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Background: Borderline personality disorder (BPD) and bipolar disorder (BD) are common psychiatric diagnoses. Impulsivity and affective instability are prominent features of both illnesses, complicate treatment and are associated with poor clinical outcomes. Yet, little is known about sensorimotor control in these populations, whether they differ in their speed and accuracy of performance, and their ability to restore efficient performance following errors.

Methods: Twenty females with DSM-IV BPD, 20 females with DSM-IV BD and 20 age- and cognitive-ability matched healthy control participants completed a simple, brief reaction time task in which two single-attribute stimuli were mapped to distinct motor responses.

Results: Inspection of response latencies and errors showed that both the BPD and BD participants were able to respond as quickly and accurately as controls, reducing reaction times gently prior to errors, but that BPD participants showed prolonged post-error slowing (PES) before resuming normative levels of speed and accuracy.

Limitations: BD and BPD participants were taking psychotropic medication.

Conclusions: These findings suggest that BPD and BD individuals can achieve normative speed-accuracy trade-offs; but that only BPD individuals exhibit differentially slowed recovery following errors, indicating a specific impartment in basic sensorimotor control.

Key words: bipolar disorder, borderline personality disorder, post-error slowing

Problems with behavioural control are a cardinal feature of both borderline personality disorder (BPD) and bipolar disorder (BD) (Paris, 2005; Swann et al., 2009). Clinically, these difficulties are often understood in terms of heightened impulsivity and its frequent expression in alcohol and drug misuse, risky sexual behaviours, irritability, and self-harm (Cassidy et al., 2001; Haw et al., 2001). Individuals with diagnoses of BPD or BD report elevated scores on self-report measures of motoric impulsiveness (Dougherty et al., 1999; Swann et al., 2004) and can exhibit corresponding impairments on Go/No-Go or Continuous Performance tasks that (partly) tap inhibitory action control (Rentrop et al., 2008; Silbersweig et al., 2007). This kind of motor or 'rapid response' impulsivity may be an important factor in BPD and BD (Swann et al., 2002) that complicates effective treatment and undermines the prospects for good clinical outcomes (Kim et al., 2013; Links et al., 1999; Sio et al., 2011).

While the centrality of heightened impulsivity and behavioural control problems in BPD and BD is widely acknowledged (Peters et al., 2013; Sebastian et al., 2013), much less is known about other forms of sensorimotor control — for example, the performance of speeded decision or choice reaction time tasks. Efficient sensorimotor performance involves achieving a stable balance between speed and accuracy of cognitive-motor operations to minimise errors that might be costly in cognitive or emotional terms (Forstmann et al., 2010; Heitz and Schall, 2012). Psychomotor slowing is a common feature of several clinical populations and is usually associated with the presence of depressive symptoms (Bervoets et al., 2014; Caligiuri and Ellwanger, 2000). However, sensorimotor control performance, as balanced speed and accuracy of responding, in both BPD and BD remains largely unexplored.

Both impulsivity and mood and affective instability in BPD and BD could plausibly undermine the capacity of affected individuals to achieve and then maintain stable balances

between the speed and accuracy of speeded reaction time performance. Impulsivity is often manifested as action without delay, voluntary direction or differential control by conditioned stimulus (as reward or punishment) (Bari and Robbins, 2013; Robbins et al., 2012). This might lead to (relatively) fast but error-prone patterns of behaviour in either or both BPD and BD (Swann et al., 2009). Similarly, trait negative urgency, as the tendency to lose behavioural control when experiencing negative emotions, is a prominent feature of affective instability in BPD (Miller et al., 2003) and a strong correlate of maladaptive behaviours initiated in order to regulate or relieve negative emotional states (Fischer et al., 2004). By contrast, trait positive urgency has been reported in euthymic BD and has been linked to poor psychosocial functioning (Muhtadie et al., 2014). Collectively, these clinical observations highlight the possibility that BPD and BD will be associated with impaired regulation of sensorimotor performance as a sustained optimal balance between speed and accuracy.

