analyses. A hierarchical regression analysis was calculated to investigate whether dissociation predicted error rates when controlling for aversive tension (separate item of the DSS-4).

Correlations of error rates with borderline symptom severity were assessed with the BSL-23 and associations with impulsivity were explored with the BIS and the UPPS as predictors. As correlation analyses were explorative, no correction for multiple comparisons was applied. Significance was assessed with two-tailed tests, if not indicated otherwise.

As reported below, participants made more errors in the 'neutral' compared to the 'aversive' condition. Possible reasons for this unexpected observation are described in the discussion section. With respect to our hypothesis on the influence of aversive emotions on learning, correlation analyses were restricted to the aversive condition.

The Shapiro-Wilk test was used to test the distributions for deviations from normality. If significant, results from Spearman's non-parametric correlation test (ρ ; "rho") were reported. Statistical analyses were performed with SPSS version 20 (IBM Corp. Armonk, NY).

3 Results

3.1 Ratings and psychometric measures

Aversive pictures elicited higher arousal scores (condition main effect: $F(1,35)=169.74$, $p<0.001$, $\eta_p^2=0.83$) and were rated more negatively ($F(1,35)=236.60$, $p<0.001$, $\eta_p^2=0.87$). BPD patients rated the pictures as more arousing compared to controls (group main effects: $F(1,35)=10.87$, $p<0.01$, $\eta_p^2=0.24$) but not more negatively ($F=1.51$, $p=0.23$, $\eta_p^2=0.04$). Dissociation was observed in the BPD sample in the aversive condition (2.55 ± 2.50 (mean \pm std)) and in the neutral condition (2.26 ± 2.41). All dissociation ratings from controls were '0'. A potential correlation of arousal ratings with dissociation scores was assessed but was not significant (Spearman's $\rho=0.16$, $p=0.48$). BPD patients scored significantly higher on the BSL, BIS and UPPS, excluding the 'Sensation Seeking' scale, compared to HCs (Table 2).

3.2 Group interaction analysis

In the 'acquisition' and 'reversal' phases, the 2 (group; BPD, HC) x2 (condition; aversive, neutral) x2 (run; 1, 2) ANOVA did not reveal significant group interactions ($F_s<1.6$) or main effects of group ($F_s<1.4$). A significant three-way interaction was found in the 'retention' phase ($F(1,32)=8.80$, $p<0.01$, $\eta_p^2=0.31$). BPD patients compared to HCs made more errors in the first run of the 'neutral' condition (see Table 3; $t(28.62)=2.83$, $p<0.01$). From the first to the second run, the BPD group improved ($t(19)=2.89$, $p<0.01$), while HCs did not change ($t(12)=1.00$, $p=0.34$). One must consider that some participants did not enter the retention phase in either run of the 'neutral' condition, reducing the sample size in the analysis. In the 'acquisition' and 'reversal' phases, a significant run main effect was detected ('acquisition': $F(1,34)=8.70$, $p<0.01$, $\eta_p^2=0.20$, 'reversal': $F(1,32)=23.44$, $p<0.001$, $\eta_p^2=0.42$), indicating a reduction of errors in the second compared to the first run. A condition main effect in the 'acquisition' phase ($F(1,34)=5.34$, $p<0.05$, $\eta_p^2=0.14$) indicated that both groups made less errors in the aversive condition compared to the neutral condition.

3.3 Analyses on the relationship between ratings and outcome measures

3.3.1 Arousal and dissociation

Acquisition

In the BPD group, the correlation of arousal with the error rate had a medium effect size. This finding was complemented by correlations of arousal with lose-shift and win-stay (Figure 2a). With statistical control for dissociation, the correlation of arousal with the error rate still demonstrated a trend ($r=0.42$, $p=0.06$). Valence was not associated with the error rate ($\rho=0.04$, $p=0.85$). No significant correlations of arousal ($r=0.19$, $p=0.5$) and valence ($r=0.33$, $p=0.2$) with the error rate were observed in HCs. Putting all subjects together in a correlation analysis revealed a significant association between arousal and error rate ($r=0.33$, $p<0.05$).

