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Common and Distinct Modulation of Electrophysiological Indices of Feedback Processing by Autistic and Psychopathic Traits

Virginia Carter Leno,

Yale School of Medicine, Child Study Center, 230 South Frontage Road, New Haven, Connecticut, USA

Adam Naples,

Yale School of Medicine, Child Study Center, 230 South Frontage Road, New Haven, Connecticut, USA

Anthony Cox,

Yale School of Medicine, Child Study Center, 230 South Frontage Road, New Haven, Connecticut, USA

Helena Rutherford, and

Yale School of Medicine, Child Study Center, 230 South Frontage Road, New Haven, Connecticut, USA

James McPartland

Yale School of Medicine, Child Study Center, 230 South Frontage Road, New Haven, Connecticut, USA

Virginia Carter Leno: virginia.m.carter_leno@kcl.ac.uk; Adam Naples: Adam.naples@yale.edu; Anthony Cox: Dookie_1000@hotmail.com; Helena Rutherford: Helena.rutherford@yale.edu; James McPartland: James.mcpartland@yale.edu

Abstract

Both autism spectrum disorder (ASD) and psychopathy are primarily characterized by social dysfunction; overlapping phenotypic features may reflect altered function in common brain mechanisms. The current study examined the degree to which neural response to social and non-social feedback is modulated by autistic versus psychopathic traits in a sample of typically-developing adults (N=31, 11 males, 18–52 years). Event-related potentials were recorded whilst participants completed a behavioral task and received feedback on task performance. Both autistic and psychopathic traits were associated with alterations in the neural correlates of feedback processing. Sensitivity to specific forms of feedback (social, non-social, positively-valenced, negatively-valenced) differed between the two traits. Autistic traits were associated with decreased sensitivity to social feedback. In contrast, the antisocial domain of psychopathic traits was associated with an overall decrease in sensitivity to feedback, and the interpersonal manipulation domain was associated with preserved processing of positively-valenced feedback. Results suggest

Correspondence to: James McPartland, James.mcpartland@yale.edu.

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distinct alterations within specific mechanisms of feedback processing may underlie similar difficulties in social behavior.

Keywords

Autism spectrum disorder; Psychopathic traits; Feedback processing; Event-related potentials; Electroencephalography

Autism spectrum disorder (ASD) and psychopathy represent distinct clinical entities, with distinct neurodevelopmental etiologies. Nevertheless, the primary impairment in both groups is that of social dysfunction, suggesting potential commonalities in the brain bases of both disorders. The comparative study of ASD and psychopathy has proved helpful in elucidating impairments in distinct processes, which may underlie at-times similar difficulties in social reciprocity (Blair, 2005a). One process which may be key to adaptive social functioning is feedback processing. Appetitive and aversive social cues constitute a feedback system that shapes ongoing behavior through expected associative contingencies (Baumeister, Vohs, DeWall, & Zhang, 2007). Both social and non-social rewards act as reinforcers that modulate on-going behaviour, and individual sensitivity to both reward and social cues mediates this relationship (Kohls, Peltzer, Herpertz - Dahmann, & Konrad, 2009). To maintain appropriate social behavior, one must be able to detect negative feedback and modulate behavior accordingly. The current study aims to uncover common and unique patterns of neural sensitivity to different types of social feedback associated with autistic and psychopathic traits.

ASD is a neurodevelopmental disorder characterized by impairments in social communication, and restrictive and repetitive behaviors (American Psychological Association, 2013), with atypical social functioning as the unifying feature (McPartland, Coffman & Pelphrey, 2011). Individuals with ASD often lack the inherent interest in social information seen in typically developing individuals, as demonstrated by a breadth of behavioral studies (for an overview see Chevallier, Kohls, Troiani, Brodtkin, & Schultz, 2012). The decrease in interest towards social information and atypical social behavior seen in individuals with ASD may stem from decreased motivation to engage with towards social stimuli (Chevallier, Kohls, et al., 2012; Dawson, Webb, & McPartland, 2005). Difficulties in processing and assessing the of reward value of social information may be present from an early age, leading to decreased motivation to attend towards, and thus less exposure to, social cues. Consequently, fewer opportunities are presented for an experience-expectant system to specialize for social information during developmentally sensitive periods (Nelson, 2001). In support of this hypothesis, individuals with ASD display atypical neural response to social feedback both for social reward (e.g., smiling faces; Scott-Van Zeeland, Dapretto, Ghahremani, Poldrack, & Bookheimer, 2010; Dichter, Richey, Rittenberg, Sabatino, & Bodfish, 2012) and social loss (e.g., social exclusion; Masten et al., 2011; McPartland, Crowley, et al., 2011a). This pattern of selectively decreased sensitivity extends to the broad autism phenotype, with decreased neural activity found during anticipation of social rewards, but not non-social rewards, in individuals with high levels of autistic traits (Cox et al., 2015). Electrophysiological studies of feedback processing focus upon the

