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Brain potentials implicate temporal lobe abnormalities in criminal psychopaths

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Abstract

Psychopathy is associated with abnormalities in attention and orienting processes. However, few studies have examined the neural systems underlying these processes in psychopaths. To address this issue, behavioral responses and event-related potentials (ERPs) were recorded while 80 incarcerated males, classified as psychopathic or nonpsychopathic using the Hare Psychopathy Checklist-Revised, completed a three-stimulus auditory oddball task. Consistent with hypotheses, processing of target stimuli elicited larger fronto-central negativities (N550) in psychopaths than in nonpsychopaths. Psychopaths also showed an enlarged N2 and reduced P3 during target detection. Similar ERP modulations have been reported in patients with amygdala and anterior temporal lobe damage. These data suggest that the ERP abnormalities observed in psychopaths may be related to dysfunction of the anterior temporal lobe. The data are interpreted as supporting the hypothesis that psychopathy may related to anomalies or dysfunction of the paralimbic system – a system that embraces parts of the temporal and frontal lobes.

Brain potentials implicate temporal lobe abnormalities in criminal psychopaths

Psychopathy is a personality disorder defined by a cluster of interpersonal, affective and behavioral characteristics, including glibness, impulsivity, poor behavioral controls, shallow affect, and lack of empathy, guilt, and remorse (Hare, 1991, 1993). Although there is good agreement regarding the assessment and behavioral correlates of psychopathy (Hare, 2003), relatively little is known about the neurocognitive processes implicated in the disorder. One cognitive domain that has been shown to be abnormal in psychopathy involves attentional and orienting processes (see reviews by Arnett, 1997; Hare, 2003; Kosson & Harpur, 1997; Newman & Lorenz, 2002). In general, psychopaths tend to exhibit relatively small increases in skin conductance in anticipation of a variety of noxious stimuli (e.g., Flor, Birbaumer, Hermann, Ziegler, & Patrick, 2002; Hare, Frazelle, & Cox, 1978; Hare & Quinn, 1971; Lykken, 1957), as well as in response to emotional stimuli, including threatening images (Blair, Jones, Clark, & Smith, 1997), slides of mutilated faces (Mathis, 1970), and emotional sounds, both positive and negative (Verona, Patrick, Curtin, Bradley, & Lang, 2004). The skin conductance response is a component of the orienting reflex (Hare, 1973; Sokolov, 1963), suggesting that psychopathy is associated with abnormal orienting/attentional responses to salient or novel stimuli.

Event-related potential (ERP) studies have been used to study aspects of the orienting response for many years, particularly with "oddball" paradigms. In one type of oddball task, low probability task-irrelevant novel stimuli, and low- probability task-relevant target stimuli, are presented against a background of frequent or standard stimuli (Courchesne, Hillyard, & Galambos, 1975). Both novel and target stimuli are associated with a sequence of electrical components, the most prominent of which is a large broadly distributed positive wave, termed P3 or P300 (Sutton, Braren, Zubin, & John, 1965). The P3 elicited by target stimuli has a parietal maximum topography (termed P3b) while novel stimuli elicit a P3 with a fronto-central maximum, also known as the P3a (Courchesne et al., 1975). The P3 components elicited by novel and target stimuli are believed to be related to processes involving attentional capture, allocation of cognitive resources, and contextual updating – all components linked to 'orienting processes'.

There have been only eight published ERP studies on psychopathy (Flor et al., 2002; Forth & Hare, 1989; Jutai & Hare, 1983; Jutai, Hare, & Connolly, 1987; Kiehl, Hare, McDonald, & Liddle, 1999; Kiehl, Smith, Hare, & Liddle, 2000; Raine & Venables, 1988; Williamson, Harpur, & Hare, 1991). Seven studies have reported information concerning P3 components, though only four studies employed paradigms in which the salience of stimuli was manipulated in a manner expected to elicit a canonical P3 response (Jutai et al., 1987; Kiehl, Hare, McDonald, & Liddle, 1999; Kiehl et al., 2000; Raine & Venables, 1988). Jutai et al. (1987) found no difference between psychopaths and nonpsychopaths in the amplitude or latency of the P3. Visual inspection of the waveforms in their study indicated that the P3 amplitude was smaller, albeit nonsignificantly, in the psychopaths than in nonpsychopaths. However, Jutai et al. did not record from parietal electrodes, which is the optimal site for detection of the P3. In contrast, Raine and Venables (1988) reported that the amplitude of parietal P3 to visual target stimuli was greater in psychopaths than in nonpsychopaths. More recent studies have reported that the P3 elicited during visual oddball tasks is substantially smaller over frontal, central and parietal sites in psychopaths than in nonpsychopaths (Kiehl, Hare, McDonald, & Liddle, 1999; Kiehl et al., 2000). In the remaining P3 studies, there was little evidence indicating that the P3 was abnormal in psychopaths. However, these latter studies did not employ paradigms that manipulated the salience of the stimuli. In summary, the evidence regarding abnormality of the P3 in psychopathy is inconclusive, but suggests that under some circumstances the P3 may be reduced in psychopaths. However, perhaps more illuminating is that abnormal late (i.e., later than 300ms post-stimulus) ERP negativities appear to be uniquely characteristic of psychopaths during tasks that manipulate the salience of the stimuli.

