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Error-Related Processing in Adult Males with Elevated Psychopathic Traits

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Abstract

Psychopathy is a serious personality disorder characterized by dysfunctional affective and behavioral symptoms. In incarcerated populations, elevated psychopathic traits have been linked to increased rates of violent recidivism. Cognitive processes related to error processing have been shown to differentiate individuals with high and low psychopathic traits and may contribute to poor decision making that increases the risk of recidivism. Error processing abnormalities related to psychopathy may be due to error-monitoring (error detection) or post-error processing (error evaluation). A recent 'bottleneck' theory predicts deficiencies in post-error processing in individuals with high psychopathic traits. In the current study, incarcerated males (n = 93) performed a Go/NoGo response inhibition task while event-related potentials (ERPs) were recorded. Classic time-domain windowed component and principal component analyses were used to measure error-monitoring (as measured with the error-related negativity [ERN/Ne]) and post-error processing (as measured with the error positivity [Pe]). Psychopathic traits were assessed using Hare's Psychopathy Checklist-Revised (PCL-R). PCL-R Total score, Factor 1 (interpersonal-affective traits), and Facet 3 (lifestyle traits) scores were positively related to post-error processes (i.e., increased Pe amplitude) but unrelated to error-monitoring processes (i.e., ERN/Ne). These results support the attentional bottleneck theory and further describe deficiencies related to elevated psychopathic traits that could be beneficial for new treatment strategies for psychopathy.

Keywords

Event-related potentials; error-processing; psychopathy; error-related negativity; error positivity

Psychopathy is a serious personality disorder characterized by affective and behavioral symptoms. Psychopaths are defined by their overall absence of moral emotions and an

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impulsive lifestyle (Hare, 2003). Just less than one percent of the general population is estimated to meet the established clinical criteria for psychopathy, though the rate increases to 15–25% in incarcerated settings (Hare, 2003). Some studies have found that psychopaths are up to four times more likely to violently recidivate in the twelve months following institutional release compared to non-psychopathic criminals (Rice & Harris, 1997). As such, understanding and treating psychopathy is vital to the management of institutional populations. Additionally, previous treatment attempts have often proven unsuccessful for this population (Rice & Harris, 1997), suggesting a richer understanding of psychopathy is necessary to develop efficacious rehabilitation techniques.

Hare's Psychopathy Checklist-Revised (PCL-R; Hare, 2003) is the most common and validated instrument for assessing psychopathic traits in forensic settings. Factor analyses of the PCL-R finds a two-factor model of psychopathic traits, with Factor 1 reflecting interpersonal-affective traits and Factor 2 consisting of lifestyle, developmental, and antisocial traits (Harpur, Hare, & Hakstian, 1989). More recently, a four-Facet model of psychopathic traits has been identified with latent dimensions related to interpersonal (Facet 1), affective (Facet 2), lifestyle (Facet 3), and developmental/antisocial traits (Facet 4; Hare & Neumann, 2006).

Psychopathy is associated with both affective and cognitive deficits in numerous experimental paradigms. For example, male psychopaths are characterized by reduced responses to affective stimuli including physiological reactions to unpleasant stimuli (March, Parker, Sullivan, Stallings, & Conners, 1997) and identification of facial expressions of emotion (Meyers, McLellan, Jaeger, & Pettinati, 1995). Cognitive deficits in male psychopathy mainly center on response modulation deficits captured in passive avoidance learning (Newman & Kosson, 1986) and probabilistic learning paradigms (Budhani, Richell, & Blair, 2006). In these latter tasks, male psychopaths continually perseverate, exhibiting an inability to adjust their performance to meet the demands established by external sources. Such dysfunctions have been hypothesized to be manifestations of abnormalities in limbic (Blair, 2003) and surrounding paralimbic regions (Kiehl, 2006). Several paralimbic regions, like the anterior cingulate cortex (ACC), are associated with error processing (Steele et al., 2013; Steele, Claus, et al., 2014).These deficits in impulsivity and failing to use information received from past errors to improve subsequent behavior (Newman, 1987) may be one of the reasons why psychopathy is associated with increased rates of recidivism (Hemphill, Hart, & Hare, 1994).

Response inhibition and error-monitoring (i.e., error processing) have been explored using several types of inhibition tasks (e.g., Go/NoGo, Stroop, Stop-signal, Flanker, Wisconsin Card Sorting Task, and Task-Switching; for review see Niendam et al., 2012). These tasks target cognitive control processes elicited by a stimulus associated with inhibiting a response and error-monitoring processes elicited by an incorrect motor response to that same stimulus. Because of excellent temporal resolution, event-related potentials (ERPs) have frequently been used to separate the sequential error-monitoring and post-error processing elicited by an error in response inhibition tasks. The two most frequently investigated error-related ERP components are the error-related negativity (ERN/Ne) and the error positivity (Pe). The fronto-central ERN/Ne occurs 50–150 ms after an erroneous response, and reflects the initial detection of an error, or conflict experienced between intended and actual responses (Falkenstein, 2004; Gehring, Goss, Coles, Meyer, & Donchin, 1993). The centro-parietal Pe occurs 200–500 ms after an error, and is involved in more elaborate error-processing stages, including the conscious and motivational significance of an error (Ullsperger, Harsay, Wessel, & Ridderinkhof, 2010), or potential affective reactions to an error (Overbeek, Nieuwenhuis, & Ridderinkhof, 2005). Whereas the ERN/Ne is present whether or not the participant was consciously aware of the error, the Pe is only present when participants were consciously aware of the error (Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001). Source localization (Dehaene, Posner, & Tucker, 1994; Herrmann, Rommler, Ehlis, Heidrich, & Fallgatter, 2004; van Veen & Carter, 2002) and functional magnetic resonance imaging (fMRI; Edwards, Calhoun, & Kiehl, 2012; Kiehl, Liddle, & Hopfinger, 2000) studies converge on the ACC as one of the neural generators for both the ERN/Ne and the Pe, albeit separate sub regions. The early error-related processes captured by the ERN/Ne arise from caudal regions of the ACC (cACC), whereas later processes captured by the Pe engage both the cACC and rostral regions of the ACC (rACC; Edwards, et al., 2012; van Veen & Carter, 2002).