feedback related negativity (FRN), a negative event-related potential component (ERP) found 200–300ms after feedback delivery over the frontal lobes. Amplitudes are greater in response to sub-optimal outcomes, such as incorrect responses or losses, as compared to optimal outcomes (Yeung, Botvinick, & Cohen, 2004). Greater FRN amplitudes are found in individuals who rate higher task involvement, suggesting it indexes the motivational salience of outcomes (Yeung, Holroyd, & Cohen, 2005). FRN amplitude and latency are normative in ASD for non-social feedback (Larson, South, Krauskopf, Clawson, & Crowley, 2011; McPartland et al., 2012) but atypical for social feedback (Stavropoulos & Carver, 2015).

Psychopathy is also characterized by difficulties in social functioning. It is composed of two components, an interpersonal style characterized by a lack of remorse and empathy, and a tendency to use others for personal gain and patterns of antisocial, impulsive and aggressive behaviour (Frick & White, 2008). These two underlying dimensions are thought to be independent, and etiologically separable (Frick, Lilienfeld, Ellis, Loney, & Silverthorn, 1999; Harpur, Hare & Hakstian, 1989).

Individuals with psychopathic traits have a specific neurocognitive profile, which is proposed to underlie the behavioural phenotype. The two domains implicated in models of psychopathy are impairments in reinforcement learning and in the processing of social cues. Individuals with psychopathic traits demonstrate selective impairment in processing negative but not positive feedback (Blair, Mitchell, Leonard, et al., 2004), and decreased neural response to feedback for punishment but preserved response to reward (Dikman & Allen, 2000; Von Borries et al., 2010). Individuals with psychopathic traits are also less sensitive to social cues, specifically being less adept at recognising fearful faces (Marsh & Blair, 2008). Adults with psychopathic traits and young people with callous-unemotional traits (thought to be a developmental precursor to adult psychopathy) show reduced neural activity in response to sad and fearful faces (Jones, Laurens, Herba, Barker, & Viding, 2009; Marsh et al., 2008; White et al., 2014). Reduced sensitivity to negative feedback and negatively-valenced social cues in individuals with psychopathic traits is hypothesized to lead to the development of atypical patterns of social functioning and empathic difficulties (Blair, 2005b).

Specifically regarding the FRN component, individuals with higher scores on the ‘fearless dominance’ aspect of psychopathic traits (characterized by impairments in interpersonal sensitivity) show reduced FRN amplitudes to negative feedback (Schulreich, Pfabigan, Derntl & Sailer, 2013). Individuals scoring higher on questionnaires of antisocial personality show decreased FRN response to social, as compared to non-social, feedback (Pfabigan, Alexopoulos, Bauer, Lamm, & Sailer, 2011). These studies suggest that psychopathic tendencies are associated with alterations in FRN amplitude, and also, as reported elsewhere (Carré, Hyde, Neumann, Viding, & Hariri, 2013), that different dimensions of psychopathy may have distinct neural correlates.

Comparative studies suggest independent mechanisms underpin phenotypic similarities (e.g., atypical empathic functioning) in psychopathy and ASD (Jones, Happé, Gilbert, Burnett, & Viding, 2010; Rogers, Viding, Blair, Frith, & Happe, 2006; Schwenck et al., 2012). Only one study has explored whether independent patterns of neural functioning are also found between the two groups (O’Nions et al., 2014). This study compared patterns of

activity in the amygdala between children with ASD and children with conduct problems and callous-unemotional traits during a Theory of Mind task, which required the ability to represent the mental states of another individual. Results showed differential neural responses during between the two groups. Whether a similar differentiation is found across different domains (e.g., feedback processing), and in typically developing adult samples, remains unexplored.

The current study investigated common and distinct patterns of neural response to different types of feedback associated with autistic and psychopathic traits in a sample of typically developing adults. We examined the association between autistic and psychopathic traits and FRN component amplitude elicited by positively and negatively-valenced feedback presented in social, non-social or neutral contexts. We hypothesized that individuals with autistic traits and those with psychopathic traits would show an attenuated FRN amplitude to feedback in a social context, and that individuals with psychopathic traits would show a preserved FRN response to positively-valenced feedback. Given evidence for independent neural correlates among subtypes of psychopathic traits (Carré et al., 2013), we also sought to explore the relationships between different dimensions of psychopathic traits and FRN amplitude.

