

# **Enhanced post-error slowing discriminates borderline personality disorder from bipolar disorder in sensorimotor performance**

Kate E A Saunders (kate.saunders@psych.ox.ac.uk)<sup>a</sup>

Guy M Goodwin (guy.goodwin@psych.ox.ac.uk)<sup>a</sup>

Robert D Rogers (r.rogers@bangor.ac.uk)<sup>b</sup>

<sup>a</sup>University Department of Psychiatry, Warneford Hospital, Oxford, OX3 7JX

<sup>b</sup>School of Psychology, Adeilad Brigantia, Penrallt Road, Gwynedd LL57 2AS

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**Correspondence:** Dr K Saunders, University Department of Psychiatry, Warneford Hospital, Oxford. OX3 7JX

Background: Borderline personality disorder (BPD) and bipolar disorder (BD) are common psychiatric diagnoses. Impulsivity and poor behavioural controls are common features of both illnesses, complicate treatment and are associated with worse clinical outcomes.

However, little is known about sensorimotor control in these populations and whether they differ in their speed and accuracy of performance and their ability to restore performance following mistakes.

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 two distinct motor responses.

Results: Inspection of latencies and errors showed that both 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 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 slowed recovery following errors may distinguish BPD from BD in assessments of sensorimotor performance.

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

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 as 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 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). Motor or 'rapid response' impulsivity may be one factor in BPD and BD (Swann et al., 2002) that complicates treatment and undermines clinical and vocational outcomes (Kim et al., 2013; Links et al., 1999; Sio et al., 2011).

While the centrality of impulsivity and behavioural control problems in the experience and presentation of both 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, in the performance of speeded decision or choice reaction time tasks. Efficient sensorimotor performance involves achieving an appropriate balance between speed and accuracy of cognitive-motor operations to minimise performance errors that might be costly in cognitive or emotional terms (Forstmann et al., 2010; Heitz and Schall, 2012). The clinical characteristics of BPD and BD — namely, emotional lability and heightened impulsivity — suggests that achieving stable balances between the speed and accuracy of sensorimotor performance is impaired in both of these populations.

Psychomotor slowing has been reported in a number of psychiatric conditions and is usually associated with the presence of depressive symptoms (Bervoets et al., 2014; Caligiuri and

Ellwanger, 2000) however, its relationship to mood instability has been largely unexplored. Impulsivity is often manifested as action without delay, voluntary direction or obvious differential control by the stimulus (Bari and Robbins, 2013; Robbins et al., 2012)(REF ROBBINS Review,). This might be expected to lead to faster yet more inaccurate responses. although the behavioural modulation associated with impulsivity may be moderated by environmental constraints (Tzagarakis et al., 2013) 2013). Negative urgency or the tendency to lose behavioural control when experiencing negative emotions has been described BPD (Miller et al., 2003) and is thought to be a strong correlate of engagement in a variety of maladaptive behaviours to regulate or relieve negative emotion (Fischer et al., 2004). By contrast positive urgency has been reported in euthymic BD and was found to be associated with poorer psychosocial functioning (Muhtadie et al., 2014).

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, 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 can indexed by a complex of electroencephalogram (EEG) signals including the error-related negativity (ERN) generated by midline cortical systems and the anterior cingulate cortex (ACC, Botvinick et al., 1999; Larson et al., 2014). While there have been two reports that ERN amplitudes (and possibly later positive amplitudes) are diminished following errors in BPD compared to controls (de Bruijn et al., 2006; Ruchow et al., 2006), there have been little investigation of PES specifically and how effectively individuals with BPD (or BD) can 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; Ruchow 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; Ruchow 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 ( $\approx 4\%$ ), 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. So, 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).

BPD is associated with rejection sensitivity in the context of close relationships (Arntz and Veen, 2001; Dixon-Gordon et al., 2013; Staebler et al., 2011; Stern et al., 1997). Possibly, this aspect of the disorder is linked to broader impairments in repairing cognitive and emotional processing following aversive events. 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 help to distinguish 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 those with BD (, range 0-3) and healthy volunteers (, range 0-2). None met criteria for diagnosis. Clinical groups were recruited from community settings via adverts

placed 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 old.

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 eligibility. The IPDE was developed by the World Health Organisation Alcohol, Drug Abuse and Mental Health Administration and has good inter-rater reliability and temporal stability similar to those instruments used to diagnose axis 1 disorders. All participants reported Hamilton Depression Scale (HAMD) scores and Young Mania Rating Scale (YMRS) scores of less than 7. Those with current alcohol and drug misuse were excluded.

