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Review article

Psychopathy and neurodynamic brain functioning: A review of EEG research

Abby P. Clark*, Andrew P. Bontemps, Blair D. Batky, Emelia K. Watts, Randall T. Salekin*

University of Alabama, United States

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ABSTRACT

Studies related to psychopathy and EEG have increased over the past decade making it a good time to examine where the field is on this topic as well as to determine future directions. The current study reviewed 68 research reports that focused on psychopathy and various components of EEG. We examined early, mid, and late level ERP processing as well as spectra analyses. The results indicate that psychopathic individuals exhibit generally unencumbered performance categorizing cognitive stimuli and demonstrate the typical facilitation of physical responses commensurate with an intact orienting response. Moreover, the results suggest that individuals with elevated psychopathic traits are especially adept at screening out distracting threat-related and other irrelevant information allowing them to allocate attention to stimuli that are goal-relevant. Those with elevated psychopathic traits also do not appear to have significant impairments in associative learning or error processing. Where psychopathic individuals diverge most from those with low levels of these traits is in relation to processing affect-laden content. In some contexts, psychopathic individuals appear to quickly terminate the processing of emotional information and in other contexts (e.g., seeing others in pain) they elaborately process emotional information both of which may help explain their prototypical lack of conscience. Much of the aberrant functioning of those with elevated psychopathic traits depends on the psychopathy factor being examined with F1 traits showing less cognitive impairment than F2 traits. Recommendations for future research are provided.

1. Introduction

Psychopathy is a severe personality condition that is characterized by a collection of interpersonal, affective, and behavioral traits that include superficial charm, manipulation, lack of guilt, irresponsibility, and antisocial conduct (Hare, 1991/2003). Because the condition exacts a large toll on society, a great deal of work has been generated to better understand the etiology of the syndrome. Over the years, studies have been conducted to pinpoint the distinct psychophysiological functioning of the psychopathic individual (e.g., Hare, 1970; Tillem et al., 2018). In this regard, electroencephalography (EEG) investigations have been produced to better decipher the neural dynamics of individuals with psychopathic traits (e.g., Decety et al., 2015; Gao et al., 2018; Hare and Quinn, 1971; Hung et al., 2013; Jutai and Hare, 1983; Krusemark et al., 2016; Raine and Venables, 1990; Williamson et al., 1991). The purpose of the current study is to summarize the EEG research on psychopathy in order to explore the neurodynamics of those with elevated psychopathic traits.

To meet this aim, we accumulated articles on psychopathy and EEG from peer-reviewed English language investigations published online from 1980–2019. Articles were located from major publication databases including Medline, Pubmed, and PsycInfo. In addition, we examined reference lists of prior narrative reviews and individual studies on psychopathy and EEG. Databases were searched using the following words: psychopathy with electro*, EEG, ERP, time series analyses, P100, P200, P300, P550, P600, N100, N200, N300, N450, N550, CNV, ERN, FRN, and LPP. Studies resulting from the searches were filtered according to the following criteria: (i) studies were excluded if they did not include a modern, and/or well-accepted psychopathy scale or psychopathy estimate (e.g., Antisocial Process Screening Device (APSD), Psychopathy Checklist-Revised (PCL-R), Psychopathy Checklist-Youth Version (PCL-YV), Psychopathic Personality Inventory (PPI), Self Report Psychopathy (SRP), Triarchic Psychopathy Measure (TriPM)) and (ii) studies were excluded if they examined antisocial personality disorder (APD) alone.[1] A PRISMA diagram outlines the specific number of studies examined and the process for selection of articles (see supplemental materials).

* Corresponding authors.
E-mail addresses: apclark1@crimson.ua.edu (A.P. Clark), rsalekin@ua.edu (R.T. Salekin).

[1] The authors are aware of the early research conducted on psychopathy and EEG at the Burden Neurological Institute in Bristol, UK and the Broadmoor Hospital, also in the UK (e.g., Fenton et al., 1978) and research in the USA such as that at the University of California-Los Angeles (UCLA) (e.g., Syndulko, 1978). However, these works and other early works (e.g., Blackburn, 1979) are not included in the current review because no contemporary psychopathy measures were used, making cross study comparisons difficult. If readers are interested, we recommend they obtain original sources.

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A total of 68 studies survived the filtering process and met criteria for the present study. Early (e.g., P100, N100), mid (e.g., N200, P300), and late (e.g., P550 and LPP) Event Related Potentials (ERPs) were examined as well as time frequency (spectra) data, hemispheric difference analyses, and other spatial finding information (e.g., site analyses, sLORETA) from each relevant investigation. Independent coding and ratings were produced followed by team meetings to resolve any discrepancies. Study authors were contacted, if necessary, to gain further clarity regarding reported EEG research findings.

2. Psychopathy measurement and factor structure

One standard for the assessment of psychopathy is the Psychopathy Checklist-Revised (PCL-R) which is a multidimensional construct underpinned by interpersonal, affective, lifestyle, and antisocial facets (Hare, 1991/2003; Hare et al., 2018). Initially, two broad factors were identified for this measure including Factor 1 (F1), an interpersonal/affective dimension (e.g., superficial charm, arrogance, and lack of empathy), and Factor 2 (F2), an impulsivity/antisocial dimension (e.g., impulsive, irresponsible, proneness to boredom, and social deviance) (e.g., Harpur et al., 1989). Later, factor analytic studies revealed narrower facets including interpersonal (facet 1), affective (facet 2), lifestyle (facet 3), and antisocial (facet 4) domains (Hare, 2003). Although the Psychopathy Checklist is arguably one of the most dominant models for psychopathy, other psychopathy measures have also emerged. Three additional measures include the Psychopathic Personality Inventory (PPI; Lilienfeld and Andrews, 1996), the Self Report Psychopathy-4 (SRP-4; Palhaus et al., 2017), and the Triarchic Measure of Psychopathy (TriPM; Patrick, 2010). The PPI is undergirded by three factors including Fearless Dominance (FD), Self-Centered Impulsivity (SCI), and Cold Heartedness (CH) (Lilienfeld, 1991; Lilienfeld and Andrews, 1996; Neumann et al., 2008). The SRP-4 maintains the same factor structure as the PCL-R with interpersonal, affective, lifestyle, and antisocial facets (Hare, 2003). The TriPM includes the sub-factors of boldness, meanness, and disinhibition (Patrick, 2010). Although the alignment is imperfect, each sub-dimension can be placed into roughly three categories including grandiose manipulation (PCL-Interpersonal, PPI-Fearless Dominance, TriPM-Boldness), callous-uncaring (PCL-Affective, PPI-Cold-Heartedness, TriPM Meanness), and daring-impulsivity (PCL-Lifestyle, PPI-Self-Centered Impulsivity, TriPM-Disinhibition). The exception is that the SRP adds the fourth antisocial factor to be consistent with the well-known PCL four-factor model (SRP-4; Hare, 2003). Although lacking complete alignment, the factors have, to some extent, overlapping nomological networks (see Bresin et al., 2014).[2]

3. Theoretical models for psychopathy

A number of theoretical perspectives have been advanced for psychopathy (see Patrick, 2018). Two theories have received considerable attention in the past decade. These include the Response Modulation hypothesis (RM; Bencic Hamilton et al., 2018; Patterson and Newman, 1993) and the Fearlessness (Low-Fear) hypothesis (Lykken, 1957; Sylvers et al., 2011). The RM perspective suggests that individuals with elevated psychopathic traits exhibit a basic deficit in the allocation of attention to peripheral stimuli. Although the theory has been altered and elaborated upon over the years, the basic premise is that once engaged in a dominant response set the psychopath's attentional focus becomes unduly narrow precluding adequate processing of additional stimuli. This includes but is not limited to punishment (Bencic Hamilton and Newman, 2018; Patterson and Newman, 1993). Alternately, the Fearlessness (Low-Fear) model points to a relative absence of fear as the precursor to the disorder. This model posits that psychopathic individuals have an inadequate fear response, which gives rise to other features of the disorder such as grandiosity, superficial charm, lack of guilt, and risk-taking. The Fearlessness model highlights the amygdala as the area of the brain implicated whereas the RM attention model underscores the prefrontal brain region. Studies have shown support for each theory (e.g., Lykken, 1957; Hare, 1965; Patterson and Newman, 1993) although there is still considerable debate (e.g., Patrick, 2018; Smith and Lilienfeld, 2015). Further complicating the issue pertaining to the best explanatory model is the possibility that the theories, and related brain circuitry, are intertwined, with top-down processing affecting bottom-up processing and vice versa (Lykken, 1957; Bencic Hamilton and Newman, 2018; Sylvers et al., 2011).

EEG findings could shed light on various theoretical models by lending greater support for one theory (e.g., RM) versus another (e.g., Fearlessness), and/or potentially illuminating the manner in which individual theories may be integrated or otherwise advanced in order to better understand psychopathy. Specifically, EEG allows for the examination of key brain functions such as alerting, orienting, memory-updating, associative learning, and error processing, as well as elaborative cognitive and emotional processing, all of which have linkages to psychopathy (e.g., Hare, 1993). Given the clinical description of psychopathy, which includes superficial charm, grandiosity, manipulation, deceit, and a conning interpersonal style (Cleckley, 1941/1976; Hare and Hart, 1993), we hypothesize that psychopathic individuals will not show deficits in EEG components related to alerting, orienting, working memory, associative learning, error processing, inhibiting a response or processing of general cognitive information. However, we do expect that the processing of affective information will be aberrant and this will be apparent through the various EEG/ERP findings. Specifically, we hypothesize that there will be deficits in the psychopathic individuals' attention to threat and aberrations in the processing of other emotional stimuli (e.g., face stimuli, emotional language stimuli, and visual emotional stimuli) that will be evidenced in the EEG findings. It is expected that there will be no deficits in associative learning (e.g., connecting two previously unrelated stimuli), error processing (e.g., recognizing that one has just made a mistake), or inhibition (e.g., being able to stop an ongoing behavior). In the following sections, we provide a brief description of the ERPs, their assumed neural generators, typical tasks used to elicit their response, and a summary of the EEG findings.

4. Early (ERP) processing: attention, alerting, and memory

For the present review, we examined relations between psychopathy and the P100, N100, and P200. These ERPS are early in the processing stream and to some extent preconscious. Thus, these initial aspects of neuronal functioning could be relevant for better understanding psychopathy due to their connection to automatic attention, altering, and early components of memory. Moreover, these early components may provide hints as to what information is captured (not captured) and what information might make its way further into the working memory. Aberrations in these ERPs could come in the form of strengths or deficits with regard to performance on behavioral tasks.

4.1. Psychopathy and P100

The P100 reflects attentional processes like achieving and maintaining an alert state, preparing to react to stimuli, and allocating attention to potentially significant events (Hillyard and Anllo-Vento, 1998). The P100 provides a relatively direct and sensitive index of alerting as well as where attention is directed in space. The more a participant's attention is aimed toward an upcoming target, the larger the P100 amplitude. The P100 is typically generated by either the primary visual cortex (striate cortex) and/or the extrastriate cortex

[2] There is research to suggest that FD of the PPI and Boldness of the TriPM do not align with the PCL factors (e.g., Malterer et al., 2010), although originally, the authors of the newly developed measures (PPI, TriPM) claimed some connection to the PCL (e.g., Lilienfeld and Andrews, 1996).

(Hillyard and Anllo-Vento, 1998) and is indexed at the occipital lobe but may draw on other neurogenerators. Common tasks to elicit the P100 include visual stimuli (light), threat stimuli (shock), and other attention related tasks (e.g., the attention network task; Posner & Rothbart, 2010).

To date, five studies have examined the P100 ERP with psychopathic individuals (Anton et al., 2012; Baskin-Sommers et al., 2012; Hiatt-Racer et al., 2011; Raine and Venables, 1990; Williamson et al., 1991). Two studies showed no difference in the P100 amplitude. Specifically, Raine and Venables (1990) demonstrated that male offenders with elevated psychopathic traits appropriately oriented and adapted to flashing light. Williamson et al. (1991) found that male inmates with elevated psychopathic traits demonstrated a faster reaction time, and better performance to lexical decisions (i.e., "Is it a word or not") but exhibited no difference from non-psychopathic individuals with respect to P150 amplitudes. Two studies noted lower amplitudes to threat stimuli (electric shock) in male offenders (P140; Baskin-Sommers et al., 2012) and female offenders when threat was task irrelevant (Anton, Baskin-Sommers, et al., 2012). Given the aforementioned findings, both Anton et al. (2012) and Baskin-Sommers et al. (2012) concluded that those with elevated psychopathic traits found it easier to ignore threat-related distractors when they were pursuing a dominant goal. Hiatt-Racer et al. (2011) observed a lower P100 for alerting (but not orienting) in a sample of multi-problem youth recruited from family service and counseling agencies.

In sum, of the studies examining the P100, 40% of the studies (2 studies) showed no difference in P100 waves, 40% (2 studies) showed a decrease in response to threat only, and 20% (1 study) showed a decrease in P100 amplitude in an alerting response for those with elevated psychopathic traits.

At the component level, Baskin-Sommers et al. (2012) examined the two broad psychopathy (PCL) factors (i.e., F1 and F2). Their findings were significant for F1 (interpersonal affective traits) but not F2 (impulsive/antisocial traits) indicating that those offenders with high F1 traits were able to ignore threat stimuli (shock) whereas those with high F2 were not. Using the same study paradigm, this general finding was reversed in female offenders where those with higher F2 scores exhibited a lower P100 to threat (Anton et al., 2012). Hiatt-Racer et al. (2011) also examined the psychopathy components and found no difference in P100 amplitude across the facets on the attention network task (see Table 1, Section A).

4.2. Psychopathy and N100

The N100 reflects arousal, selective attention, location of attention, and perception (Hillyard et al., 1973). The N100 is often evoked by auditory stimuli, but can also be elicited by visual stimuli (visual discrimination) (Hansen and Hillyard, 1980). The N100 amplitude is larger when focusing attention (Luck et al., 1990). The N100 is indexed in the frontal and central brain regions and is assumed to be generated by a network of neural populations in the primary and associative auditory cortices, superior temporal gyrus, planum temporale and in frontal and motor areas. Common tasks to elicit the N100 in psychopathy research include auditory and visual stimuli tasks, classical conditioning tasks, and emotion oddball-style tasks.

A total of fourteen studies examined the relation between psychopathy and the N100 (Anderson and Stanford, 2012; Anderson et al., 2015; Bencic Hamilton et al., 2014; Cheng et al., 2012; Flor et al., 2002; Forth and Hare, 1989; Heritage and Benning, 2013; Jutai and Hare, 1983; Jutai et al., 1987; Raine and Venables, 1990; Rothemund et al., 2012; Sadeh and Verona, 2012; Varlamov et al., 2011; Williamson et al., 1991). Four studies found larger N100 amplitudes for those with elevated psychopathic traits, versus those with low levels of psychopathic traits, but some of these findings were conditional. Specifically, Anderson and Stanford (2012) observed larger amplitudes to a unique affective processing task where community participants viewed pictures with varying degrees of emotional content and were asked to simply watch the stimuli (implicit condition), or were asked to explicitly acknowledge emotional content in the pictures (explicit condition). Those with elevated psychopathic traits exhibited higher N100 amplitudes to the explicit condition compared to those with low levels of psychopathic traits but showed no difference in amplitudes to the implicit condition.