Considering error processing is related to regions known to be abnormal in individuals high in psychopathic traits, including the ACC, unique insights into error processing would be possible when investigating response inhibition within an incarcerated sample. Few reports of ERN/Ne or Pe differences related to a sample measuring psychopathy are found in the literature. Reduced ERN/Ne amplitudes have been measured in individuals with elevated psychopathic traits (Dikman & Allen, 2000; Heritage & Benning, 2012). Recently, increased ERN/Ne has been identified in a community sample with a criminal history and elevated psychopathic traits as measured with the Psychopathy Checklist: Screening Version (PCL-SV; Bresin, Finy, Sprague, & Verona, 2014). Other studies have not identified ERN/Ne differences related to psychopathic traits in standard tasks (Brazil et al., 2009; Brazil et al., 2011; Munro et al., 2007) but have in an affective flanker (Munro, et al., 2007). Other impulsive populations, such as externalizing disorders, have shown reduced ERN/Ne amplitudes (Hall, Bernat, & Patrick, 2007). In a report comparing incarcerated psychopaths to a community control sample, Brazil et al. found reduced Pe amplitude in the psychopathy group (Brazil, et al., 2009). In this experiment, incarcerated psychopathic individuals exhibited specific deficiencies in the neural correlates of post-error response modulation, including the conscious evaluation of information received from errors, as indexed by reduced Pe amplitude. Similarly, individuals who score high on externalizing have been shown to exhibit reduced positivity post-error-related-feedback amplitudes relative to low scoring individuals (Bernat, Nelson, Steele, Gehring, & Patrick, 2011). However, the only report to incorporate a large sample of incarcerated individuals assessed with the PCL-R used an adult female sample (Maurer et al., *in press*). High scoring individuals exhibited reduced Pe amplitude but no ERN/Ne difference relative to low scoring individuals. Direct comparison between male and female individuals with psychopathic traits proves difficult for many reasons. Of note for the current endeavor, male psychopathy is associated with deficits in response perseveration and female psychopathy is not (Vitale & Newman, 2001). Other than this most recent publication, comparisons are usually made between high scoring incarcerated individuals and community controls or within a sample made entirely of individuals recruited from the community. Considering dimensional analyses are best suited for measuring relationships between specific cognitive functions and psychopathic traits (Walters, Ermer, Knight, & Kiehl, 2015), previous explorations have yet to fully describe the interplay between psychopathic traits and cognitive processes elicited by a Go/NoGo task in a large incarcerated sample.

Although there are few studies, primarily using community samples, investigating error-related processing in psychopathy, both the ERN/Ne and Pe have been identified as measures that differentiate between individuals with high and low psychopathic traits. The Pe has consistently been identified as a marker of elevated psychopathic traits, although the ERN/Ne has not, especially in incarcerated samples. The two general interpretations for reduced Pe amplitude in psychopathology are decreased evaluation of the error or general dysfunction of the circuits that generate the Pe. Recently, however, increased amplitudes of Pe have been linked to poor outcomes in drug treatment (Steele, Fink, et al., 2014) and increased attentional resources devoted to the processing of errors (Larson, Steffen, & Primosch, 2013). In the former study, individuals who prematurely dropped out of drug treatment exhibited greater Pe amplitudes at baseline than those individuals who completed treatment. In the latter study, individuals who underwent mindfulness training showed reduced Pe amplitude post-training. Taken together, increased Pe amplitudes could identify risk for poor future outcomes and be a marker for increased evaluation (or over evaluation) of an error.

If increased Pe amplitudes were elicited in individuals who scored high on psychopathic traits, particularly, traits related to affective processing and behavioral impulsivity, this could be interpreted as difficulty with allocating attention, as suggested by a recent attentional bottleneck theory (Newman & Baskin-Sommers, 2012). In this “bottleneck” theory, individuals with high psychopathic traits become hyper focused on a single aspect of a task. This focus comes at the price of subsequent cognitive functions making it difficult to move beyond the current cognitive process. For example, in a startle paradigm, individuals with high psychopathic traits show an attenuated startle response (Baskin-Sommers, Curtin, & Newman, 2013). With careful manipulation, no startle reduction was found in high scoring individuals when attentional resources were maximized (Baskin-Sommers, et al., 2013) suggesting an attentional bottleneck in cognitive, specifically affective, processing. If individuals with high psychopathic traits are unable to cognitively move beyond an early stage of error processing, this could explain why they also have difficulty learning from experiences, specifically, errors (Newman, 1987).

To directly compare the prevailing interpretations of error processing in individuals with elevated psychopathic traits, a Go/NoGo task was employed here to elicit response errors while ERPs were collected. Considering much of the previous literature has focused on a community samples with psychopathic (Bresin, et al., 2014; Dikman & Allen, 2000; Heritage & Benning, 2012) or externalizing traits (Bernat, et al., 2011; Hall, et al., 2007) and the few experiments with incarcerated individuals contrast high-scoring individuals with a community sample (Brazil, et al., 2009; Brazil, et al., 2011; Munro, et al., 2007), it is difficult to firmly predict whether an analysis consisting entirely of incarcerated individuals will identify dysfunction in early error-detection processes, post-error response modulatory processes, or both in individuals with elevated psychopathic traits. It could be predicted that high scoring incarcerated individuals would under evaluate errors manifested in no ERN/Ne differences but reduced Pe amplitude relative to low scoring incarcerated individuals. This relationship has been previously identified when comparing incarcerated individuals who had a PCL-R Total score greater than 26 and a community sample without PCL-R scores (Brazil, et al., 2009). On the other hand, it could be predicted that high scoring individuals would have difficulty moving beyond error processing to understand the implications of a response error as suggested by the Newman and Baskin-Sommers' bottleneck hypothesis (2012). If high scoring individuals have difficulty moving beyond the initial error-processing stage, no ERN/Ne differences would be measured but increased Pe amplitude would be measured compared to low scoring individuals.

Of primary interest here is to better delineate the cognitive processes that differentiate high and low scorers in the hope to better understand error evaluation in a large incarcerated sample. Thus, it is reasonable to hypothesize that psychopathy will be associated with Pe abnormalities, but the direction of these effects is unclear. A secondary interest here is to better outline which PCL-R Factors and Facets contributing to the overall construct of psychopathy are associated with error-monitoring processes measured in this Go/NoGo task. To this end, PCL-R Total, Factor, and Facet scores were related to the ERN/Ne and Pe amplitude to help identify which psychopathy measures best explain differences between high and low scorers. Both traditional time-domain windowed component measures were used as well as principal component analyses (PCA). PCA is best used to separate overlapping ERP components (Dien, 1998; Dien, Khoe, & Mangun, 2007) providing a more sensitive measure than time-domain components and has been successfully used previously with this task (Steele, Fink, et al., 2014). Taken together, such an understanding of psychopathy overall could potentially help in developing new, more effective treatment techniques.