To date, abnormally large late ERP negativities, maximal at frontal and central sites, have been reported in psychopaths during a contingent negative variation task (Forth & Hare, 1989), emotional lexical decision task (Williamson et al., 1991), a concrete/abstract discrimination task, a concrete/abstract lexical decision task, and an emotional polarity discrimination task (Tasks 1, 2, and 3, respectively, in Kiehl, Hare, McDonald, & Brink, 1999), as well in a response inhibition task (Kiehl et al., 2000), and a visual oddball task (Kiehl, Hare, McDonald, & Liddle, 1999). One common denominator of the studies that have observed late ERP negativities in psychopaths is that the eliciting stimuli were task-relevant or salient and engaged attention, orienting, and decision making processes (for review see Kiehl, in press). It may be possible that the late ERP negativities reflect abnormal attention and orienting processes in psychopaths. Some studies suggest that psychopaths ‘overfocus’ attention on stimuli of immediate interest and effectively ignore other stimuli (Jutai & Hare, 1983; Jutai et al., 1987; Newman, Schmitt, & Voss, 1997). Still unresolved, however, are the neural systems implicated in salient stimulus processing in general and psychopathy in particular.

One method used to investigate the potential generators underlying the processing of salient, or oddball, stimuli was to record ERPs in patient populations with localized brain insults. The main tenet of this research is that if the circuits involved in salient stimulus processing are damaged it should lead to observable abnormalities in the scalp recorded ERPs. These studies found that frontal, temporal, parietal, and limbic structures are engaged during processing of oddball stimuli (see review by Soltani & Knight, 2000). Interestingly, in patients with temporal lobe damage several studies found clear evidence for late fronto-central ERP negativities during processing of target stimuli (Johnson, 1993; Yamaguchi & Knight, 1993). Patients with temporal lobe damage, relative to controls or patients with parietal lobe damage, had enlarged N2b, smaller P3, and a late fronto-central negativity (Yamaguchi & Knight, 1993). Similar effects were observed in epilepsy patients following resection of the amygdala and anterior superior temporal gyrus for the treatment of intractable seizures (Johnson, 1993). These data suggest that the medial and lateral temporal lobes are implicated in the elicitation of late ERP negativities during the context of auditory oddball tasks. The functional significance of these late ERP negativities in psychopathic individuals and patients with temporal lobe damage may be related to a number of mental processes. Impairments in medial temporal lobe regions may lead to alternative strategies or cognitive processes to be recruited to process salient stimuli. The recruitment of such resources may reconfigure the neural generators associated with processing salient stimuli to produce the late ERP negativities.

Another avenue available for examining the neural circuits implicated in target detection is event-related functional magnetic resonance imaging (fMRI). These studies have shown that in healthy participants target stimuli elicit activity in diverse and widespread neuronal networks, including medial (i.e., bilateral amygdala) and lateral temporal lobe, anterior and posterior cingulate, and frontal and parietal cortex (Clark, Fannon, Lai, Benson, & Bauer, 2000; Kiehl, Laurens, Duty, Forster, & Liddle, 2001; Kiehl, Laurens, Duty, Forster, & Liddle, 2001; Kiehl & Liddle, 2003). The results are in close parallel to the intra-cranial electrode data recorded from patients with brain pathology during similar tasks (Clarke, Halgren, & Chauvel, 1999a, 1999b). Thus, there is substantial evidence suggesting that the medial and lateral aspects of the temporal lobe are implicated in salient stimulus processing tasks. However, the suggestion that the primary processing deficit in psychopaths is related to the salience of the stimuli is hampered by the fact that the tasks shown to elicit the late ERP abnormalities in psychopaths often involved relatively complex stimuli and decision-making (e.g., about different classes of language stimuli). Thus, it has been difficult to isolate the neurocognitive processes underlying the late ERP negativities observed in psychopaths. To address this issue, the present study employed an auditory ‘oddball’ task to selectively manipulate the salience of the stimuli. The primary hypothesis was that during processing the salient stimuli psychopaths’ ERPs would be characterized by late negativities.