In a separate study with male inmates, Anderson et al. (2015) found those with elevated psychopathic traits compared to those with lower levels of psychopathic traits exhibited larger N100 amplitudes to an auditory oddball task, showing greater attention to novel stimuli. Flor et al. (2002) examined an at-risk adult community sample and noted that those with elevated psychopathic traits exhibited greater activation (larger N100) contingent on hemisphere (right hemisphere) and site (central and parietal sites) for the first half of the acquisition in a Pavlovian learning task (classical conditioning task). During this task, psychopathic individuals conditioned more rapidly making the necessary association between the conditioned stimulus (CS; face) and the unconditioned stimulus (UCS; odor). In a different study, using a sample of offenders, Sadeh and Verona (2012) observed an enhanced N100 for attention to visual stimuli commonly designed to elicit fear. Their findings indicate that early selective attention is relatively strong in psychopaths and resistant to subsequent interference by potentially irrelevant secondary stimuli. However, Sadeh and Verona (2012) also noted that individuals with psychopathic traits devoted more attention to processing unpleasant versus neutral images but this finding only held true for complex images.

Using community participants, Anderson and Stanford (2012) demonstrated that those with elevated psychopathic traits exhibited elevated N100 amplification on explicit differentiation of emotional versus non-emotional pictures compared to those with low levels of psychopathic traits, although in the same study, there was no N100 difference on this task for implicit differentiation or for a Go/No-go component of the study. The latter findings suggest no differences were noted in terms of impulsivity or implicit picture viewing. Six N100 studies found no differences in N100 amplitude between those with elevated versus low level psychopathic traits on study tasks. Specifically, using an inmate sample, Raine and Venables (1990) found no variance in the N100 for a flashing light reflecting no difference overall in the P1-N1 complex. Forth and Hare (1989) observed no difference in the N100 between psychopathic and non-psychopathic male inmates in a forewarned reaction time task. Using a mixed sample of those on bail, parole, and non-legally involved community members, Rothemund et al. (2012) noted no difference for the N100 on extinction in the Pavlovian learning task. Jutai and Hare (1983) observed similar N100 amplitudes for performance on a passive attention task where inmates were asked to listen for tone pips. Jutai et al. (1987) similarly observed no difference between psychopathic and non-psychopathic offenders on the N100 during an auditory (speech) oddball task. Finally, also utilizing an inmate sample, Williamson et al. (1991) found no difference in the N150 on a lexical decision task where their performance on the task itself was superior with similar neural effort.

Five studies observed smaller N100 amplitudes for total psychopathy scores on several paradigms including a box-Stroop task (color words surrounded by a colored rectangular frame; Bencic Hamilton et al., 2014), visual pain stimuli (Cheng et al., 2012), a Go/No-go task (Varlamov et al., 2011), a Pavlovian learning task (face and shock stimuli; Rothemund et al., 2012), and a maze task (with distractor tone pips). In the latter, the lower N100 was associated with equally proficient task performance early on in the task suggesting less neural effort needed for those with elevated traits (Jutai and Hare, 1983). The Cheng et al. (2012) finding of a lower N120 indicated less initial orientation to pain stimuli. All of the latter studies included offender samples, with the exception of Varlamov et al. (2011) who utilized institutionalized personality disordered patients rather than inmates.

In sum, at the total score level and allowing each study to count only

Table 1
Psychopathy and EEG Findings: Early Processing (P100, N100, P200).

Author Year	Sample	Measure	Task/ERP/electrode site	Outcome
Section A				
P100				
Anton et al. (2012)	N = 74; age 18-45; 0% male; offenders	PCL-R	Fear conditioning task P100 (Pz, O1 O2)	Higher P100 (alternative focus) Lower P100 (threat focus (irrelevant)) (total and F2)
Baskin-Sommers et al. (2012)	N = 101; age 30.72; 100% male; inmates	PCL-R	Fear conditioning task P140 (Fz, FCz, Cz, Pz)	Higher P140 (alternative focus) Lower P140 (threat focus (irrelevant)) (total and F1)
Hiatt-Racer et al. (2011)	N = 43; age 9-14 years; 40% male; community	APSD	Attention Network Task P100 (*M* of 14 electrodes; near O1 and O2)	Lower P100 (alerting) Higher P100 (orienting, ns)
Raine and Venables (1990)	N = 32; age 32.5; 100% male; offenders	PCL	Visual stimuli (flashes of white light) P100 (Cz, T3, P3, T4, P4)	No difference P100
Williamson et al. (1991)	N = 16; age 18-41; 100% male; inmates	PCL	Lexical Decision Task P150-N180 (Fz, Cz, Pz, PT3, PT4)	No difference P150
Section B				
N100				
Anderson and Stanford (2012)	N = 40; age 18-57; 48% male; community	PPI-R	Affective picture oddball (task 1: implicit differentiation; task 2: explicit differentiation); with a Go/No-go component N100 (Fz, Pz, Cz)	No difference in N100 (Task 1) No difference in N100 (Go/No go) Higher N100 (Task 2)
Anderson et al. (2015)	N = 59; age 34.9; 100% male; inmates	PCL-R	Auditory oddball task N100 (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4)	Higher N100 to target (total, facets 1, 4)
Bencic Hamilton et al. (2014)	N = 91; age 18-45; 100% male; inmates	PCL-R	Boxstroop task N100 (Fz)	Lower N100 to incongruent versus neutral stimuli (F1)
Cheng et al. (2012)	N = 43; age 15-18; 100% male; juvenile offenders	PCL:YV	Visual pain stimuli (pain-self; pain-other) N120 (32 channel; not specified)	Lower frontal N120 to pain-self stimuli
Flor et al. (2002)	N = 21; age 30.83; 100% male; at-risk community	PCL-R	Pavlovian conditioning task N100 (F2, F3, F4, C3, Cz, C4, P3, Pz, P4)	Higher N100 (RH) acquisition
Forth and Hare (1989)	N = 23; age 18-45; 100% male; inmates	PCL	Forewarned reaction time task (win, neutral) N100 (Fz, Cz, Pz)	No difference in N100
Heritage and Benning (2013)	N = 66; age 36; 44% male; ER patients screened for psychopathy	PPI-estimate	Lexical decision stop signal task N100 (Fz)	Lower N100 (IA)
Jutai and Hare (1983)	N = 21; age 28.6; 100% male; inmates	PCL	Maze task/airplane task plus irrelevant tone pip N100 (C3, C4)	No difference in N100 amplitude or latency Lower N100 s when attention diverted (resulted in improved task performance) on initial trial
Jutai et al. (1987)	N = 24; age 29.1; 100% male; inmates	PCL	Single Task (oddball with speech sounds; Task 1) Dual Task (distraction; Task 2) N100 (Cz, T3, T4)	No difference in N100 (Task 1 or Task 2)
Raine and Venables (1990)	N = 32; age 32.5; 100% male; offenders	PCL	Visual stimuli (flashes of white light) N100-P200 (Cz, T3, P3, T4, P4)	No difference in N100
Rothemund et al. (2012)	N = 22; age 22-43; 100% male; bail or parole and community	PCL-R	Pavlovian learning task (pictures and shock) N100 (C3, C4, P3, P4)	Lower N100 for acquisition Lower N100 habituation (RH) No Difference in N100 for extinction
Sadeh and Verona (2012)	N = 52 (63); age 18-50; 82.5% male; probation, parole, local jail	PCL:SV	Picture viewing paradigm (neutral, unpleasant; clear figure ground versus complex scene) VN100 (O1, Oz, O2)	Higher N100 unpleasant complex pictures (F1) Lower N100 unpleasant familiar pictures (F1) Lower N100 amplitude (F2)
Varlamov et al. (2011)	N = 69; age 32.71; 100% male; personality disordered patients	PCL-R/ PCL-SV	Go/No-go Task N100 (Fz, F7, F8)	Lower N100 to negative feedback
Williamson et al. (1991)	N = 16; age 18-41; 100% male; inmates	PCL	Lexical Decision Task P150-N180 (Fz, Cz, Pz, PT3, PT4)	No difference in N180
Section C				
P200				
Anderson and Stanford (2012)	N = 40; age 18-57; 46% male; community	PPI-R	Affective picture oddball (task 1: implicit differentiation; task 2: explicit differentiation) P200 (Fz, Pz, Cz)	Lower P200 (Task 1) Lower P200 (trend on Task 2) No difference in P200 (Go/No go)
Brislin et al. (2018)	N = 254; age = 29.4; 65% male; community	TriPM	Face Viewing Task P200 (Pz)	Lower P200 (Callous-aggression)
Carolan et al. (2014)	N = 34; age = 20.26; 38% male; undergraduates	PPI-R SF	Emotional stroop (eStroop) (EAP 200-300 ms) EAP (AF4, F2, F4, F6, FC2, FC4, C2, C4)	Lower P200 to negative stimuli
Flor et al. (2002)	N = 21; age 30.83; 100% male; at-risk community	PCL-R	Pavlovian conditioning task P200 (F2, F3, F4, C3, Cz, C4, P3, Pz, P4)	Higher P200 to acquisition, habituation, extinction (frontal and central)
Jutai and Hare (1983)	N = 21; age 28.6; 100% male; inmates	PCL	Maze task/airplane task plus irrelevant tone pip P200 (C3, C4)	No difference in P200 amplitude No difference in P200 latency
Rothemund et al. (2012)	N = 22; age 22-43; 100% male; bail or parole and community	PCL-R	Pavlovian conditioning task (pictures and shock) P200 (F3, F4, C3, C4)	Higher P200 during acquisition
Varlamov et al. (2011)	N = 69; age 32.71; 100% male; personality disordered patients	PCL-R/ PCL-SV	Visual Go/No-go Task P200 (Fz, F7, F8)	No difference in P200

(*continued on next page*)

Table 1 (*continued*)

Author Year	Sample	Measure	Task/ERP/electrode site	Outcome
Williamson et al. (1991)	N = 16; age 18-41; 100% male; inmates	PCL	Lexical Decision Task P240 (Fz, Cz, Pz, PT3, PT4)	Lower P240 peaks for affective words

Note: PCL = Psychopathy Checklist; PCL-R = Psychopathy Checklist-Revised; PCL-YV = Psychopathy Checklist-Youth Version; PCL-SV = Psychopathy Checklist –Screening Version; PPI = Psychopathic Personality Inventory; TriPM = Triarchic Psychopathy Measure; F1 = Factor 1 of the PCL; F2 = Factor 2 of the PCL; IA = Impulsive Antisocial; EAP = early anterior positivity; RH = right hemisphere of the brain. If a factor or facet is mentioned in relation to a specific ERP it means that the other factors/facets are non-significant. Age is presented as a range unless unavailable in which case the arithmetic mean is presented.

once, 15% of studies (2 studies) showed an increased N100 amplitude, 43% (6 studies) showed no difference, and 21% (3 studies) showed a decreased amplitude in response to a variety of paradigms. Twenty-one percent (3 studies) showed mixed results based on the task.

At the component level, Sadeh and Verona (2012) noted that high F1 traits were associated with greater allocation of cognitive resources to emotional stimuli at initial perception (N100) when the pictures were complex and those with elevated F1 scores also showed the greatest orienting to unpleasant pictures of high complexity. Those with elevated F2 traits allocated less attention to processing pictures overall. At the facet level, Anderson et al. (2015) found the larger N100 amplitude for an auditory oddball task was specific to facet 1 and 4 of the PCL but did not find this effect for facets 2 and 3. Finally, Heritage and Benning (2013) found that the PPI-R FD was unrelated to N100 amplitudes to a signal stop task whereas PPI-R IA showed lower N100 amplitudes to a stop signal task. The authors argued that individuals with primarily FD traits were capable of devoting attention to pertinent peripheral information whereas those with elevated IA traits were not (see Table 1, Section B).

4.3. Psychopathy and P200

The P200 represents higher order perceptual processing modulated by attention and linked with memory. The P200 is part of a cognitive matching system that compares sensory inputs with stored memory (Luck and Hillyard, 1994). Typical sites for measuring the ERP include frontal-central and parietal-occipital areas. Higher P200 amplitudes suggest greater neuronal activity aimed toward matching stimuli. Typical tasks include visual search tasks, language context tasks, and the oddball tasks. Eight studies have examined psychopathy in relation to the P200 (Anderson and Stanford, 2012; Brislin et al., 2018; Carolan et al., 2014; Flor et al., 2002; Jutai and Hare, 1983; Rothemund et al., 2012; Varlamov et al., 2011; Williamson et al., 1991).

Two studies observed enlarged P200 amplitudes for psychopathic individuals in comparison to non-psychopathic individuals. Specifically, Flor et al. (2002) discovered a higher P200 to the Pavlovian conditioning task (face + odor) during acquisition, habituation, and extinction. Similarly, Rothemund et al. (2012) found a higher P200 amplitude on a similar Pavlovian conditioning task, which used a shock rather than odor for the UCS (face + shock). Together, the studies demonstrate better differentiation and learning for those with elevated psychopathic traits versus those with lower levels of psychopathic traits. In addition, three studies showed no difference in the P200 at total psychopathy score level for two types of tasks including a visual maze (Jutai and Hare, 1983) and visual Go/No-go (Anderson and Stanford, 2012; Varlamov et al., 2011).

Four studies observed smaller P200s to four separate tasks; these tasks were primarily affective in nature. Specifically, Anderson and Stanford (2012) found a lower P200 to an affective implicit differentiation task, Carolan et al. (2014) using an undergraduate sample found a lower P200 to an emotional Stroop (e-stroop), and Williamson et al. (1991) using an inmate sample observed a lower P240 to a lexical decision task. With regard to the latter study, although the P240 was lower, performance on the task itself was unhampered. Finally, Brislin et al. (2018) using an undergraduate sample found a lower P200 to a face viewing task (fearful and neutral face stimuli) for callous aggression.

To summarize, at the total score level, 25% of studies (2 studies) found evidence for higher P200 amplitudes, 37.5% (3 studies) found evidence for no difference in P200 amplitudes, and 25% (2 studies) found evidence for lower P200 amplitudes in response to a variety of tasks. One study (12.5%) found mixed findings for a multiple tasks (see Table 1, Section C).

4.4. Section summary

Cleckley (1941/1976) referred to the psychopathic individual as alert and attentive. Specifically, he referred to the psychopath's "perfect orientation" (p. 350) and referenced his "alert and friendly appearance" (p. 339). Of the studies reviewed in this section, the findings indicate that the wider construct of psychopathy does not appear to show deficits in orienting or alerting, as do, for example, other personality conditions such as conduct disorder (CD) and antisocial personality disorder (APD) (see Lijfitt et al., 2012; Pickworth et al., 1990). However, the findings from these early ERP components may suggest subtle neuronal differences for those with elevated versus low levels of psychopathic traits, especially for threat or irrelevant information when it is peripheral to the task (Anton et al., 2012; Baskin-Sommers et al., 2012; Jutai and Hare, 1983). Early ERPs also tend to show that those with elevated psychopathic traits adequately inhibit responses (stop-task; Heritage and Benning, 2013) and efficiently associate stimuli (P200; Flor et al., 2002; Rothemund et al., 2012). Across studies, however, even in this early time window, the independent invesigations show that those with elevated psychopathic traits perform less well when attending to threat or affective/emotion information (implicit vs. explicit differentiation, face viewing, emotional Stroop, and a lexical decision task). Only one study found a deficit to alerting with a sample recruited from community mental health facility where multi health problems were the norm (i.e., Hiatt-Racer et al., 2011).