Materials and Methods

Participants

Study participants were recruited from the local community in New Haven, Connecticut through flyers and word-of-mouth advertising. In total, 66 participants volunteered to take part in the study and were pre-screened using online-questionnaires. From this sample, 41 were invited to participate. Selection of participants was based on scores of autistic traits and psychopathic traits, with the aim of inviting a sample with a range of traits to complete the EEG paradigm. To be invited to take part, participants must have reported being at least 18 years old with no chronic illness, current or historical psychiatric diagnosis (including a diagnosis of ASD), seizures, learning or intellectual disability, motor impairments, heart or urinary condition, brain injury, brain disease or brain malformation. All participants had normal or corrected to normal vision and hearing and were not taking any psychoactive medication. Of the forty-one selected participants, one was excluded due to report of a psychiatric diagnosis, one due to use of psychoactive medication, one due to the EEG data loss, one due to atypical EEG data, and six due to excessive ocular EEG artifact causing them to fall below the minimum threshold of acceptable trials (25%, as in McPartland et al., 2012). The final sample included in the analyses was comprised of 31 participants; participant characteristics are displayed in Table 1.

Behavioral Measures

Questionnaires

Autistic Traits: Social Responsiveness Scale – Adult Version (SRS-A; Austin, 2005). The SRS-A is a 65-item self-report questionnaire designed to assess characteristics associated with autism in the general population. The SRS-A correlates with the widely-used Autism Diagnostic Interview-Revised (ADI-R) ($r=0.7$), has good inter-rater (parent-teacher $r=0.8$)

and test-retest (over a 3 month period $r=0.83$) reliability (Constantino & Todd, 2005). Internal consistency of the SRS-A was high in our sample ($\alpha=.91$).

Psychopathic Traits: Self-Report Psychopathy Scale–Short Form (SRP-4-SF; Paulhus, Neumann, and Hare, in press) is designed to measure psychopathic traits in the general adult population. The SRP-4-SF consists of 29 items designed to cover the four main facets of psychopathy, with subscales indexing interpersonal manipulation (e.g. ‘I would get a kick out of ‘scamming’ someone’), affective callousness (e.g. ‘People sometimes say that I’m cold-hearted’), erratic lifestyle (e.g. ‘I rarely follow the rules’), and antisociality (e.g. ‘I was convicted of a serious crime’). The SRP-4-SF correlates with externalizing and criminal behavior (Neumann & Pardini, in press) and has been used to differentiate neural correlates associated with independent facets of psychopathic traits (Carré, Hyde, Neumann, Viding, & Hariri, 2013). Internal consistency of the SRP-SF-4 was high in our sample ($\alpha=0.88$), similar to elsewhere (Lockwood, Bird, Bridge, & Viding, 2013).

General Procedures

Informed consent was obtained from all participants prior to the testing session. Participants were given verbal instructions informing them they would take part in a computer game. The task required participants to press a button as quickly as possible after a target was displayed. Participants were informed that throughout the task they would receive different types of live feedback on their performance, either (1) from an ‘observer’ viewing their performance in another room; or (2) in the form of candy (participants were given the choice of Hershey’s Kisses or Reeses Pieces), or (3) in the form of geometric shapes. All videos were pre-recorded but participants were deceived to encourage task involvement and to increase ecological validity for social reinforcement. After task completion, participants were debriefed and informed that videos were pre-recorded, and compensated \$40.

Experimental Paradigm

The feedback paradigm was created with E-Prime 2.0 software (Psychology Software Tools) and presented on a 17-inch colour monitor (60 Hz, 1024 x 768 resolution) in a sound attenuated room during conditions of low ambient illumination. The feedback paradigm was designed to give six conditions of video feedback based upon task performance. All stimuli and images were centered and presented on a plain black background. Figure 1 presents a schematic of block and trial structure. Blocks began with a cue image combined with text, informing the participant whether they would be playing ‘to gain positive social feedback/candy/shapes’ (positive valence) or to ‘avoid negative social feedback/losing candy/losing shapes’ (negative valence) paired with a pictorial descriptor of the type of context (social, non-social or neutral). There were six block types in total (positive social, negative social, positive non-social, negative non-social, positive neutral, negative neutral). Each trial began with the presentation of a fixation cross (jittered between 800–1200ms), followed by the target stimulus (500ms), during which the participant was instructed to press the response button. After a response was detected, or stimulus presentation ended, a blank screen was displayed (750ms). Next the participant was given immediate feedback on their performance. If the response was correct then positive feedback in the form of a circle was displayed (1000ms), however if the response was incorrect then negative feedback in the

form of a square was displayed (1000ms). Following feedback, a blank screen was again displayed (250ms) and the next trial would begin. Feedback stimuli were equiluminous and comparable in size (approximately 2.5cm x 2.5cm). Each block began with the same task criteria. Participants were given a controller with which to make their responses and were instructed to use the index finger of their dominant hand to make their responses. Participants were asked to focus upon the task and to try to move as little as possible. Participants were given a short practice round (5 trials, no feedback video was displayed) before beginning the main task. Study staff were careful not to give praise or encouragement to participants during the task to avoid diminished responsivity to task feedback due to external social reinforcement (Gewirtz & Baer, 1958).