Figure 2 around here

In line with our second hypothesis, higher dissociation ratings in patients were associated with higher error rates (one-tailed significance tests,

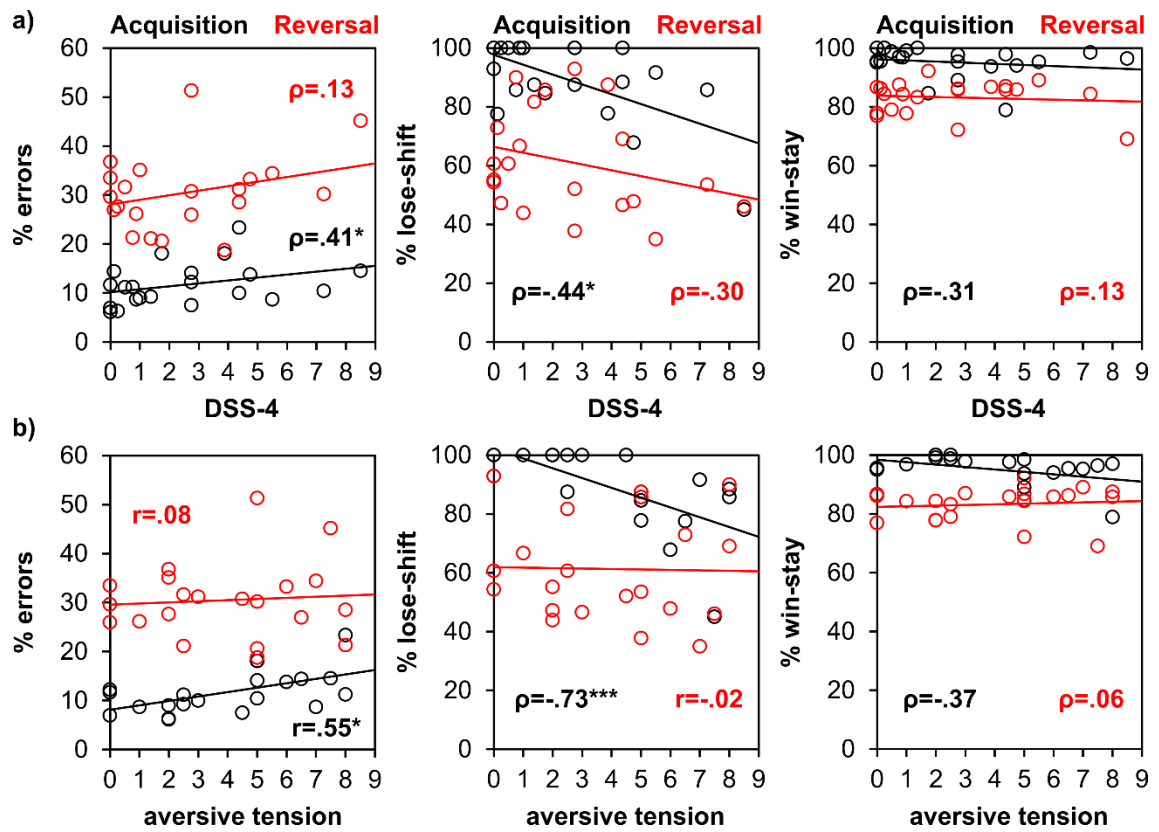


Figure 3a). The scores of aversive tension and dissociation were closely associated in the BPD sample ($r=0.56$; $p<0.01$). An exploratory correlation analysis of aversive tension scores with error rate showed a significant association in BPD patients (