### ***Psychometric and self-report assessments***

Participants completed self-report measures of state positive and negative affect (PANAS, Watson et al., 1988), and assessments of trait aggression and impulsivity using the Buss-Perry Questionnaire (Buss and Perry, 1992) and the Barratt Impulsivity Scale (BIS, Barratt, 1965). Cognitive ability was estimated using Standard Ravens Progressive Matrices (Raven et al., 2004).

### ***Two-choice reaction time task***

On each trial, one of 2 letter characters (an 'X' or an 'O') was presented in white against a black background on a standard computer visual display. Participants in each group (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.

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  $6.67^\circ$ . 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 of 40 trials, 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 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); a drift-diffusion 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  $\nu$ , 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 to three 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 ( $T_{er}$ ) time spent on decision-irrelevant processes. The model was applied to all trials except the trial following an error as there were significant between group differences in reaction time between groups.

*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 Progressive Matrices, Raven et al., 2004) and self-report measures of trait affect, aggression and impulsivity 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 analyses of variance with the between-subject factor of group. Repeated measures ANOVAs were run on mean reaction times and error rates for the 5 trials preceding errors and for the 5 trials following errors with the 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). Error rates were arcsine transformed as variances would be proportional to means (Howell, 1987). Tables, figures and text report the original untransformed data.

## Results

The BPD, BD and control participants were matched for age ( $F(2,57)=0.524$ ,  $p=0.595$ ) and cognitive ability as measured by the Raven's Matrices ( $F(2,57)=1.174$ ,  $p=0.316$ ). Current symptoms of depression and mood elevation were low although the BPD group had significantly higher scores on the HAM-D compared to the BD group and controls ( $F(2,57)=13.5$ ,  $p<0.001$ , Table 1). BPD participants reported lower trait and state positive affect ( $F=4.391$ ,  $p=0.017$  and  $F=4.539$ ,  $p=0.014$ ) and higher trait and state negative affect ( $F=26.9$ ,  $p<0.001$  and  $F=12.16$ ,  $p=0.001$ ) compared to the other two groups. BPD was also associated with significantly higher impulsivity (BIS-11;  $F=13.275$ ) and aggression (AQ;  $F(2,57)=19.618$ ) compared to BD and controls. Compared to controls, BD participants reported higher trait negative affect ( $t(38)=3.099$ ,  $p=0.004$ ) and reported higher levels of impulsivity ( $t(38)=3.378$ ,  $p=0.002$ ). While their total aggression scores did not differ from those of the controls, they reported significantly higher hostility ( $t(38)=2.579$ ,  $p=0.014$ ).

< Table 1 about here >

BPD and BD participants did not significantly differ with respect to past admission to hospital ( $\chi^2(1)=1.615$ ,  $p=0.204$ ) or past detention under the mental health act ( $\chi^2(1)=0.525$ ,  $p=0.469$ ). BPD participants were more likely to be taking antidepressant medication ( $\chi^2(1)=3.600$ ,  $p=.058$ ) or receiving psychological treatment ( $\chi^2(1)=6.144$ ,  $p=0.038$ ) than the BD and healthy volunteers (see Supplemental Materials). However, overall, there was no significant difference between the number of participants from each of the two clinical groups taking psychotropic medication ( $\chi^2(1)=2.133$ ,  $p=0.144$ ). Fourteen participants in the BPD group and 9 in the BD group reported early physical or sexual abuse compared with none in the HC group. There was no significant difference between the two clinical groups ( $\chi^2(1)=2.56$ ,  $p=0.11$ ).

### ***Choice reaction time task***

Overall, there was no significant differences in mean latencies for correct responses between the BPD participants, BD disorder patients, and healthy volunteers (376ms, 346ms vs 347ms, respectively,  $F(2,57)=1.787$ ). Similarly, there were no significant group differences in the latencies for incorrect (error) trials (329ms, 321ms vs 302ms respectively),  $F(2,57)=0.518$  or error rates (0.08, 0.071 vs 0.071),  $F(2,57)=0.617$ ). No participants completed the task error-free.

<Table 2 about here>

### ***EZ-diffusion model***

The three groups did not differ with respect to drift rates ( $F(2, 57)=1.66$ ,  $p=0.199$ ), boundary separation ( $F(2,57)=0.195$ ,  $p=0.823$ ) or non-decision time ( $F(2,57)=0.507$ ,  $p=0.605$ ).