For a trial to be considered correct a button press must have been detected during target presentation. If a response was detected before or after the target was presented, this was considered incorrect. The duration of target presentation for subsequent trials was adjusted based on performance on the preceding trial. Following each correct response, target presentation duration decreased by 75ms, with a minimum of 20ms. Following each incorrect response, the presentation duration increased by 50 ms, with a maximum of 300ms.

This approach allowed task difficulty to be adaptively adjusted to individual performance level to ensure a success rate of approximately 40%, to give sufficient incorrect trials for analysis. At the end of a trial block, a feedback video was displayed, informing the participant of their performance in the block (i.e., number correct or incorrect). 10 videos were recorded for each block type, corresponding to each of 10 potential outcomes. Feedback in the social context condition consisted of dynamic videos of the ‘observer’ verbally informing the participant of how many trials they got wrong (negative valence; ‘You got XX wrong’) or right (positive valence; ‘You got XX right’). Feedback in a non-social context condition consisted of videos of candy being concealed (negative valence) or revealed (positive valence), the number of which was contingent upon how many trials the participant got wrong or right (see Figure 2 for example). Feedback in the neutral context condition consisted of videos of white shapes being concealed (negative valence) or revealed (positive valence), the number of which was contingent upon how many the participant got wrong or right. Each block consisted of 10 trials, and there were 8 blocks of each type of feedback (positive social, negative social, positive non-social, negative non-social, positive neutral, negative neutral) giving 80 trials for each feedback condition and 48 blocks in total. The order of block type was pseudo-randomised such that no same feedback block was presented consecutively. The paradigm lasted approximately 35 minutes.

ERP Procedures

EEG was recorded continuously throughout the task using a 128 Electrical Geodesics Hydrocel Sensor Net (Electrical Geodesics Inc., Eugene, OR) and a NetAmps 300 amplifier. Once the task and EEG procedure had been fully explained, the 128 lead Geodesic Sensor Net was placed upon the participant’s head as per manufacturer instructions. All impedances were kept below 40 kilo-ohms. Participants were positioned approximately 80cm viewing distance from the screen, giving a viewing angle of 17.90° x 17.90°.

EEG Data Collection and Processing

EEG was recorded continuously at 500Hz using NetStation 4.3. Cz served as the online reference point for all electrodes. EEG data was processed using Netstation v. 4.4 software. Data was low-pass filtered at 30Hz and high-pass filtered at 0.1Hz offline prior to segmentation. Filtered data was segmented into epochs lasting 100ms pre to 450ms post stimulus. Artifact detection settings were set to 200 μ v for bad channels, 140 μ v for eye blinks, and 100 μ v for eye movements. Channels with artifacts on more than 40% of trials were marked as bad channels and replaced through spline interpolation. Segments that contained eye blinks, eye movement or more than ten bad channels were excluded. Data were re-referenced to an average reference and baseline corrected to the 100ms pre-stimulus onset epoch. Trial-by-trial data was subsequently averaged at each electrode for each condition (positive social/non-social/neutral, negative social/non-social/neutral) separately for each participant. Participants with greater than 75% bad trials (Schneider, Eschman, & Zuccolotto, 2002) were subject to additional processing using ocular artifact removal (Gratton, Coles, & Donchin, 1983). This enabled inclusion of an additional 12 participants in overall analyses. The mean number of trials per subject was 277. There were no significant differences between groups in the percentage of good trials when the sample was divided into low as compared to high SRS and SRP-SF-4 subscale trait scores later in the analyses. Electrodes of interest were selected based on prior literature (McPartland et al., 2012) and observed component amplitudes. The selected temporal window for component analysis was based on visual inspection of the grand average of all participants' data and confirmed in individual averages. Minimum FRN amplitude and latency to peak were extracted at electrodes 5, 6, 11, 12 (Figure 3) in the time window 200–350ms post-stimulus presentation. All amplitudes and latencies were exported to SPSS (v. 19) for analysis.