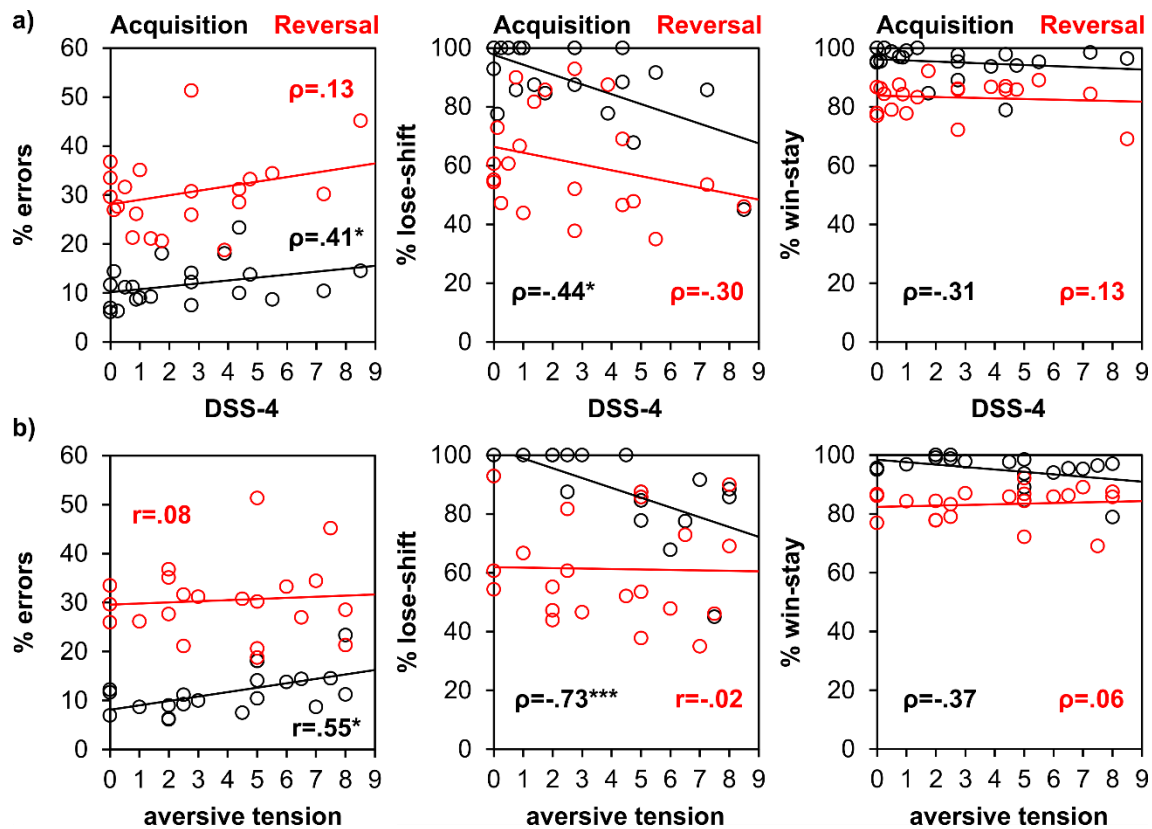


Figure 3b). To further elucidate this finding, a hierarchical regression analysis was conducted. Compared to the model with tension as the single predictor ($R^2=0.30$, $p<0.05$), adding dissociation did not increase explained variance (R^2 -change=0.00, $p=0.83$).

Figure 3 around here

Reversal and retention

No significant correlations with the error rate were found in the analysis of arousal, valence, dissociation and tension ratings (correlation coefficients <0.40).

3.3.2 BSL-23 and impulsivity scores

Correlations were assessed individually for the BPD group. Analyses with the complete sample did not yield significant results. Significance of correlations with impulsivity scores were not corrected for multiple comparisons.

Acquisition

BSL-23 ratings from 19 patients were available for analyses and did not show a significant correlation with the error rate in acquisition ($r=0.03$, $p=0.89$). A positive

correlation of the UPPS subscale ‘Lack of Premeditation’ with the error rate was significant (Table 4).

Reversal and retention

A significant association of patients’ BSL-23 ratings with reversal errors was found. This was complemented by a significant correlation with lose-shift but not win-stay responses (

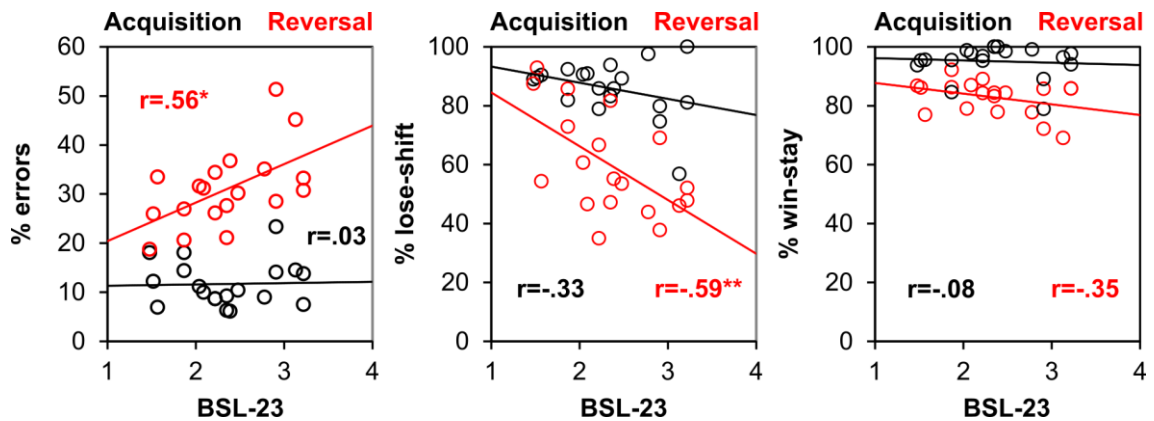


Figure 4). In contrast, BSL-23 ratings were not associated with the error rate in the ‘retention’ phase ($\rho = -0.03$, $p = 0.92$). The UPPS subscale ‘Urgency’ showed a significant positive correlation with the reversal error rate (Table 4).