Methods

Participants. The participants were 80 male inmates from a federal maximum-security prison facility near Vancouver, British Columbia. Volunteers were selected for the study if they were between 18 and 55 years of age, were free from any reported serious head injury or neurological impairment and had no DSM-IV Axis I diagnosis (American Psychiatric Association, 1994). Volunteers participated in two sessions: a videotaped semi-structured interview and the experimental recording session. Information from the interview and an extensive review of institutional files were used to complete the PCL-R on each inmate. Each of the 20 items on the PCL-R is scored on a 3-point scale (0-2) according to the extent to which it applies to the inmate. Inter-rater reliability for two raters for a subset of the inmates (n=30) was .83. Event-related potentials (ERPs) for one sample (n=44) was collected by the first author (KK) and a subsequent sample (n=36) was collected by the second author (AB). To control for the effect of these different experimenters, time of data acquisition, and to illustrate the reproducibility of the results, the two samples were analyzed separately. Within each sample, inmates with a PCL-R score of 30 or above were defined as Psychopaths and those with a PCL-R score below 30 were defined as Nonpsychopaths. Sample 1 consisted of 23 Psychopaths [mean PCL-R score 32.5 (SD 1.7)) and 21 Nonpsychopaths [mean PCL-R score 20.85 (SD 5.99)). Sample 2 consisted of 18 Psychopaths [mean PCL-R score 33.94 (SD 2.48)) and 18 Nonpsychopaths [mean PCL-R score 20.35 (SD 6.39)).

For Sample 1, the mean age and years of formal education were 33.9 and 35.8, and 11.0 and 11.4 years for Psychopaths and Nonpsychopaths, respectively. For Sample 2, mean age and years of formal education were 32.5 and 31.4, and 10.4 and 11.2 years for Psychopaths and Nonpsychopaths, respectively. The National Adult Reading Test (NART) and Quick tests were used to assess IQ.

NART and Quick scores were unavailable for 4 inmates. For Sample 1 the NART and Quick scores for Psychopaths were 108.9 (SD 9.6) and 103.2 (SD 11.85) and for Nonpsychopaths they were 107.6 (SD 10.3) and 103.5 (SD 8.5), respectively. For Sample 2 the NART and Quick scores for Psychopaths were 112.3 (SD 7.3) and 105.45 (SD 10.8) and for Nonpsychopaths they were 110.9 (SD 9.36) and 105.8 (SD 9.21), respectively. For both samples, there were no group differences in age, years of formal education, NART or Quick scores (all p's > .50). Each inmate was paid $5.00 for the PCL-R interview and $10.00 for the experiment. The total of $15.00 was equivalent to two days prison wage. The study was conducted in accordance with Institutional and University ethical standards.

Stimuli. The target (1500 hz tones), novel (e.g., ramped tones, random sounds) and standard (1000 hz tones) stimuli were presented with a probability level of .10, .10 and .80, respectively. All stimuli were 200 milliseconds in duration with a random 1000 – 1500 ms inter-stimulus interval. The only constraint on the order of stimulus presentation was that two low probability stimuli could not occur one after the other; otherwise the presentation of stimuli was random. Six runs of 64 stimuli were collected. Participants were instructed to respond as quickly and accurately as possible to the target stimulus and to ignore the standard and novel stimuli. The hand used to respond to the target stimulus was counterbalanced across participants. Two runs of 20 stimuli were given as practice.

Event-related Potential Recording. Scalp potentials were recorded from tin electrodes (ElectroCap International) placed over 29 electrode sites according to standard placement guidelines of the International 10-20 System. Vertical and horizontal electrooculargrams (EOG) were monitored from a bipolar electrode pair located on the lateral and supra orbital ridges of the right eye. All

EEG electrodes were referenced to the nose. Two additional channels, left and right mastoids, were recorded. Electrical impedances were maintained below 10 kohms throughout the experiment. The EEG channels (SA instruments) were amplified (20,000 gain) with a bandpass of .01 to 100 Hz, digitized on-line at a rate of 256 samples per second, and recorded on computer hard disk. The length of the recording epoch was 1200 milliseconds with a 100 millisecond pre-stimulus baseline. Single-trials with voltages greater than (+ or -) 75 microvolts at any electrode site or EOG artifact were excluded. Four participants (all nonpsychopaths from Sample 2) were excluded because of excessive artifacts (greater than 40% of target trials). After exclusion of these participants, there were no significant group differences in the number of trials averaged in any condition. The ERPs were digitally filtered with a zero-phase shift 30 Hz low pass filter to reduce electromyographic contamination and ambient electrical noise.