One central aspect of sensorimotor performance is the ability to adjust performance following mistakes (Yeung and Summerfield, 2012). Typically, people tend to slow their responses once they have made an error in so-called 'post-error slowing' (PES) (Danielmeier et al., 2011)(Laming, 1979; Rabbitt, 1967), presumably reflecting the activation of control processes that reset cognitive-motor operations to restore accurate responding (Dutilh et al., 2012; Laming, 1979; Rabbitt, 1967). These error monitoring and post-error adjustments are mediated by midline circuits encompassing the anterior cingulate cortex (ACC) and pre-supplementary area (Danielmeier et al., 2011; Garavan et al., 2002; King et al., 2010; Li et al., 2008; Ridderinkhof, 2004; Soshi et al., 2014) and can be indexed by a complex of electroencephalogram signals including the error-related negativity (ERN) (Botvinick et al., 1999; Larson et al., 2014). BPD is associated with reduced ACC volume (Hazlett et al., 2005) and diminished task-elicited signalling within midline cortical and interconnected limbic sites

(Ruocco et al., 2013; Silbersweig et al., 2007; Tebartz van Elst et al., 2003). Accordingly, there have been two reports that ERN (and possibly, later positive) amplitudes are diminished following errors in BPD compared to controls (de Bruijn et al., 2006; Ruchsow et al., 2006). However, there has been little investigation of PES specifically in BPD or BD, and how effectively affected individuals recover following mistakes when making speeded decisions.

Previous investigations of the ERN in BPD have involved the presentation of stimuli with multiple attributes sometimes mapped to the same response ('congruent' stimuli) or to different and competing responses ('incongruent' stimuli) (de Bruijn et al., 2006; Ruchsow et al., 2006). Following errors, healthy controls typically show reductions in the facilitation of reaction times on congruent compared to incongruent trials (the 'congruency' effect) as they readjust performance (Botvinick et al., 1999). By contrast, BPD individuals show no change in this measure, suggesting a failure to modulate an impulsive response-style following errors (de Bruijn et al., 2006). One difficulty with this approach, however, is that the use of multi-attribute stimuli makes it difficult to attribute changes in post-error congruency effects (or ERN amplitudes) in BPD individuals to problems managing conflicts between stimulus attributes or difficulties recalibrating speed and accuracy of responding following errors.

Here, we asked one group of females with diagnoses of DSM-IV BPD, one group of females with diagnoses of DSM-IV BD (tested in the euthymic state), and a group of age and cognitive ability-matched female healthy volunteer participants to complete a speeded binary-choice reaction time (RT) task, with two visually-presented stimuli (an 'X' and an 'O') mapped to two motor responses (left index-finger and right index-finger key-presses).

Our design had 3 critical features. First, in contrast to previous experiments (de Bruijn et al., 2006; Ruchsow et al., 2006), these stimuli did not involve any multiple attributes that might have engaged broader executive conflict-monitoring processes impaired in these groups. Second, the task instructions emphasised speed of responding at an explicit pre-instructed error rate (≈ 4%), allowing a test of how effectively individuals with BPD and BD can minimise reaction times against explicit error rates. Third, BD is associated with problems sustaining attention (Clark et al., 2002), raising the possibility that changes in sensorimotor performance in this group will be confounded by attentional failures. Therefore, in comparison with earlier protocols involving EEG with 500 trials (de Bruijn et al., 2006) and 600 trials (Ruchsow et al., 2006), our task protocol was brief (only 240 trials).

We tested the hypothesis that individuals with BPD (relative to BD and healthy volunteers) would find it difficult to maintain fast and accurate sensorimotor performance and show particular problems in readjusting their performance following mistakes. The results provide new information about the cognitive and behavioural impairments that characterise and might distinguish between these clinical populations (Antoniadis et al., 2012; Ghaemi et al., 2014).

Method

The experiment was funded by the Oxfordshire Health Services Research Committee and approved by the Oxfordshire NHS research ethics committee (OxRecA – 10/H0604/64).

All participants provided written informed consent.

Participants

Twenty women with DSM-IV BPD, 20 women with DSM-IV BD (but without comorbid BPD) and 20 healthy volunteers with no history of psychiatric illness participated. BPD traits were present in BD individuals (mean number of criteria met= 1.5; range: 0-3) and healthy volunteers (mean number of criteria met= 0.0; range: 0-2). None met criteria for diagnosis of BPD. Clinical groups were recruited from community settings via clinician referral, adverts in outpatient departments and local websites. None had required hospital admission or crisis team support in the preceding month. All participants were aged between 18 and 60 years.

