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Error-related brain activity in relation to psychopathic traits in multi-problem young adults: An ERP study

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ABSTRACT

One of the most prominent issues in psychopathy is the inability to adequately monitor one's performance and learn from one's mistakes. We investigated the relationship between psychopathic traits, as measured with the Youth Psychopathy Inventory – Short Version, and both early and late error-related brain activity in an at-risk sample of male young adults. These multi-problem young adults (age 18–27) are severely dysfunctional in society and suffer from multiple problems including financial problems, delinquency, psychological problems, and drug use. Our final sample consisted of 115 multi-problem young adults and 26 controls. Participants performed an Eriksen-Flanker task during EEG measurements. We used the difference wave of the error-related negativity (ΔERN) as a measure of early error processing and the error positivity (Pe) as a measure of late error processing. Multi-problem young adults showed reduced ERN amplitudes compared to controls, but did not differ in Pe amplitude. We found no statistically significant relation between psychopathic traits and ERN and Pe amplitudes within the multi-problem group. Thus, we found evidence for dysfunctional error-processing in multi-problem young adults compared to controls. However, within the multi-problem sample we did not find evidence for a relationship between psychopathic traits and dysfunctional error-processing. One explanation may be that this is due to the specific developmental stage of our young adult participants in which a transition between error-processing deficits, as present in adolescents high in psychopathic traits, and error-processing overcompensation, as present in adults high in psychopathic traits, may occur.

1. Introduction

Psychopathy is a personality disorder characterized by affective callous-unemotional traits, impulsive and irresponsible behavior, and grandiose-manipulative interpersonal traits, with antisocial behavior either included in its definition (Hare & Neumann, 2008) or viewed as a consequence (Cooke & Michie, 2001). Psychopathic traits are related to a plethora of problems, both affective and cognitive. One of the major issues is the failure to adapt behavior to changing or new situations (e.g., to learn from mistakes). For instance, individuals with high psychopathy scores show impaired passive avoidance learning (Newman & Kosson, 1986), impaired reversal learning (Budhani, Richell, & Blair, 2006), and impaired fear conditioning (Birbaumer et al., 2005). A prerequisite for behavioral adaptation is the ability to monitor one's own performance, which is reduced in psychopathy and helps explain these behavioral deficits (Schulreich, 2016). An essential part of performance monitoring is the ability to process error-related information and when this is reduced, individuals may fail to adequately adapt their behavior.

So far, most studies on the association between error processing and psychopathy have focused on samples high in psychopathic traits, specifically in adolescent and adult incarcerated populations. Lately, more attention in forensic research is drawn to antisocial young adults and their specific needs for treatment and intervention. Since young adulthood is now regarded as a developmental stage distinct from adolescence in which both neurobiological and psychosocial changes occur (Arnett, 2000) it may prove useful to study error processing within dysfunctional populations who are challenged in making a successful transition to adulthood (Osgood, Foster, & Courtney, 2010). Multi-problem young adults (18–27 years old) are such a population: they lack a stable income, do not have the prerequisites to get a job, often show serious psychological dysfunction and drug use, most of them have engaged in criminal activities of ranging seriousness (e.g., from shoplifting to violent crimes), and two thirds of them have had Child Protection Service (CPS) interference, chiefly due to juvenile delinquency and experienced maltreatment (Van Duin et al., 2017). In

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view of the heterogeneity of their problems, we expect their psychopathic traits to vary from very low to very high. As psychopathy is better represented dimensionally than taxonomically (Edens, Marcus, Lilienfeld, & Poythress, 2006; Guay, Ruscio, Knight, & Hare, 2007; Murrie et al., 2007), in order to improve theoretical embedding it is particularly useful to study it as a dimensional construct.

Because error processing is a fast process, it is often investigated using event-related potentials (ERPs) in the electroencephalogram (EEG). Due to the high temporal resolution, it can adequately measure rapid brain processing of errors. The main components of interest are the error-related negativity (ERN) and the error positivity (Pe). The ERN occurs within approximately 100 ms after an error has been made (Holroyd & Coles, 2002) and is thought to represent the early, automatic, and unconscious processing of an error (Bernstein, Scheffers, & Coles, 1995), whereas the Pe occurs between approximately 200 to 400 ms after an error has been made (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1990) and is thought to represent a conscious and more elaborate, late processing of an error (Ullsperger, Harsay, Wessel, & Ridderinkhof, 2010). Evidence from source localization (Dehaene & Tucker, 1994; van Veen & Carter, 2002) and fMRI studies (Edwards, Calhoun, & Kiehl, 2012; see Ridderinkhof, Ullsperger, & Crone, 2004) both indicate that the ERN and Pe are generated by the anterior cingulate cortex, which in turn is theorized to play an important role in problems with motivation and regulation of behavior in psychopathy (Koenigs, 2012). However, literature suggests that early and late error processing are related to psychopathic traits differently.