Methods

Participants

Participants included 104 male offenders recruited from two correctional facilities in MASKED FOR REVIEW ranging from 19 to 55 years of age (*M* = 34.53, *SD* = 9.41) at the time of electroencephalography (EEG) collection. Ninety-three participants committed at least 6 response errors are included in analysis below. It has been identified that six errors is necessary to measure a reliable ERP signal related to response errors (Meyer, Riesel, & Proudfit, 2013; Olvet & Hajcak, 2009; Pontifex et al., 2010). Approximately 12% were left-hand dominant, 44% self-identified as Hispanic, 46% as White, 10% as Black/African American, 20% as American Indian, 6 % as Asian, and 17% selected Other. Participants were informed of their right to terminate participation at any point and were advised that their participation was not associated with institutional benefits or their facility or parole status. Participants received remuneration at the hourly labor wage of the facility. The work was approved by the MASKED FOR REVIEW Office of the Human Research Protections. All subjects provided written informed consent prior to data collection.

Assessments

Psychopathy was assessed using the PCL-R (Hare, 2003). In the current sample, PCL-R Total scores ranged from 7 to 38 (*M* = 22.08, *SD* = 7.69). Approximately 10% of lab-wide and 8.6% (8 of 93) of the sample reported PCL-R assessments were double rated with interclass correlations of .96 and 1.00, respectively. We examined a two-factor and a four-facet model of psychopathic traits. Consistent with a previous report (Harpur, et al., 1989), PCL-R Factor 1 and Factor 2 scores were significantly correlated ($r = .53$, $p < .001$). See table 1 for correlations among assessment measurements. For display purposes, upper and lower quartiles of psychopathy measures are displayed. Supplemental table 1 contains a summary of the full group and upper and lower quartiles based on PCL-R Total score.

Additional assessments were administered to assess intelligence quotient (IQ), substance dependence, mental illness, and traumatic brain injury (TBI). Participants were excluded from analyses if they had a full-scale IQ less than 70, reported a TBI accompanied with a significant loss of consciousness, or history of psychosis. Full-scale IQ was estimated from the Vocabulary and Matrix reasoning sub-tests of the Wechsler Adult Intelligence Scale (*M* = 95.11, *SD* = 14.69; WAIS-III; Wechsler, 1997). An IQ score was unavailable for one participant. Substance dependence and mental illness were measured using the Structured Clinical Interview for DSM-IV Axis I Disorders – Patient Version (SCID I-P; First, Spitzer, Gibbon, & Williams, 1995). Substance dependence was calculated by summing the total number of substances (alcohol and drug) for which participants met lifetime dependence diagnoses (possible range 0–7; *M* = 2.22, *SD* = 1.64). The number of substance dependencies was unavailable for five participants. Age, substance dependence, and IQ were not correlated with measures of psychopathy (Table 1). Therefore, these measures were not included in our regression analyses described below. No participant was beyond three standard deviations from the mean of each assessment; therefore, no outliers were identified.

Stimuli and Task

EEG data were collected in a small room separate from the general population housing. After placement of electrodes, participants were seated in a comfortable chair 60 cm away from a computer monitor on which the task stimuli were presented and were instructed to refrain from excessive blinking and movement during data collection. Participants then performed a Go/NoGo response inhibition task (Kiehl, et al., 2000) consisting of two experimental runs, each comprising 245 visual stimuli. Stimuli were presented to participants using the Neurobehavioral Systems Inc. visual presentation software package, Presentation. Each stimulus appeared for 250 ms in white text within a continuously displayed rectangular fixation box against a black background. Participants were instructed to respond as quickly and accurately as possible with their right index finger every time the target Go stimulus (a white “X”) appeared, and to withhold a response whenever the distracter NoGo stimulus (a white “K”) appeared. Targets appeared at higher frequency (84%, 412 trials, with 206 on each run) than distracters (16%, 78 trials, with 39 on each run) to establish a strong stimulus-response mapping on Go trials. Two “K’s” were never presented sequentially. The inter-stimulus interval was pseudo-randomly jittered (1–3 seconds for a stimulus onset asynchrony [SOA] average of 1.5 seconds). The SOA between Go stimuli varied to the constraint that three Go stimuli were presented within each 6 second period. The NoGo stimuli were interspersed among the Go stimuli in a pseudo-random manner subject to two constraints: the minimum SOA between Go and NoGo stimuli was 1000 ms, and the SOA between successive NoGo stimuli was in the range of 8 to 14 seconds. Hits were defined as successful responses to “Go” stimuli, whereas False Alarms were defined as incorrect responses to “NoGo” stimuli. Prior to recording, each participant performed a block of ten practice trials to ensure that directions were clearly understood.

EEG Recordings

EEG data were collected using two computers and a 64-channel BioSemi amplifier. The first computer used Presentation software to deliver the stimuli, accept responses, and send digital triggers to the other computer when a stimulus or response occurred. The second computer acquired electroencephalographic data using BioSemi software and amplifiers. All channels were low-pass filtered using a fifth-order sinc filter with a half-power cutoff of 204.8 Hz and then digitized to 1024 Hz during data collection. EEG activity was recorded using sintered Ag-AgCl active electrodes placed in accordance with the 10–20 International System. The participant’s nose was used as a reference. Six electrodes were placed on the participant’s face to measure electrooculogram, placed above, below, and medial to the canthus of each eye. All offsets were kept below 10 kΩ.