Participants were screened by an experienced psychiatrist (KS) using the SCID-1RV (American Psychiatric Association, 1994) and International Personality Disorders Examination (IPDE, Loranger et al., 1996) to confirm their eligibility. The IPDE has good inter-rater reliability and good temporal stability comparable to those instruments used to diagnose Axis 1 disorders. All participants reported Hamilton Depression Scale (HAM-D) scores and Young Mania Rating Scale (YMRS) scores of less than 7.

Participants with current alcohol and drug misuse problems were excluded.

Psychometric and self-report assessments

Participants completed several self-report scales: the Positive and Negative Affect Scale (PANAS)(Watson et al., 1988), the Barratt Impulsivity Scale (BIS-11)(Patton et al., 1995) and the Buss-Perry Questionnaire (Buss and Perry, 1992). Cognitive ability was estimated using Raven's Standard Progressive Matrices (Raven et al., 2004).

The PANAS consists of 2 subscales of 20 items, rated using a 5-point Likert scale, to measure positive and negative aspects of emotional experience. Cronbach's α coefficients for the state (momentary) version of Positive Affect subscale and the Negative Affect subscale were .90 and .87 respectively (Watson et al., 1988). The BIS-11 is a 30 item questionnaire designed to assess the personality/behavioural construct of impulsiveness. Its items are scored using a 4-point scale. Here, we used the 3 subscales for motor, attentional and non-planning impulsivity. It has good internal consistency, with Cronbach' α coefficients of 0.83 in psychiatric samples (Patton et al., 1995). Finally, the Buss-Perry Aggression Questionnaire (AQ) is a widely used assessment of trait aggression, with 29 items rated on a 7-point Likert scale (Buss and Perry, 1992). In general terms, the AQ has good psychometric properties (Harris, 1997) but there is some uncertainty about its factor structure to measure physical aggression, verbal aggression, anger and hostility (Bryant and Smith, 2001). Cronbach's α for these subscales range between 0.72 and 0.85 (Buss and Perry, 1992).

Two-choice reaction time task (as shape discrimination)

On each trial, 1 of 2 letter characters (an 'X' or an 'O') was presented in white against a black background on a standard computer display. Participants (all BPD, BD and healthy volunteers) were instructed to press the 'c' key with the index finger of their left hand when the letter 'X' was presented; and the 'm' key with the index-finger of their right hand when the letter 'O' was presented. These letter-response assignments were not counter-balanced.

Letter character stimuli were presented in Times New Roman font and were 35mm height by 35mm wide. Viewed at a distance of approximately 300mm, they subtended a visual angle of 6.67°. On each trial, the stimuli were displayed until participants responded. An inter-trial interval was set at a 500ms delay between the last response and next stimulus presentation.

Errors were signalled by an immediate auditory tone of 523Hz. Participants completed 6 blocks of 40 trials. At the end of each block, a feedback screen indicated the number of errors and mean reaction times for that block. Participants were instructed to respond as fast as possible but to keep the numbers of errors to a maximum of 3 or 4 per block; and that, if they made more than 4 errors in any block, they should slow down; if they made fewer errors than 3 or 4 per block, participants should increase their speed of responding.

EZ-diffusion model. Reaction time and accuracy were modelled using the EZ-diffusion model (Van Ravenzwaaij and Oberauer, 2009; Wagenmakers et al., 2007); an approach that is suited to the examination of individual and experimentally-manipulated differences in drift and boundary parameters (Van Ravenzwaaij and Oberauer, 2009; Wagenmakers et al., 2007) and is suitable for datasets with small sample sizes (Ratcliff, 2008; Wagenmakers et al., 2008).

The EZ-diffusion model estimates drift rates v, boundary separations a, and non-decision times T_{er} from the mean reaction time (*MRT*), the variance of the mean reaction time (*VRT*) and the proportion of trials that were answered correctly (P_c). Thus, the model transforms observed variables into 3 unobserved variables, allowing statistical analysis to be conducted on the latent rather than observed variables; the latent variables having clear psychological interpretations. The drift rate (v) represents the speed of information uptake; the boundary separation (a) is a measure of response caution, and non-decision time (Ter) time spent on decision-irrelevant processes. The model was applied to all trials except trials following errors as there were significant between group differences in these reaction times.