5. Early- and mid-level (ERP) processing: face processing, mismatch detection (cognitive control), and memory updating

For the current review, we examined the relations between psychopathy and the N170, N200, and P300 ERPs.[3] Early-to-mid-level ERP processing via EEG represents important aspects of the time window for neural functioning that could be particularly relevant to psychopathy. For example, EEG research examining N170, N200, and P300 potentials, in those with high levels of psychopathic traits, could provide relevant information regarding potential aberrations in face processing, mismatch detection, and/or the identification of stimuli and memory updating. These mental processes and corresponding ERPs may exhibit

[3] The components here (N170, N200) overlap in time with the early components reviewed in the previous section. However, because the N170 and N200 represent distinct processes (e.g., face processing, mismatch detection), they are covered in this section.

themselves in the form of strengths or difficulties. In the next sections, we cover the N170, N200, and P300 ERPs.

5.1. Psychopathy and N170

The N170 ERP component has been shown to be dominant for identification of faces and eyes and is substantially reduced or absent in response to non-facial stimuli (Bentin et al., 1996; Jeffreys, 1989). The N170 is most commonly measured at occipito-temporal electrode sites. The N170 is generated by a network containing the posterior fusiform and inferior-temporal gyri, which have been associated with face processing. The N170 tends to display right hemisphere lateralization. Typical tasks that elicit the N170 are visual stimuli of faces and/or eyes (Lane et al., 1999).

Three studies have tested the N170 in relation to psychopathic traits (Almeida et al., 2014; Brislin et al., 2018; Eisenbarth et al., 2013). When examining high and low levels of psychopathic traits at the total score level, no differences were noted. However, Almeida and colleagues (2014) observed lower N170 amplitudes for FD, but enhanced N170 amplitudes for high scorers on CH in response to emotional and neutral faces in a community sample. Brislin and co-investigators (2018), also using a community sample, found lower N170 amplitudes for a callous aggression scale of the TriPM for a face recognition task (fear faces). Interestingly, Eisenbarth et al. (2013), using a female inpatient forensic sample, found no N170 differences for face processing on an affective picture paradigm, but did observe the difference at N200, where the amplitudes were observed to be lower for those with elevated psychopathic traits. Eisenbarth et al.'s (2013) findings may indicate a potential gender difference and/or inpatient versus community sample difference.

To summarize, 100% of the studies found no difference at the total score level. At the factor score level, one study found evidence for increased N170 amplitude, whereas two studies found evidence for reduced N170 amplitude (one for FD and one for Callous Aggression) (see Table 2, Section A).

5.2. Psychopathy and N200

The N200 is related to mismatch detection and reflects general executive and cognitive control functions (i.e., stimulus identification, attentional shifts, inhibition of motor response, maintenance of context information, response selection timing) as well as language functions (Luck and Hillyard, 1994). When the N200 is elicited in the context of tasks requiring response inhibition, the functional interpretation of the component centers on cognitive control (sustained attention and response control). The N200 is located primarily over anterior scalp sites. Increases in the N200 amplitudes reflect better mismatch detection. The neural generators for the N200 depend upon the task but can be from the auditory cortical region, frontal lobe, and the hippocampus. Common tasks used to elicit this ERP include the Continuous Performance Task (CPT), the Stop Signal Task (SST), the Erikson Flanker Task, and the Go/No-go task.

A total of nine studies have examined the N200 in relation to psychopathic traits (e.g., Anderson and Stanford, 2012; Anderson et al., 2015; Eisenbarth et al., 2013; Hung et al., 2013; Kiehl et al., 2006, 2000; Kim and Jung, 2014; Munro et al., 2007b), one of which tested the N2pc which is measured at sites P3 and P4 (Krusemark et al., 2016). Four studies found an enlarged N200 for those with elevated compared to low levels of psychopathic traits on several different tasks (Hung et al., 2013; Kiehl et al., 2006; Kim and Jung, 2014; Krusemark et al., 2016). Specifically, two studies reported a stronger N200 for those with elevated psychopathic traits on the auditory oddball task with adolescent offenders and adult offenders (Hung et al., 2013; Kiehl et al., 2006). Auditory oddball tasks involve the repeated presentation of auditory stimuli that is periodically, interrupted by novel auditory stimuli (i.e., oddball stimuli). A third study showed a stronger N200 to a Go/No-go task for undergraduate students with elevated psychopathic traits (Kim and Jung, 2014). Finally, using a male inmate sample and a visual search task, Krusemark et al. (2016) showed that those with elevated psychopathic traits exhibited a greater N2pc amplitude to color stimuli when color was set congruent. The elevated N2pc was interpreted as indicating superior processing for the correct stimuli (color).

Three studies found no difference in the N200 between those with elevated versus lower levels of psychopathic traits on three separate cognitive tasks. Specifically, Anderson et al. (2015) showed no difference on the N200 for inmates on an auditory oddball task and Anderson and Stanford (2012) demonstrated no difference for a community sample on an affective picture oddball. Munro et al. (2007b), using male forensic inmates as well as staff as participants, found no difference in the N200 on a Go/No-go task, although this latter finding did near significance for an elevated N200 amplitude (indicating better performance for those with elevated psychopathic traits). Two studies did however find lower N200 amplitudes for two affective tasks, including an affective face oddball task (Anderson and Stanford, 2012) and a mood induction affective picture paradigm for angry and fearful face expression, but the findings were specific to Factor 2 of the PCL-R (Eisenbarth et al., 2013). Also, one study (Kiehl et al., 2000) found a lower N200 to the cognitive Go/No-go task with prisoners.

In sum, at the total score level, 33.3% of studies (3 studies) found increased N200 amplitudes, 44.4% of studies (4 studies) found no difference in N200 amplitudes, and 11.1% of studies (1 study) found lower N100 amplitudes. One study (11.1%) found mixed findings for a variety of cognitive tasks (see Table 2, Section B).

5.3. Psychopathy and P300

The P300 waveform reflects resources allocated to working memory representations and selecting responses (Donchin and Coles, 1988; Kok, 2001; Luck et al., 2000). The P300 can occur between 300 and 600 ms. Peaks at the shorter end of this time range are considered to reflect superior cognitive performance in memory updating (Glenn and Raine, 2014; Houlihan et al., 1998). The P300 timeframe has also been referred to as an earlier component (P3a), which is strongest at frontal sites and is thought to be elicited by detecting the novelty of the stimulus, and a later component (P3b), which is strongest at parietal sites and thought to be associated with the process of response generation to a stimulus. The neural generators for the P300 are widespread across the brain. Common tasks for examining the P300 include the visual and auditory oddball paradigm tasks.[4]

Thirty-two studies have tested the relation between psychopathy and the P300 (e.g., Anderson and Stanford, 2012; Anderson et al., 2011, 2015; Anton et al., 2012; Brazil et al., 2012, 2011; Carlson and Thái, 2010; Carlson et al., 2009; Drislane et al., 2013; Gao et al., 2018; Jutai et al., 1987; Kiehl et al., 2006; Rothemund et al., 2012; van Dongen et al., 2018; van Heck et al., 2017; Varlamov et al., 2011). Twelve studies reported larger P300 amplitudes for those with elevated psychopathic traits in comparison to those with low levels of psychopathic traits, in a variety of study tasks. Specifically, Anderson and Stanford (2012), using a community sample, found a larger P300 amplitude for an affective differentiation task. Carlson and Thái (2010) and Raine and Venables (1988) using community and inmate samples, respectively, found larger P300 s on versions of an expectancy continuous performance task (CPT). Carlson et al. (2009) found a larger P300 for undergraduate students with elevated psychopathic traits on a rotated heads task. Flor et al. (2002), using an at-risk community sample and a Pavlovian task also found an elevated P300. Anton et al. (2012) using

[4] Oddball tasks involve the continuous presentation of a stimulus with the occasional introduction of a novel/new stimulus (the oddball). The new stimulus is thought to draw attention because it has not yet been heard or seen.

Table 2
Psychopathy and EEG Findings: Mid Processing (N170, N200, P300).

Author Year	Sample	Measure	Task/ERP/electrode site	Outcome
Section A **N170**				
Almeida et al. (2014)	N = 54; age 18-37; 100% male; community	PPI-R	Emotional and neutral faces N170 (P7, P8)	Lower N170 (FD) Higher N170 (CH)
Brislin et al. (2018)	N = 254; age 29.4; 65% male; community	TriPM	Face Viewing Task N170 (P8)	Lower N170 for fearful faces (Callous-aggression and Disinhibition)
Eisenbarth et al. (2013)	N = 23; age 24-52; 0% male; forensic inpatient	PCL-R	Mood induction task using affective picture paradigm N170 (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4)	No difference in N170
Section B **N200**				
Anderson and Stanford (2012)	N = 40; age 18-57; 46% male; community	PPI-R	Affective picture oddball (task 1: implicit differentiation; task 2: explicit differentiation); Go/No-go N200 (Fz, Pz, Cz)	Lower N200 (Task 1) No difference (Task 2) No difference (Go/No-go)
Anderson et al. (2015)	N = 59; age 34.9; 100% male; inmates	PCL-R	Auditory oddball N200 (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4)	No difference on N200
Eisenbarth et al. (2013)	N = 23; age 24-52; 0% male; forensic inpatient	PCL-R	Mood induction task using affective picture paradigm N200 (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4)	Lower N200 for angry and fear facial expressions (F2)
Hung et al. (2013)	N = 40; age 13-19; 100% male; juvenile offenders	PCL-YV	Auditory oddball Emotional syllables (fear and sad) and non-vocal sounds MMN (Fz)	Higher MMN to fearful syllables (F2)
Kiehl et al. (2006)	N = 80; age 18-55; 100% male; inmates	PCL-R	Auditory oddball N200 (avg across ROIs)	Higher N200 (fronto-central for target and centro-parietal for novel)
Kiehl et al. (2000)	N = 36; age 18-55; 100% male; forensic inpatient	PCL-R	Go/No-go N275 (F7, Ppz, F8, F3, Fz, F4, T3, T4, C3, Cz, C4, P3, Pz, P4)	Lower N275 (No-go stimuli; lower lateralization)
Kim and Jung (2014)	N = 30; age 0.2; 33% male; undergraduates	PPI-R	Go/No-go sLORETA N200 (C1, C3, Cz, C4, C2, P1, P3, Pz, P4, P2)	Higher N200 latency (No-go; central and parietal)
Krusemark et al. (2016)	N = 70; age 18-55; 100% male; inmates	PCL-R	Visual search task N2pc (P3, P4) Midline (Fz, FCz, Cz, Pz) Lateral (O1, O2, P3, P4, F3, F4)	Higher N2pc response to set-congruent information
Munro et al. (2007b)	N = 30; age 46.25; 100% male; forensic inmates and staff	PCL R	Go/No-go N200 (Fz, FCz, Cz1, Cz2)	No difference in N200 (although a trend for higher amplitude)
Section C **P300**				
Anderson and Stanford (2012)	N = 40; age 18-57; 46% male; community	PPI-R	Affective picture oddball (task 1: implicit differentiation; task 2: explicit differentiation); Go/No-go task P300 (Fz, Pz, Cz)	Lower P300 (Task 1) No difference on P300 (Go/No go) Higher P300 (Task 2)
Anderson et al. (2011)	N = 57; age early 20 s; 0% male; undergraduates	PPI-R	Auditory (2 stimulus) and visual oddball (2 stimulus) P300 auditory (P3, Pz, P4, C3) P300 visual (P3, Pz)	Higher P300 for auditory (total and FD) Higher P300 visual (total)
Anderson et al. (2015)	N = 59; age 34.9; 100% male; inmates	PCL-R	Auditory oddball (3 stimulus) P300 (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4)	No difference in P300 (marginal) Lower P300a (facet 1)
Anton et al. (2012)	N = 74; age 18-45; 0% male; offenders	PCL-R	Fear conditioning task P300 (Pz, O1, O2)	Lower P300 (threat focus) Higher P300 (alternative focus) (total and F1)
Brazil et al. (2012)	N = 59; age 38.01; 100% male; forensic inpatient	PCL-R	Visual oddball (3 stimulus) P3a (FCz) P3b (Pz)	Higher P300 (P3a)
Brazil et al. (2011)	N = 36; age 36; forensic inpatient	PCL-R	Arrowhead Erikson Flanker task P300 (Cz)	No difference in P300
Carlson and Thái (2010)	N = 60; age 18-23; 33.0% male; undergraduates	PPI	Expectancy AX-CPT P300 (Fz, Cz, Pz)	Higher P300 (FD) Higher P300b (FD)
Carlson et al. (2009)	N = 96; age 17-24; 35.8% male; undergraduates	PPI	Rotated heads task P300 (F3, Fz, F4)	Higher P300 (FD) Lower P300 (SCI)
Cheng et al. (2012)	N = 43; age 15-18; 100% male; juvenile offenders	PCL:YV	Visual pain stimuli (pain-self; pain-other) P300 (32 channel; not specified)	Lower central P300 to pain-self stimuli
Drislane et al. (2013)	N = 140; age 19-59; 100% male; inmates	PCL-R	Affective picture viewing paradigm and noise probes P300 (Pz)	Lower P300 amplitude (total and F1)
Eisenbarth et al. (2013)	N = 23; age 24-52; 0% male; forensic inpatient	PCL-R	Mood induction task using affective picture paradigm P300 (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4)	No difference in P300

(*continued on next page*)

Table 2 (*continued*)