Three components were analyzed by measuring the peak amplitude, relative to a 100 millisecond prestimulus baseline, in the following latency windows 175-265 ms (N2), 275-425 ms (P3), and 425-625 ms (N550). These windows were centered upon the peak latency of each of the components in the grand average waveforms. Separate ANOVAs were performed on midline, medial and lateral sites. These ANOVAs included factors of Group (Psychopath and Nonpsychopath), Condition (standard, target and novel), and Site (frontal (F7, F3, Fz, F4, F8), fronto-central (Fc7, Fc3, Fcz, Fc4, Fc8), central (T3, C3, Cz, C4, T4), temporo-parietal (Tp7, P3, Pz, P4, Tp8), and temporo-occipital (T5, O1, Oz, O2, T6)). For medial and lateral ANOVAs there was an additional factor of Hemisphere (right and left). Midline (Fpz) and medial (Fp1, Fp2) ANOVAs also included an additional level of Site (prefrontal). Following the ANOVA, planned comparisons were performed on the predicted effects. Type I error rate was maintained below .05 by using the Dunn-Bonferroni correction. Other effects of interest were tested using simple effects analyses or Tukey's multiple comparisons. The Geisser-Greenhouse correction was used for any repeated measures containing more than one degree of freedom in the numerator (Geisser & Greenhouse, 1958).

Results

Behavioral data. Sample 1. There were no significant group differences (all p's > .25) in the percentage of correct hits (Psychopaths, 97.28, SD = 6.07; Nonpsychopaths, 98.0, SD = 3.6), reaction times (Psychopaths, 486.90 ms, SD = 92.8; Nonpsychopaths, 459 ms, SD = 62.9), or numbers of false alarms to novel stimuli (Psychopaths, 0.82, SD = 1.6; Nonpsychopaths, 1.0, SD = 1.5)) or standard stimuli (Psychopaths, 9.1, SD = 5.7; Nonpsychopaths, 8.52, SD = 4.4).

Sample 2. As in Sample 1, there were no significant group differences (all p's > .13) in the percentage of correct hits (Psychopaths 93.6, SD = 12.4; Nonpsychopaths, 98.8, SD = 2.3), reaction times (Psychopaths, 424 ms, SD = 79.3; Nonpsychopaths, 404 ms, SD = 88.8), or numbers of false alarms to novel stimuli (Psychopaths 1.7, SD = 1.4; Nonpsychopaths, 2.5, SD = 3.0), or standard stimuli (Psychopaths, 12.7, SD = 7.6; Nonpsychopaths, 15.6, SD = 7.6).

Event-related potentials. Grand mean ERPs for target, novel and standard stimuli for Sample 1 are presented in Figures 1, 2, and 3, respectively. Sample 2 grand mean ERPs for target, novel and standard stimuli are presented in Figures 4, 5, and 6, respectively.

N2 amplitude analyses.

Sample 1. The N2 peak amplitude for target stimuli was larger for Psychopaths than for Nonpsychopaths. This effect was greatest at fronto-central sites. The N2 elicited by novel stimuli was larger for Psychopaths than for Nonpsychopaths at centro-parietal sites (main effect of Group, midline, $F (1, 42) = 4.01$, $p < .05$; medial, $F (1, 42) = 4.57$, $p < .05$; lateral $F (1, 42) = 5.62$, $p < .025$; Group x Condition X Site trend, midline, $F (10, 420) = 2.28$, $p < .10$; medial $F (10, 420) = 2.13$, $p < .10$; Group x Condition trend, medial, F (2, 84) = 2.4, p < .10; Group x Condition x Site trend, lateral, F (8, 336) = 2.188, p < .10).

Across all participants the N2 was larger for target and novel stimuli than for standard stimuli (main effect of Condition, midline, F (2, 84) = 65.33, p < .001; medial, F (2, 84) = 68.68, p < .001; lateral, F (2, 84) = 54.14, p < .001). For target stimuli, the N2 had a fronto-central distribution, asymmetrically larger on the left hemisphere than the right hemisphere (Condition X Site interaction, midline, F (10, 420) = 35.94, p < .001, medial, F (10, 420) = 33.01, p < .0001, lateral, F (8, 336) = 12.74, p < .001; Site x Hemisphere interaction, medial, F (5, 210) = 6.26, p < .001; Condition x Site x Hemi interaction, medial, F (10, 420) = 4.08, p < .001, lateral F (8, 336) = 2.57, p < .05; main effect of Site, midline, F (5, 210) = 11.06, p < .001, medial, F (5, 210) = 10.91, p < .001, lateral, F (4, 168) = 7.45, p < .005).

Sample 2. The N2 elicited by target and novel stimuli was larger for Psychopaths than for Nonpsychopaths at midline sites (Psychopathy x Condition interaction, F (2, 60) = 3.40, p < .05). There were no significant group effects at medial or lateral sites and no group differences in the N2 elicited by standard stimuli.