Data Reduction and Analysis

Pre-processing included down-sampling to 512 Hz, bad channel detection and replacement, epoching, eye-blink removal, and low-pass filtering to 15 Hz. Bad channels were identified as having activity four standard deviations away from the mean of the surrounding electrodes. ERP epochs were defined relative to the response, from 1000 ms pre- to 2000 ms post-response. An independent component analysis (ICA) eye-blink removal was also performed. The ICA utility in the EEGlab software (Delorme & Makeig, 2004) was used to derive components; then, using an in-house template-matching algorithm (Jung, Makeig, Westerfield, Courschesne, & Sejnowski, 2000), blink components were identified and removed from the data. Individual subject ICA decompositions where no eye-blinks were identified and removed were visually inspected to identify eye-blink components which, when present, were then removed. Classic time-domain response-locked ERP components relative to a False Alarm were extracted: mean amplitude for the ERN/Ne, the negative deflection occurring −50–100 ms post-response, and the Pe, the positive deflection occurring 75–500 ms were extracted, consistent with previous studies (Falkenstein, 2004; Gehring, et al., 1993). Response-locked components were baseline corrected with a −200 to −50 ms window. Within each trial, individual electrodes in which activity exceeded ± 100 μV were omitted from analyses. Applying these criteria to all electrodes, 16.57 % of response-locked trials were excluded from analyses. A varimax rotated PCA was carried out on the covariance matrix derived from all electrodes and a three-component response-locked solution was extracted from False Alarm trials accounting for 89.58% of the variance. PCA has been shown to separate overlapping ERP components (Dien, 1998; Dien, et al., 2007) providing a more sensitive measure than time-domain components.

Linear, stepwise regressions were carried out to predict mean ERN/Ne and Pe amplitudes (measured with classic windowed components and extracted principal components) using psychopathy variables (PCL-R Total score, PCL-R Factor scores, or PCL-R Facet scores). To capture the medial frontal distribution of the ERN/Ne and central-parietal distribution of the Pe, nine electrodes were selected for each component (ERN/Ne: F3, Fz, F4, FC3, FCz, FC4, C3, Cz, & C4; Pe, C3, Cz, C4, CP3, CPz, CP4, P3, Pz, & P4) reflecting maximal time-domain activation. Using these electrodes, latency differences between high and low scoring individuals (first and fourth quartiles) were calculated for the ERN/Ne and Pe. Principal component 3 (PC3) exhibited a similar temporal and spatial distribution as the ERN/Ne (Figure 1); therefore, the ERN/Ne specific electrodes were used in analysis of this component. PC1 and PC2 exhibited similar temporal and spatial distributions as the Pe (Figure 1); therefore, the Pe specific electrodes were used in analysis of these components. Linear regressions were carried out with time-domain components as dependent variables and principal components as independent variables. Results confirm the relation between time-domain and principal components described above (see supplemental Table 2). Analyses were carried out with only those participants who made six or more errors, a cutoff suggested for stable results (Meyer, et al., 2013; Olvet & Hajcak, 2009; Pontifex, et al., 2010). Effects that did not reach statistical trend ($p > .10$) were not reported.

Results

Behavioral Results

Response times (RT) and frequency for Hits and False Alarms were analyzed. As expected, participants responded faster to NoGo (False Alarm) stimuli (M = 344 ms, SD = 44 ms) compared to Go (Hit) stimuli (M = 657 ms, SD = 53 ms), $t(92) = 37.13$, $p < .001$. Participants made significantly more errors to NoGo stimuli (M = 19.99, SD = 9.00) compared to Go stimuli (M = 7.66, SD = 12.52), $t(92) = 18.82$, $p < .001$. RTs to Hits were positively correlated with age ($r = .38$, $p < .001$) and negatively correlated with Facet 3 ($r = -.22$, $p = .037$). Marginal relationships between RTs to Hits was found for substance dependence ($r = -.21$, $p = .054$), PCL-R Total Score ($r = -.18$, $p = .091$), and Factor 2 ($r = -.19$, $p = .067$). Go accuracy was marginally related to IQ ($r = .176$, $p = .093$). NoGo RTs and accuracy were related to age ($r = -.36$, $p < .001$, $r = .36$, $p < .001$, respectively). Post-error slowing (PES) was calculated as the RT difference between Hits preceded by a False alarm and Hits proceeded by a Hit (Rabbitt, 1966). There was significant PES (M = 22 ms; SD = 83 ms), $t(93) = 2.55$, $p = .012$. PES was negatively correlated with Facet 3 ($r = -.21$, $p = .040$) and marginally with Factor 2 ($r = -.20$, $p = .061$) and marginally positively correlated with age ($r = .17$, $p = .096$) but not with other assessment measures, r's < .16.

ERP Results

The Pe was positively correlated with Go accuracy ($r = -.27$, $p = .009$) and negatively correlated with Go RTs ($r = -.45$, $p < .001$) and NoGo accuracy ($r = -.22$, $p < .031$). Pe was marginally negatively correlated with age ($r = -.18$, $p = .078$). PC1 was negatively correlated with Hits RT ($r = -.22$, $p = .031$). PC2 was correlated with PCL-R Total score (Figure 1; $r = .25$, $p = .018$), Factor 1 (Figure 2; $r = .21$, $p = .044$), Facet 1 (Figure 3; $r = .22$, $p = .032$), and Facet 3 (Figure 3; $r = .24$, $p = .020$). PC2 was marginally positively correlated with Factor 2 ($r = .20$, $p = .052$). PC2 was positively correlated with Go accuracy ($r = .35$, p =.001) and negatively correlated with RTs to Hits ($r = -.59$, p < .001) and NoGo accuracy (r

= .24, *p* = .021). PC3 was marginally positively correlated with PCL-R Total Score (*r* = .20, *p* = .053), Factor 2(*r* = .18, *p* = .079), Facet 1 (*r* = .19, *p* = .070), and Facet 3(*r* = .19, *p* = .070). PC3 was positively correlated with IQ (*r* = .21, *p* = .040) and negatively correlated with RTs to Hits (*r* = −.30, *p* = .003) and NoGo accuracy (*r* = −.23, *p* = .027). PC3 was marginally positively correlate with NoGo RTs (*r* = .19, *p* = .071). Pe and PC2 latency for high scoring individuals (291 ms, 251ms, respectively) peaked earlier than low scoring individuals (362 ms, 275 ms, respectively; *t*(44) = 2.47, *p* = .018; *t*(44) = 2.14, *p* = .038, respectively). PC3 latency for high scoring individuals (179 ms) peaked marginally earlier than low scoring individuals (247 ms; *t*(44) = 1.956, *p* = .057). The ERN/Ne was not correlated with any of the assessment measures. See supplemental table 3 for correlations among ERP and assessment measures.