Previous studies on early error-processing (as measured with the ERN) in community samples have found some associations between the ERN and psychopathy, but findings have been quite diverse. In a task involving pleasant, neutral, aversive, and non-words, one study found impulsive psychopathic traits to be related to a smaller ERN (Heritage & Benning, 2013). Similarly, impulsive psychopathic traits have been associated with a reduced ERN in a neutral task (Bresin, Sima Finy, Sprague, & Verona, 2014; Pasion, Cruz, & Barbosa, 2016). However, other findings in neutral tasks point to a relation between interpersonal traits and an increased ERN (Pasion et al., 2016), no association between affective psychopathic traits and the ERN (Bresin et al., 2014), and low-socialized students having smaller ERNs during punishment than reward conditions (Dikman & Allen, 2000). Within antisocial samples, findings have fairly consistently failed to observe a significant relationship between psychopathy scores and ERN amplitude. Studies in violent adult male offenders (Brazil et al., 2009; Steele, Maurer, Bernat, Calhoun, & Kiehl, 2015), psychopathic patients (Brazil et al., 2011), incarcerated adolescents (Maurer et al., 2015, 2018), and incarcerated female offenders (Maurer et al., 2016) found no evidence for a relationship between psychopathic traits and ERN abnormalities. All these studies used cognitive tasks (either a Go Nogo task or a Flanker task) without affective components. One earlier study also did not find any relation between psychopathic traits and the ERN in a letter Flanker task, but did find that violent offenders showed a reduced ERN compared to healthy controls in an affective Flanker task employing angry and fearful faces as stimuli (Munro et al., 2007), suggesting early error processing may be impaired when specifically processing affective information. One study did find a reduced ERN in psychopathic individuals compared to controls in a reinforcement learning task (Von Borries et al., 2010). Thus, although in community samples findings have been inconsistent, in antisocial samples psychopathic traits seem to be unrelated to the ERN during affectively neutral tasks, suggesting general early error processing is likely intact in psychopathy.

In contrast, previous research has provided evidence for dysfunctional late error processing (as measured with the Pe) in relation to psychopathic traits, but the results have been less consistent than for early error processing. Most studies have found a negative relation between psychopathic traits and the Pe, indicating that psychopathy is associated with reduced late error processing. These include studies in violent adult male offenders (Brazil et al., 2009), in incarcerated adolescents (Maurer et al., 2015), and in incarcerated female offenders (Maurer et al., 2016). However, Munro et al. (2007) found no difference between violent offenders and healthy controls on the Pe in neither a letter Flanker nor an affective face Flanker task and no relation between Pe and psychopathic traits was found in a community sample (Heritage & Benning, 2013). Likewise, in incarcerated adolescents no relation between Pe and self-reported psychopathic traits was found (Maurer et al., 2018). Lastly, Steele, Claus et al. (2015) found an opposite relation between psychopathic traits and the Pe, indicating that offenders with higher psychopathic traits had an increased Pe, and later showed this increased late error processing to also be predictive of rearrest (Steele, Claus et al., 2015). In short, dysfunctions in the later stage of error processing do seem to be present in psychopathy, but it remains unclear why the direction of the relation differs between samples. Another unsolved question is which specific psychopathic factors (i.e., grandiose manipulative, callous unemotional, and impulsive irresponsible) contribute in what way to the relationship with error processing. Older studies did not differentiate between factors (Brazil et al., 2009; Munro et al., 2007) and more recent studies have not consistently found the same factor to be of relevance (Maurer et al., 2015, 2016; Steele, Claus et al., 2015).

Where other studies focused on adolescents or adults, here we aim to extend these results in a sample of young adults (18–27 years old) who are severely dysfunctional in society and suffer from multiple problems including financial problems, a low educational level, criminal activities of ranging seriousness (e.g., from shoplifting to violent crimes), psychological problems, and drug use (Van Duin et al., 2017). To our knowledge, this is the first study to investigate psychopathic traits and error processing in a large sample of dysfunctional individuals in this specific developmental stage. Within this sample, we employed a letter Flanker task, similar to previous studies (Brazil et al., 2009; Munro et al., 2007). We included a group of healthy controls to assess whether the task worked appropriately and to investigate whether multi-problem young adults as a group perform differently compared to a healthy population. The inclusion of the three psychopathic factors as distinct predictors allows for investigation of possible differential associations between the separate factors and error processing. Based on previous findings, we expected to find no association between psychopathic factors and early error processing (ERN) and tested the hypothesis that the three psychopathic dimensions are related to late error processing (Pe) in multi-problem young adults. Specifically, we expected the total psychopathy score to be negatively related to Pe amplitude. As findings on the specific factors are scarce and inconsistent, we formulated no specific hypotheses on which psychopathic factor(s) could drive the effect. Studying these associations may prove useful in the prospective possibility of targeting error-related brain activity as a relevant process for intervention, as it is related to criminal recidivism (Aharoni et al., 2013) and seems to be changeable in both healthy controls (Larson, Steffen, & Primosch, 2013) and psychopaths (Konicar et al., 2015). However, before error-related brain activity can possibly be used for intervening on an individual level, more knowledge on the robustness of the association between psychopathy and error processing in specific samples is first necessary.