As in the Sample 1 above, across all participants, the N2 was larger for target and novel stimuli than for standard stimuli (main effect of Condition, midline, F (2, 60) = 52.62, p < .001, medial, F (2, 60) = 54.00, p < .001, lateral, F (2, 60) = 57.76, p < .001). The target N2 was maximal at fronto-central sites, while the novel N2 had a more posterior distribution (Condition x Site interaction, midline, F (10, 300) = 29.85, p < .001, medial, F (10, 300) = 32.28, p < .001, lateral, F (8, 240) = 12.98, p < .001; main effect of Site, midline, F (5, 150) = 14.83, p < .001, medial, F (5, 150) = 18.00, p < .001, lateral, F (4, 120) = 11.11, p < .001).

P3 amplitude analyses.

Sample 1. There were no overall group differences in the amplitude of the P3. At temporal sites the P3 was slightly larger on the left (Ft3, T3, T5) than the right hemisphere (Ft4, T4, T6) for Psychopaths, this effect was reversed for Nonpsychopaths (Group x Site x Hemisphere interaction, lateral, $F(4, 168) = 2.53$, $p < .05$).

Across all participants, the P3 was larger for target and novel stimuli than for standard stimuli (main effect of Condition, midline, $F(2, 84) = 58.85$, $p < .001$, medial, $F(2, 84) = 48.59$, $p < .001$, lateral, $F(2, 84) = 23.10$, $p < .001$). The target P3 had a posterior distribution, while the P3 elicited by novel stimuli had a fronto-central distribution (Condition x Site interaction, midline, $F(10, 420) = 32.41$, $p < .001$, medial, $F(10, 420) = 23.61$, $p < .001$, lateral, $F(8, 336) = 11.29$, $p < .001$). The target P3 was slightly larger over the right hemisphere than the left hemisphere at fronto-central electrodes and this hemispheric asymmetry switched at parietal electrodes (Condition x Site x Hemisphere interaction, lateral, $F(8, 336) = 2.56$, $p < .05$; main effect of Site, midline, $F(5, 210) = 31.18$, $p < .001$, medial, $F(5, 210) = 28.51$, $p < .001$), lateral, $F(4, 168) = 39.70$, $p < .001$).

Sample 2. The P3 for target stimuli and novel stimuli was slightly, though significantly, smaller for Psychopaths than for Nonpsychopaths at medial sites. This latter effect was limited to the P3 for novel stimuli at lateral sites (Group x Condition interaction, midline, $F(2, 60) = 2.43$, $p < .10$, medial, $F(2, 60) = 3.08$, $p < .05$, lateral, $F(2, 60) = 4.23$, $p < .025$; main effect of Group, midline, $F(1, 30) = 3.26$, $p < .10$, medial, $F(1, 30) = 4.01$, $p < .05$, lateral, $F(1, 30) = 3.78$, $p < .10$). We note however, that the Psychopaths' small P3 for target stimuli may have been due to the large fronto-central negativity in the 350-600 millisecond window (see below).

As in sample 1, the P3 was larger for target and novel stimuli than for standard stimuli (main effect of Condition, midline, $F(2, 60) = 33.23$, $p < .001$, medial, $F(2, 60) = 28.41$, $p < .001$, lateral, F

(2, 60) = 12.53, p < .001). The P3 for target stimuli was maximal at parietal sites, while the P3 to novel stimuli had a more fronto-central distribution (Condition x Site interaction, midline, F (10, 300) = 20.56, p < .001, medial, F (10, 300) = 13.56, p < .001,lateral, F (8, 240) = 6.02, p < .002; main effect of Site, midline, F 5(, 150) = 12.78, p < .001; medial, F (5, 150) = 12.72, p < .001, lateral, F (4, 120) = 30.55, p < .001). There were no hemispheric asymmetries for the P3 in this sample.

N550 amplitude analyses.

Sample 1. As predicted, the N550 elicited by target stimuli was significantly larger for Psychopaths than for Nonpsychopaths (Group x Condition interaction, midline, F (2, 84) = 3.44, p < .05, medial, F (2, 84) = 3.92, p < .05, lateral, F (4, 168) = 6.23, p < .01; main effect of Group, midline, F (1, 42) = 4.39, p < .05, medial, F (1, 42) = 4.57, p < .05, lateral, F 1, 42) = 3.67, p < .10). This effect was largest at fronto-central electrode sites (Group x Condition x Site interaction, midline, F (10, 420) = 2.076, p < .025, medial, F (10, 420) = 2.02, p < .05, lateral, F (8, 336) = 2.32, p < .025; Group x Site interaction, midline, F (5, 210) = 5.57, p < .01, medial, F (5, 210) = 6.04, p < .01). At many sites, the N550 elicited by target stimuli was more than twice the amplitude in Psychopaths as it was in Nonpsychopaths (see Table 1).