Post-error slowing (PES). The most popular way to quantify PES is to compare trials that follow errors with those that follow correct responses. However, this approach is vulnerable

to being confounded by longer-term changes in behaviour over the course of an experiment (Dutilh et al., 2012). For example, if participants' motivation wanes as the experiment progresses, responses become slower and less accurate. Since most correct trials will be in the early part of the game when motivation is higher whereas error trials will be in the later part of the experiment, any calculation which compare post-correct and post-error will tend to overestimate PES even if real post-error slowing is absent (Dutilh et al., 2012). Conversely, if a participant is initially slow but highly accurate but becomes faster and less accurate as the experiment progresses, PES may be underestimated. Here, we adopted the technique proposed by Dutilh et al (2012) to quantify PES by comparing RTs and error rates on immediately post-error trials with RTs and error rates on immediately pre-error correct trials.

Statistical analysis

Participant-group matching. Between-group differences in age, cognitive ability (as Raven's Standard Progressive Matrices, Raven et al., 2004) and self-report measures of trait affect, impulsivity and aggression were analysed by analysis of variance (ANOVA) with the single between-group factor of group (BPD, BD and healthy volunteers).

Choice reaction time. Participants' mean reaction times (ms) for correct trials, proportionate error rates, EZ-diffusion model parameters (v, a, and T_{er}, correct trials only) and PES were also analysed by ANOVAs with the single between-subject factor of group. Mean reaction times and error rates for the 5 trials preceding errors and for the 5 trials following errors were tested with repeated measures ANOVAs that included the between-subject factor of group and the within- subject factor of trial (Pre Error Tr5, Pre Error Tr4, Pre Error Tr3, Pre Error Tr2 and Pre Error Tr1) or (Post Error Tr1, Post Error Tr2, Post Error Tr3, Post Error Tr4 and Post Error Tr5). Post-hoc test were completed with two-sample t- or Tukey tests. Error rates

were arcsine transformed as the variances of error rates would be proportional to their means (Howell, 1987). However, tables, figures and text report original untransformed data.

Results

The BPD, BD and healthy control participants were well-matched for age ($F(2,57)= 0.524$) and cognitive ability as measured by the Raven's Matrices ($F(2,57)= 1.174$). Symptoms of current depression and mood elevation were low although the BPD group reported significantly higher scores on the HAM-D compared to the BD group and healthy control participants ($F(2,57)= 13.5$, $p<0.001$, Table 1). BPD participants reported lower trait and state positive affect ($F=4.391$, $p< 0.05$ and $F= 4.539$, $p< 0.05$) and higher trait and state negative affect ($F= 26.9$, $p<0.001$ and $F= 12.16$, $p< 0.0001$) than the other 2 groups. BPD was also associated with elevated impulsivity (BIS-11; $F= 13.275$, $p<.0001$) and aggression ($F(2,57)=19.618$, $p< .0001$) compared to BD and controls. BD participants reported higher trait negative affect than the controls ($t(38)= 3.099$, $p< 0.005$) and reported higher levels of impulsivity ($t(38)= 3.378$, $p< 0.005$). While their total aggression scores did not differ from those of the controls, they did report significantly higher hostility ($t(38)= 2.579$, $p< 0.05$).

< Table 1 about here >

BPD and BD participants did not significantly differ with respect to past admissions to hospital ($\chi^2(1)=1.615$, $p=0.204$) or past detention under Mental Health legislation ($\chi^2(1)=0.525$). BPD participants were more likely to be taking antidepressant medication ($\chi^2(1)= 3.600$ $p= .058$) or receiving psychological treatment ($\chi^2(1)= 6.144$,$p< 0.05$) than the BD and healthy volunteers. However, overall, there was no significant difference between the number of participants from the two clinical groups taking psychotropic medication ($\chi^2(1)=$

2.133). Fourteen participants in the BPD group and 9 participants in the BD group reported early physical or sexual abuse compared with none in the healthy controls group; the difference between the two clinical groups being statistically non-significant ($\chi2(1)= 2.56$).

Choice reaction time task

There was no significant differences in mean latencies for correct responses between the BPD participants, BD participants, and the healthy controls (see Table 2) ($F(2,57)= 1.787$) or between the latencies for incorrect (error) trials ($F(2,57)=0.518$), or error rates ($F(2,57)=0.617$). No participant completed the choice reaction time task error-free.

< Table 2 about here >

EZ-diffusion model

The three groups did not differ reliably with respect to drift rates ($F(2, 57)=1.66$), boundary separation ($F(2,57)=0.195$, $p=0.823$) or non-decision time ($F(2,57)=0.507$) (see Figure 1).