Data Analysis

Descriptive statistics were computed for demographic variables of age, sex, ethnicity, and handedness. First a repeated-measures ANOVA was run with response (correct/incorrect) as a within-subject factors to verify the presence of an FRN in our sample. To assess the relationship between trait scores and FRN amplitude three 2 x 3 x 2 ANCOVAs were conducted with response x context (social/non-social/neutral) x valence (positive/negative) as within-subjects factors, and continuous trait scores as covariates. First we tested the relationship between autistic traits and neural response using an ANCOVA with SRS total score as a covariate. We focused on the total score of the SRS, rather than subscales, as literature indicates it is best represented by a single factor (Constantino et al., 2004).

Next we tested the relationship between psychopathic traits and neural response using an ANCOVA with SRP-SF-4 as a covariate. We also conducted a further, separate ANCOVA using the subscales of the SRP-SF-4 (affective callousness, interpersonal manipulation, antisociality erratic lifestyle) as covariates. We decided a priori to conduct additional analyses using the SRP-SF-4 subscales due to previous literature suggesting that underlying facets of psychopathic traits are independent constructs (Frick et al., 1999; Harpur, Hare & Hakstian, 1989) and are associated with distinct neural signatures (Carré et al., 2013). Post hoc planned paired *t*-tests were used in groups of individuals with low and high trait scores, divided by median split, to explore any interaction effects. Cohen's *d* and eta-squared (η^2)

are reported indicating the effect sizes ($d=.20$ and $\eta^2=0.1$ representing small effects, $d=.50$ and $\eta^2=.06$ representing medium effects, and $d=.80$ and $\eta^2>.14$ representing large effects, Cohen, 1973, 1988). All FRN amplitudes are reported in microvolts (μv).

Results

Demographic Information

Table 1 gives the demographic information for the overall sample. A main effect of response was found, indicating that feedback following an incorrect response ($M=-1.59$, $SD=2.50$) elicited greater FRN amplitudes than that following a correct response ($M=-0.88$, $SD=2.81$) [$F(1, 30)=9.10$, $p=0.005$, $\eta^2=.23$]. This verified the presence of the FRN following feedback in our sample.

Autistic traits—A response (correct/incorrect) x context (social, non-social, neutral) x valence (positive, negative) x SRS score ANCOVA identified a response x context x SRS interaction [$F(2,58)=3.28$, $p<0.05$, $\eta^2=.10$]. The sample was divided into low and high SRS scores based upon median split (median=41), to explore the directionality of the interaction (Table 2). There were no significant differences in age, sex, race or handedness between the low as compared to the high SRS group (see Table 1). The low group comprised of 15 participants ($M=27.40$) and the high group comprised of 16 participants ($M=55.19$). In the low SRS group greater FRN amplitude was seen following an incorrect response ($M=-1.22$, $SD=2.07$), as compared to a correct response ($M=-.07$, $SD=2.44$), within the *social* context condition only [$t(14)=-3.06$, $p=0.009$, $d=.72$, see Table 2]. No significant differences were found between incorrect and correct responses in the non-social or neutral context [non-social comparison $t(14)=-1.07$, $p=0.30$; neutral comparison $t(14)=-.11$, $p=0.92$].

Within the high SRS group, greater FRN amplitude was seen following an incorrect response ($M=-2.13$, $SD=3.02$) compared to a correct response ($M=-.83$, $SD=3.52$) within the *non-social* context condition [$t(15)=-4.21$, $p=0.001$, $d=1.14$, see Table 2]. No significant differences in FRN amplitude were found between incorrect and correct responses in the social or neutral context [$t(15)=-.91$, $p=0.38$; $t(15)=-1.12$, $p=0.26$ respectively]. Comparison of grand average waveforms detailing the difference in FRN amplitude following incorrect relative to correct responses to feedback across social, non-social and neutral contexts, in individuals with low and high levels of autistic traits can be seen in Figure 4.

Inspection of data suggested a trend towards more males in the high SRS group ($p=0.06$). Therefore, the original ANCOVA was re-run, with sex added as an additional covariate. This test found no main effect or interaction with sex, suggesting that an imbalance in the ratio of male to female participants between groups was not driving results.

Psychopathic traits—No interaction was found with total SRP-SF-4 score. However, a response x context x antisociality subscale interaction [$F(2,52)=5.25$, $p=0.008$, $\eta^2=.17$] and a response x valence x interpersonal manipulation subscale interaction [$F(1,26)=5.06$, $p=0.03$, $\eta^2=.16$] were found. To check that findings were not driven by differences in

autistic traits between low and high psychopathic trait groups, correlations between autistic and psychopathic traits were examined. No significant correlations were found between SRS and any of the SRP-SF-4 subscales.