Author Year	Sample	Measure	Task/ERP/electrode site	Outcome
Flor et al. (2002)	N = 21; age 31.19; 100% male; at-risk community	PCL-R	Pavlovian conditioning task P300 (F2, F3, F4, C3, Cz, C4, P3, Pz, P4)	No difference in P300 habituation. No difference in P300 extinction Higher P300 for acquisition (Four way interaction P300 on acquisition).
Forth and Hare (1989)	N = 23; age 18-45; 100% male; prison inmates	PCL	Forewarned reaction time task (win, neutral) P300 (Fz, Cz, Pz)	No difference in P300
Gao, Raine, & Schug (2011)	N = 75; age 23-56; 100% male; community	PCL-R	Auditory oddball task (3 stimulus) P300 (Fz, Pz)	Lower P300b to targets (unsuccessful) Shorter frontal P300 latency to non-targets (successful) Higher parietal P300 to non-targets (successful)
Gao et al. (2018)	N = 250; age 8-19; 63.5% male; Chinese community	APSD	Auditory oddball task P300 (P3, P4)	Higher P300 (Total) Higher P300 (GM traits; LH) Lower P300 (DI traits; LH)
Hiatt-Racer et al. (2011)	N = 54; age 9-14 years; 41% male; community	APSD	Attention Network Task P3b (*M* of 8 electrodes; near Pz)	No difference in P300b
Hung et al. (2013)	N = 40; age 13-19; 100% male; juvenile offenders	PCL-YV	Auditory oddball Emotional syllables (fear and sad) and non-vocal sounds P3a (Fz, Cz)	No difference in P300a
Jutai et al. (1987)	N = 24; age 29.1; 100% male; inmates	PCL	Auditory oddball (speech) task 1 Auditory oddball plus distraction task 2 P300 (Cz, T3, T4)	No difference on P300 (Task 1)
Kiehl et al. (2006)	N = 80; age 18-55; 100% male; inmates	PCL-R	Auditory Oddball Task P300 (avg across ROIs)	Higher P300 in left hemisphere (sample 1) Lower P300 (medial sites; sample 2)
Kiehl et al. (1999a, 1999b)	N = 21; age 18-55; 100% male; forensic inpatient	PCL-R	Visual oddball task P300 (C3, Cz, C4)	Lower P300 (less lateralized)
Kiehl et al. (2000)	N = 36; age 18-55; 100% male; forensic inpatient	PCL-R	Go/No-go P375 F7, Ppz, F8, F3, Fz, F4, T3, T4, C3, Cz, C4, P3, Pz, P4	Lower P375 (Go stimuli; parietal; lower lateralization)
Kim and Jung (2014)	N = 30; age 20.2; 33% male; undergraduates	PPI-R	Go/No-go sLORETA P300 (AF3, FP1, FPz, AF4, C1, C3, Cz, C4, C2, F1, F3, Fz, F4, F2, FC1, FC3, FCz, FC4, FC2) P300 latency (FC1, FC3, FCz, FC4, FC2, C3, C4)	Lower P300 (NoGo; frontal) Higher P300 latency (NoGo; C3 and C4) Lower frontal central current density in NoGo P300 (sLORETA)
Munro et al. (2007a)	N = 30; age 46.25; 100% male; inmates and staff	PCL-R	Letter Flanker Task Face Flanker Task P300 (Fz, FCz, Cz, Pz)	No P300 difference
Munro et al. (2007b)	N = 30; age 46.25; 100% male; forensic inmates and staff	PCL R	Go/No-go Task P300 (Fz, FCz, Cz1, Cz2)	No difference on P300 (inhibitory)
Raine and Venables (1988)	N = 28; age 22-60; 100% male; prisoners	PCL	Continuous performance task (visual targets and non-targets) P300 (P3, P4) P300 latency (T3, T4, P3, P4)	Higher P300 amplitude Slower P300 recovery
Rothemund et al. (2012)	N = 22; age 22-43; 100% male; bail or parole and community	PCL-R	Pavlovian conditioning task (pictures and shock) P300 (C3, C4, P3, P4)	No difference in P300
Schulreich et al. (2013)	N = 21; age 21-29; 0% male; college students	PPI-R	Time estimation task Facial feedback stimuli P300 (Pz)	No difference in P300
van Dongen et al. (2018)	N = 70; age 20.5; 51% male; community	TriPM-meanness	Passive viewing empathy task P300 (Pz)	No difference in P300 (meanness)
van Heck et al. (2017)	N = 55; age 18-56; 47% male; community	SRP-SF	Villain-victim empathy task P300 Fz, Cz, Pz	No difference in P300
Venables et al. (2015)	N = 139; age 29.6; 100% male; adjudicate substance abuse treatment	PCL-R	Picture viewing (IAPS; pleasant, unpleasant, neutral) P300 (Pz)	Lower P300 (F2; mostly related to Facet 4 (antisocial))
Venables and Patrick (2014)	N = 154; age 18-64; 100% male; inmates	PCL-R	Three stimulus oddball including rotated heads P300 F3, Fz, F4, C3, Cz. C4, P3, Pz, P4	Lower P300 (facet 4) at anterior (frontal/central). Lower P300 response to novel picture stimuli (facet 3)
Verona et al. (2012)	N = 45; age 19-51; 82.5% male; legally involved	PCL: SV	Emotional-linguistic Go/No Go Task P300 (Fz, FCz) Fz, FCz, Cz, Pz	No difference in P300 and emotional processing (facet 1) Lower P300 and emotional processing (facet 2) Higher P300 to negative emotional processing (facet 3 and facet 4)

Note: APSD = Antisocial Process Screening Device; PCL = Psychopathy Checklist; PCL-R = Psychopathy Checklist-Revised; PCL-YV = Psychopathy Checklist-Youth Version; PCL-SV = Psychopathy Checklist –Screening Version; PPI = Psychopathic Personality Inventory; IAPS = International Affective Picture System; EAP = Early Anterior Positivity; CH = Cold Heartedness; FD = Fearless Dominance; LRP = Lateralized Readiness Potential. If a facet is mentioned in relation to a specific ERP it means that the others are non-significant. Age is presented as a range unless unavailable in which case the arithmetic mean is presented.

an offender sample and a fear conditioning task found an elevated P300 (alternate focus). Verona et al. (2012), using legally involved male adults, found an elevated P300 on an emotional Go/No-go task. Three studies found an increased P300 for auditory oddball tasks in community and inmate samples (Gao et al., 2011, 2018; Kiehl et al., 2006) and two studies found increased P300 amplitudes for visual oddball tasks in a male forensic sample (P3a; Brazil et al., 2012) and a female undergraduate sample (Anderson et al., 2011).

Seventeen of the studies report no difference between those with elevated versus those with low level psychopathic traits on a variety of tasks including two studies examining brain response to the Go/No-go task in a community sample (Anderson and Stanford, 2012; Anderson et al., 2015) and male forensic inmate sample (Munro et al., 2007b). Using a forensic sample, Brazil et al (2011) showed that there was no difference in P300 amplitude on an arrowhead Erikson Flanker task[5]. Using male inmates, Munro et al. (2007a) observed no P300 amplitude difference for those with elevated versus lower levels of psychopathic traits on a letter Flanker task and face Flanker task. Employing a sample of female inpatients, Eisenbarth et al. (2013) found no P300 difference for an affective picture paradigm. Both Flor et al. (2002) and Rothemund et al. (2012), using an at-risk community sample and offender sample, respectively, found no P300 differences on Pavlovian conditioning tasks (habituation and extinction). Using an inmate sample, Forth and Hare (1989) found no P300 difference on a forewarned reaction time task. With an at-risk adolescent community member sample seeking mental health services, Hiatt-Racer et al. (2011) found no difference in the P300 to an attention network task. In a sample of young offenders, Hung et al. (2013) found no difference in the P300 on an auditory oddball task with emotional syllables. In a sample of inmates, Jutai et al. (1987) found no P300 difference on a standard auditory oddball speech task. Venables et al. (2015) found no difference in the P300 amplitude for an offender sample. Similarly, van Dongen et al. (2018) found no differences in P300 amplitude for a community sample. Finally, in a sample of female university students, Schulreich et al. (2013) found no P300 difference between those scoring high in psychopathic traits versus those scoring low on a facial feedback task. van Heck et al. (2017) and Verona et al. (2012) also found no P300 difference.

Ten studies report smaller P300 amplitude for elevated psychopathy scores for a variety of study tasks. Specifically, Kiehl et al. (1999a, b, 2006) found a lower P300 for an auditory oddball task with an inmate sample and Kiehl et al. (2000) and Kim and Jung (2014) found lower P300s and a greater P300 latency for a Go/No-go task, respectively, in inmate and university student samples. The remaining six studies found lower P300s to primarily affective tasks including a lower P300 amplitude for an affective picture viewing task (implicit differentiation) in a community sample (Anderson and Stanford, 2012), a fear conditioning task in an inmate sample (threat focus; Anton et al., 2012), a rotated heads task in an undergraduate sample (Carlson et al., 2009) and male inmate sample (Venables and Patrick, 2014), a visual pain stimuli task in young offenders (Cheng et al., 2012), and an affective picture viewing task in a male inmate sample (Drislane et al., 2013).

To summarize, at the total score level and only allowing the studies to count once, 15.6% of the studies (5 studies) found greater P300 amplitudes, 53.1% (17 studies) found no difference in amplitude, and 15.6% (5 studies) found evidence for smaller P300 amplitudes for those with elevated versus low levels of psychopathic traits. The bulk of the latter findings were for affective tasks. Five studies (15.6%) found mixed findings.

Twelve studies examined psychopathy components in relation to P300 (Anderson et al., 2011; Anderson, Steele et al., 2015; Anton et al., 2012; Brazil et al., 2011; Carlson and Thái, 2010; Carlson et al., 2009; Drislane et al., 2013; Gao et al., 2018; Schulreich et al., 2013; Venables et al., 2015; Venables and Patrick, 2014; Verona et al., 2012). Verona et al. (2012) found that F2 (facets 3 and 4) was associated with a larger P300 for negative emotional processing. With respect to the psychopathy four facet model, Verona et al. (2012) found that the P300 was reduced for the PCL-SV facet 2 (deficient affect), for emotional processing. Relatedly, Brazil et al. (2012) and Gao et al. (2011) found that the lower P300 to orienting appeared to be most strongly linked to antisocial personality (F2). Similarly, Venables and Patrick (2014) discovered a significant link between higher scores on facet 4 (antisocial) and reduction in P300 amplitude at anterior (frontal/central) relative to posterior (parietal) scalp sites for an oddball task. A similar finding was noted in Venables et al. (2015), where a reduced P300 was specific to F2 of the PCL-R. Facet 3 (lifestyle) was also related to markedly reduced P300 amplitude in response to novel stimuli. One study found that F1 was related to reduced P300 for an affective picture viewing task (Drislane et al., 2013). Anderson et al. (2011) found that the P300 amplitude was positively associated with PPI-R total scores, but the effect was driven by the FD subscale. Carlson and Thái (2010) also found an increase in P300 amplitude but only for FD. Schulreich et al. (2013) observed no difference in amplitude for FD versus SCI and both were unrelated to P300 (see Table 2, Section C).

5.4. Section summary

Cleckley (1941/1976) described psychopaths as those who function well in social settings, rising, in some cases, to high positions in society. He stated “It must be remembered that even the most severely and obviously disabled psychopath presents a technical appearance of sanity, often one of high intellectual capacities, and not infrequently succeeds in business or professional activities for short periods, sometimes for considerable periods” (p. 191). Hare (1993) referred to psychopathic individuals as quite capable in their ability to sense others’ needs, and use that information for the purposes of manipulation and gain. However, others have suggested that psychopathic individuals may have difficulty processing facial expressions (especially fear) (Blair, 2010), matching stimuli (Gorenstein and Newman, 1980; Newman et al., 2007), as well as paying attention to and updating novel information (Kiehl et al., 2000). The N170, N200, and P300 can help answer some of these questions. In the current review, with respect to face processing, there is no evidence of a deficit (i.e., no difference in the N170 at the total score level). There is only evidence of a deficit in face processing at the factor level, and corresponding evidence of compensatory factors which eliminate the deficit at the total score level (Almeida et al., 2014; Brislin et al., 2018). With regard to mismatch detection (N200), the bulk of studies show no difference in amplitudes suggesting those with elevated psychopathic traits are equally capable of detecting a mismatch and demonstrate similar cognitive control. With regard to working memory, overall, it appears there is limited evidence for a deficit in this area (see also Gao and Raine, 2009; Glenn and Raine, 2014). At the factor level, several studies suggest that those with elevated especially F1 psychopathic traits may display superior memory up-dating (Raine and Venables, 1990; Sutker and Allain, 1987; see also Hare, 1984), whereas those with elevated F2 traits exhibit a deficit. Venables and Patrick (2014) state that their findings of a lower P300 specific to impulsivity “establish P3 as a neurophysiological point of contact between psychopathy and externalizing proneness” (p. 427).

6. Associative learning (CNV) and error processing

Theorists of the psychopathic personality have argued that those with elevated psychopathic traits are less likely to “connect the dots” or associate relevant variables when needed (Gorenstein and Newman, 1980; Patterson and Newman, 1993; Newman et al., 2007; Walter, 1964, 1966). Similarly, theorists have suggested that those with

[5] The Flanker task is a set of response inhibition tests used to assess the ability to suppress responses that are inappropriate in a particular context. Various forms of the task, typically with letter strings are employed to measure information processing and selective attention.

elevated psychopathic traits have an impairment in error processing (Bencic Hamilton et al., 2018; Brazil et al., 2011). Even Cleckley's (1941) work with certain clinical cases suggests that psychopathic individuals are incapable of learning from experience. EEG output could represent a very important step in understanding the information processing that occurs in those with elevated psychopathic traits and is pertinent to associative learning indexed through the Contingent Negative Variation (CNV) and the error processing ERPs. These time-locked ERPs could be affected, for example, by potential difficulties in adjusting one's response to stimuli due to an imbalance in punishment and reward processing (Newman et al., 2007) or other associative learning deficits. If individuals with elevated psychopathic traits have deficits with either of these cognitive processes (association, error processing), it could explain a bold, blame externalizing personality style with little ability to learn from experience. Below, we review the research on the CNV and error processing as they pertain to psychopathy.

6.1. Psychopathy and contingent negative variation (CNV)

CNV is an ERP that peaks (260–470 ms) after a warning system and represents expectancy. The neural generators for the CNV are reported to be most prominent at the scalp vertex and are symmetrical. The CNV is observed in the fore period between the warning and the imperative stimulus. An elevated CNV amplitude is thought to represent better neuronal processing of the warning stimuli. Common tasks for the CNV include warning signals (tones, light flashes) typically signifying whether participants will win or lose something. The forewarned reaction time task is a common task to elicit the CNV. This experimental paradigm consists of a warning signal (S_1) followed by a fixed time interval (e.g., 1.5 s), followed by an imperative stimulus (S_2) instructing the participant to carry out a response (usually a button press motor response). The negative potential develops in the S_1-S_2 interval and rapidly resolves when the participant performs the required response to S_2. The terminal CNV reflects sustained attention/emotion and motor preparation (Loveless & Sanford, 1974).

Five studies have examined CNV in relation to psychopathy (Carlson and Thái, 2010; Flor et al., 2002; Forth and Hare, 1989; Rothemund et al., 2012; Varlamov et al., 2011). Four studies found a similar or stronger CNV for those with elevated psychopathic traits in comparison to those with lower levels of psychopathic traits for tasks administered but the findings were conditional on the psychopathy dimension being examined or the hemisphere the brain being examined (Carlson and Thái, 2010; Forth and Hare, 1989; Flor et al., 2002; Rothemund et al., 2012). Specifically, Carlson and Thái (2010), using an undergraduate sample, discovered a higher CNV on the expectancy continuous performance task (CPT), but this was only for PPI FD scores rather than SCI, or CH (which showed weaker CNVs). Using an at-risk community sample, Flor et al. (2002) found a higher CNV on the right hemisphere on extinction trials in the Pavlovian conditioning task. Rothemund and colleagues' (2012) using a mixed sample of legally and non-legally involved community members noted a higher CNV on the left hemisphere to a variant of the Pavlovian conditioning task but a lower terminal CNV (CNVt). Forth and Hare (1989) found an elevated CNV amplitude for inmates with high psychopathic traits for early CNV but not late CNV (CNVt) in a forewarned reaction time task. The authors concluded that the lack of a terminal CNV may indicate that emotional modulation is disturbed. Finally, Varlamov et al. (2011) found a lower CNV for a Go/No-go task in a group of personality disordered patients with comorbid conditions.