2. Methods and materials

2.1. Participants

Participants were 127 male multi-problem young adults (age 18–27), recruited at the start of day treatment program *De Nieuwe Kans* (DNK; translated as “New Opportunities”). DNK provides a multimodal day treatment program for multi-problem young adults with a history of delinquency (81% had a criminal record) and Child Protective Services contact (65%), financial problems, a low educational level, and drug use (53% has regularly used cannabis for at least 5 years). Young adults are referred to DNK by youth care, probation services, mental health services, municipal or social organizations, and can also sign up themselves. This program employs cognitive behavioral techniques and rehabilitation components, such as cognitive skills training, drug treatment, and education (Luijks et al., 2017). The current study is part of a larger cohort study which includes 696 multi-problem young adults. Additionally, 27 age and gender group matched healthy controls were included in the present study. Controls were selected to be following or have finished secondary education. Six multi-problem young adults were excluded because they felt the task took too long and failed to complete it, six multi-problem young adults and one control subject were excluded because less than six error trials were usable for analysis (Olvet & Hajcak, 2009). The final sample included 115 multi-problem young adults and 26 healthy controls.

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The study has been approved by the Medical Ethical Committee of the VU University Medical Center (registration number 2013.422 - NL46906.029.13) and all participants provided written informed consent. Participants received a reimbursement of 30 euros for their participation in the EEG protocol and an fMRI protocol, which was administered on another day.

2.2. Instruments

As a measure of psychopathic traits, we employed the Youth Psychopathy Inventory – Short Version (Van Baardewijk et al., 2010). The YPI-SV is a self-report measure that distinguishes three factors of psychopathy: an affective callous-unemotional factor, a behavioral impulsive-irresponsible factor, and an interpersonal grandiose-manipulative factor. It has been validated in young adults (Colins & Andershed, 2015). We used the Measurements in the Addictions for Triage and Evaluation Questionnaire (MATE) to assess current and historic drug use. In order to measure intelligence, we used the short form of the Wechsler Adult Intelligence Scale third version (WAIS-III SF) consisting of four subtests (Blyler, Gold, Iannone, & Buchanan, 2000): digit symbol coding, information, block design, and arithmetic. The WAIS-III-SF was only assessed in the multi-problem group.

2.3. Task & procedure

The Eriksen Flanker task was employed to measure error processing (Eriksen & Eriksen, 1974) during EEG measurement. Stimuli were four letter strings (HHHHH, SSSSS, HHSHH, SSHSS) presented on a monitor placed 150 cm away from the participant. Participants were required to respond to the middle letter. They responded by pressing on a button on a response box with their left index finger when the middle letter was an S and their right index finger when the middle letter was an H. Each trial consisted of (1) a fixation cue for 150 ms, (2) one of the letter-string stimuli for 52 ms, (3) a blank screen for 648 ms, and (4) a feedback symbol for 500 ms which indicated whether the given response was correct (+), incorrect (-), or too late (!). Responses were defined as too late when they were given later than 700 ms after stimulus onset. We used an intertrial interval of 100 ms. Thus, one trial lasted for 1450 ms. The entire task lasted for 9 min and 40 s and was performed in five blocks in between which participants could take a break for as long as they wanted. The task is identical to that used by (Marhe, van de Wetering, & Franken, 2013).

The measurements were performed in the Erasmus Behavioral Lab of the Institute for Psychology at the Erasmus University Rotterdam. Participants were seated in a comfortable chair in a sound-attenuated room with dimmed lights. A trained researcher explained the task, followed by a practice run consisting of eight trials. In total, five blocks of 80 trials were administered and participants could take breaks for as long as they liked in between the blocks.

2.4. EEG recording and processing

We used a Biosemi ActiveTwo System amplifier to measure brain activity with EEG from 32 scalp sites and one additional scalp sites (FCz). Silver chloride (Ag/AgCl) electrodes were placed upon the scalp according to the 10–20 International System. Two electrodes were placed on the left and right mastoids to record reference activity. Two electrodes were placed below and above the left eye to measure the vertical electro-oculogram (VEOG) and two electrodes were placed at the outer canthi of both eyes to measure the horizontal electro-oculogram (HEOG). Signals were digitized with a sampling rate of 512 Hz and 24-bit analogue-to-digital conversion, and filtered offline. Data were filtered using a low cutoff of 0.15 Hz and a high cutoff of 30 Hz (24 dB/octave slope). Data were segmented into 1100 ms epochs (500 ms pre-response to 600 ms post-response). Ocular artifacts were corrected using the Gratton and Coles algorithm (Gratton, Coles, & Donchin, 1983). The −100 ms to 0 ms pre-response period was used as baseline. Additional artifact rejection was performed automatically. We employed a minimum amplitude of -100μV and a maximum amplitude of +100μV.

2.5. Data analysis

For the behavioral data (accuracies, reaction times), we used mixed ANOVAs to investigate basic task effects (congruency on accuracy, correctness on reaction time, and post-error slowing; PES) and whether these differ between groups. For other measures, we performed independent sample t-tests with group as independent variable to compare the multi-problem group with the healthy control group. We used Pearson correlations to investigate the relation between behavioral measures, covariates (age, IQ, and drug use) and psychopathic traits within the multi-problem group.