Regression Analyses

Separate linear, stepwise regressions were performed to assess unique contributions to the mean ERN/Ne and Pe amplitude measured with classic windowed components and PCA. Each regression included an ERP measure as the dependent measure and one PCL-R measure (Regression 1: PCL-R Total; Regression 2: Factor; Regression 3: Facet scores).

No regressions predicting the windowed ERN/Ne component or PC3 were significant. No regressions predicting the windowed Pe component or PC1 were significant.

All three of the regressions performed predicting the Pe-related principal component PC2 were significant (Table 2). PCL-R Total score (Regression 1), Factor 1 (Regression 2), and Facet 3 (Regression 3) were each unique predictors of PC2.

Discussion

This study is the first to examine the relationship between clinical levels of psychopathy and behavioral and electrophysiological measures of error processing in a large, incarcerated male sample. Using classic time-domain windowed components and principal component analysis (PCA), error-monitoring and post-error processes were measured. Psychopathy scores were positively related to post-error processes, as measured with increased Pe amplitude, but not error-monitoring processes, as measured with intact ERN/Ne. PCL-R Total score, Factor 1, and Facet 3 were each positively related to Pe amplitude suggesting the measures of interpersonal-affective and lifestyle traits related to psychopathy were related to greater neural activation measured with the Pe amplitude. Post-error slowing (PES) was negatively correlated with measure of the Pe, suggesting Pe amplitude was reduced as post-error slowing increased. This is supported by evidence that both PES (Danielmeier & Ullsperger, 2011) and the Pe (Edwards, et al., 2012) have been localized to the cACC. PES was also negatively correlated with Facet 3 suggesting a detrimental relationship between lifestyle traits, including impulsivity and post-error processing. Therefore, greater Pe activation appears to be related to poor behavioral control and future outcomes (c.f., Steele, Fink, et al., 2014). A positive relationship between psychopathy and Pe amplitude supports a recent theory of an attentional bottleneck specific to individuals with high psychopathic traits (Newman & Baskin-Sommers, 2012).

Pe amplitudes have been interpreted to reflect elaborative error-processing which may include evaluating the motivational significance of an error (Ullsperger, et al., 2010), or potential affective reactions to an error (Overbeek, et al., 2005). Here, increased Pe amplitude is likely related to increased processing of the response error. Newman and Baskin-Sommers (2012) outline an attentional bottleneck hypothesis in which individuals with high psychopathic traits have difficulty moving beyond specific stages of cognitive processing. This effect has been highlighted in a fear-potentiated startle paradigm (Baskin-Sommers, et al., 2013) and could easily be applied to the Go/NoGo response inhibition paradigm used here. The current findings suggest incarcerated individuals with high psychopathic traits are able to identify an error was made, as indexed by comparable ERN/Ne amplitudes between high and low scoring individuals. However, high scoring individuals exhibit post-error processes that differentiate them from low scoring individuals, as indexed by increased Pe amplitudes. Individuals with elevated interpersonal-affective and impulsive traits associated with Factor 1 and Facet 3, respectively, exhibit greater Pe amplitude following a response error. The increased Pe amplitude reported here suggests these individuals have difficulty moving beyond error processing (i.e. a bottleneck in error-processing) with little change in behavior. Similarly, post-error slowing was negatively related to Facet 3 scores suggesting individuals with lifestyle traits, reflecting impulsivity did not change their behavior after committing a response error.

Considering the paucity of previous explorations of the Pe and psychopathic traits, the findings presented here are unique. Cognitive and affective processing have been identified using error-monitoring tasks (Edwards, et al., 2012), so it is curious that Factor 1 and Facet 3 have not been identified previously as unique contributors to Pe amplitude. The only previous published report relating PCL-R and Pe in an adult male sample (Brazil, et al., 2009) compared incarcerated individuals to healthy controls and did not examine Factor or Facet scores. Incarcerated individuals who scored higher than 26 on the PCL-R exhibited less positive Pe amplitudes than a community control sample. Although this work helps to identify differences between incarcerated individuals who score high on the PCL-R and non-incarcerated individuals, a large-scale continuous analysis of psychopathic traits may be preferred to fully understand the relationship between the continuous PCL-R measure of psychopathy and ERP measures of error monitoring and post-error processing. We used a full sample of incarcerated individuals with a wide range of PCL-R scores to understand the full range of psychopathic traits and identified PCL-R Total score, Factor 1, and Facet 3 to be positively related to Pe amplitude. Only a single study used a large incarcerated sample though it was a female sample (Maurer, et al., *in press*) instead of a male sample. Similar to the male sample presented here, interpersonal-affective traits of psychopathy were related to Pe amplitude, but in the opposite direction. Further analyses are needed to tease apart these sex-related differences but they could be anticipated considering manifestation of psychopathy is not identical between sexes (Vitale & Newman, 2001). Finally, PCA proved to be more sensitive to differences between high and low scoring individuals than classic time-domain windowed analyses. PCA, a data-driven approach, has been identified to be more appropriate than independent component analysis (ICA) for analysis of ERPs (Dien, 1998; Dien, et al., 2007).

Limitations

Understanding the cognitive processes associated with error processing in an incarcerated sample with elevated psychopathic traits has proven difficult. Previously, community samples (Dikman & Allen, 2000; Heritage & Benning, 2012) with elevated psychopathic traits or incarcerated samples were compared to a community control sample (Brazil, et al., 2009; Munro, et al., 2007) have been used. Large incarcerated male samples, as presented here, have yet to be examined. Comparing the current findings with previous published reports is therefore difficult. The large incarcerated sample presented here included a wide range of PCL-R Total scores (7–38) but did not include very low scoring individuals. In the only previous exploration of the Pe and psychopathic traits in adult males, an incarcerated sample of individuals with PCL-R Total scores greater than or equal to 26 was compared to a community control sample (Brazil, et al., 2009). Community controls typically score below 3 on the PCL-R (Neumann & Hare, 2008), which makes direct comparison between this study and the Brazil et al. (2009) study difficult. However, using a continuous measure of psychopathic traits allows for a richer understanding of psychopathy and its relationship to error-processing in general and post-error processing, indexed by Pe amplitude, specifically.