Response x context x SRP-SF-4 antisociality subscale interaction—To further explore the interaction, the sample was divided by quartile (lower quartile=12, upper quartile=15) instead of by median split, as 7 participants fell on the median score (median=13). There were no significant differences in age, sex, race or handedness between the low as compared to the high antisociality group (see Table 1). The low group comprised of 14 participants ($M=11.43$), and the high group comprised of 9 participants ($M=16.11$). In the low group greater FRN amplitude was found for incorrect ($M=-1.12$, $SD=2.90$) compared to correct ($M=-.46$, $SD=3.05$) responses within the non-social context condition [$t(13)=-3.10$, $p=0.008$, $d=.82$]. A trend towards greater FRN amplitude following incorrect ($M=-.95$, $SD=2.22$) compared to correct ($M=-.11$, $SD=2.91$) responses was seen within the social context condition [$t(13)=-1.92$, $p=0.08$, $d=.57$]. No differences in FRN amplitude were found following incorrect ($M=-.52$, $SD=2.74$) as compared to correct ($M=-.92$, $SD=2.39$) feedback within the neutral context condition [$t(13)=-1.03$, $p=0.32$, $d=.28$]. Within the high group, no differences in FRN amplitude were seen between incorrect and correct responses within the social, non-social or neutral context conditions (see Table 3, all $p=0.211$, $.696$, $.207$ respectively).

Response x valence x SRP-SF-4 interpersonal manipulation subscale interaction—The sample was divided into low and high groups based upon median split of the interpersonal manipulation subscale scores (median=16). The low group was comprised of 15 participants ($M=11.40$), and the high group comprised 16 participants ($M=18.69$). There were no significant differences in age, sex, race or handedness between the low as compared to the high interpersonal manipulation group (see Table 1). In the low group, greater FRN amplitude was seen following incorrect ($M=-1.79$, $SD=2.02$) compared to correct responses ($M=-.73$, $SD=2.19$) in the *negatively-valenced* conditions [$t(14)=-3.74$, $p=0.002$, $d=.98$]. No difference in FRN amplitude was seen between incorrect ($M=-1.59$, $SD=1.93$) and correct ($M=-1.19$, $SD=2.31$) responses in the *positively-valenced* conditions [$t(14)=-1.01$, $p=0.33$].

In the high group, a trend towards greater FRN amplitude following incorrect ($M=-1.48$, $SD=2.88$) versus correct responses ($M=-.52$, $SD=3.67$), was seen in the *positively-valenced* feedback conditions [$t(15)=-2.02$, $p=0.06$, $d=.55$]. No difference in FRN amplitude was seen between incorrect ($M=-1.50$, $SD=3.24$) and correct ($M=-1.08$, $SD=3.21$) responses in the *negatively-valenced* conditions [$t(15)=-1.17$, $p=0.26$]. Comparison of grand average waveforms detailing the difference in FRN amplitude following incorrect relative to correct responses to negatively and positively-valenced feedback, in individuals with low and high levels of interpersonal manipulation can be seen in Figure 5.

Discussion

The present study is the first to use ERPs to examine common and distinct alterations in feedback processing associated with autistic and psychopathic traits. Feedback processing

was examined by measuring neural response to positively and negatively-valenced feedback in social, non-social, and neutral contexts in a sample of typically developing adults. Atypical feedback processing was associated with high levels of both autistic and psychopathic traits; however independent associations to different forms of feedback were found between autistic and psychopathic traits. As predicted, individuals with autistic traits showed a normative response only to non-social feedback. However, counter to our hypotheses, individuals with psychopathic traits did not display normative sensitivity to non-social feedback. Dissociation between sub-types of psychopathic traits was found. Individuals with antisocial traits demonstrated an overall attenuation of sensitivity to feedback. However, individuals with interpersonally manipulative traits showed a normative response to feedback when it was positively-valenced.

Our finding of altered feedback processing in both individuals with autistic traits and in those with psychopathic traits aligns with the suggestion that disruptions in feedback processing may represent a cross-diagnostic endophenotype for psychiatric illness (Hyman, 2007). The processing of positive and negative feedback may be a key adaptive process in shaping ongoing behaviour (Baumeister, Vohs, DeWall, & Zhang, 2007). However, the different pattern of neural response during feedback processing between individuals with autistic traits and those with psychopathic traits suggests that surface level commonalities in social dysfunction may be driven by distinct neural mechanisms. Individuals with autistic traits showed significantly reduced sensitivity to feedback presented in a social context. Response to feedback varied by subtype of psychopathic traits; with those high in antisocial traits displayed an overall decrease in sensitivity to feedback whereas those high on the interpersonal manipulation subscale showed specific insensitivity to negatively-valenced feedback. Patterns of distinct neural sensitivity concord with previous research reporting independent mechanisms underlying surface level similarities between individuals with ASD, and individuals with psychopathic (Jones et al., 2010) and callous-unemotional traits (O’Nions et al., 2014; Schwenck et al., 2012). Although social dysfunction is the defining characteristic of both ASD and psychopathy, independent mechanisms underpin phenotypic overlap and suggest distinct etiologies and intervention approaches. Our results demonstrate that understanding the neural mechanisms underlying specific domains of function across psychiatric disorders offers clinically relevant information about cognition and behavior (Insel et al., 2010).