ERPs were quantified by averaging the mean amplitudes in a specific time window across a response condition (correct or incorrect). For the ERN we used a time window of 25–100 ms post-response (Marhe et al., 2013) on the FCz electrode where amplitudes were highest, for the Pe we used a time window of 250–400 ms post-response (Brazil et al., 2009) on the Cz electrode where amplitudes were highest. We performed a 2 × 2 mixed ANOVAs with response condition (correct vs. incorrect) as within subject factor and group (multiproblem young adult vs. control) as between subject factor to assess whether expected differences between correct and incorrect trials occurred and whether these differences varied with group (response condition x group interaction). Finally, hierarchical multiple linear regression analyses were used to examine associations between distinct psychopathic traits and error-related brain activity. Analyses were performed on the ERN difference wave (ΔERN) to isolate variation related to performance monitoring (Luck, 2014). We calculated difference waves by subtracting the mean amplitudes for the correct trials from the mean amplitudes for the incorrect trials for each participant. As the ERN is a negative peak, a more negative difference wave indicates increased early error-related brain processing. For the Pe, a more positive amplitude indicates increased later stage error-related brain processing.

3. Results

3.1. YPI validation

Unexpectedly, the multi-problem young adults scored slightly lower on the grandiose-manipulative interpersonal trait of psychopathy than the controls (M = 11.33 vs. 13.20), whereas they scored similar to the controls on the affective callous-unemotional trait (M = 10.74 vs. 11.56), the impulsive-irresponsible behavioral trait (M = 12.21 vs. 11.88), and the total score (M = 34.28 vs. 36.64; see Table 1). Possibly, this is a chance finding that has no consequences for our analysis as we are interested in psychopathic traits within the experimental group.

Table 1
Participants characteristics.

	Multi-problem young adults (N = 115)		Healthy controls (N = 26)		
	M	*SD*	*M*	*SD*	*p*
Age (years)	22.46	2.32	23.10	2.60	.216
IQ	82.29	10.12	.	.	.
Education					
No secondary education	93%	.	0%	.	.
Secondary education following	0%	.	42%	.	.
Secondary education finished	7%	.	58%	.	.
Questionnaires					
YPI-SV grandiose manipulative interpersonal	11.33	3.84	13.20	3.75	.028
YPI-SV affective callous-unemotional	10.74	3.53	11.56	3.11	.287
YPI-SV impulsive-irresponsible behavioral	12.21	3.14	11.88	2.64	.624
YPI-SV total	34.28	8.12	36.64	6.15	.174
Cannabis use past 30 days	14.14	13.38	3.92	6.14	< .001
Years of regular cannabis use	4.25	3.73	1.17	2.41	< .001
Error processing					
ΔERN (μV)	−4.94	4.75	−7.55	5.02	.013
ΔPe (μV)	5.90	5.08	7.42	5.08	.169
Accuracy	.81	.16	.87	.09	.015
Reaction time (ms)	441.39	77.03	447.45	46.57	.701
Congruency effect	.13	.15	.16	.11	.381
Correctness effect (ms)	45.19	30.77	41.74	28.20	.601
Post-error slowing (ms)	41.44	39.35	45.14	30.14	.837

Nonetheless, to ensure the validity of the YPI in our sample, we investigated internal validity by checking Cronbach's alpha for each subscale. For the interpersonal factor α = 0.76, for the affective factor α = .65, for the behavioral factor α = .70, and for the total score α = .80. These figures are consistent with the literature (Colins & Andershed, 2015). Moreover, to ensure criterion validity of the YPI in our sample we performed correlation analyses between the YPI subscales and relevant external criterium constructs: reactive aggression, proactive aggression, current cannabis use, and lifetime cannabis use. For the interpersonal factor we found positive correlations with both proactive (r = 0.20, $p < 0.05$) and reactive (r = 0.39, $p <$ .001) aggression. For the affective factor we found positive correlations with both proactive (r = .19, $p <$ .05) and reactive (r = 0.30, $p < 0.01$) aggression. For the behavioral factor we found positive correlations with both proactive (r = .42, $p <$ .001) and reactive (r = .44, $p < 0.001$) aggression, as well as recent (r = 0.20, $p < 0.05$) and lifetime (r = 0.20, $p < 0.05$) cannabis use. Finally, we performed a confirmatory factor analysis on the three-factor structure of the YPI using the lavaan package in R (Rosseel, 2012). The RMSEA and CFI indices for the three-factor model were 0.05 and .90, consistent with the literature (Colins & Andershed, 2015). Together, these findings indicate that the YPI is a valid instrument in our sample.