Future directions

Highlighted here, post-error processing is deficient in individuals with high PCL-R Total score, Factor 1, and Facet 3 scores. This finding should guide future researchers and clinicians in targeting these specific measures of the PCL-R in similar individuals in replicating and extending these findings. Specific treatments targeting error evaluation and affective processing could prove most successful. Error evaluation has been previously targeted with mindfulness treatment in community samples, successfully reducing Pe amplitude (Larson, et al., 2013). Also, an intensive decompression intervention has proven successful at reducing rates of recidivism and callous/unemotional traits in at-risk juvenile samples (Caldwell, McCormick, Umstead, & Van Rybroek, 2007). Though treating adult psychopathic individuals has proven difficult (Rice & Harris, 1997), with the current findings and the work with juvenile offenders, hope remains for future interventions in adult offenders with elevated psychopathic traits. Also, sex-related differences should be further delineated considering the recent report in female psychopathy (Maurer, et al., *in press*).

With the temporal resolution of ERP separation of cognitive processes is possible but spatial localization is more difficult. Considering previous localization of the Pe to the ACC (Edwards, et al., 2012; van Veen & Carter, 2002), it is reasonable to predict this brain region plays a part in increased Pe amplitude observed in the current study. However, without an fMRI experiment in a sample similar to the one presented here, firm spatial conclusions are not possible. It is likely the ACC and other paralimbic regions previously identified with this Go/NoGo task (Kiehl, et al., 2000; Steele, et al., 2013; Steele, Claus, et al., 2014) would be useful in identifying regions that differentiate between high and low psychopathic individuals. Many of these regions have been previously identified in both structural (Boccardi et al., 2011; Cope et al., 2014; Ermer, Cope, Nyalakanti, Calhoun, & Kiehl, 2011) and functional MRI (Kiehl et al., 2001; Kiehl et al., 2004). With fMRI data, networks of activation could be added to the cognitive functions identified here for an understanding of error processing deficiencies in individuals with high psychopathic traits. Such work could provide additional insights to initial resting fMRI networks related to high psychopathic traits (Juarez, Kiehl, & Calhoun, 2012). With this full picture, more effective treatments could be developed that could include psychopharmacological and behavioral modification treatment with the hope of reducing poor future outcomes.

Conclusion

Individuals with high psychopathic traits, relative to individuals with low psychopathic traits, make up a large percentage of incarcerated individuals (Hare, 2003) and are more likely to violently recidivate (Hemphill, et al., 1994). With a sample of 93 incarcerated adult males, error-processing was assessed using ERPs recorded during a Go/NoGo, response inhibition task. Individuals with high psychopathic traits exhibited greater Pe amplitude than individuals with low psychopathic traits. PCL-R Total score, Factor 1, and Facet 3 were all predictive of increased Pe amplitude. This suggests the interpersonal-affective and lifestyle measures of the PCL-R (Factor 1 and Facet 3) are specifically predictive of increased Pe amplitude. Increased Pe has also been linked to poor future outcomes (Steele, Fink, et al., 2014) and error evaluation (Larson, et al., 2013). Taken together, the results presented here suggest a specific cognitive deficit in error processing unique to individuals who score high on PCL-R Total score, Factor 1, and Facet 3 that could be attributed to an attentional bottleneck (Newman & Baskin-Sommers, 2012). This specific cognitive deficit should be targeted when developing new treatment techniques designed to increase long-term positive outcomes in incarcerated populations.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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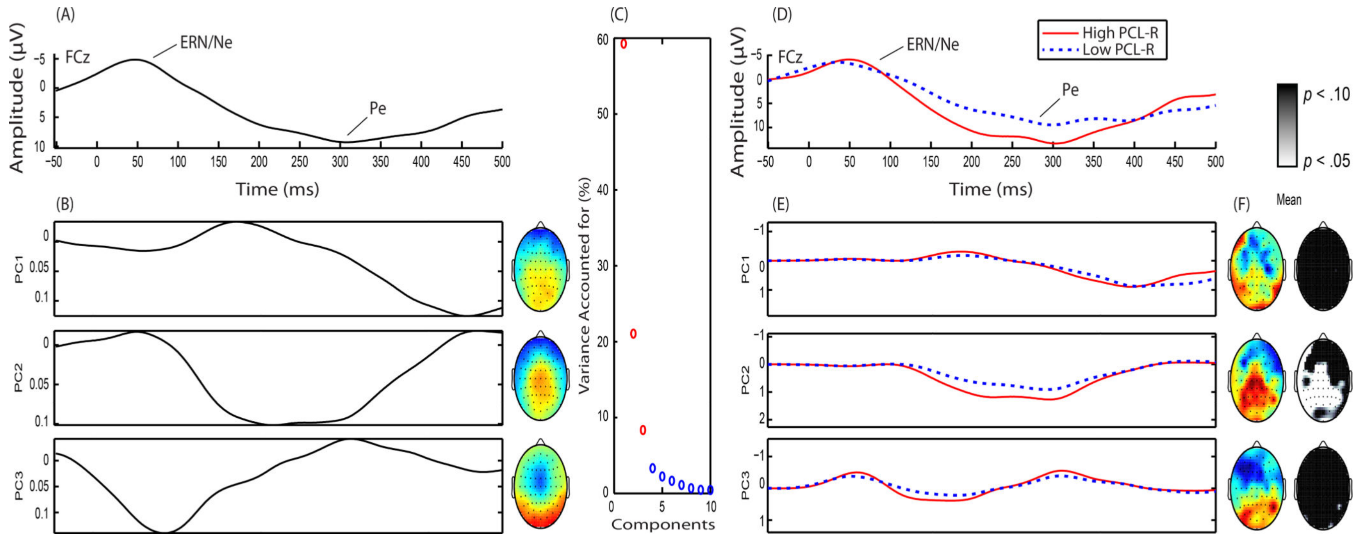

Figure 1.

Response-locked event-related potential (ERP) and Principal Component Analysis (PCA) with Psychopathy Checklist-Revised (PCL-R) Total score: (A) Grand average ERP waveform plotted at FCz. ERP components of interest (ERN/Ne & Pe) are identified. (B) Principal components extracted accounting for 89.58% of the variance and topographical depiction of the mean spatial distribution for each principal component. (C) Scree plot of singular values which was used to determine a three-component solution. (D) Grand average waveforms plotted at FCz by PCL-R Total score. Upper (solid red line; *n* = 23) and lower (dashed blue line; *n* = 23) quartiles are plotted for display purposes. (E) Principal components are plotted for upper and lower quartiles of PCL-R Total score. (F) Topographical difference (color) and correlation (black & white) maps are plotted for each principal component highlighting individuals which high PCL-R Total scores have increased Pe amplitude.