As in our prior work (Cox et al., 2015; McPartland et al., 2012), the current study found individuals with higher levels of autistic traits displayed typical patterns of neural responsiveness to feedback presented in a non-social context; however, the neural response was attenuated for feedback presented in social contexts. As FRN amplitude is dependent upon task involvement and has been proposed to reflect a neural index of the motivational salience of outcomes (Yeung et al., 2005), these results suggest that individuals with high levels of autistic traits found social feedback less salient. This finding adds to the body of literature that proposes a specific impairment in individuals with ASD in processing social information with relatively preserved processing of non-social information (McPartland, Wu, Bailey, Mayes, Schultz & Klin, 2011b). Our results are also compatible with observations of atypical neural response to computer simulated social rejection (Masten et al., 2011; McPartland, Crowley, et al., 2011a), suggesting that feedback in social situations

may be processed differently, or to a lesser degree, in both individuals with autistic traits, and those with ASD. Although our study focused upon autistic traits in typically developing adults, results may also help to explain aspects of the behavioral phenotype of ASD. Diminished response to social ostracism (Sebastian et al., 2009) and inappropriate social behavior may reflect an inability to use negative social feedback to modulate behavior.

Regarding associations between psychopathic traits and feedback processing, the current study did not find an association between neural response and overall level of psychopathic traits, but instead found independent associations between antisocial and interpersonally manipulative traits and neural response to feedback. This differentiation between sub-facets of psychopathic traits is in line with research suggesting they represent independent constructs (Frick et al., 1999; Harpur, Hare & Hakstian, 1989) with dissociable neural signatures (Carré et al., 2013). Participants with high levels of antisocial traits demonstrated an overall attenuated neural response to feedback. However, given the literature reporting difficulties in processing social cues in antisocial populations (Marsh & Blair, 2008) yet preserved processing of non-social cues (Pfabigan et al., 2011), we expected a differentiation in neural response between social and non-social contexts. This was not seen, as individuals with antisocial traits failed to show a FRN in response to suboptimal outcomes in both social and non-social contexts. This is consistent with a recent study finding reduced FRN amplitudes to both social and non-social feedback in typically developing individuals with high levels of psychopathic traits, although this study found associations with the ‘fearless dominance’ aspect of psychopathy, rather than the antisocial dimension (Schulreich et al., 2013). This lack of sensitivity to feedback could underlie the preponderance of impulsively aggressive acts associated with antisocial traits, as cues to inhibit inappropriate behaviors may be insufficiently salient to modulate behavior.

Unlike those with antisocial traits, participants with traits indicative of interpersonal manipulation demonstrated a preserved neural response to feedback when the feedback was positively-valenced. This is in line with previous reports that individuals with psychopathic traits demonstrate decreased sensitivity to negatively-valenced feedback, yet preserved sensitivity to positively-valenced feedback (Blair, Mitchell, Leonard, et al., 2004). A lack of neural response to negatively-valenced feedback may lead to difficulty in forming adaptive behavior-response contingencies to inhibit future maladaptive behavior. This sensitivity to negatively-valenced feedback may be key in emotional aversive conditioning processes and in the consequent development of appropriate socialization and empathic functioning (Blair, 2005b). The pattern of selective neural response seen in our results may explain the calculated and callous nature of some individuals with high levels of psychopathic traits. If the systems that govern reward are intact, yet those that process punishment are impaired, this may lead to an interpersonal style that is focused upon obtaining goals, without consideration for the negative consequences of their actions. This implies that interventions to improve empathic functioning should focus on rewards gained for not engaging in maladaptive and manipulative interpersonal behaviour rather than threats of punishment. Additionally, our findings support the importance of sub-typing individuals with psychopathic traits, given the distinct patterns of feedback processing associated with the interpersonal manipulation, as compared to the antisocial, facets of psychopathy.