Across participants, the N550 was larger for target stimuli than for novel or standard stimuli (main effect of Condition, midline, F (2, 84) = 17.53, p < .001, medial, F (2, 84) = 13.33, p < .001, lateral, F (2, 84) = 7.85, p < .002), this effect having a fronto-central distribution. (main effect of Site, midline, F (5, 210) = 86.36, p < .001, medial, F (5, 210) = 94.91, p < .001, F (4, 168) = 105.23, p < .001; Condition x Site interaction, midline, F (10, 420) = 28.444, p < .001, medial, F (10, 420) = 25.68, p < .001, lateral, F (8, 336) = 28.393, p < .001; Site x Hemisphere interaction, medial, F (5, 210) = 3.78, p < .015; Condition x Site x Hemisphere interaction, medial, F (10, 420) = 2.74, p < .05).

Sample 2. As in Sample 1, N550 elicited by target stimuli was significantly larger for Psychopaths than for Nonpsychopaths. This effect was greatest at fronto-central sites (Group x Condition x Site interaction, midline, $F (10, 300) = 1.78$, $p < .10$; Group x Condition interaction, midline, $F (2, 60) = 7.23$, $p < .002$, medial, $F (2, 60) = 7.20$, $p < .01$, lateral, $F (2, 60) = 6.15$, $p < .01$; main effect of Group, midline, $F (1, 30) = 6.29$, $p < .025$, medial, $F (1, 30) = 6.95$, $p < .01$, $F (1, 30) = 8.52$, $p < .007$).

Across all participants, the N550 was larger for target than for novel or standard stimuli, an effect greatest at fronto-central electrodes (Condition x Site interaction, midline, $F (10, 300) = 12.70$, $p < .001$, medial, $F (10, 300) = 13.36$, $p < .001$, lateral, $F (8, 240) = 10.95$, $p < .001$; main effect of Condition, midline, $F (2, 60) = 18.38$, $p < .001$, medial, $F (2, 60) = 15.25$, $p < .001$, lateral, $F (2, 60) = 7.16$, $p < .001$; main effect of Site, midline, $F (5, 150) = 19.84$, $p < .001$, medial, $F (5, 150) = 17.36$, $p < .001$, lateral, $F (4, 120) = 27.17$, $p < .001$).

Discussion

Consistent with hypothesis, analyses of the electrophysiological data revealed that psychopathic inmates, relative to demographically matched nonpsychopathic inmates, showed an aberrant, large, late ERP negativity during target detection (N550). Psychopaths also had an enlarged N2 and a slightly reduced fronto-central P3 (Sample 2 only) during target detection. The N550 was nearly twice the amplitude in psychopaths as in nonpsychopaths (see Figures 1, 4 and Table 1). These data demonstrate that a simple salient stimulus discrimination between tone types is sufficient to elicit late ERP negativities in psychopaths. Thus, the late ERP negativities do not appear to be necessarily related to language stimuli or other complex task demands as employed in prior studies (Kiehl, Hare, McDonald, & Brink, 1999; Kiehl et al., 2000; Williamson et al., 1991). There remain however, a number of possible interpretations for the enlarged N2, reduced P3, and aberrantly large N550 in psychopaths relative to nonpsychopaths.

One interpretation for the aberrant ERPs in psychopaths is that they reflect abnormal cognitive processes associated with target detection. Theory and research suggest that psychopathy is associated with abnormal attention and orienting processes (Harpur & Hare, 1990; Kosson & Harpur, 1997). For example, Jutai and Hare (1983) have argued that psychopaths allocate a relatively large proportion of their attentional resources to things of immediate interest, effectively ignoring other stimuli. This perspective is known as the ‘over-focusing’ hypothesis of psychopathy. A similar prediction might be made by the response modulation hypothesis (Newman, 1998). In this view, psychopaths may devote more attentional resources than others to process stimuli of interest and they may fail to modulate their responses to otherwise salient stimuli. The N2 potential associated with processing auditory oddball stimuli has been related to volitional attentional processes (Naatanen, 1990). The N2 elicited by target stimuli was larger for psychopaths than for nonpsychopaths suggesting greater allocation of attentional resources by psychopaths for processing the primary stimulus. One might expect that 'over-focusing' on target stimuli might lead to behavioral differences between groups. That is, if psychopaths were over-allocating attentional resources to process the target stimuli then superior target detection response speeds might be predicted for psychopaths compared to nonpsychopaths. No such effect was observed. Additionally, if psychopaths were 'over-focusing' on the task relevant stimuli, we might also have observed a greater number of false alarms to nontarget standard and/or novel stimuli for psychopaths compared to nonpsychopaths (i.e., poor response modulation). No such effects were observed. Indeed, the N2 component was found to be larger for psychopaths than for nonpsychopaths during processing of novel stimuli suggesting that psychopaths allocated greater attentional resources than did nonpsychopaths for processing both target and novel stimuli. It should be noted however, that the absence of group differences in performance in the present study may have been due to ceiling effects.