<Figure 1 about here>

### ***Post error slowing (PES)***

Mean correct latencies tended to decrease (see Figure 2),  $F(4)= 7.644$ ,  $p< .0001$ ; while errors tended to increase,  $F(4)= 7.619$ ,  $p< .01$ ) over the 5 trials preceding an incorrect response.

However, these patterns did not differ between the BPD participants, the BD participants or healthy participants,  $F(2,57)= 2.32$  and  $F(2, 57)= 0.012$ .

<Figure 2 about here>

By contrast, mean correct latencies following an error differed between groups (see Figure 2),  $F(2,57)= 6.598$ ,  $p=0.003$ ). 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 inset; Figure 2). Post-hoc Tukey tests indicated that PES was significantly greater in BPD participants compared with the BD participants ( $p<0.05$ ) and healthy volunteers ( $p<0.05$ ). PES in the BD participants was marginally larger than in the controls; this difference was not statistically 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 ( $F(2,57)=0.098$  and  $F(2, 57)= 0.177$ ).

### ***Correlational analysis***

There were no significant correlations 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 ( $-.108 \leq r \leq .290$ ).

## **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) Clinical experience attests to the difficulties associated with effectively differentiated these illnesses and highlight the need to learn more about the cognitive and emotional processes that differentiate them.

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 volunteers. Notably, the prolonged PES in the BPD was quite transitory, with reaction time and error rates returning to levels comparable to the BD participants and controls with one trial. Therefore, these data demonstrate a specific change in sensorimotor performance that differentiates BPD individuals from (euthymic) BD I individuals.

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; Ruchow et al., 2006). These experiments demonstrate that, compared to controls, BPD patients show 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; Ruchow et al., 2006). 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 reductions in reactions times, and reduced 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 is distinguishing feature across the two diagnoses. Previous investigations using 'flanker' stimuli show that, in comparison with healthy 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; Ruchow et al., 2006). The present findings, 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).

There are several candidate explanations for PES (Dutilh et al., 2012). These 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 the response option that just produced an error, 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) , distraction of attention (such that errors are infrequent and 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 achieve an explicit error rate.

Possibly, these changes in PES relate to structural and functional features of BPD. Post-error adjustment is mediated by action-monitoring processes supported in the medial prefrontal cortex and especially anterior cingulate cortex (Botvinick et al., 1999; Koban and Pourtois, 2014; Van Veen and Carter, 2002). BPD is associated with reduced ACC volumes (Hazlett et al., 2005) and diminished ACC activity under conditions of behavioural inhibition (as part of a Go/No-Go task) in the context of negative emotional arousal (Silbersweig et al., 2007). A recent study has found no difference in performance or BOLD signal in BPD when compared to healthy individuals when completing a Go/No-Go task under neutral conditions suggesting that negative emotion may play an important role in modulating response inhibition (van Eijk et al., 2015).

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). The present findings that euthymic BD participants exhibit choice reaction times, error rates and PES quite comparable with age and ability-matched healthy volunteers is consistent with earlier observations that deficits in sustained attention relate to target detection and not simply changes in response bias (Harmer et al., 2002).



## Limitations

We acknowledge a number of limitations to the study. First, the relatively small sample size although this is larger than three previous studies (deBrujin et al., 2006, Ruschow et al., 2006; Vega et al., 2015). Second, the relatively low number of error across meant that we were unable to compare the EZ-model parameters for pre and post error trials (Dutilh et al., 2012). Third, all error trials were followed by feedback in the form of a beep which may have distracted participants, possibly confounding an interpretation in terms of PES. However, given that the error frequencies did not differ between groups the increased distraction in the BPD group is likely to be a true phenomenon. Fourth, 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, multiple dose studies in healthy volunteers are inconsistent (Serretti et al., 2010). The impact of SSRIs on 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 the BPD group has significantly higher levels of self-reported state negative affect. A number of studies have explored the impact of negative affect on PES and have not found any significant differences in performance (Hajcak et al., 2004; Olvet and Hajcak, 2012). We found no correlation between state or trait negative affect and PES in our three participant groups.

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 and BD can be distinguished in terms of the action-monitoring processes operating following errors. PES may be a promising neuropsychological endophenotype for BPD.

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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 ( $\pm$ 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 ( $\pm$ standard errors) and error rates ( $\pm$ 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 ( $\pm$ 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.