In sum, at the total score level, 40% of studies (2 studies) investigating the CNV found evidence to support a greater CNV amplitude for those with elevated psychopathic traits, 20% (1 study) found no difference, and two studies (40%) found evidence for a lower CNV amplitude (see Table 3, Section A).[6]

6.2. Error-Related Negativity (ERN)

ERN is generated by the detection of one's own error and peaks between 0–100 ms after an erroneous response. ERN is fundamental to response-reinforcement associations, behavioral monitoring, and adaptation. Differentiation can also be made between the detection of one's own error (rERN; sometimes referred to as Ne) and the detection of another's error (oERN) (see Brazil et al., 2011). There is also a positive error related ERP (referred to as Pe). The Pe is a slow wave with maximum amplitude peaking between 200 to 400 msec after response onset. The ERN/Ne reflects initial, automatic error-correction and action-monitoring processes (Yeung and Summerfield, 2012), including the motivational (Debener et al., 2005; de Bruijn et al., 2009; Ullsperger et al., 2010) appraisal of such stimuli. Additionally, the ERN/Ne is said to arise within the cognitive, caudal division of the ACC (cACC), whereas both caudal and rostral portions (rACC) of the ACC contribute to the Pe amplitude (Edwards et al., 2012). Projections from the basal ganglia to the ACC, insular cortex, dorsolateral prefrontal cortex (dlPFC), and the posterior medial fontal cortex (pmFC) are related to various aspects of error processing (Brazil et al., 2012; Holroyd et al., 2004; Holroyd and Coles, 2002). Feedback related negativity (FRN) is another term used to reflect error processing. Common tasks for examining error processing include the flanker task and Go/No-go tasks.

Thirteen studies have examined ERN in relation to psychopathic traits (Brazil et al., 2009, 2011; Bresin et al., 2014; Heritage and Benning, 2013; Maurer et al., 2016a,b; Munro et al., 2007a; Pasion et al., 2016; Schulreich et al., 2013; Steele et al., 2016; van Heck et al., 2017; Varlamov et al., 2011; von Borries et al., 2010). Three studies found a larger ERN to study tasks for those with elevated psychopathic traits, but differences tended to be dependent on the dimension of psychopathy being tested (Bresin et al., 2014; Schulreich et al., 2013; Steele et al., 2016). Specifically, Bresin et al. (2014), using an at-risk community sample, observed a higher ERN (greater detection of error) for F1 psychopathy on a flanker task but also observed a lower ERN (lower detection of error) for F2. Similarly, using a female college sample, Schulreich et al. (2013) found larger FRN amplitudes for a facial feedback task but this was specific for FD scores and SCI evidenced a lower FRN. Pasion et al. (2016) found a higher ERN for boldness, but a lower ERN for disinhibition. Finally, using an inmate sample, Steele et al. (2016) observed a higher Pe amplitude on a Go/No-go task for those with elevated PCL-R facets 1 and 3.

Eight studies found no difference between psychopathic and non-psychopathic individuals in the ERN for study designed tasks (Brazil et al., 2009, 2011; Maurer et al., 2016a,b; Munro et al., 2007a; Steele et al., 2016; van Heck et al., 2017; von Borries et al., 2010). Specifically, using forensic inpatient and control samples, Brazil et al. (2009) found no difference in the ERN amplitude, or latency, for the Erikson flanker task. However, Brazil et al. (2009) did find a lower Pe at the very late stages of error processing. In another study, using a forensic sample, Brazil et al. (2011) found no difference in the rERN but did find a lower oERN on the Arrowhead flanker task when participants were watching others make errors. With a young male inmate sample, Maurer et al. (2016a,b) found no difference between psychopathic and non-psychopathic offenders in the ERN on a Go/No-go task, but did find a lower Pe specific to facet 4 (antisocial). With an all-female sample, Maurer et al. (2016a,b) also observed no difference in the ERN/Ne or on a Go/No-go task, but did find a lower Pe amplitude for PCL total and F1 scores. Alternatively, using an inmate sample, Steele et al. (2016) found

[6] Howard, Fenton, and Fenwick (1984) conducted one of the very early studies on psychopathy and the CNV for those interested in earlier investigations on this topic.

Table 3
Psychopathy and EEG Findings: CNV, Error processing, Late Ps and Ns, LPPs, and Spectra.

Author Year	Sample	Measure	Task/ERP/electrode site	Outcome
Section A **CNV**				
Carlson and Thái (2010)	N = 60; age 18-23; 38.9% male; undergraduates	PPI	Expectancy AX-CPT CNV (Fz, Cz, Pz)	Higher CNV (FD) Lower CNV (CH)
Flor et al. (2002)	N = 21; age 31.19; 100% male; at-risk community	PCL-R	Pavlovian conditioning task CNV (F2, F3, F4, C3, Cz, C4, P3, Pz, P4)	Lower iCNV acquisition (LH) Higher tCNV acquisition (RH) Higher tCNV extinction (RH)
Forth and Hare (1989)	N = 23; age 18-45; 100% male; prison inmates	PCL	Forewarned reaction time task (win, neutral) CNV (Fz, Cz, Pz)	Higher early CNV (iCNV) No difference in late CNV (tCNV) (approached trend)
Rothemund et al. (2012)	N = 22; age 22-43; 100% male; bail or parole and community		Pavlovian conditioning task (shock) CNV (C3, P3) CNVt (C3, C4, P3, P4)	Higher iCNV acquisition Lower tCNV acquisition
Varlamov et al. (2011)	N = 69; age 32.62; 100% male; personality disordered patients	PCL-R/ PCL-SV	Go/No-go Task CNV Fz, F7, F8	Lower CNV
Section B **Error Processing (ERN)**				
Brazil et al. (2009)	N = 34; age 39; 100% male; forensic inpatient and control	PCL-R	Erikson Flanker Task ERN/Ne (FCz, Cz) Pe (Cz)	No difference ERN amplitude No difference ERN latency Lower Pe (latter stages of error processing)
Brazil et al. (2011)	N = 36; age 36; forensic inpatient	PCL-R	Arrowhead Erikson Flanker Task oERN (FCz, Cz) rERN (FCz, Cz) LRP (C3, C4)	No differences in rERN amplitude or latency Lower oERN amplitude No difference in LRP
Bresin et al. (2014)	N = 55; age 19-53; 69% male; at-risk community	PCL-SV	Flanker Task ERN (Cz)	Higher ERN (F1)
Heritage and Benning (2013)	N = 66; age 36; 44% male; ER patients screened for psychopathy	PPI-estimate	Lexical decision stop signal task ERN (Fz)	Lower ERN (IA)
Maurer et al. (2016a)	N = 100; age 16-20; 100% male; inmates	PCL:YV	Go/No-go ERN/Ne (Fz) Pe (Fz)	No difference in ERN Lower Pe (Facet 4)
Maurer et al. (2016b)	N = 121; age 18-55; 0% male; inmates	PCL-R	Go/No-go ERN/Ne (F3, Fz, F4, FC3, FCz, FC4, C3, Cz) Pe (C3, Cz, C4, P3, Pz, P4, FO3, FOz, F04)	No difference in ERN/Ne Lower Pe (Total and F1)
Munro et al. (2007a)	N = 30; age 46.25; 100% male; inmates and staff	PCL-R	Letter Flanker Task Face Flanker Task ERN (FCz, Cz) Pe Fz, FCz, Cz, Pz	Lower ERN for face flanker errors No difference for Pe
Pasion et al. (2016)	N = 32; age 18-55; 100% male; community	TriPM	Simons task ERN (Fz)	Higher ERN (boldness) Lower ERN; greater latency (disinhibition)
Schulreich et al. (2013)	N = 21; age 21-29; 0% male; college students	PPI-R	Time estimation task Facial feedback stimuli FRN (FCz v Cz) RCZa – ROI	Higher FRN amplitudes (FD) Lower FRN amplitudes (SCI) Lower RCZa activity in the FRN time range for negative faces (FD)
Steele et al. (2016)	N = 93; age 19-55; 100% male; inmates	PCL-R	Go/No-go ERN/Ne (F2, F3, F4, FC2, FC3, FC4, C2, C3, C4) Pe (C2, C3, C4, CP2, CP3, CP4, P2, P3, P4)	No difference in ERN/Ne Higher Pe amplitude (Facet 1 and Facet 3)
van Heck et al. (2017)	N = 55; age 18-56; 47% male; community	SRP-SF	Villain-Victim Empathy task ERN Fz, Cz, Pz	No difference in ERN
Varlamov et al. (2011)	N = 69; age 32.62; 100% male; personality disordered patients	PCL-R/ PCL-SV	Go/No-go Task fERN	Lower fERN
von Borries et al. (2010)	N = 31; age 18-55; 100% male; violent offenders inpatient	PCL R	Probabilistic learning task rERN (Cz; 0-200 ms) fERN (Cz; 200-400 ms)	No differences in fERN Smaller rERN, psychopaths displayed smaller amplitudes in the 100% condition between BH1 and BH2
Section C **P450/P550/P600**				
Howard and McCullagh (2007)	N = 34; age 33.3; 100% male; inmates	PCL-SV	3 stimulus oddball vigilance affective task 3 stimulus oddball categorization affective task P450 (Pz) P550 (Pz)	Lower P450/ P550 (Pz) to targets with high arousal background (vigilance task). Higher P450/ P550 (Fpz) to targets with high or low arousal background for vigilance task (F2)
Kiehl et al. (1999a)	N = 29; age 18-60; 100% male; forensic inpatient	PCL-R	Lexical Decision Task Task 1 and 2 (abstract/concrete words) Task 3 (positive/negative words) P600 (F3, F4, C3, C4)	No difference in P600 to word type (task 1) Lower P600 (task 2; frontal) Lower P600 to negative words (task 3)

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Table 3 (*continued*)

Author Year	Sample	Measure	Task/ERP/electrode site	Outcome
van Heck et al. (2017)	N = 55; age 18-56; 47% male; community	SRP-SF	Villain-Victim Empathy task P400-P600 Fz, Cz, Pz	Lower P400-P600
Section D **N300/N400/N450/N550**				
Cheng et al. (2012)	N = 43; age 15-18; 100% male; juvenile offenders	PCL:YV	Visual pain stimuli (pain-self; pain-other) N360 (32 channel; not specified)	Lower N360 to pain-other
Hiatt-Racer et al. (2011)	N = 43; age 9-14 years; 41% male; community	APSD	Attention Network Task N450 (*M* 6 near Cz)	No difference in N450
Howard and McCullagh (2007)	N = 34; age 33.3; 100% male; inmates	PCL-SV	3 stimulus oddball vigilance affective task and 3 stimulus oddball categorization affective task N350 (Fpz, Fz, Cz)	Higher N350 to unpleasant low arousal (vigilance task) Higher N350 (frontal) but psychopaths responded normally to semantic mismatch (categorization task)
Kiehl et al. (2006)	N = 80; age 18-55; 100% male; inmates	PCL-R	Auditory Oddball Task N550 (average across ROI)	Higher N550 (targets; fronto-central)
Kiehl et al. (1999a)	N = 21; age 18-55; 100% male; forensic inpatient	PCL-R	Visual oddball task (2 stimulus) N550 (Fpz, F3, Fz, F4, C3, Cz, C4)	Higher N550 (centro-frontal)
Kiehl et al. (1999b)	N = 29; age 18-60; 100% male; forensic inpatient	PCL-R	Lexical Decision Task Task 1 & 2 (abstract/concrete words) and Task 3 (positive/negative words) N350 (F3, F4, C3, C4)	Higher N350 to concrete and abstract words (task 1; frontal and central; LH) Higher N350 to abstract words (task 2 trend; lateral, frontal, midline, central) Higher N350 to positive and negative words (task 3; frontal and central)
Varlamov et al. (2011)	N = 69; age 32.71; 100% male; personality disordered patients	PCL-R/ PCL-SV	Go/No-go Task N300 (Fz, F7, F8)	No difference in N300
Williamson et al. (1991)	N = 16; age 18-41; 100% male; inmates	PCL	Lexical Decision Task N500 (Fz, Cz, Pz, PT3, PT4)	Higher frontal N500 (larger on LH)
Section E **LPP and Slow Wave**				
Anderson and Stanford (2012)	N = 40; age 18-57; 46% male; community	PPI-R	Affective picture oddball (task 1: implicit differentiation; task 2: explicit differentiation); Go/No-go task LPP (Fz, Pz, Cz)	Lower LPP (Task1) No difference in LPP (Go/No go component of Task 1) Higher LPP (Task 2)
Anderson et al. (2015)	N = 59; age 34.9; 100% male; inmates	PCL-R	Auditory oddball task (3 stimulus) Early Slow wave (SW) (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4)	Lower early slow wave (total, facets 1, 3, 4) Lower late slow wave (facet 1)
Baskin-Sommers et al. (2013)	N = 136; age 18-45; 100% male; inmates	PCL-R	Picture task (pleasant, neutral, unpleasant; familiarity/unfamiliarity) LPP (Pz)	Lower LPP in pleasant/unpleasant familiar pictures compared to neutral (total and F2)
Brennan et al. (2018)	N = 76; age 14-24; 70% male; community	YPI	Cyberball task 128 electrode (used electrodes in the occipital area; 71, 72, 75, 76, 77, 78, 82, 83, 84, 85, 86, 90, 91, 92, 97) SW	Higher SW (micro rejection; ambiguous exclusion) Lower SW (favorable events; inclusion) Interaction where lower SW during ambiguous exclusion along with higher psychopathic traits leads to higher anger and aggression
Brislin et al. (2018)	N = 254; age 29.4; 65% male; community	TriPM	Face Viewing Task LPP (Pz)	Lower LPP (Disinhibition)
Carolan et al. (2014)	N = 34; age 20.26; 38% male; undergraduates	PPI-R SF	Emotional stroop (eStroop) LPP (Pz, POz, P1, P2, PO3, PO4)	Lower LPP to emotional stimuli
Cheng et al. (2012)	N = 43; age 15-18; 100% male; juvenile offenders	PCL:YV	Visual pain stimuli (pain-self; pain-other) LPP (32 channel; not specified)	Lower LPP to pain-self stimuli Higher parietal LPP to pain-other Higher central LPP to pain-other (F2)
Decety et al. (2015)	N = 38; age 19.4; 49% male; community	LSRP	Visual pain stimuli LPP (Cz, CPz, Pz, POz)	Lower LPP in empathic concern condition.
Eisenbarth et al. (2013)	N = 23; age 24-52; 0% male; forensic inpatient	PCL-R	Mood induction task using affective picture paradigm LPP (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4)	No difference in LPP
Howard and McCullagh (2007)	N = 34; age 33.3; 100% male; inmates	PCL-SV	3 stimulus oddball vigilance affective task 3 stimulus oddball categorization affective task Positive Slow Wave (pSW; 600-1000 ms)	Lower pSW to affective living things (categorization task)
Jutai et al. (1987)	N = 24; age 29.1; 100% male; inmates	PCL	Single Task (oddball speech) Dual Task (distraction) SW (Cz, T3)	Higher SW amplitude
Medina et al. (2016)	N = 33; age 21; 100% male; college students	PPI-R	Picture viewing (IAPS; pleasant, unpleasant, neutral) LPP (64 channel; P1, Pz, P2, CP1, CPz, CP2)	Lower LPPs to unpleasant images (FD) Higher LPPs to pleasant images (total)
Rothemund et al. (2012)	N = 22; age 22-43; 100% male; bail or parole and community	PCL-R	Pavlovian conditioning task (pictures and shock) LPC (C3, C4, P3, P4)	No difference

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Table 3 (*continued*)