It is relevant to note that one study has reported that the N2 is reduced in psychopaths compared to nonpsychopaths (Kiehl et al., 2000). At first glance it might appear that this finding is in contrast to the current finding of enlarged N2 in psychopaths. The N2 reported in Kiehl et al (2000) was elicited by visual stimuli during a Go/No go task. The N2 component of the visual evoked response is typically assessed in the 200-300 ms post-stimulus window and is maximal at frontal sites. On the other hand, the auditory N2 elicited by target stimuli during oddball detection peaks around 200ms post-stimulus and is maximal at central sites. Thus, there is a family of N2 components elicited by visual and auditory stimuli that have distinct topographies and likely reflect different neurocognitive processes (Falkenstein, Hoormann, & Hohnsbein, 1999; Naatanen, 1990).

The P3 response elicited by target and novel stimuli was slightly smaller in psychopaths than in nonpsychopaths in Sample 2. There is mixed evidence for P3 abnormality in psychopathy. Two ERP studies have found that psychopathy is associated with reduced P3 during some cognitive tasks (Kiehl, Hare, McDonald, & Liddle, 1999; Kiehl et al., 2000), while one study has found that psychopathy is associated with enlarged P3 components (Raine & Venables, 1988). The P3 elicited by target and novel stimuli has been related to a number of cognitive processes, including attention, working memory or contextual updating, and also orienting processes (Friedman, Cycowicz, & Gaeta, 2001; Pritchard, 1981). The P3(s) elicited by target and novel stimuli likely reflect the coordinated activity of dozens of neural generators (Halgren & Marinkovic, 1996; Halgren, Marinkovic, & Chauvel, 1998; Kiehl, Laurens et al., 2001; Kiehl et al., 2001; Kiehl & Liddle, 2003). It is possible that subtle differences in task demands or experimental methodology may lead to modulations of one or more of these neural generators. These latter manipulations may enable detection of the contextual conditions in which abnormalities are observed in the scalp recorded P3 in psychopaths. Thus, at the present time it is not clear whether the P3 is abnormal in psychopathy. Future studies should consider selectively manipulating variables known to modulate the P3 (i.e., probability, task difficulty) to determine whether the cognitive processes underlying this component are implicated in psychopathy.

With respect to the late ERP negativities (N550) observed in psychopaths it is difficult to draw firm conclusions regarding a cognitive interpretation of this waveform. The waveform appears to begin as early as 400 ms post-stimulus and evolves over the next several hundred milliseconds. The 400-600 ms post-stimulus time window is likely related to processes of response termination and evaluation as participants' mean reaction time was approximately 450 ms. One ERP study has shown that psychopaths are characterized by larger early contingent negative variation (CNV) than are nonpsychopaths (Forth & Hare, 1989). The CNV is believed to be related to attention and motor preparedness and the large early CNV in psychopaths was interpreted as being consistent with the hypothesis that psychopaths are proficient at focusing (even over focusing) on salient events of interest. It is also noteworthy that all of the studies that have observed late ERP negativities in psychopaths required a manual response following a salient stimulus (Forth & Hare, 1989; Kiehl, Hare, McDonald, & Brink, 1999; Kiehl, Hare, McDonald, & Liddle, 1999; Kiehl et al., 2000; Williamson et al., 1991). It is therefore possible that some aspect of the motor preparedness, perhaps related to processes such as response conflict or response modulation, may be reflected in the late ERP negativity in psychopathy. Future studies should examine paradigms that manipulate these variables to more clearly establish any cognitive processes that may be involved in generating the late ERP negativities in psychopaths.