In the ‘retention’ phase, the BIS total score and the BIS ‘motor impulsiveness’ subscale showed significant negative correlation with the error rate. As the retention error rate distribution deviated from normality (Shapiro-Wilk test: $p < 0.001$), correlations were non-parametrically assessed and significance was not supported by this analysis (total: $\rho = -0.41$, $p = 0.08$, motor impulsiveness: $\rho = -0.22$, $p = 0.37$) (Table 4).

Figure 4 around here

4 Discussion

With a combined acquisition and reversal learning task, we investigated the influence of emotion and dissociation on operant conditioning in patients with BPD and a healthy control (HC) group. Results found no group differences in the acquisition and reversal learning phases. Contrary to our hypothesis, the patients' performance was not impaired with exposure to aversive compared to neutral stimuli. However, stimulus arousal was found to predict errors in the acquisition phase. This supports an emotion-related increase in error rate in BPD patients. In line with our hypothesis, higher dissociation scores were associated with worse acquisition learning. Additionally, patients with higher BPD symptom severity performed worse in response reversal. This preliminary study presents evidence for a possible detrimental effect of emotional arousal and aversive tension on operant conditioning in BPD patients. Furthermore, it reveals a deficit in adaptive responding to unexpected feedback associated with borderline psychopathology.

By manipulating emotional content (i.e., aversive versus neutral scenes), we aimed to characterize the effect of emotions on operant conditioning in BPD patients. In line with previous studies (Barker et al., 2014; Berlin et al., 2005; Dinn et al., 2004) no group differences were detected in reversal learning. While no group-by-condition interactions were found, participants made more errors in the 'neutral' compared to the 'aversive' condition. Except for picture content (i.e., aversive scenes with human beings versus animals), all task parameters were similar between conditions and time effects of condition order were controlled for by balancing. Therefore, it can be concluded that the difference in error rates resulted from differences in the processing of picture stimuli. Nonetheless, in the 'aversive' condition, subjects with higher arousal ratings made more errors than subjects with lower arousal ratings. Furthermore, aversive pictures were rated higher in arousal than neutral pictures. Hence, stimulus arousal was not the reason for different error rates between conditions. It is possible that the animal pictures were more distracting or more difficult to discriminate as some pictures shared a high number of similar features (e.g. more than 10 pictures of birds, many photos were taken in front of the woods). Otherwise, the 'aversive' condition may have induced a state of increased attention that was beneficial for learning. During debriefing we did not ask whether participants felt differently when viewing neutral and aversive pictures. Without more information available, it is not possible to trace the source of the increased difficulty in learning in the neutral condition. To prevent the influence of unspecific stimulus effects,

the subsequent analyses were limited to the 'aversive' condition. Results should be regarded as preliminary.

To further elucidate the influence of aversive emotions on learning, an unplanned follow-up analysis was performed focusing on picture ratings. Results showed that stimulus arousal ratings were higher in the BPD compared to the control group. In addition, BPD patients with higher arousal ratings made more errors than BPD patients with lower arousal ratings in the acquisition phase. It may be speculated, that patients endorsing higher arousal ratings perceived the aversive pictures as more intrusive. This may have made the context of learning more stressful and, in effect, slowed down acquisition learning. This evidence supports a potential detrimental influence of task-irrelevant stimulus arousal on operant conditioning in BPD. However, as arousal ratings were gathered after the experiment, it is equally possible that making more errors caused patients to endorse higher arousal ratings.

Our findings complement and extend an earlier report showing impaired classical conditioning in BPD patients with high dissociation (Ebner-Priemer et al., 2005). The presence of dissociative states is closely related to aversive tension, which describes a state of stressful arousal that is not necessarily linked to a specific emotion (Stiglmayr et al., 2001). We found that in the case of operant conditioning, state-dissociation does not explain variance in error rates above the effect of aversive tension.