Author Year	Sample	Measure	Task/ERP/electrode site	Outcome
Sadeh and Verona (2012)	N = 63; age 18-50; 82.5% male; probation, parole, local jail	PCL:SV	Picture viewing paradigm (neutral, unpleasant; clear figure ground v complex scene) LPP (Cz, CPz, Pz)	Lower LPP magnitude (IA (F2) and emotion only).
van Dongen et al. (2018)	N = 70; age 20.5 (2.2); 51% male; community	TriPM-meanness	Passive viewing empathy task LPP (Pz)	Lower LPP (meanness)
Venables et al. (2015)	N = 139; age 29.6 (9.4); 100% male; adjudicated substance abuse treatment	PCL-R	Picture viewing (IAPS; pleasant, unpleasant, neutral) LPP (Pz)	Lower LPP for aversive scenes versus pleasant scenes
Williamson et al. (1991)	N = 16; age 18-41; 100% male; inmates	PCL	Lexical Decision Task LPC (650-800 ms) (Fz, Cz, Pz, PT3, PT4)	Lower LPC
Section F P1100-P1400				
Marcoux et al. (2014)	N = 24; age 21-50; 100% male; outpatient and community	PCL-R PPI-R	Pseudo-dynamic visual stimuli of pain, neutral, no pain 124 Electrodes; focus near P1-P3	Higher P1100 (somatosensory gating) for the anticipation of pain detected by mean energy ratios.
Marcoux et al. (2013)	N = 30; age 23.0; 100% male; undergraduates	LSRP	Pseudo-dynamic visual stimuli of pain, neutral, no pain 124 Electrodes; focus near P1-P3	Higher P1400 (somatosensory resonance) over the parietal cortex contralateral to the stimulated hand for pain (self).
Section G Interhemispheric stimulation				
Hoppenbrouwers et al. (2013)	N = 28; age 22-55; 100% male; at-risk community	PCL-R	Long Interval Intracortical Inhibition TMS Letter-Number Sequencing	Lower dorsolateral prefrontal cortex functioning Abnormal right to left functional connectivity
Hoppenbrouwers et al. (2014)	N = 31; age 33.4; 100% male; at-risk community	PCL-R	Stimulation at F5 (LH) and F6 (RH) DLPFC Measured cortical-evoked potentials (CEPs) over LH under C3 and CEPs over RH under C4. To record activation of the DLPFC they used AF3 an AF4	Higher right to left interhemispheric signal propagation (ISP) No difference in interhemispheric inhibition. No difference on the cortical evoked potentials (CEPs) Longer cortical silent periods (CSPs; RH only) Higher CSP difference in left to right motor cortex No differences in short interval intracortical inhibition (SICI)
Section H Spectra analyses				
Calzada-Reyes et al. (2013)	N = 58; age 29.8; 100% male; violent offenders	PCL-R	Resting EEG activity LORETA Alpha (C3, T3 Pz) Beta (P3, T5, O1 O2)	Higher beta activity in fronto-temporal-limbic regions Lower alpha in left centro-temporal and parieto-central regions
Decety et al. (2015)	N = 38; age 19.4; 49% male; community	LSRP	Visual pain stimuli Alpha (avg all sites) Mu (alpha density at Cz, C1, C2, C3, C4, C5, C6) Gamma (left frontal, right frontal, left temporal, right temporal, left parietal, and right parietal ROIs)	Lower gamma coherence in empathic concern condition Lower gamma coherence in left frontal to right parietal, and right temporal regions (total and primary) Lower mu (8-13 Hz; total, primary, and secondary when perceiving others in distress No difference in alpha
Tillem et al. (2019)	N = 61; age 14-24; 72% male; community	YPI	Go/No-go Alpha response	Higher alpha suppression (parietal-occipital)
Tillem et al. (2016)	N = 99; age 18-45; 100% male; inmates	PCL-R	IAPS (unpleasant, neutral, pleasant; familiar and unfamiliar)	Higher theta coherence during unpleasant familiar pictures (F1) Higher theta coherence to novel affective pictures (F2)
Tillem et al. (2018)	N = 162; age 17-63; 62.8% male; community	SRP-SF	Resting state (8 or 6 minutes) F3, Fz, F4, FC5, FC1, FC2, FC6, C3, Cz, C4m P3, Pz, P4, O1, O2, Fp1, Fp2	Less efficient alpha1 Less efficient gamma
van Dongen et al. (2018)	N = 70; age 20.5 (2.2); 51% male; community	TriPM-meanness	Passive viewing empathy task mu suppression (C4)	No difference in mu suppression

Note: APSD = Antisocial Process Screening Device; LSRP = Levenson Self Report Psychopathy; PCL = Psychopathy Checklist; PCL-R = Psychopathy Checklist-Revised; PCL-YV = Psychopathy Checklist-Youth Version; PCL-SV = Psychopathy Checklist –Screening Version; PPI = Psychopathic Personality Inventory; IAPS = International Affective Picture System; CH = Cold Heartedness; FD = Fearless Dominance; LRP = Lateralized Readiness Potential; RH = right hemisphere; LH = left hemisphere. If a facet is mentioned in relation to a specific ERP it means that the others are nonsignificant. Age is presented as a range unless unavailable in which case the arithmetic mean is presented.

no difference in the ERN/Ne for a Go/No-go task, but found a higher Pe for those with elevated psychopathic traits. Using a violent offender sample, von Borries et al. (2010) found no difference in the fERN between psychopathic and non-psychopathic individuals but did find lower rERN for those high in psychopathic traits on a probabilistic learning task. One additional study found a weaker overall ERN (Munro et al., 2007a) for face flanker errors on the face flanker task in male inmates and staff. While the majority of studies found elevated or equal ERN amplitudes for psychopathic versus non-psychopathic individuals, one study found a lower fERN to a Go/No-go task in personality disordered patients (Varlamov et al., 2011). Many of the differences appeared to be related to Pe which is later in the processing stream. In sum, at the total score level, 0% of studies (no studies) found an increased ERN amplitude, 84.6% of the studies (11 studies) found no difference in ERN amplitude, and 15.4% of the studies (2 studies) found a decreased ERN amplitude when comparing individuals with high and low levels of psychopathic traits (see Table 3, section B).

6.3. Section summary

Some theoretical models for psychopathy suggest that psychopathic individuals are unable to: (i) sustain attention, (ii) "put on the brakes" when required, or (iii) contemplate their errors (Lykken, 1957; Gorenstein and Newman, 1980). This could mean that they are unable to devote sufficient attention to upcoming stimuli even when cued to do so (S1-S2) and they may fail to adjust their behavior to meet calls for caution (e.g., Newman et al., 2010; Vitale et al., 2005). The CNV and ERN offer the opportunity to examine the evidence for these types of deficits. The studies in this review, however, examining the CNV (Forth and Hare, 1989; Jutai et al., 1987; Raine and Venables, 1987; Rothemund et al., 2012) do not provide evidence of a deficit but rather suggest that psychopathic individuals devote sufficient attention to upcoming targets while they wait for a second cue. Thus, the anticipation-related CNV findings from the current review support the hypothesis that psychopaths are equally proficient and potentially extra-efficient at mobilizing attentional processes in their preparation for the imperative stimulus (Forth and Hare, 1989; Rothemund et al., 2012). Only two studies (Flor et al., 2002; Varlamov et al., 2011) found psychopathic individuals showed a weaker initial CNV differentiation in one hemisphere and only during extinction, where a weaker CNV might be expected (the S1 is no longer providing viable information about when S2 will appear). The findings by Carson and Thai (Carlson and Thái, 2010) may shed light on differences based on the factor of psychopathy indexed. In their study, those with elevated FD scores exhibited higher CNVs, and, those with elevated CH scores, showed lower CNVs. The findings suggest that reinforcement decision making guided by the potential involvement of the ACC, orbitofrontal cortex (OFC), ventral striatum, and the amygdala may be, for the most part, intact for those individuals with elevated psychopathic traits (e.g., Schoenbaum et al., 2006; Haber et al., 2006). Forth and Hare (1989) argued that previous claims that the psychopathic individual might show lower CNVs is "based on the false premise that psychopaths are generally poor at learning relations between events" (p. 677).

With regard to error processing, the ERN amplitudes between psychopathic and non-psychopathic individuals primarily did not differ, suggesting that error processing in those with elevated psychopathic traits may also be intact. Where differences existed, they appeared to be subtle. First, in one study those with elevated psychopathic traits showed aberrant neuronal activity to seeing others make errors (difference in ERNo). Additionally, there could be a deficit in the latter stages in error processing (Pe) which may represent a downstream affective component of error processing (e.g., the degree to which psychopathic individuals perseverate about an error). These findings may also align with the findings for the CNVt where the emotional processing of the event, after initial cognitive processing (CNVi), is lower.

7. Mid-late (ERP) processing: language processing, elaborative emotional processing, and pain processing

Late processing via EEG allows for the examination of language, late inhibition, elaborative emotional processing, and pain processing. Specifically, the late positive waves (P400-P600) and negative waves are used to examine a variety of human functions including language processing, late orienting, and inhibition. The Late Positive Potential (LPP) taps elaborative processing of stimuli including stimuli with emotional content. Very late positive waves (beyond 1000 ms) have been employed to examine pain processing and gating. Thus, EEG outputs for late positive and late negative waveforms could be informative with respect to the psychopathic personality (Cleckley, 1941).

7.1. Late Ps: P450/P550/P600

The P400-P600 s have been associated with language and later cognitive emotional processing. Neurogenerators are likely located in the left hemisphere for language tasks, but could have other neural generators for late attention and orientation. Common tasks involve lexical decision-making and word tasks. Three studies investigated late positive components (beyond 400 ms). Using a prisoner sample, Kiehl et al. (1999a) found no difference in the P600 in terms of word recognition but did observe lower P600 waves to two separate components of the word recognition task. One involved distinguishing between abstract and concrete words and a second called for a distinction between emotional and non-emotional words. Using a male inmate sample and a vigilance task where affective pictures were presented in the background, Howard and McCullagh (2007) found that those with elevated psychopathic traits produced smaller P450 s to target stimuli. However, those with elevated facet 2 (affective traits) produced significantly higher P450 and P550 s to affective stimuli (high and low arousal background stimulation) in a three-stimulus oddball. No significant differences were noted for the P450 or P550 in the categorization task. Kiehl et al. (1999b) focused on total scores whereas Howard and McCullagh (2007) found that differences primarily pertained to facet 2 (affective). A third study found lower P400-P600 for an empathy task.

To briefly summarize, only three studies investigated late P-waves. Two of the studies (66.67%) found mixed results in response to a word recognition task and an affective task, and one study (33.33%) found lower P400- P600 waves to an empathy task (Van Heck et al., 2017) (see Table 3, section C).

7.2. Psychopathy and N300-N550

Mid-to-late negative (N) waveforms have been used to primarily reflect semantic expectancy, semantic meaning integration, and semantic incongruency (Williamson et al., 1991). The neurogenerators implicated in the N550 include left hemisphere regions. The N550 waveform has been examined with the affective lexical decision task. Less frequently studied N components, such as the N300 have been used to test inhibition (Go/No-go; Kiehl et al., 2000), and have also been used to test the processing of faces and emotional information (Howard and McCullagh, 2007; see also Campanella et al., 2005). In these latter studies with face stimuli and emotional stimuli, increases in the negative waveforms (e.g., N300) are thought to index a reaction to the affective components of the stimuli (e.g., faces or pictures). The N450 has been used to examine late stage attention (Hiatt-Racer et al., 2011).

Eight studies have investigated N300 to N550 ERPs in relation to psychopathy (Cheng et al., 2012; Hiatt-Racer et al., 2011; Howard and McCullagh, 2007; Kiehl, Hare et al., 1999, 1999; Kiehl, Bates, et al., 2006; Varlamov et al., 2011; Williamson et al., 1991). Kiehl et al. (1999b) found that inmates with elevated psychopathic traits had higher N350 amplitudes in the frontal and central areas, primarily on the left hemisphere, for a lexical decision task. A higher N350 was also noted for two other components of the task including the detection of abstract versus concrete words, and positive versus negative words. Howard and McCullagh (2007) found higher N350s for inmates with psychopathic traits when viewing unpleasant affective pictures, whereas the effect was reversed in non-psychopathic individuals who showed a greater N350 to pleasant affective pictures in addition to a higher N350 when categorizing affective stimuli. Varlamov et al. (2011) found no difference for the N300 on a Go/No-go task in a sample of personality disordered patients.

Cheng and colleagues (2012) used visual pain stimuli and found that young offenders with elevated psychopathic traits showed a lower N360 to viewing others' pain. With regard to the N450, Hiatt-Racer et al.'s (2011) study, using an adolescent community sample, showed no difference between psychopathic versus non-psychopathic participants on an attention orienting task at this late stage. Three studies examining the N500/N550 found larger N500/N550 amplitudes for a variety of tasks including an auditory oddball task (Kiehl et al., 2006), a visual oddball task (Kiehl, Hare et al., 1999), and a lexical decision making task (Williamson et al., 1991) with adult inmate samples.

In sum, at the total score level, 62.5% of the studies (5 studies) showed higher late N amplitudes, 25% (2 studies) showed no difference, and 12.5% (1 study) of the studies showed lower late N amplitudes to a variety of tasks (see Table 3, Section D).

7.3. Late positive potential (LPP) and slow wave (SW)

The Late Positive Potential (LPP) is marked by a positive deflection beginning around 400–500 ms post stimulus and lasts for a few hundred milliseconds. Other related ERPs include the Slow Wave (SW) and Late Positive Component (LPC). The LPP is linked to recognition memory, emotional processing, and re-evaluation of information (Hajcak et al., 2010). LPP enhancement can be attenuated by top-down regulation strategies, such as suppression and reappraisal (Hajcak et al., 2010). The LPP is reported to be largest over parietal sites. However, potential neurogenerators for eliciting the LPP include an extensive brain network comprised of both cortical and subcortical structures (Liu et al., 2012). Tasks common for this ERP are wide ranging and can include, for example, oddball, repetition and recognition paradigms (e.g., old and new word lists), and emotional paradigms (e.g., auditory and visual emotional stimuli).

Seventeen studies tested the LPP or SW in relation to psychopathic traits (Anderson and Stanford, 2012; Anderson et al., 2015; Baskin-Sommers et al., 2013; Brennan et al., 2018; Brislin et al., 2018; Carolan et al., 2014; Cheng et al., 2012; Decety et al., 2015; Eisenbarth et al., 2013; Howard and McCullagh, 2007; Jutai et al., 1987; Medina et al., 2016; Rothemund et al., 2012; Sadeh and Verona, 2012; van Dongen et al., 2018; Venables et al., 2015; Williamson et al., 1991). Four studies found an elevated LPP (Anderson and Stanford, 2012; Cheng et al., 2012; Jutai et al., 1987; Medina et al., 2016). Specifically, Anderson and Stanford (2012) found community participants high in psychopathic traits versus community members low in psychopathic traits exhibited lower LPPs in response to implicit emotional stimuli. However, when asked to categorize pictures based on whether they had emotional content (explicit recognition task), those with elevated psychopathic traits were found to produce elevated LPPs. Cheng et al. (2012) observed greater LPP amplitudes in those with elevated psychopathic traits when observing others in pain. Jutai et al. (1987) observed stronger SW amplitudes in inmates related to an oddball speech task. Finally, Medina et al. (2016) found an elevated LPP to pleasant visual stimuli.

Three studies found no difference in the LPP between psychopathic and non-psychopathic individuals on several experimental tasks (Anderson and Stanford, 2012; Eisenbarth et al., 2013; Rothemund et al., 2012). Using community participants, Anderson and Stanford (2012) found no LPP difference on the Go/No-go portion of a picture viewing task. With a sample of female inpatients, Eisenbarth et al. (2013) observed no difference in the LPP to a mood induction affective picture paradigm. Finally, Rothemund et al. (2012) found no difference in the LPP to a Pavlovian conditioning task (face + shock pairing) in legally involved and community adults.