<Figure 1 about here>

Post error slowing (PES)

Mean correct latencies tended to decrease ($F(4)= 7.644$, $p< .0001$) while errors tended to increase ($F(4)= 7.619$, $p< .01$) over the 5 trials preceding an incorrect response (see Figure 2). However, these patterns of reaction time did not differ between the BPD participants, the BD participants or healthy participants, $F(2,57)= 2.32$ and $F(2, 57)= 0.012$ respectively.

<Figure 2 about here>

By contrast, mean correct latencies following an error differed between groups (see Figure 2), $F(2,57)= 6.598, p< 0.005$). Following Dutihl et al (2012), PES (estimated as the difference between mean reaction times on the immediately post- and pre-error trials) was significantly greater in the BPD than in BD participants or healthy volunteers (see Figures 2 and 3). Post-hoc Tukey tests indicated that PES was significantly greater in BPD participants compared with the BD participants ($p<0.05$) and healthy control ($p<0.05$). PES in the BD participants was marginally larger than in the controls; however, this difference was not reliable ($p=.774$).

Finally, the increased PES in the BPD compared to the BD and healthy participants did not persist beyond the first trial following an error. Neither mean correct latencies nor errors differed over the subsequent 4 trials (see Figure 2)($F(2,57)=0.098$ and $F(2, 57)= 0.177$).

Correlational analysis

There were no significant associations between overall mean reaction times, reaction times for correct or error trials, error rates, any EZ-diffusion parameters (v, a, and T_{er}) and impulsivity as measured as BIS-11 scores within or pooling across participant groups. PES was not significantly correlated with BIS-11 scores in any of the groups ($-.108=<r=<.290$).

Discussion

BPD and BD I are both characterised by high levels of impulsivity and poor behavioural control that complicate their treatment and undermine good clinical outcomes (Kim et al., 2013; Links et al., 1999; Sio et al., 2011). While recent investigations indicate that BPD and BD can be distinguished using clinical, historical and personality characteristics (Bayes et al., 2014; Bayes et al., 2016) and in terms of affective features (Pauselli et al., 2015), relatively

little is known about the extent of impairments in basic aspects of sensorimotor performance that might be linked to the impulsivity and affective instability of these two disorders.

Detailed inspection of the pattern of response latencies and errors showed essentially normal sensorimotor performance in both clinical groups prior to errors, but then markedly prolonged PES in the BPD participants compared to both the BD participants and healthy control participants. Notably, the prolonged PES in the BPD was transitory, with reaction time and error rates returning to levels comparable to the BD participants and controls with one trial. Therefore, our findings demonstrate a specific punctate change in sensorimotor performance apparent in BPD individuals but not (euthymic) BD I individuals, possibly reflecting divergent manifestations of their characteristic impulsivity and affective instability.

Previous investigations of error-processing in BPD have involved multi-attribute 'flanker' stimuli in which two stimulus features map either to the same motor (or No-Go) responses on congruent trials or to conflicting motor (or No-Go) responses on incongruent trials (de Bruijn et al., 2006; Rentrop et al., 2008; Ruchsow et al., 2006). These experiments tend to show that, compared to controls, BPD patients exhibit increased reaction times for correct responses compared to controls when the stimulus features map to distinct motor responses (de Bruijn et al., 2006), but unchanged or faster reaction times (with more errors) when stimulus features map to go versus no-go responses (Rentrop et al., 2008; Ruchsow et al., 2006). Consistent with other findings that individuals with diagnoses of BPD are not consistently impaired in the performance of Go/No-Go tasks (van Eijk et al., 2015), our findings extend this evidence-base by demonstrating that, under conditions of single-attribute stimuli mapped to distinct motor responses, individuals with BPD (and individuals with BD) can respond as quickly and accurately as controls, replicating earlier findings of marginal facilitation of

reactions time speed, and improved accuracy, prior to errors (Laming, 1979; Rabbitt, 1967). Thus, these findings show that neither BPD and BD are necessarily associated with gross failures to achieve and manage stable speed-accuracy trade-offs (Heitz and Schall, 2012).