Our results have the implication, that arousal levels within and beyond therapy settings may impede learning and, in effect, may decrease therapeutic benefits. It is highlighted, that patients should learn to better monitor their tension levels and need to develop effective stress regulation skills in psychotherapy. This is acknowledged by many specialized therapy concepts of BPD.

Moreover, we found a significant impairment in reversal learning with increased BPD symptom severity, although no group differences were observed. In line with previous work (Berlin et al., 2005), higher impulsivity scores were associated with more reversal errors. A significant correlation was found with the urgency aspect of impulsivity which has been proposed to be related to dysfunctional emotion regulation in BPD patients (Whiteside et al., 2005). Reversal learning is associated with the ventromedial prefrontal (vmPFC) and orbitofrontal cortices (OFC) (Berlin et al., 2005; Tsuchida et al., 2010). This investigation provides preliminary evidence that core aspects of BPD

psychopathology are associated with reversal learning impairments which might have neural substrates in the vmPFC and OFC.

Notably, significant correlations were found for arousal and dissociation with acquisition but not reversal learning errors, and BPD symptoms with reversal but not acquisition learning errors. Acquisition and reversal partly involve different learning mechanisms and different neural networks (Budhani et al., 2007). Differential outcomes have also been reported by Budhani et al. (2006), who found deficits in reversal but not acquisition errors in individuals with psychopathy. Therefore, the findings may indicate, that arousal and BPD symptoms interact differentially with both types of learning.

We found an improvement in the retention of learned stimulus-outcome associations in BPD patients. The group interaction indicated that patients improved to the level of healthy participants in the second run. Since we did not have a-priori hypotheses on retention, we refrain from further discussion.

Strengths of this study are an accurately diagnosed patient sample and a strict control of medication, drug use, and current depressive episodes. In addition to the limitations already addressed above, the sample size was too small to detect correlations at small-to-medium effect sizes; thus non-significant results may not necessarily reflect the absence of an effect but rather inadequate sample size. Future studies should include a clinical control group to assess the specificity of findings for BPD.

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5 References

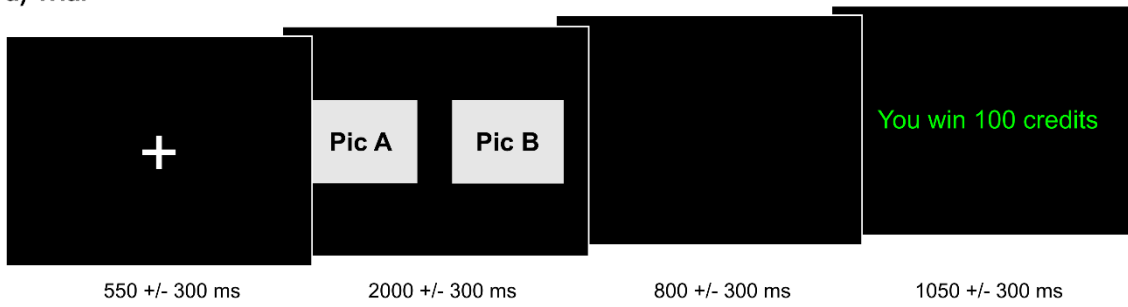
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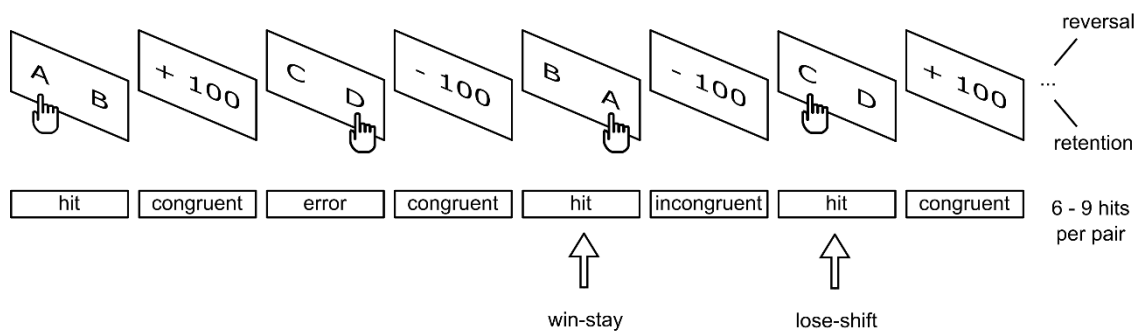
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6 Figure captions and legends

a) Trial



b) Acquisition



c) Reversal (pair AB) & Retention (pair CD)