The current study found distinct patterns of neural sensitivity to feedback associated with autistic and psychopathic traits. Results suggest studying psychiatric traits in typically developing populations may offer insights into how differences in neural functioning underpin variation in behavior. Results also add to literature suggesting that distinct mechanisms may underlie common phenotypic features, suggesting that consideration of equifinality in psychopathology is crucial. A critical next step is exploring the developmental stability of these patterns of neural sensitivity; given the high heritability of both autistic and psychopathic traits (Jones et al., 2009), specific neural alterations in feedback processing may also be heritable, representing one biological manifestation of genetic risk for atypical social development. Additionally, as the current study used a self-report methodology, results could be affected by participants' willingness to disclose said traits. Further studies would benefit from utilizing multi-informant measures.

Insight into the neural mechanisms of feedback processing and its relationship to social performance may be used in conjunction with behavioral assessment to impute subtypes relevant to etiology. Additionally, future treatment formulations may benefit from evaluation of disparately affected or preserved functional domains to tailor interventions to improve mechanistic functioning in specific areas of vulnerability rather than the 'one-size-fits-all' treatments that may be indicated by descriptive diagnostic categories.

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Figure 1.
Trial structure

Figure 2. Screenshot of neutral feedback video to illustrate how feedback in neutral and non-social contexts was concealed (negative valence) and revealed (positive valence). The sliding centerpiece moved forward or backward to conceal or reveal shapes or candy.

Figure 3.
FRN Montage (electrodes 5, 6, 11, 12)

Figure 4. Difference in FRN amplitude (incorrect – correct) for negative feedback within social, non-social and neutral contexts in individuals with low (left hand panel) and high (right hand panel) levels of autistic traits

Figure 5. Difference in FRN amplitude (incorrect – correct) for negatively and positively-valenced feedback in individuals with low (left hand panel) and high (right hand panel) levels of interpersonal manipulation

Table 1

Demographic information for total sample, and when split into low and high trait groups on the SRS-A, and the SRP-SF-4 antisociality and interpersonal manipulation subscales

Mean (SD)	Total Sample (N=31)	Low SRS (n=15)	High SRS (n=16)	Low SRP-SF-4 Antisociality subscale (n=14)	High SRP-SF-4 Antisociality subscale (n=9)	Low SRP-SF-4 Interpersonal Manipulation subscale (n=15)	High SRP-SF-4 Interpersonal Manipulation subscale (n=16)
Age	23.35 (6.74) (n=30)	24.94 (8.60) (N=14)	21.96 (4.40)	22.77 (4.76)	25.69 (11.39) (n=8)	22.75 (4.69)	23.96 (8.45) (n=15)
Sex (M:F ratio)	11:20	5:10	6:10	3:11	4:5	4:11	7:9
Race							
Caucasian	15	5	10	6	5	8	7
Asian	9	7	2	5	3	3	6
African	4	2	2	3	0	4	0
Black/West Indian	1	0	1	0	1	0	1
Hispanic	2	1	1	0	0	0	2
Handedness (L:R ratio)	4:27	0:15	4:12	3:11	0:9	3:12	1:15

SRP-SF-4 indicates Self Report Psychopathy-Short Form-4

SRS-A indicates Social Responsiveness Scale-Adult Version

Table 2

FRN minimum amplitude following incorrect and correct responses in social, non-social and neutral context, by level of autistic traits, as rated by the SRS-A

FRN Mean Amplitude in Microvolts	Low SRS (n=15)	High SRS (n=16)
Social	Mean (SD)	
Correct	.07 (2.44) *	-1.70 (2.93)
Incorrect	-1.22 (2.07) *	-2.04 (2.96)
Non-Social		
Correct	-.50 (3.20)	-.83 (3.52) *
Incorrect	-1.20 (2.66)	-2.13 (3.02) *
Neutral		
Correct	-.54 (2.47)	-1.67 (3.08)
Incorrect	-.59 (2.10)	-2.24 (2.75)

* significant difference between means at $p < 0.01$

SRS-A indicates Social Responsiveness Scale-Adult Version

Table 3

FRN minimum amplitude following incorrect and correct responses in social, non-social and neutral contexts, by level of antisocial traits, as rated by the SRP-SF-4 antisociality subscale

FRN Mean Amplitude in Microvolts	Low Antisocial (n=14)	High Antisocial (n=9)
Social	Mean (SD)	
Correct	-.11 (2.91)	-1.82 (2.81)
Incorrect	-.95 (2.22)	-2.54 (3.38)
Non-Social		
Correct	-1.03 (3.27) *	-1.47 (3.62)
Incorrect	-1.12 (2.90) *	-1.69 (3.33)
Neutral		
Correct	-.52 (2.74)	-2.18 (3.37)
Incorrect	-.92 (2.39)	-1.37 (3.20)

* significant difference between means at $p < 0.01$

SRP-SF-4 indicates Self Report Psychopathy-Short Form-4