While the BPD participants and BD participants were indistinguishable in terms of their performance prior to errors, their latencies to respond on the first trial following an error was markedly lengthened compared to the BD and healthy volunteers; suggesting that prolonged PES may be a specific feature of BPD. Previous investigations using 'flanker' stimuli show that, in comparison with healthy and non-clinical participants, BPD participants continue to show congruency effects over reaction times following errors (de Bruijn et al., 2006), diminished ERN amplitudes and sometimes diminished Pe amplitudes (de Bruijn et al., 2006; Ruchsow et al., 2006). The present findings, collected with single-attribute stimuli mapped to distinct motor responses, demonstrate that BPD is associated with prolonged PES in the absence of the need to manage attentional and response-based conflicts triggered by multi-dimensional stimuli (Botvinick et al., 1999; Yeung and Summerfield, 2012).

PES is very likely a highly complex behavioural phenomenon, probably reflecting the operation of co-occurring cognitive control processes (Dutilh et al., 2012; Regev and Meiran, 2014; Soshi et al., 2014; Yeung and Summerfield, 2012). These mechanisms include increased response caution (such that errors prompt individuals to accumulate more information before making a following decision)(Rabbitt and Rodgers, 1977), an a priori bias (such that people become negatively-biased against response options that just produced errors (Rabbitt and Rodgers, 1977), decreased variability in bias (such that errors induce individuals to improve the timing of the onset of information accumulation, Laming, 1979), orienting or attentional towards error signals as infrequent and/or surprising events (Notebaert et al.,

2009), or delayed start-up (such that errors delay the start of evidence accumulation while individuals reassess their own performance and overcome disappointment (Rabbitt and Rodgers, 1977). Using a database of 1,094,886 lexical decisions, Dutilh et al (2012) demonstrated that increased response caution in drift-diffusion models accounts almost exclusively for PES in healthy volunteers, suggesting that PES can be explained in terms of self-regulation processes and cognitive control: that is, individuals alter response thresholds by speeding up after each correct response but being more cautious following errors.

In principle the increased PES observed here in the BPD participants might involve any of the above. However, we tentatively suggest that it reflects a temporary caution following errors of commission, signalled here by the absence of any increase in errors thereafter (relative to the BD and controls). The finding that the PES in BPD participants was not evident beyond a single trial and that reaction time and accuracy returned to pre-error levels suggests a single discrete adjustment of their speed-accuracy trade-offs. Rentrop et al (2008) report an absence of PES in BPD participants compared to controls while performing a sequential Go/No-Go task, suggesting that BPD is associated with impairments in managing speed-accuracy trade-offs. Our findings, using a short, simplified two-choice reaction time task (without attentional conflicts), refute this assertion and indicate that individuals with diagnosis of BPD can slow their speed of responding to restore an explicit error rate.

Possibly, these changes in PES relate to structural and functional features of BPD. Post-error adjustments are mediated by action-monitoring processes supported in the medial prefrontal cortex and ACC (Botvinick et al., 1999; Danielmeier et al., 2011; Garavan et al., 2002; Koban and Pourtois, 2014; Ridderinkhof, 2004; Soshi et al., 2014; Van Veen and Carter, 2002). BPD is associated with reduced ACC volumes (Hazlett et al., 2005; Tebartz van Elst

et al., 2003) and diminished neural signalling within the medial prefrontal cortex and ACC linked to affective features (Ruocco et al., 2013) or behavioural inhibition under emotionally negative (Silbersweig et al., 2007) but not emotionally neutral conditions (van Eijk et al., 2015). Errors during the performance of our binary-choice reaction time task were signalled by auditory cues, raising the possibility that the prolonged PES observed in our BPD compared to BD participants also reflects emotional or attentional responses to this feedback.

Finally, neuropsychological assessments have consistently shown that euthymic BD I patients show longer reaction times and increased numbers of errors while completing continuous-performance task (CPT, Lee et al., 2015; Torres et al., 2010), possibly reflecting impairments in sustained attention (Bourne et al., 2013; Clark et al., 2005). Our findings that euthymic BD participants exhibit choice reaction times, error rates and PES comparable with age and ability-matched healthy controls is consistent with observations that deficits in sustained attention relate to changes in target detection and response bias (Harmer et al., 2002).