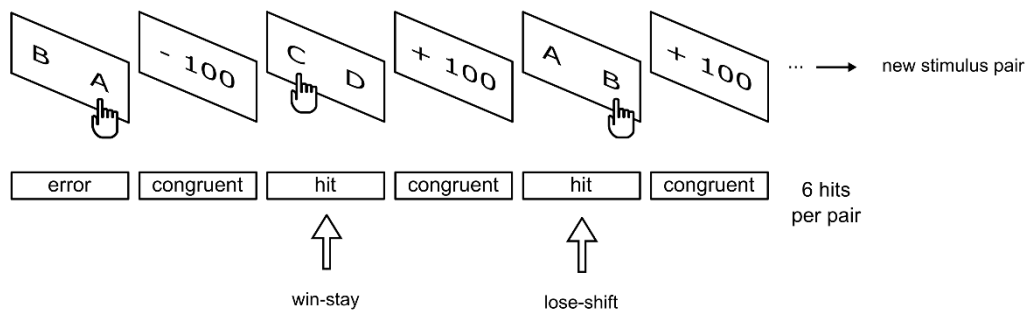


Figure 1. Experimental study design. A) Experimental trial (Pic=picture). B) Acquisition learning phase; and C) Late phases (reversal and retention).

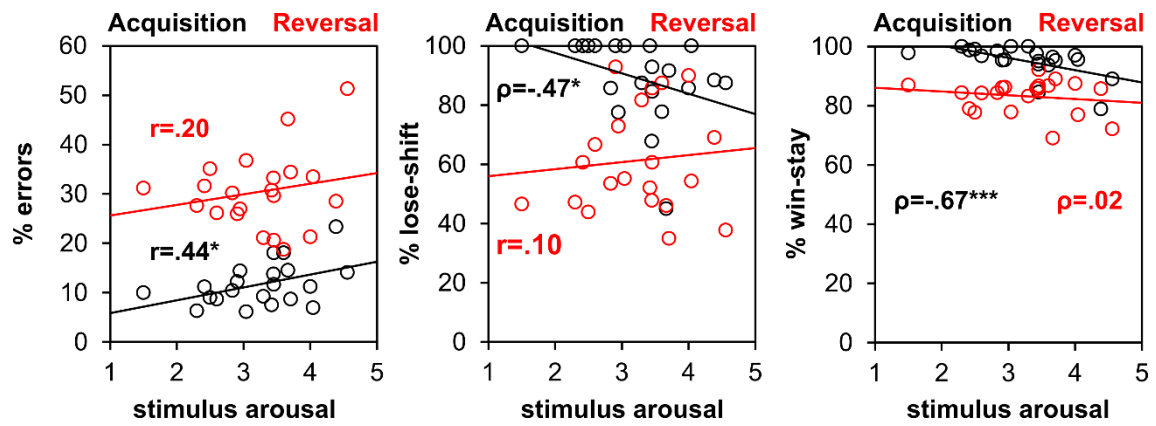


Figure 2. Association of arousal ratings with operant conditioning in BPD patients. Error rates from each patient are displayed in black ('acquisition') and red ('reversal'). Correlations with outcome measures, $*p < 0.05$, r = Pearson correlation, ρ = Spearman's rho. Lines indicate linear association.