Eleven studies found a lower LPP in relation to psychopathy to several different experimental tasks but the findings were somewhat conditional (Anderson and Stanford, 2012; Anderson et al., 2015; Baskin-Sommers et al., 2013; Brislin et al., 2018; Carolan et al., 2014; Cheng et al., 2012; Decety et al., 2015; Howard and McCullagh, 2007; Sadeh and Verona, 2012; Venables et al., 2015; Williamson et al., 1991). Specifically, Anderson and Stanford's (2012) community participants with elevated psychopathic traits showed a lower LPP to the affective picture oddball where differentiation was implicit (no instruction to determine whether pictures had emotional content). In separate studies, lower LPPs were found for an auditory oddball task (lower early SW; Anderson et al., 2015), a picture task (pleasant and unpleasant familiar pictures; Baskin-Sommers et al., 2013), a face viewing task (Brislin et al., 2018), and an emotional Stroop task (e-Stroop; Carolan et al., 2014) with inmate and community samples. Cheng et al. (2012) and Decety et al. (2015) found lower LPPs to visual pain stimuli in young and adult offenders and Howard and McCullagh (2007) also found lower positive SWs in an inmate sample to an affective vigilance task and an affective categorization task (oddball). Brennan et al. (2018) found an interaction where elevated psychopathic traits and lower SW amplitudes predicted aggression. Finally, using a prisoner sample, Williamson et al. (1991) observed a lower SW amplitude to emotional words but a normal SW amplitude to neutral words.

In sum, at the total score level, 11.8% of studies (2 studies) found a greater LPP amplitude, 23.5% of studies (4 studies) found no difference in the LLP amplitude and 47.2% of the studies (8 studies) found a reduced LPP amplitude related to elevated psychopathic traits. Additionally, 17.5% of studies (3 studies) found mixed findings based on the study tasks.

At the component level, Anderson et al. (2015) noted that facets 1, 3, and 4 accounted for most of the variance in the lower SW amplitude. Sadeh and Verona (2012) found that elevated F1 scores were linked to lower LPP and thus reduced downstream processing of information containing emotional content (pictures). Similarly, Medina et al. (2018) found lower LPPs for FD and unpleasant stimuli, whereas the LPP was elevated for for pleasant stimuli (psychopathy total sore). Howard and McCullagh (2007) observed the lower LPP for both F1 and F2 of the PCL on an emotion processing task. Baskin-Sommers et al. (2012) also found that the effect for the lower LPP in their study was associated with F2. Brislin et al. (2018) found a negative relationship with LPP and disinhibition as defined by the TriPM (similar to PCL facet 3). And, van Dongen et al. (2018) found a negative relationship between TriPM meanness and the LPP when community participants were viewing an empathy task (see Table 3, Section E).

7.4. P1100 and P1400

In a unique set of studies, Marcoux and colleagues electrically stimulated the hand of participants at a fixed frequency known to produce a response at the somatosensory cortex and simultaneously introduced a series of images to gate (diminish) the response of the somatosensory stimulation in undergraduate and outpatient personality disordered samples (Marcoux et al., 2013, 2014). The experimenters showed that gating was found to be more important in pain conditions and more salient for those individuals with elevated psychopathic traits. Thus, those with psychopathic traits were quicker to diminish pain (Marcoux et al., 2013, 2014). In sum, 100% of the studies suggest higher amplitudes to one's own pain and quicker efforts to diminish pain (see Table 3, Section F).

7.5. Section summary

Cleckley (1988) believed psychopathic individuals had some type of language deficit which he referred to as "semantic aphasia." Cleckley also believed that the psychopathic individual's emotions were short-lived or reactive more so than deep felt. Cleckley (1988) stated "the conviction dawns on those who observe [the psychopath] carefully that here we deal with a readiness of expression rather than a strength of feeling" (p. 348). Others have similarly written about the emotional deficits observed in the psychopath. For instance, Johns and Quay (1976) stated that the psychopath "knows the words but not the music" and Blair (2010) has suggested a basic failure to encode emotionally relevant information at the level of the amygdala. Whatever the mechanism, there does seem to be strong agreement of an emotional deficit. ERPs allow one to examine the potential mechanisms, at least indirectly. With respect to language and sematic aphasia, the evidence is limited. However, Williamson et al. (1991) indicated some irregularities in language processing as did Kiehl et al. (1999a, b), and other studies showed deficits in picture viewing (Anderson and Stanford, 2012). A marked finding in the late ERPs is that the LPP findings demonstrated that those with elevated psychopathic traits may terminate the processing of emotional information early (e.g., faces, emotional Stroop, seeing others in pain). One study, however, showed that psychopathic individuals focused more intensely on viewing others' in distress/pain (e.g., Cheng et al., 2012) even though in two other studies those with elevated psychopathic traits were quick to diminish their own pain (Marcoux et al., 2013, 2014).

8. Spectra analyses (Alpha, Beta, Gamma, Theta, and Mu)

EEG power spectra analyses is often performed with eyes-open and eyes-closed conditions and in some cases these waves are examined in relation to a specific task. To date, only six studies have examined time frequency domain (alpha, beta, gamma, theta, mu). Calzada-Reyes and co-investigators (2013) utilized a sample of incarcerated violent offenders and performed EEG analyses when participants completed resting state tasks including eyes-open and eyes-closed conditions. These researchers observed an excess of beta activity at left parieto-temporal regions and bilateral occipital areas and a decrease in alpha band on left centro-temporal and parieto-central locations in the psychopath group. LORETA signified an increase in beta activity in the psychopath group, relative to the non-psychopath group within fronto-temporo-limbic regions. Beta activity at the left-parietal occipital region was positively correlated with superficial charm and failure to accept responsibility; however, beta activity was negatively correlated with glibness and superficial charm at the left posterior temporal region. Greater beta activity is congruent with increased cognitive activity and potentially the ability to demonstrate superficial charm and other psychopathy related features, however, the differential levels of beta across the head sites is unclear and requires further explanation.

Tillem et al. (2016) found that male inmates with elevated F1 psychopathic traits had higher theta coherence during unpleasant familiar pictures. Those with elevated F2 psychopathic traits had higher theta coherence to novel affective pictures but not necessarily to familiar pictures. The authors concluded that F1 differences in theta coherence could be related to load or it is also possible that those with elevated psychopathic traits devote greater attention to unpleasant pictures whereas the F2 differences may be related to affective salience. The authors suggest that their findings may facilitate understanding of the mechanisms responsible for the aberrant affective responses associated with psychopathy.

Decety et al. (2015), using a community sample, found that psychopathy was associated with less left frontal to right parietal gamma coherence (25–40 Hz) and less coherence in left frontal to right temporal regions. These findings were specific to empathic concern versus affective sharing tasks. Global alpha was not found to be related to psychopathic traits although mu suppression was related to elevated psychopathy when viewing painful stimuli. The finding that psychopathy was related to greater mu suppression may suggest that psychopathy is related to increased somatosensory resonance similar to the findings of Marcoux and colleagues (Marcoux et al., 2013, 2014). However, in a separate study using community participants, van Dongen et al. (2018) did not find that mu suppression was related to elevated psychopathic traits when viewing pictures of aggression. Although, the van Dongen et al. (2018) study examined TriPM meanness alone and this may differ from the broader psychopathy construct measured in the Decety et al. investigation.

Tillem et al. (2019) examined alpha response to a Go/No-go task and found attention anomalies in those with elevated psychopathic traits. Using a community sample of youth, these authors noted that individuals high in psychopathy overallocate attention to visual cues during a Go/No-go task, which was related to enhanced parieto-occipital alpha suppression and this over allocation of attention reduced the neural resources needed for motor control which was evidenced by lower central alpha activity during No-go trials.

Tillem et al. (2018) also examined connectivity using graph analyses to estimate how well, and in what manner, neural regions communicate with one another. This was performed by quantifying various network characteristics using metrics of network efficiency. The results from the study indicated that individuals with elevated F1 traits had less efficient communication within alpha (i.e., long-range neural communication) and gamma (i.e., short-range neural communication) frequency bands (see also Fell et al., 2003). Tillem et al. (2018) concluded that "psychopathic traits were associated with alterations in the basic efficiency of neural communication" (p. 1) related to short and long range connectivity (see Table 3, section H).

8.1. Section summary

Cleckley (1988) has stated that although charming "the psychopath always shows general poverty of affect" and "do[es] not … appear capable of achieving in sincerity the major emotions" (p.348). Spectra analyses lend support to theories of psychopathy which indicate some cognitive dexterity combined with a significant emotional deficit. The findings by Calzada-Reyes et al. (2013) of higher beta waves may offer confirmation of a brain correlate that is associated with greater activation. Moreover, greater beta activity is also indicative of cortical-subcortical interactions, alertness, and brain arousal. These greater activations were correlated with superficial charm and other interpersonal aspects of psychopathy with this sample. Decety et al. (2015) study findings provide support for an emotional deficit with the mu/alpha band suppression when perceiving others in distress. Some of the findings also fit with theory given that psychopaths are thought to be alert and cognizant of their surroundings but to show a general lack of concern for others. One study showed disrupted short- and long-range neural communication (Tillem et al., 2018) suggesting less efficient communication although this research is in its infancy and further investigation is needed on spectra data to draw firm conclusions.

9. Site analyses: scalp location and hemispheric differences

A number of studies have attempted to examine location or the topography of neural firing through site analyses. Such analyses may provide key information on potential hemispheric differences (asymmetry) or contralateral brain differences for various cognitive functions. Typically, site analyses use a repeated measures ANOVA with electrode site entered as a within subjects measure. This allows researchers to discover an area of the brain where a specific ERP is particularly prominent when compared to other sites. Heat maps (energy maps) typically use multiple t-tests to illustrate areas of the brain where the ERP is particularly prominent with respect to a specific cognitive function.

Thirty-three studies performed site by psychopathy ERP interaction analyses. An additional sixteen studies used heat maps. Twenty-two studies found psychopathy by site ERP interactions. Eleven studies found no ERP site by psychopathy interactions. Across the twenty-one interpretable studies reporting site differences, the findings were wide-ranging. Three found interactions with the N100 (Bencic Hamilton et al., 2014; Cheng et al., 2012; Flor et al., 2002), two found interactions with N200 (Kim and Jung, 2014; Krusemark et al., 2016), twelve studies found site interactions involving the P300 (Anderson et al., 2011; Brazil et al., 2012; Carlson and Reinke, 2010; Cheng et al., 2012; Flor et al., 2002; Gao et al., 2011; Hung et al., 2013; Kiehl et al., 2006; Kiehl, Hare et al., 1999; Kim and Jung, 2014; Raine and Venables, 1988; Venables and Patrick, 2014), two found interactions with the N350 (Howard and McCullagh, 2007; Kiehl et al., 1999a), and two found interactions for the LPP (Jutai et al., 1987; Williamson et al., 1991). An additional two studies found specific differences across sites for the CNV (Carlson et al., 2010; Flor et al., 2002). Single studies noted significant site by psychopathy interactions for the N120 (Cheng et al., 2012), N180 (Williamson et al., 1991), P200 (Flor et al., 2002), N275 (Kiehl et al., 2000), N350 (Howard and McCullagh, 2007), N360 (Cheng et al., 2012), P375 (Kiehl et al., 2000), P450 (Howard and McCullagh, 2007), N550 (Kiehl et al., 2006), P600 (Kiehl et al., 1999a), terminal CNV (Flor et al., 2002), and ERN (Munro et al., 2007a).

Although very preliminary, in one study, Hoppenbrouwers et al. (2014) observed a global increase in "right to left interhemispheric signal propagation (ISP)" in psychopathic individuals. They also found that psychopathic offenders exhibited significantly longer cortical silent periods (CSPs) in the right hemisphere but not the left hemisphere and that the CSPs measured from the left and right motor cortex differed in psychopathic offenders. In a second study, Hoppenbrouwers et al. (2013) activated excitatory fibers along the corpus collosum with TMS to look at the interhemispheric signal propagation (ISP) for those with psychopathic traits providing information on interhemispheric connectivity from the dorsal lateral prefrontal cortex (dlPFC). The authors reported abnormalities in right to left functional connectivity and also noted intra-cortical inhibition in the right but not left hemisphere for psychopathic offenders. The authors concluded that the right to left connectivity is affected but the left to right connectivity is intact. These findings require replication as the investigators utilized participants that were recruited from halfway houses where co-occurring problems were the norm including significant drug use (over 80% of sample). As put by the authors, the results may represent the cognitive abilities of unsuccessful psychopathic offenders.

9.1. Section summary

The findings from site analyses indicate that across several studies and tasks, greater activation was exhibited across the scalp for a variety of ERPs (N100, N200, P300, LPP) for those with elevated psychopathic traits. With respect to lateralization, eight studies found significant results regarding hemispheric asymmetry (Flor et al., 2002; Jutai et al., 1987; Kiehl et al., 1999a, 1999; Kiehl et al., 2006; Hoppenbrouwers et al., 2014; Kim and Jung, 2014; Williamson et al., 1991). Of the eight studies, half indicated significantly reduced lateralization of ERP signals (N200, N275, P300, P375) in individuals who have elevated psychopathic traits (e.g., Williamson et al., 1991; Kiehl et al., 1999a, 1999; Kim and Jung, 2014). Other studies suggest that the brains of psychopathic individuals are simply differently lateralized (Jutai et al., 1987; Flor et al., 2002; Kiehl et al., 2006; Hoppenbrouwers et al., 2014). In sum unfortunately, it is difficult to ascertain much cumulative information from the site analyses. Rather, what can be learned, is that additional site analyses work with increasingly sophisticated techniques and greater levels of systematization is required to further what we know regarding localization.

10. Conclusions and future directions

Psychopathic individuals are thought to have abnormalities in their neural functioning that contribute to the syndrome. However, it is not exactly clear what the neural abnormalities may be, especially given the two different dominant theories for psychopathy. With respect to neural functioning, the RM theory (Newman et al., 2011) might suggest top-down deficits in processing peripheral information whereas Fearlessness (Low-Fear) models (Lykken, 1957; Quay, 1965) would most likely predict bottom-up deficits. The neurological abnormalities are likely more complex and potentially subtle. Psychophysiological research can facilitate our understanding of these abnormalities for those with elevated psychopathic traits. EEG studies can advance our understanding of the various theoretical models and treatments for psychopathy (e.g., Fenton et al., 1978; Raine, 1989; Syndulko, 1978).

The aim of the current review was to examine EEG data (ERPs, spectra) to determine the specific similarities and differences in neural functioning for those with elevated levels of psychopathic traits in comparison to those with low levels of psychopathic traits. Given the descriptions of the psychopathic individual as grandiose, charming, manipulative, deceptive, and conning, it was expected that their performance would be unencumbered on primarily cognitive tasks. As such, those with elevated psychopathic traits would exhibit normal orienting, memory updating, associative learning, and error processing as indexed by various ERPs. Deficits were, however expected in the realm of emotional functioning including attention to threat, language processing of emotional content, and responsiveness to pictorial stimuli with emotional content.