Limitations

We acknowledge a number of limitations to the study. First, although larger than three previous studies (deBrujin et al., 2006, Ruschow et al., 2006; Vega et al., 2015), the sample size of the present current study is relatively small. Second, the relatively low number of errors meant that we were unable to compare the EZ-model parameters for pre- and post-error trials (Dutilh et al., 2012). Third, the BPD and BD groups were taking psychotropic medication, possibly slowing reaction times. However, we did not find any evidence of between-group differences in reaction times beyond PES and the two clinical groups were broadly matched for medications, with the exception of antidepressants. In healthy non-clinical samples, single doses of SSRIs can impair reaction times on a variety of

neuropsychological tests; by contrast, the effects of multiple dose studies in healthy volunteers are inconsistent (Serretti et al., 2010). The impact of SSRIs upon response times in BPD is unknown so we cannot rule out the possibility that their use in the present experiment is a confounding factor. Finally, although previous studies have explored the impact of state negative affect on PES and have found only very limited effects upon performance (Hajcak et al., 2004; Olvet and Hajcak, 2012), our sample of BPD individuals reported significantly high levels of state negative affect than our control participants, raising the possibility that our findings reflect, at least to some extent, differences in momentary emotional experience.

Notwithstanding these concerns, the present findings demonstrate that individuals with diagnoses of DSM-IV BPD, but not individuals with diagnoses of DSM-IV BD, exhibit unchanged response times and error rates, but prolonged PES, while performing a short two-choice reaction time task to an explicit error rate. These findings indicate that BPD may be associated with a specific problem in action-monitoring processes operating following errors.

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Authors' contributions

Prof Rogers and Dr Saunders devised the rationale for the study; Dr Saunders and Prof Rogers and Goodwin designed the study; Dr Saunders collected the data; Dr Saunders and Prof Rogers analysed the data; all three authors were responsible for writing the manuscript.

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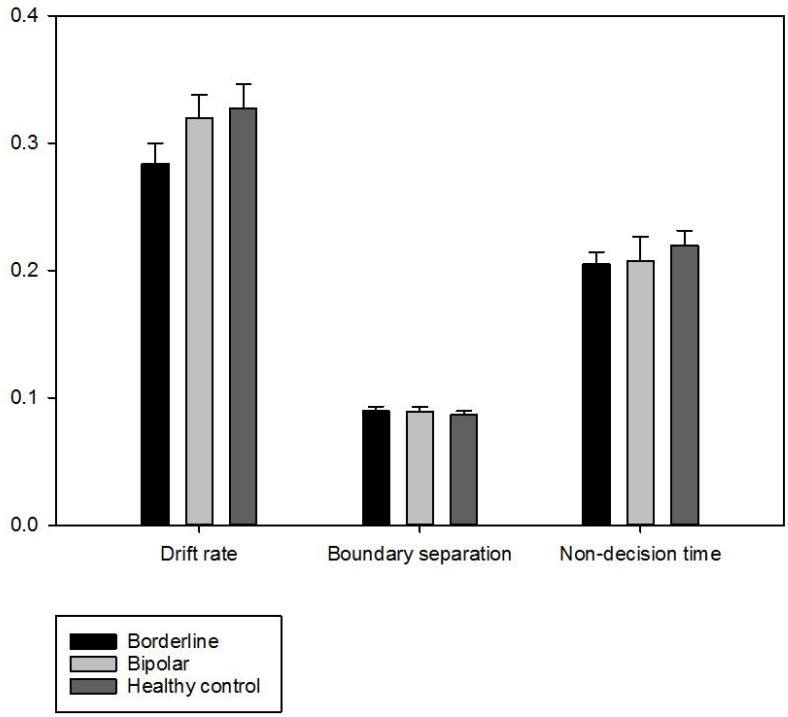

Figure 1. Mean (±standard errors) EZ-diffusion model parameters for 20 individuals with DSM-IV borderline personality disorder, 20 (euthymic) individuals with DSM-IV bipolar disorder and 20 non-clinical healthy controls in a simple choice reaction task.