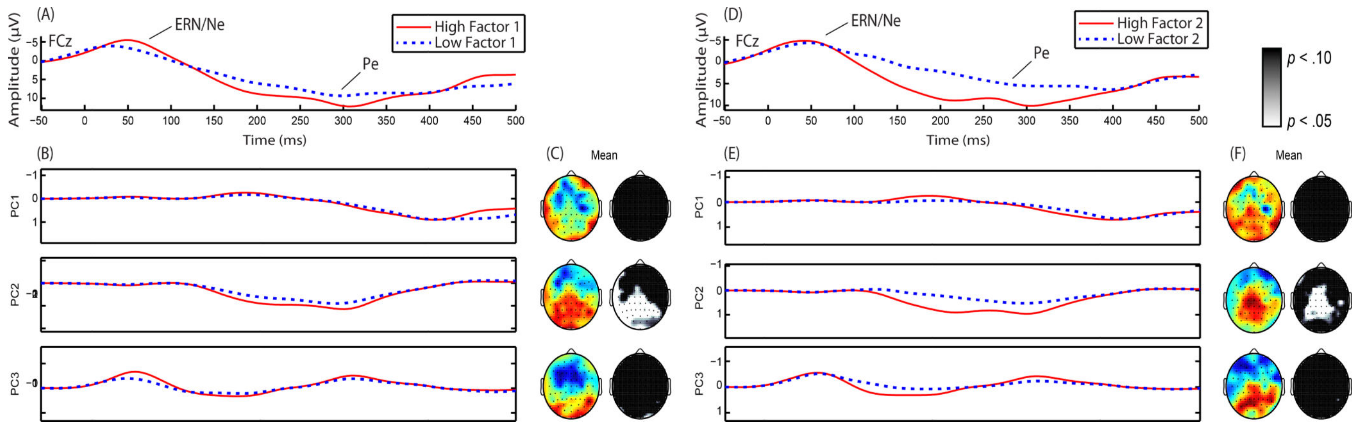

Figure 2.

Response-locked event-related potential (ERP) and Principal Component Analysis (PCA) with Psychopathy Checklist-Revised (PCL-R) Factor scores: (A) Grand average waveforms plotted at FCz by PCL-R Factor 1 scores. Upper (solid red line; *n* = 26) and lower (dashed blue line; *n* = 32) quartiles are plotted for display purposes. (B) Principal components are plotted for upper and lower quartiles of PCL-R Factor 1 scores. (C) Topographical difference (color) and correlation (black & white) maps are plotted for each principal component highlighting individuals which high PCL-R Factor 1 scores have increased Pe amplitude. (D) Grand average waveforms plotted at FCz by PCL-R Factor 2 scores. Upper (solid red line; *n* = 23) and lower (dashed blue line; *n* = 27) quartiles are plotted for display purposes. (E) Principal components are plotted for upper and lower quartiles of PCL-R Factor 2 scores. (F) Topographical difference (color) and correlation (black & white) maps are plotted for each principal component highlighting individuals which high PCL-R Factor 2 scores have increased Pe amplitude.

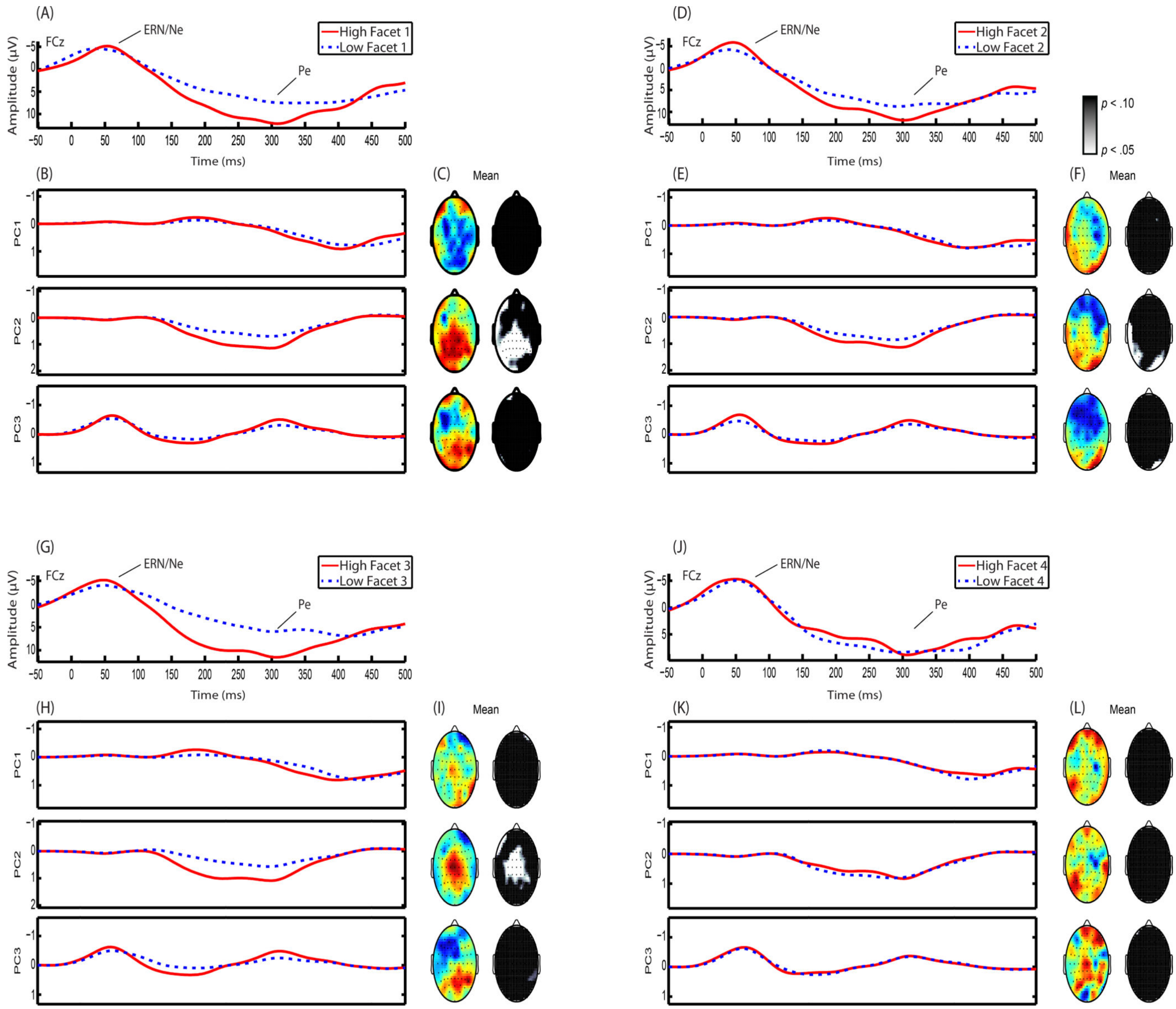

Figure 3.