3.2. Behavioral results

We tested whether the task elicited the expected pattern of basic effects. Mixed ANOVAs revealed main effects of congruency on accuracy (F = 88.09, $p < 0.001$) with congruent stimuli being more accurately responded to (89%) than incongruent stimuli (75%); a main effect of correctness on reaction time (F = 174.29, $p < 0.001$) with incorrect trials being reacted to quicker (M = 406.07 ms) than correct trials (M = 450.62 ms); and a main effect of post error slowing (F = 139.00, $p < 0.001$) with post-error trials being responded to slower (M = 449.83 ms) than other trials (M = 406.08 ms). All interactions between main effects and group were nonsignificant, indicating both groups show the same pattern of basic effects (all *ps* > .30; see Table 1).

We compared accuracies and reaction times between groups. Independent sample t-tests showed that multi-problem young adults were less accurate (t = 2.33, $p <$ .05), but the groups did not significantly differ in reaction time ($p > 0.10$). See Table 1 for an overview.

3.3. EEG results

First, the 2 × 2 mixed ANOVA with mean amplitude during 25–100 ms time window as dependent variable revealed, as expected, a significant main effect of response condition (F = 143.71, $p <$ .001), with incorrect responses showing larger negative amplitudes (M = -4.60 μV, SD = 4.54) than correct responses (M = 0.82 μV, SD = 3.46). Furthermore, there was a significant interaction with group (F = 6.30, $p <$ .05), with the differences in amplitude between incorrect and correct trials being larger in the control group (M = -7.55 μV, SD = 5.02) than in the multi-problem group (M = -4.94 μV, SD = 4.75). The 2 × 2 mixed ANOVA with mean amplitude during 250–400 ms time window as dependent variable also revealed a significant effect of response condition (F = 145.68, $p <$ .001), with incorrect responses having larger amplitudes than correct responses, but showed no interaction with group (F = 1.91, p = .17). See Table 1 for an overview, Fig. 1 for the EEG waveforms, and Fig. 2 for topographic information.

Second, within the multi-problem group, we performed correlation analyses between age, IQ, ΔERN, Pe, basic task effects, and psychopathy measures. We found significant correlations between age and the congruency effect (r = 0.231, $p <$ .05), IQ and ΔERN (r = -0.194, $p <$ .05), IQ and accuracy (r = .320, $p < 0.01$), IQ and the correctness effect (r = 0.206, $p <$. 05), IQ and PES (r = .315, $p <$ .01), ΔERN and PES (r = -.348, $p <$ .01), and the correctness effect and PES (r = .486, $p <$ .01), but no significant correlations between the psychopathy and brain measures. See Table 2 for an overview.

Third, we performed two hierarchical multiple linear regression analyses with the ERN difference wave as dependent variable, age and IQ as covariates entered in step 1, and either the three psychopathy subscales or the total psychopathy score as independent variables in step 2. In step 1, the model failed to reach significance (F = 2.42, p = 0.09, R^2 = 0.04), although IQ was a significant predictor (t = -2.20, $p <$ .05, β = -0.21). In step 2, the addition of the three psychopathy subscales or the total psychopathy score did not significantly change the model and no psychopathy measures significantly predicted the ΔERN (all *ps* > .10). The addition of drug use as a covariate had no effect on the models. See Table 3 for an overview.

Fourth, we performed two similar hierarchical multiple linear regression analyses, but with the Pe as dependent variable. In step 1, the model failed to reach significance (F = 0.914, p = .40, R^2 = .02). In step 2, the addition of the three psychopathy subscales or the total psychopathy scores did not significantly change the model and no psychopathy measures significantly predicted the Pe (all *ps* > .10). The addition of drug use as a covariate had no effect on the models. See Table 3 for an overview.

4. Discussion

In this study, we investigated the relationship between psychopathic traits and behavioral and neural indices of error processing in a large sample of multi-problem young adults and a healthy control group. Behaviorally, multi-problem young adults performed worse than controls, having lower accuracy rates. On a neural level, multi-problem young adults showed impaired early error-processing as indicated by a decreased ERN, but showed intact late error-processing as they had a similar Pe as the control group. Within the multi-problem group, neither total psychopathy scores nor psychopathic trait subscales were significantly related to any of the behavioral or brain measures. We did