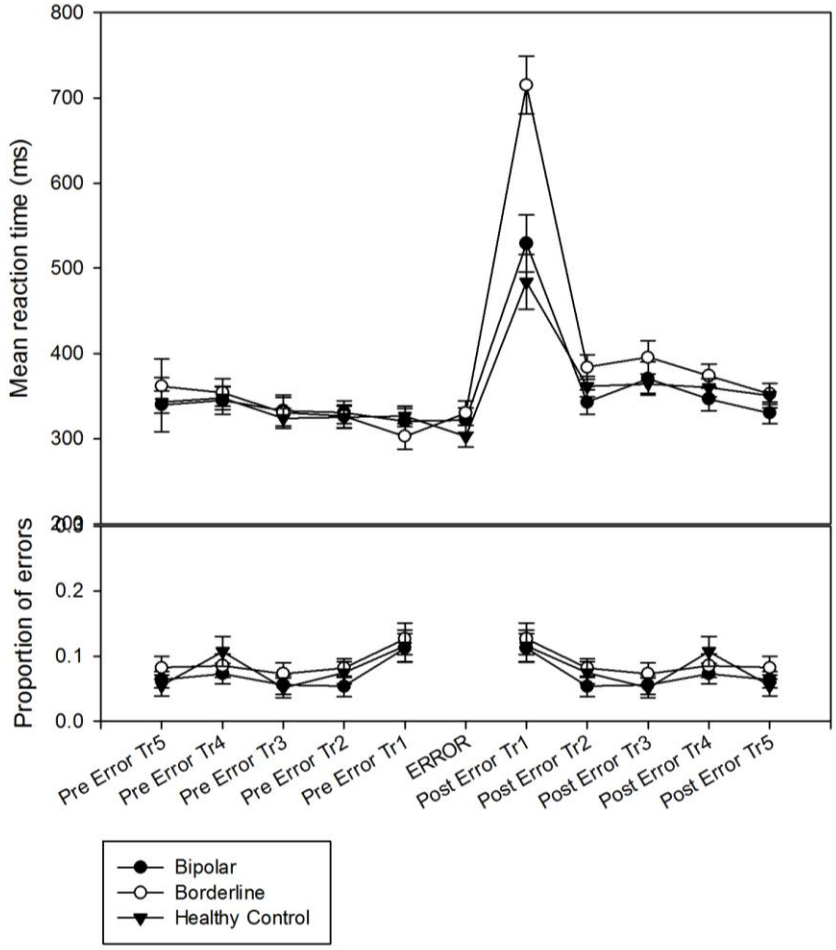

Figure 2. Mean reaction times (±standard errors) and error rates (±standard errors) for the 5 trials preceding an incorrect response, the error trial and the 5 trials following an incorrect response in 20 individuals with DSM-IV borderline personality disorder, 20 (euthymic) individuals with DSM-IV bipolar disorder and 20 non-clinical healthy controls in a binary choice reaction task.

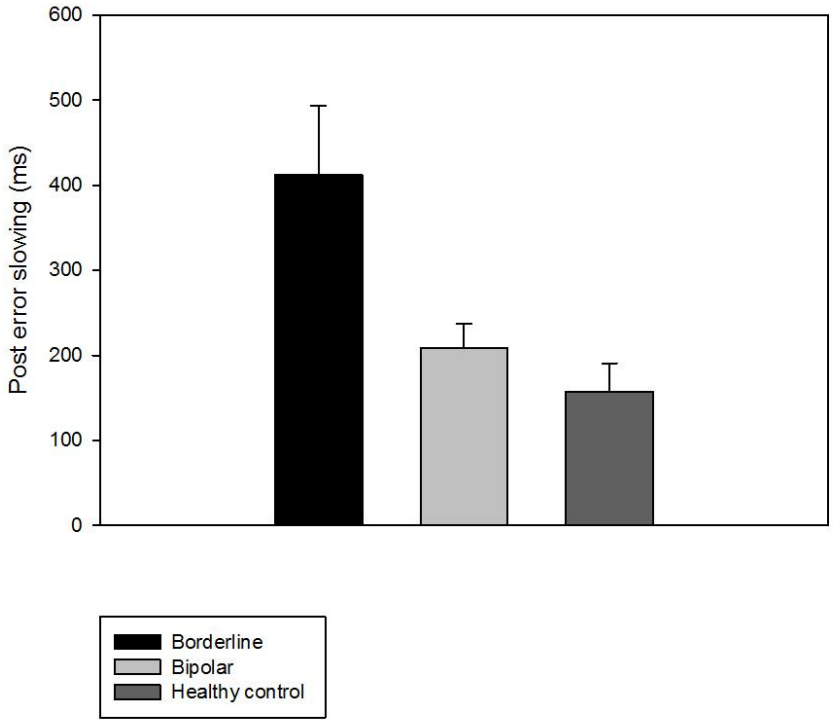

Figure 3. Post error slowing (±standard errors) in 20 individuals with DSM-IV borderline personality disorder, 20 (euthymic) individuals with DSM-IV bipolar disorder and 20 non-clinical healthy controls in a simple choice reaction task.