Studies examining ERPs within the 50–200 ms range tended to support the view that psychopathic individuals do not express difficulty in orienting to new information in their environment. Those with elevated psychopathic traits evidenced a similar or enhanced level of orienting in comparison to those with lower levels of psychopathic traits with the exception of threat stimuli (e.g., electric shock) or other irrelevant stimuli (e.g., tone pips). Face processing, mismatch detection, and memory updating (N170-P300) also did not show substantial impairment in those with elevated psychopathic traits compared to controls. Instead, there may be deficits that are specific at the factor level that are potentially compensated for by traits involved in a separate factor, as was seen with the N170 study findings. Specifically, three of the five P100 studies showed lower amplitudes to peripheral stimuli and task performance was enhanced because those with elevated psychopathic traits were not distracted by peripheral information. Similarly, only one-fifth (21%) of the N100 studies showed lower amplitudes for the tasks tested. Over half (58%) showed similar or higher amplitudes which is generally interpreted as comparable or enhanced performance. Studies showing lower amplitudes (21%) appeared to be specific to threat (electric shock) or stimuli with emotional content (pictures of others in pain) (e.g., Baskin-Sommers et al., 2012; Cheng et al., 2012).

Only one-quarter of the P200 studies showed lower amplitudes to study tasks whereas nearly two thirds (62.5%) showed no difference or higher amplitudes demonstrating similar or superior neural performance. Of the N170 studies, none (0%) showed lower amplitudes at the total score level and there were significant (but inconsistent) findings at the factor level, with some hint of potential compensatory factors (Brislin et al., 2018). Of the N200 studies, only one-tenth (11.1%) found lower amplitudes whereas over three-quarters (77.7%) exhibited no difference or higher amplitudes signifying similar or greater processing levels. With respect to the P300 studies, less than one-fifth (15.6%) showed lower amplitudes whereas over two thirds (68.7%) showed no difference or higher amplitudes, again suggesting similar or enhanced performance. Of the studies that showed lower amplitudes, the lower amplitudes tended to be specific to F2 (facets 3 and 4) and were more common to emotional content. Late P and N waveforms tended to show that those with elevated psychopathic traits had a lower brain response to emotion laden pictoral content or negative words (e.g., Williamson et al., 1991). The lower amplitudes to stimuli specific to emotional/affective content was thematic across investigations. Taken together, in terms of orienting and memory updating functions, there is insufficient evidence of a deficit, but rather perhaps subtle differences that may in some circumstances, enhance the psychopathic individual's performance. There are more clear deficits related to threat processing and the processing of emotion and affect loaded content that tend to occur downstream.

With respect to associative learning and error processing, EEG studies in this review did not show strong evidence for an impairment. Overall, with respect to CNVi only two studies (40%) found a lower CNV, whereas six-tenths (60%) evidenced similar or elevated CNVs. The terminal CNV may show more aberration, but even with the terminal CNV, the study findings are somewhat mixed. Specifically, one study found a lower CNVt (Rothemund et al., 2012), another found no difference (Forth and Hare, 1989) and a third found a stronger CNVt (Flor et al., 2002). With regard to error processing, the vast majority (84.6%) of the investigations examining ERN showed no difference indicating that those with elevated psychopathic traits do not appear to have a deficit in recognizing errors. There were some noted differences in the Pe with three of four (75%) studies examining this component showing a lower Pe which may signify less perseveration or concern over the error once initially processed. These findings argue against potential contentions that psychopathic individuals fail to learn from experience or that they are not able to detect errors (e.g., Lykken, 1957; Newman et al., 2007). These findings, as well as the N100 and P200 which focused on associative learning, show no deficit in associative learning or error processing and perhaps suggest enhanced learning in some circumstances (e.g., Rothemund et al., 2012).

Late ERPs produced the most pronounced differences suggesting that one of the signature distinctions between those high and low in psychopathic traits may come relatively late in the processing stream. Specifically, the LPP showed that those with elevated psychopathic traits terminated the processing of stimuli with emotional content much earlier than those with low levels of psychopathic traits especially if the stimuli were not affectively motivating. Perniciously, in just a few studies, those with elevated psychopathic traits gave extra attention to stimuli with pain and distress depicted (e.g., Cheng et al., 2012; Sadeh and Verona, 2012). Overall, half (47%) of the studies showed lower LPPs whereas just over one-third (34%) showed a similar or higher LPP to various tasks. As mentioned, the lower amplitudes tended to be toward viewing pain, as well as viewing pictures with emotional stimuli (animals, people). Although in ambiguous tasks more effort was required (e.g., Anderson et al., 2015). In a few studies, however higher LPPs tended to most consistently be correlated with seeing others in pain. Relatedly, Marcoux and colleagues (Marcoux et al., 2013, 2014) found that psychopathic individuals spent more time processing stimuli where others were in pain as evidenced by greater amplitudes in the somatosensory gating stages. However, those individuals with elevated psychopathic traits were quicker to gate their own pain. One study did find eleveated LPPs for veiewing pleasant stimuli (Medina et al., 2016), but the authors also found a lower LPP specific for FD and unpleasant pictoral stimuli.

10.1. Theoretical models for psychopathy

With respect to the theoretical models, the findings offer various levels of support for both theories. Much depends upon how authors' frame their studies and interpret the findings from their individual EEG investigations. For instance, the RM is supported by studies such as those conducted by Anton et al. (2012) and Baskin-Sommers et al. (2012) who examine threat processing in the context of other requisite processing (dominant goal). Baskin-Sommers et al. (2012) argue that those with psychopathic traits are so highly focused on a dominant goal that they are able to ignore the threat. However, when asked to attend to the threat, studies have shown that those with elevated psychopathic traits are able to moderate their response (Newman et al., 2011). Forth and Hare (1984) also found that those scoring high in psychopathy found it easier to ignore irrelevant tone pips that distract rather than help with performing the task. The studies by Anderson (Anderson and Stanford, 2012; Anderson et al., 2015) offer additional support for the RM theory in that their investigations demonstrate that unless the emotional information depicted in pictures was made salient (brought to their attention), those with psychopathic traits were unlikely to notice it. However, when asked to categorize ambiguous emotional pictures those with elevated psychopathic traits were able to identify the emotional stimuli even though they may have expended extra neural activity to make the correct categorization. These findings correspond with earlier findings of Newman et al. (2010) who showed that psychopathic individuals were better able to focus on fear when asked to attend to it. The Krusemark et al. (2016) study further supports RM by suggesting top-down processing referred to as a "selectivity processing" to task performance was superior in those with elevated psychopathic traits which may indicate a focused top down (cognitive control) perspective rather than a deficit in bottom-up projections.

The time series investigations by Calzada-Reyes et al. (2013) which found higher levels of beta at-rest may reflect higher rates of cortical activity potentially explaining, to some extent, the links to greater charm and interpersonal characteristics that in general require additional cognitive resources. These findings coupled with Decety et al. (2015) – which suggest that mu suppression may be linked to the uncaring aspects of psychopathy – may indicate greater support for the fearlessness hypothesis. However, the findings of Tillem et al. (2016) which indicated higher theta to unpleasant familiar pictures for those with elevated F1 traits may suggest greater load, and, thus may offer some support to the RM model. Specifically, Tillem et al. (2016) concluded that "psychopathic individuals have disrupted integration of sensory information" (p. 42). Further, although tentative, the Tillem et al. (2018) study suggests that those with elevated psychopathic traits have disruptions in short- and long-range neural communication. These areas have been reported to support RM but further delineation of the specific connection to the RM theory is needed as the findings appear open for a variety of interpretations.

Despite considerable support for the RM, a number of studies argue against RM. For instance, Brazil et al. (2012) contends that their findings do not support the RM as the group with psychopathy in their study did not show larger ERPs (P300) to targets at both frontal and parietal locations. While Brazil et al. (2012) made the general argument against RM there have also been counter arguments. Some contend that study tasks like those of Brazil et al. (2012) are not suitable to test the mechanisms related to deficient RM in psychopathy. This is because there is no competition between peripheral and central information for occupying the focus of attention (Brazil et al., 2012). Furthermore, some contend that the Baskin-Sommers et al. (2012) study demonstrates that the abnormalities in attention happen very early in the processing time window. Specifically, they argue for an early attentional bottleneck that occurs before the P300 (Baskin-Sommers et al., 2013). It is possible that the superiority in the deployment of cognition for early stage of processing (P140) in order to differentiate between stimuli reduces the need for engaging cognitive resources for differentiation at later stages in the time window of the P300.

Other studies in this review provide strong support for an emotion-based model such as the Fearlessness (Low-Fear) model. Several studies (e.g., Cheng et al., 2012; Marcoux et al., 2013) offered evidence of anomalies in pain empathy for those with elevated psychopathy scores. Specifically, Cheng et al. (2012) demonstrated that the frontal N120 and the central parietal LPP were abnormal in those with psychopathic traits and reflect an early affective arousal and a late cognitive evaluation component. It is worth mentioning that the frontal N120 can be associated with a negativity bias, and that the LPPs reflect reappraisal of unpleasant stimuli along with enhanced attentional processes (Dennis and Hajcak, 2009). Cheng et al. (2012) also found that psychopathic individuals had a higher pain threshold further highlighting a potential fear deficit. With respect to brain functioning, Cheng et al. (2012) noted that "regions of the pain matrix" were activated in both controls and aggressive CD youth, but a specific activation of the amygdala and ventral striatum was detected in the aggressive CD group. This led the authors to develop their hypothesis that those with aggressive CD may find the perception of pain in others enjoyable and rewarding (Decety et al., 2009).

Relatedly, as mentioned, Decety and colleagues (2015) showed that the EEG gamma and mu rhythm indicate that those with elevated psychopathic traits have the capacity for pain empathy although they are not likely to resonate with the feelings associated with others' pain (Cheng et al., 2008; Yang et al., 2009). The neural network for their findings includes regions coding the motivational-affective and the sensory discriminative components of processing of pain in the observer, namely, the supplementary motor area, somatosensory cortex, ACC, periaqueductal gray, and anterior insula (Akitsuki and Decety, 2009; Decety and Michalska, 2010). These findings are also backed to some extent by the Marcoux et al. studies (Marcoux et al., 2014; Marcoux et al., 2013). Howard and McCullagh (2007) found that psychopaths showed greater amplitude (P1100) for unpleasant pictures and were sensitive to contextual affective information. These authors explicitly state that their study findings "militate[s] against an account of psychopathy in terms of deficient response modulation" (p. 337). The lack of findings for associative learning and error processing anomalies in EEG output may also argue against RM.

For decades, there has been research demonstrating that there are important differences observed at the psychopathy factor level (Harpur et al., 1989). This has helped us to understand that the disorder is a multicomponent condition, and simultaneously, that the factors often display psychologically and physiologically distinct correlates (Harpur et al., 1989; Lilienfeld, 2018). The EEG output reviewed here also shows important factorial differences. These differences suggest that there may be distinct etiologies underlying psychopathy dimensions. For instance, when differences are evidenced in the N200 (lower amplitudes), these differences may be related to elevated F2 traits rather than F1 traits (Heritage and Benning, 2013). Similarly, although most studies showed comparable or enhanced P300s, unimpaired memory up-dating may be most specific to those with elevated F1 traits (Gao et al., 2018) rather than those with elevated F2 traits. Likewise, weaker ERNs might be unrelated to the broader psychopathy scores and unrelated to those with elevated F1 traits, however such deficits may be related to those with elevated F2 traits. These findings have implications for understanding the brain functioning of those with elevated psychopathic traits. That is, depending on the profile, there could be stronger or weaker amplitudes for certain ERPs, which may give rise to the enhancements or impairments in various aspects of brain functioning. These potential differences underscore the importance of multi-process models such as the dual process model (e.g., Dindo & Fowles, 2016; Fowles and Dindo, 2009; Patrick and Bernat, 2009). For instance, the dual process model suggests that F1 is accounted for by a weak defensive system (fearlessness) and F2 is accounted for by underlying disinhibition and externalizing proneness (potentially related to RM) (Fowles and Dindo, 2009). Thus, rather than solely focusing on RM and Fearlessness (Low-Fear) perspectives, multi-process models may be a way forward by examining the different dimensions of psychopathy and their neurophysiological underpinnings. It is likely the case, that there are more than two processes for the multi-components of psychopathy, and that focusing on the three primary dimensions of psychopathy may be useful in better understanding psychopathy (Salekin, 2017). In this regard, a triple process model may be more appropriate in specifying antisocial behavior (Salekin, 2016a, 2016b).

10.2. Recommendations for future research

The current review indicates that the research on psychopathy and EEG has advanced knowledge about psychopathy. At the same time, this research highlights ways to improve future investigations to further build our knowledge base. First, more consistency in reporting psychopathy total and underlying factor scores will facilitate research and help answer questions regarding whether EEG findings are specific to the wider construct of psychopathy or underpinning dimensions. Second, reporting the location of significant EEG findings as well as using sophisticated techniques (e.g., sLORETA) will enhance what we know regarding spatial knowledge. Third, reducing comorbidity and substance use problems that could cloud EEG findings could be beneficial to establishing differences in brain functioning that pertain to psychopathy, psychiatric comorbidity, and /or substance use. Specifically, some studies in this review showed profound brain deficits, but these deficits often tended to be located within multi-health problem participants or those with co-occurring substance use difficulties. It is possible that the brain anomalies for psychopathy could be more subtle given clinical descriptions put forth by Cleckley (1941/1976) and Hare (1993), making these types of distinctions critical. Fourth, even though research has demonstrated psychopathy to be dimensional/non-taxonic (Murrie et al., 2007), evident across age groups (Hawes et al., 2018), gender (e.g., Salekin et al., 1998; Vitale et al., 2005), and setting (e.g., forensic and community), and anchored to Cleckley (1941/1976) and Hare (1991/2003), more work is needed to examine moderators that may relate to the EEG findings. Finally, research designs that increasingly compare theoretical models will increase knowledge regarding psychopathy.

10.3. Conclusion

The current review examined the relations between psychopathy and EEG data including early, mid, and late timeframe processing. In addition, spectra analyses were considered. The pattern of results indicate that psychopathic individuals may have strong early selection processes paired with diminished or elaborative sustained processing of emotional information. This may signify that there are both automatic and strategic aspects to the psychopathic individuals information processing where those with elevated psychopathic traits purposefully spend less time processing distress stimuli. This notion fits with the idea that the LPP amplitude can be attenuated by voluntary top-down control (Hajcak et al., 2010). These findings may align with Hare's notion that the psychopath decides "which rules [or stimuli] to follow or ignore, based on their own self-interest, a calculating appraisal of the circumstances, and a lack of concern for the feelings and welfare of others" (p. vii, Hare, 2013). However, much more research is needed on this topic. This review consolidates research on psychopathy and EEG and offers ways to enhance future science. The findings may suggest that a focus on associative learning, error processing, and memory updating may yield small to no effects for the hallmark symptoms of psychopathy whereas an emphasis on threat and emotion processing may glean additional insights. Spectra analyses may offer further promising avenues for research. Error processing (Pe) and associative learning (CNVt), as they pertain to the psychopathic individual's emotional response to events, could prove informative. By better understanding the neurological functioning of those with psychopathic traits, we may more precisely identify the biological signature for the condition. This in turn, may help shape diagnostic and statistical manuals as well as the eventual fine-tuning of interventions, including neural interventions, for those who suffer from elevated psychopathic traits across the globe.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.neubiorev.2019.05.025.

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