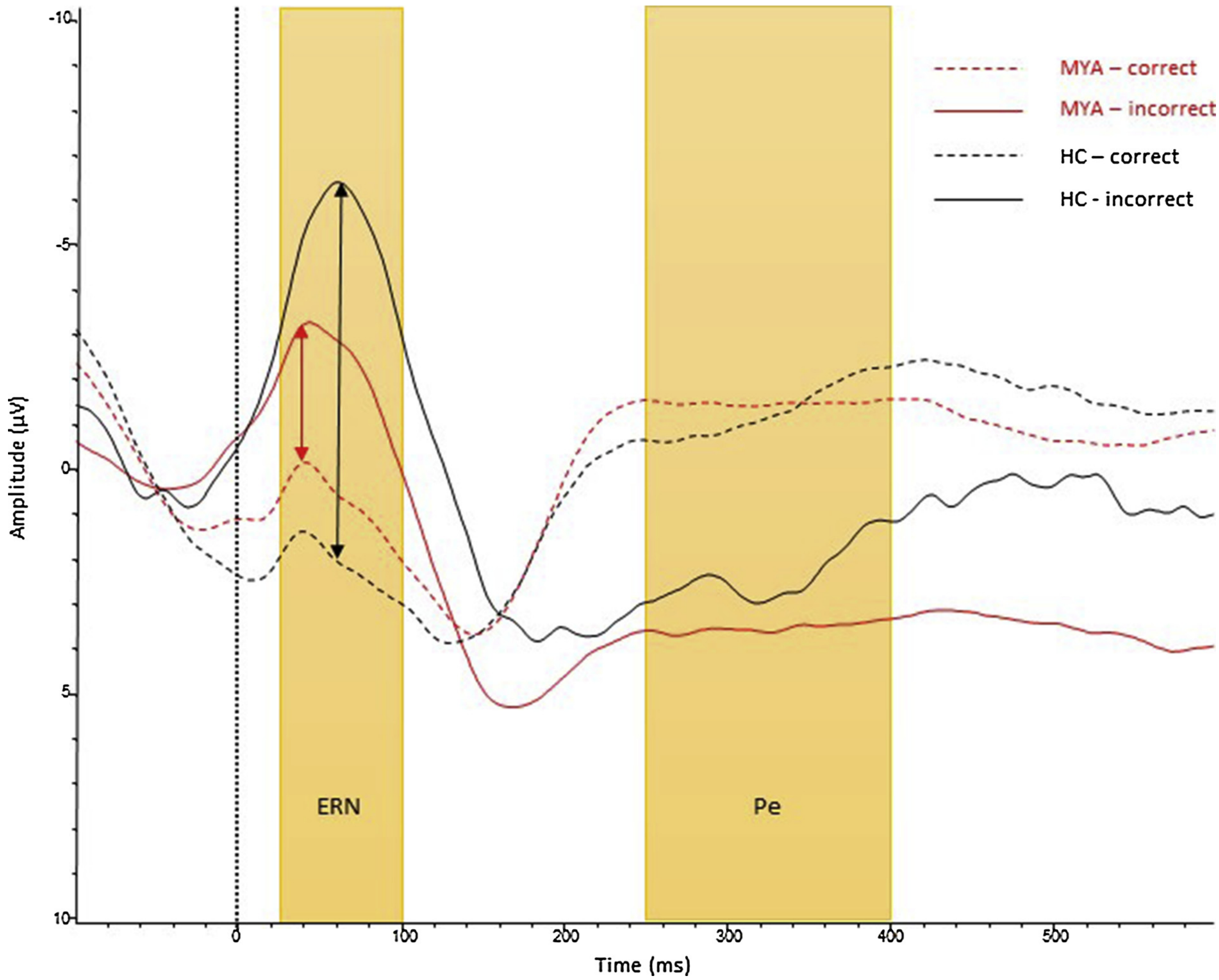

Fig. 1. XXX.

find associations between IQ and both behavioral and brain measures, in which a higher IQ always significantly related to better performance or a greater effect: a larger ΔERN, higher accuracy, a larger effect of correctness, and greater post-error slowing.

Because multi-problem young adults suffer from a score of problems and form a heterogeneous sample, it is hard to assess which issues specifically caused them to perform worse on the Flanker task and show a decreased ERN compared to healthy controls. One factor that is likely to contribute is IQ, as our multi-problem sample has a low mean IQ of 82 and our results indicate that within this sample IQ is related to both behavioral and brain measures of error-processing. Although we did not assess IQ in our control group, we can assume their mean IQ to be in the average range as we selected them to have an average education. Another factor that probably contributes is externalizing behavior, which is likely to be more prevalent in our sample than in the general population, and previous research has shown externalizing behavior to be related to a decreased ERN (Hall, Bernat, & Patrick, 2007). Nonetheless, as within multi-problem young adults a large amount of individual variability in cognitive functioning and problem behavior may be present, it is difficult to properly assess the likelihood of these options. Thus, given the heterogeneity of problems that multi-problem young adults present with, we should be careful drawing strong conclusions concerning the nature of the differences in behavioral and neural performance between multi-problem young adults and healthy controls. One viable route of investigation may be to use statistical methods such as cluster analysis to assess whether subgroups with different (risk) profiles can be identified, and whether such groups differ in terms of error-related brain activity.

Our IQ findings suggest that participants with a higher IQ alter their behavior in response to errors to a greater degree than those with a lower IQ. Additionally, on the brain level they showed better automatic error-processing. Most studies investigating the relationship between psychopathy and error processing either did not measure IQ or they matched groups on IQ, but did not include IQ in further analyses. Notable exceptions are studies in incarcerated adolescents (Maurer et al., 2015) and incarcerated females (Maurer et al., 2016) where no association between ERN activity and IQ were found, and a study in incarcerated males (Steele, Claus et al., 2015) in which IQ was positively related to ERN activity. Although specific results are slim, our findings complement the view of Blair (2013) that IQ is of relevance to brain studies in psychopathy and thus should at least be matched on or controlled for. Furthermore, our study suggests that IQ may be especially relevant to consider in samples with low intelligence. Possibly, IQ differences in the lower range have a larger impact on error processing than those in normal and higher ranges.