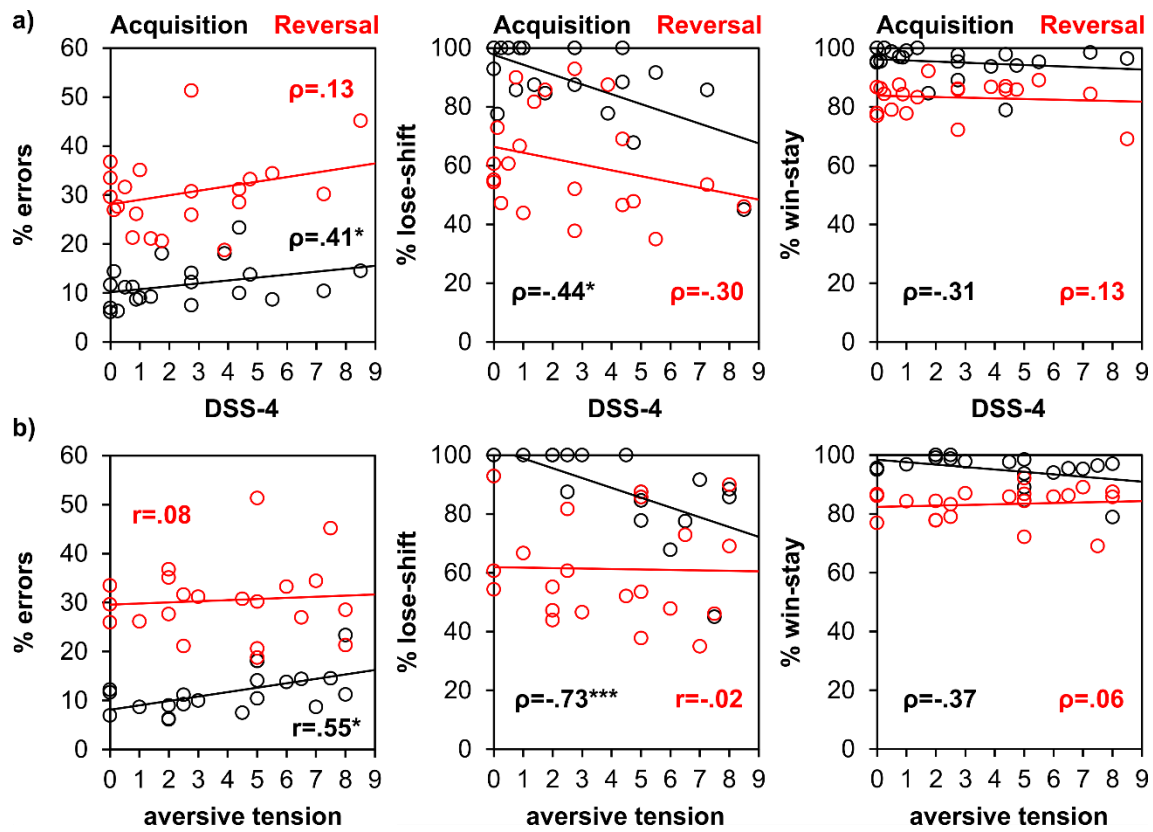


Figure 3. Association of dissociation and aversive tension (DSS-4) with acquisition learning in BPD patients. Error rates from each patient are displayed in black ('acquisition') and red ('reversal'). A) Correlations of dissociation ratings with outcome measures, $*p < 0.05$ (one-tailed), ρ = Spearman's rho. Lines indicate linear association. B) Correlation of aversive tension item scores with outcome measures, $*p < 0.05$, $***p < 0.001$, r = Pearson correlation.

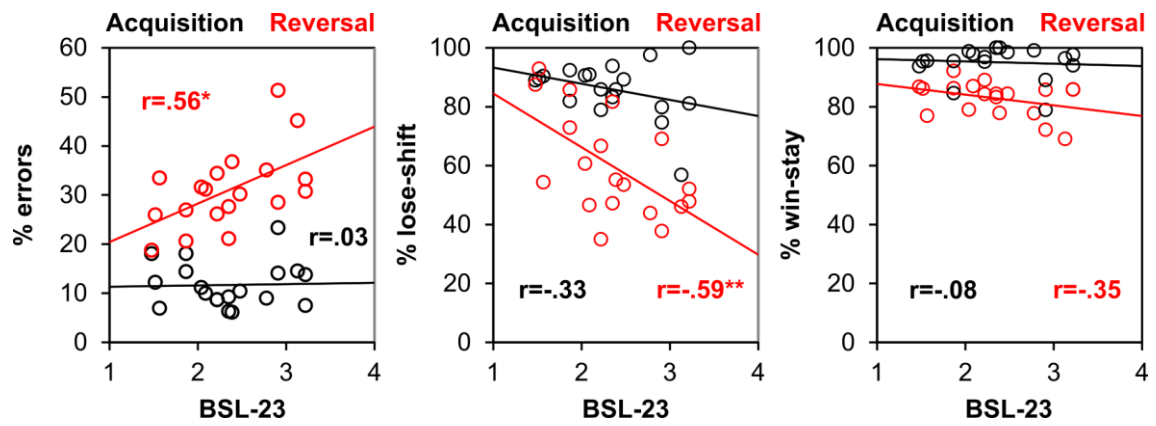


Figure 4. Ratings of symptom severity (BSL-23 score) of BPD patients were significantly correlated with the error rate and lose-shift responses in reversal learning. Error rates from each participant are displayed in black ('acquisition') and red ('reversal'). $*p<0.05$, $**p<0.01$, r = Pearson correlation. Lines indicate linear association.