Response-locked event-related potential (ERP) and Principal Component Analysis (PCA) plotted at FCz with Psychopathy Checklist-Revised (PCL-R) Facet scores: (A) Average waveforms by upper (solid red line; *n* = 34) and lower (dashed blue line; *n* = 33) PCL-R Facet 1 quartiles are plotted. (B) Principal components are plotted for upper and lower quartiles of PCL-R Facet 1 scores. (C) Topographical difference (color) and correlation (black & white) maps are plotted for each principal component highlighting individuals which high PCL-R Facet 1 scores have increased Pe amplitude. (D) Average waveforms by upper (solid red line; *n* = 28) and lower (dashed blue line; *n* = 24) PCL-R Facet 2 quartiles are plotted. (E) Principal components are plotted for upper and lower quartiles of PCL-R Facet 2 scores. (F) Topographical difference (color) and correlation (black & white) maps are plotted for each principal component highlighting minimal relationship between ERN/Ne and Pe with PCL-R Facet 2 scores. (G) Average waveforms by upper (solid red line; *n* = 31) and lower (dashed blue line; *n* = 24) PCL-R Facet 3 quartiles are plotted. (H) Principal components are plotted for upper and lower quartiles of PCL-R Facet 3 scores. (I) Topographical difference (color) and correlation (black & white) maps are plotted for each principal component highlighting individuals which high PCL-R Facet 3 scores have increased Pe amplitude. (J) Average waveforms by upper (solid red line; *n* = 24) and lower (dashed blue line; *n* = 28) PCL-R Facet 4 quartiles are plotted. (K) Principal components are plotted for upper and lower quartiles of PCL-R Facet 4 scores. (L) Topographical difference (color) and correlation (black & white) maps are plotted for each principal component highlighting no relationship between ERN/Ne and Pe with PCL-R Facet 4 scores.

Table 1

Correlations among PCL-R Variables and Covariates

Variable	PCL-R Total	PCL-R Factor1	PCL-R Factor2	PCL-R Facet 1	PCL-R Facet 2	PCL-R Facet 3	PCL-R Facet 4	Age	IQ	Sub. Dep.
PCL-R Total	___									
PCL-R Factor 1	.855**	___								
PCL-R Factor 2	.870**	.525**	___							
PCL-R Facet 1	.735**	.870**	.439**	___						
PCL-R Facet 2	.740**	.856**	.466**	.490**	___					
PCL-R Facet 3	.748**	.479**	.841**	.401**	.424**	___				
PCL-R Facet 4	.527**	.254**	.667**	.179	.260**	.345**	___			
Age	−.128	.015	−.293**	.039	−.016	−.257*	.008	___		
IQ	.166	.113	.166	.204	−.015	−.283**	.021	.111	___	
Sub. Dep.	.152	.060	.268*	.106	−.004	.304**	.038	−.138	.073	___
NoGo Acc.	−.019	.129	−.140	.122	.100	−.101	−.097	.363**	.070	−.105
Go Acc.	.094	.073	.116	.046	.082	.169	.033	−.003	.176	.047

Note. Assessments: Correlations among assessment variables. PCL-R Total is the Total score derived from the Psychopathy Checklist – Revised (Hare, 2003); PCL-R Factor 1 and Factor 2 are Factor 1 and Factor 2 scores derived from the PCL-R; PCL-R Facet 1, Facet 2, Facet 3, and Facet 4 scores are Facet 1, 2, 3, and 4 scores derived from the PCL-R (Hare, 2003); Intelligence Quotient (IQ) was calculated from the Wechsler Adult Intelligence Scale – Third Version (WAIS-III; Wechsler, 1997); Sub. Dep. is the number of substance dependencies calculated from the Structured Clinical Interview for DSM-IV Axis I Disorders-Patient Version (SCID I/P; First, et al., 1995). NoGo Accuracy is the participant's accuracy to NoGo stimuli. Go Accuracy is the participant's accuracy to Go stimuli.

* $p < .05$;

** $p < .01$.

Table 2

Psychopathy Variables and Covariates Predicting PC2 (Pe) Mean Amplitude

Regression 1 PCL-R Total Score					
Predictors	B	SE B	Wald	β	Sig
PCL-R Total	.009	.004	2.414	.245	.018
Regression 2 PCL-R Factor Scores					
Predictors	B	SE B	Wald	β	Sig
PCL-R Factor 1	.015	.007	2.045	.210	.044
PCL-R Factor 2			1.057		.725
Regression 3 PCL-R Facet Scores					
Predictors	B	SE B	Wald	β	Sig
PCL-R Facet 1			1.355		.179
PCL-R Facet 2			0.408		.684
PCL-R Facet 3	.029	.012	2.366	.241	.020
PCL-R Facet 4			−1.347		.181

Regression 1: $R^2 = .060$, $R = .245$, $F(1,92) = 5.83$, $p = .018$.

Regression 2: $R^2 = .044$, $R = .210$, $F(1,92) = 4.18$, $p = .044$.

Regression 3: $R^2 = .058$, $R = .241$, $F(1,92) = 5.60$, $p = .020$.

Note. Linear stepwise regressions with PC2 as the dependent variable and psychopathy measures as the independent. PCL-R Total is the Total Score derived from the Psychopathy Checklist – Revised (PCL-R; Hare, 2003); PCL-R Factor 1 and Factor 2 are Factor 1 and Factor 2 scores derived from the PCL-R (Hare, 2003); PCL-R Facet 1, Facet 2, Facet 3, and Facet 4 scores are Facet 1, 2, 3, and 4 scores derived from the PCL-R (Hare, 2003).