In line with previous research, within our sample of multi-problem young adults we found no significant association between psychopathic traits and the ERN in an affectively neutral task, adding to the evidence that early error processing is intact in psychopathy. Likewise, we found no significant relationship between psychopathic traits and behavioral measures of error-processing. Unexpectedly, we also did not find a significant relationship between psychopathic traits and the Pe. An interesting explanation for this finding may be that with age the relationship between psychopathic traits and the Pe changes. Maurer et al. (2015) have suggested that it may be the case that adolescents with elevated psychopathic traits suffer from late error processing

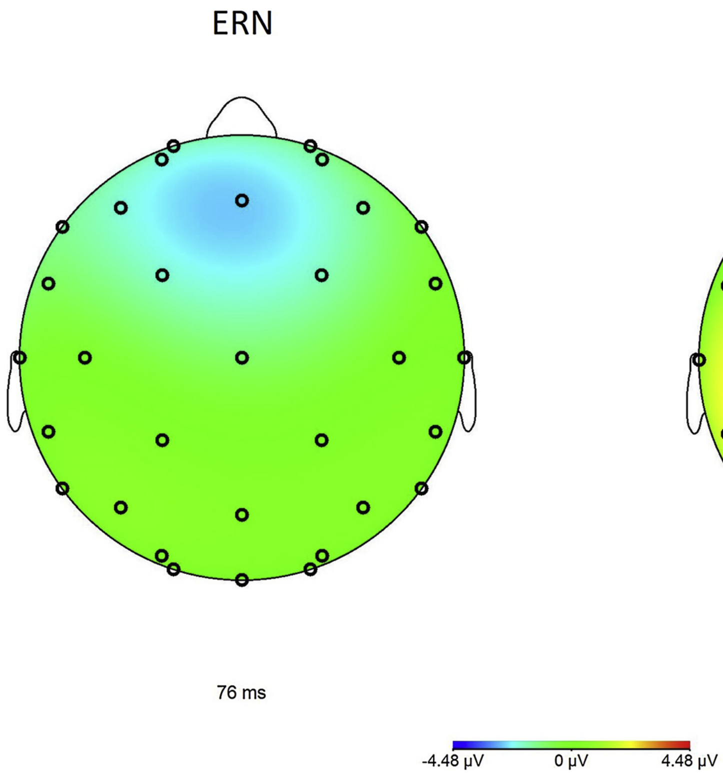

Fig. 2. XXX.

deficits (i.e., a negative relationship between psychopathic traits and the Pe), but that the relationship reverses in adulthood as a compensatory mechanism. In this manner, the brain attempts to overcome the initial error processing deficits present in adolescence. This could explain why in adolescents (mean age 17) a negative relationship between psychopathic traits and Pe has been found (Maurer et al., 2015), but in adults (mean age 34) a positive relationship between psychopathic traits and Pe has been found (Steele, Claus et al., 2015). If so, it could be speculated our sample of young adults (mean age 22) may not only be in a developmental transition period distinct from adolescence, but also in a transitional period between error-processing deficits and error-processing overcompensation. Thus, this null finding may be due to the specific age range of our sample. Additionally, it is possible that the Pe changes with age in general. Meta-analytic research has shown that another often investigated ERP, the P300, does indeed change with age (van Dinteren, Arns, Jongsma, & Kessels, 2014), but for the Pe such large-scale analyses have, to our knowledge, not been performed. Some studies have not found evidence for a change in Pe from childhood to young adulthood (Davies, Segalowitz, & Gavin, 2004; Santesso, Segalowitz, & Schmidt, 2006), but others have found a Pe increase over time in children (Grammer, Carrasco, Gehring, & Morrison, 2014). Within our own sample, the age range of participants was likely too small to uncover such effects and longitudinal research is warranted to establish the change of the Pe with age.

Another explanation could lie in the fact that in the current study we employed a self-report measure of psychopathy. One recent study found differential relations between error-related brain activity and different measures of psychopathy in the same sample (Maurer et al., 2018). Specifically, this study found an association between the Pe and Facet 4 of the Psychopathy Checklist Youth Version (PCL:YV; Hare,

Table 2
Correlation matrix of covariates, brain and behavioral measures of error processing, and psychopathic traits within the multi-problem sample (N = 115).