7 Tables

Table 1. Descriptive statistics of fulfilled criteria.

HC		Mean	Std	Min	Max
Acquisition	Aversive	8.67	1.35	6	11
	Neutral	8.60	1.81	6	12
Reversal	Aversive	3.47	0.99	2	5
	Neutral	3.47	1.13	2	5
Retention	Aversive	3.33	0.98	2	5
	Neutral	3.40	1.35	1	6

BPD		Mean	Std	Min	Max
Acquisition	Aversive	9.05	1.88	5	12
	Neutral	8.14	2.03	3	11
Reversal	Aversive	3.67	1.2	1	6
	Neutral	3.43	1.36	1	6
Retention	Aversive	3.76	1.34	1	6
	Neutral	3.24	1.22	0	5

Mean, standard deviation (std), minimum (min) and maximum (max) of the number of picture pairs is given for which subjects had learned the stimulus-reward contingency (i.e., fulfilled the learning criteria). BPD=borderline personality disorder, HC=healthy controls.

Table 2. Statistics of psychometric measures.

	HC			BPD			Significance test
	N	Mean	SD	N	Mean	SD	
BSL	14	0.12	0.10	19	2.35	0.56	p<0.001*
BIS non-planning	14	21.07	3.38	19	24.63	4.54	p<0.05
BIS motor	14	20.64	3.95	19	28.05	4.30	p<0.001
BIS attentional	14	20.36	4.48	19	29.58	4.71	p<0.001
BIS total	14	62.07	10.23	19	82.26	8.83	p<0.001
UPPS Urgency	15	1.90	0.39	21	3.26	0.41	p<0.001
UPPS Lack of Premeditation	15	2.10	0.22	21	2.42	0.47	p<0.05
UPPS Lack of Perseverance	15	1.69	0.44	21	2.52	0.53	p<0.001
UPPS Sensation Seeking	15	2.56	0.58	21	2.69	0.60	p=0.50

BPD=borderline personality disorder, HC=healthy controls, SD=standard deviation, BSL=Borderline Symptom List, BIS=Barratt Impulsiveness Scale. * Mann-Whitney U-test; all others are t-tests.

Table 3. Descriptive statistics of error rates.

		Aversive			Neutral		
		Run 1	Run 2	Total	Run 1	Run 2	Total
Acquisition	HC	13.2 (4.2)	10.2 (3.7)	11.7 (3.2)	14.5 (8.2)	11.6 (4.0)	13.0 (5.1)
	BPD	12.9 (5.6)	10.5 (5.2)	11.7 (4.3)	17.5 (7.5)	14.6 (10.4)	16.1 (7.3)
Reversal	HC	35.7 (13.9)	28.0 (5.1)	31.9 (8.3)	33.1 (8.9)	28.2 (6.4)	30.6 (6.6)
	BPD	32.9 (11.3)	26.7 (5.7)	30.5 (7.8)	32.4 (11.3)	29.1 (7.9)	30.6 (8.1)
Retention	HC	8.2 (9.1)	5.9 (6.5)	7.1 (6.6)	3.9 (5.5)	7.6 (8.1)	6.2 (4.5)
	BPD	8.0 (12.0)	9.8 (11.9)	8.9 (10.2)	13.3 (13.5)	5.1 (9.6)	9.6 (10.3)

Means and (standard deviations) are given. HC=healthy controls, BPD=borderline personality disorder.

Table 4. Correlations of impulsivity scores with error rates in BPD patients.

	BIS Total	BIS Non- planning	BIS Motor Impulsiveness	BIS Attentional Impulsiveness	UPPS Urgency	UPPS Lack of Premeditation	UPPS Lack of Preseverance	UPPS Sensation Seeking
Acquisition	0.00	0.23	-0.08	-0.15	0.08	0.51*	-0.08	0.42 [#]
Reversal	0.17	-0.07	-0.07	0.45 [#]	0.44*	-0.08	0.27	-0.38 [#]
Retention	-0.48*	-0.17	-0.49*	-0.30	0.11	0.01	-0.06	-0.15

Pearson correlation coefficients. Sample sizes in analyses: BIS: $n=19$, UPPS: $n=21$. * $p<0.05$, [#] $p<0.10$, uncorrected p-values.