	Age	IQ	ΔERN	Pe	Accuracy	Congruency effect	Correctness effect	PES	YPI Interpersonal	YPI Affective	YPI Behavioral	YPI Total
Age	1	–	–	–	–	–	–	–	–	–	–	–
IQ	−.015	1	–	–	–	–	–	–	–	–	–	–
ΔERN	−.003	−.194*	1	–	–	–	–	–	–	–	–	–
Pe	−.016	.153	−.096	1	–	–	–	–	–	–	–	–
Accuracy	−.028	.320**	−.568**	.082	1	–	–	–	–	–	–	–
Congruency effect	.231*	−.165	.091	−.085	−.227*	1	–	–	–	–	–	–
Correctness effect	−.079	.206*	−.110	.122	.150	−.140	1	–	–	–	–	–
PES	.040	.315**	−.348**	.008	.555**	−.121	.486**	1	–	–	–	–
YPI Interpersonal	−.044	.091	−.071	.156	.049	−.103	.046	−.016	1	–	–	–
YPI Affective	−.118	.074	−.052	.080	−.056	−.040	−.048	−.084	.391**	1	–	–
YPI Behavioral	−.168	.082	−.031	−.017	−.023	−.023	−.049	−.061	.420**	.367**	1	–
YPI Total	−.137	.107	−.068	.102	−.010	−.075	−.018	−.067	.805**	.761**	.745**	1

Note. IQ = Intelligence Quotient, ΔERN = Error-related negativity difference wave, Pe = error positivity, PES = post-error slowing, YPI = Youth Psychopathy Inventory.

* $p < .05$.

** $p < .01$.

Table 3
Regression models within multi-problem young adults (N = 115).

Outcome	Predictor	β	p-value β	R^2	p-value R^2
ΔERN	Step 1: age	−0.005	.961	.043	.094
	Step 1: IQ	−0.208	.037		
	Step 2: age	−0.004	.968	.047	.408
	Step 2: IQ	−0.204	.037		
	Step 2: callous-unemotional	−0.027	.799		
	Step 2: impulsive irresponsible	0.035	.754		
	Step 2: grandiose manipulative	−0.054	.629		
ΔERN	Step 1: age	−0.005	.961	.043	.094
	Step 1: IQ	−0.208	.037		
	Step 2: age	−0.010	.920	.045	.182
	Step 2: IQ	−0.204	.035		
	Step 2: total psychopathy	−0.039	.688		
Pe	Step 1: age	0.019	.846	.017	.404
	Step 1: IQ	0.128	.184		
	Step 2: age	0.009	.924	.050	.365
	Step 2: IQ	0.119	.220		
	Step 2: callous-unemotional	0.048	.657		
	Step 2: impulsive irresponsible	−0.128	.250		
	Step 2: grandiose manipulative	0.181	.105		
Pe	Step 1: age	0.019	.846	.017	.404
	Step 1: IQ	0.128	.184		
	Step 2: age	0.030	.757	.025	.450
	Step 2: IQ	0.119	.221		
	Step 2: total psychopathy	0.089	.362		

2003), but not between the Pe and four different self-report measures of psychopathy, including the YPI. It is possible that error-related brain dysfunction is specifically related to features not captured by the self-report measures. Of course, a final possibility is that there is no true relation between psychopathic traits and the Pe. Older studies (Brazil et al., 2009; Munro et al., 2007) into this relationship have been performed in small samples and had a dichotomic approach (no more than 16 participants in the psychopathic groups, no more than 18 participants in the control groups before exclusion). More recent, well-powered, and dimensional studies (Maurer et al., 2015, 2016; Steele, Claus et al., 2015) have found only small effect sizes and the direction of the effect has been inconsistent. However, evidence for cognitive deficits in psychopathy is abundant (Blair, 2013; Kiehl, 2006), suggesting it is unlikely that on a neural level they perform as normal. Therefore, it would be informative for future research to 1) perform studies in large samples which take into account the general effects of age on the Pe, for example by including larger age ranges (e.g., 16–35 years); 2) ensure that the entire range of psychopathic traits is captured in these samples; and 3) investigate the development of the relationship between psychopathic traits and the Pe by performing follow-up measurements in the same samples and test for an interaction effect between psychopathic traits and age change. If the theory of overcompensation holds, it should be shown that this effect is specific to psychopathic traits and not a general mechanism that occurs in people with a small Pe.

Limitations in the comparability of our study to others lie in the fact that we used a self-report measure to assess psychopathic traits, rather than the more extensive PCL-YV (Hare, 2003). Although the YPI has good validity (Colins & Andershed, 2015) and correlates with the PCL-YV (Andershed, Hodgins, & Tengström, 2007) it has also been suggested that the subscales of these measures are not interchangeable (Fink, Tant, Tremba, & Kiehl, 2012) and this should be taken into account when interpreting the data. Another noteworthy difference between our study and others is that our sample has a low average IQ (mean = 82), whereas other samples of which the IQ is reported have mean IQs in the normal range. Although this limits the generalizability to samples with higher IQs, below average IQs are common in forensic populations and may be relevant to study distinctly, especially since we found IQ to be related to both behavioral and brain measures of error processing. Finally, we have not specifically sampled for high psychopathic traits, but rather included a sample which we know to present with antisocial behavior. Possibly, our disparate Pe results compared to other studies may be due to multi-problem young adults presenting with more externalizing, but not specifically psychopathic problems.

In conclusion, we found evidence for dysfunctional error-processing on both behavioral and early neural indices in a group of multi-problem young adults, but did not find evidence for a relationship between psychopathic traits and dysfunctional error-processing. Future research may elucidate whether this is due to our young adult participants being in a transitional period in between error-processing deficits and error-processing overcompensation.

Disclosures

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