Another interpretation of the enlarged N2, reduced P3 and aberrant late negativity in psychopaths is that they might be a reflection of functional and/or structural abnormalities in the medial and antero-lateral aspects of the temporal lobe. Studies of patients with selective brain damage to the medial and anterior lateral temporal lobe have shown that these patients exhibit an enlarged N2, reduced P3, and late ERP negativities during processing of target stimuli in oddball tasks (Johnson, 1989; Johnson & Fedio, 1987; Yamaguchi & Knight, 1993). This sequence of electrophysiological abnormalities appears to be exclusive to patients with medial and anterior lateral temporal lobe lesions or damage. That is, these abnormalities have not been observed in patients with frontal lobe or parietal lobe damage during similar tasks (Knight, Scabini, Woods, & Clayworth, 1989; Yamaguchi & Knight, 1993). Thus, one interpretation of the enlarged N2, reduced P3, and aberrant N550 in psychopaths is that they are associated with neural abnormalities in the medial and lateral aspects of the temporal lobe during auditory target detection. It is not exactly clear how neural abnormalities in the temporal lobe would lead to the observed modulations in scalp recorded ERPs. One possible mechanism is that disturbances in the configuration of electrical generators associated with salient stimulus processing may lead to alterations in the synchronization of neural activity. These altered patterns of synchronized neural activity would likely lead to differences in the configuration of local field potentials that would then be recorded as abnormalities in the scalp recorded ERPs. It is important to note however, that the ERP data provided here is only indirect evidence of a link between temporal lobe pathology and psychopathy as it is not precisely possible to determine from the ERP data alone whether there are temporal lobe abnormalities in psychopathy. However, support for the view that psychopathy is associated with medial and anterior lateral temporal lobe dysfunction also comes from hemodynamic imaging studies of psychopathy (Kiehl, Smith et al., 2001; Kiehl et al., 2004; Veit et al., 2002). These studies suggest that during processing of certain types of linguistic and emotional stimuli the anterior superior temporal gyrus (Kiehl et al., 2004), amygdala (Kiehl, Smith et al., 2001; Veit et al., 2002), and hippocampus (Laakso et al., 2001) are dysfunctional in psychopaths. Additional support for the hypothesis of abnormal medial and anterior lateral temporal lobe function in psychopathy comes from behavioral studies of patients with temporal lobe epilepsy. There is some evidence that suggests patients with temporal lobe epilepsy have a high incidence of psychopathic-like behavior (Hill, Pond, Mitchell, & Falconer, 1957). Removal of the dysfunctional anterior temporal lobe in these epilepsy patients appears to reduce hostility, increase warmth and empathy in social relationships, and decrease inappropriate sexual behavior (Hill et al., 1957). Moreover, a number of studies have shown that psychopaths have problems with processing certain aspects of affective speech and face stimuli (Blair et al., 1997; Kosson, Suchy, Mayer, & Libby, 2002; Louth, Williamson, Alpert, Pouget, & Hare, 1998) that are similarly impaired in patients with amygdala damage (see review in Kiehl, in press). Overall, these converging results are consistent with the hypothesis that medial and anterior lateral temporal lobe structures play a prominent role in psychopathy.

It is relevant to note the medial and anterior lateral aspects of the temporal lobe may be conceptualized as part of the larger paralimbic system. The paralimbic system, defined by similarities in the structure of neurons and number of layers of cortex, was described by Brodmann (1909). The paralimbic system embraces classic limbic structures such as the amygdala and hippocampus and also includes anterior superior temporal gyrus, cingulate cortex and orbital frontal cortex (Mesulam, 2000). There is strong behavioral evidence for orbital frontal involvement in psychopathy (Damasio & Van Hoesen, 1983; Damasio, Tranel, & Damasio, 1990; Damasio, Grabowski, Frank, Galaburda, & Damasio, 1994) and there is accumulating evidence that the anterior cingulate (Kiehl, Smith et al., 2001; Veit et al., 2002) and anterior superior temporal gyrus (Kiehl et al., 2004) may play a role in the disorder. Thus, on balance there is accumulating evidence that psychopathy may be linked to abnormalities in the paralimbic system (Kiehl, in press).

ERPs associated with oddball processing are abnormal in a range of psychiatric conditions with conceptual links to psychopathy. However, the abnormalities are of a different nature than those observed in psychopathy. For example, Antisocial Personality Disorder (ASPD), which is most closely related to the behavioral facet of psychopathy, but only weakly correlated with the interpersonal and affective characteristics of psychopathy, is associated with P3 reductions during oddball tasks (L. O. Bauer, 2001; Bauer & Hesselbrock, 1999; Bauer, O'Connor, & Hesselbrock, 1994). However, these ERP studies of ASPD have not revealed any evidence of fronto-central ERP negativities as seen in psychopaths. Thus, as with other psychiatric conditions, ASPD is associated with subtle cognitive abnormalities that lead to a reduced P3. These data suggest that meaningful differences in neurobiology can be observed between ASPD and psychopathy. Similarly, studies have shown that the P3 is reduced in patients with alcoholism (Oscar-Berman, 1987; Romani & Cosi, 1989) and substance abuse problems (Amass, Lukas, Weiss, & Mendelson, 1989; D. L. Bauer, 2001; Kouri, Lukas, & Mendelson, 1996; Noldy & Carlen, 1997). Psychopathy is known to be co-morbid with substance abuse (Hare, 2003; Hemphill, Hart, & Hare, 1994). However, as with ASPD, no studies of alcohol or substance abuse have shown evidence of late ERP negativities during salient stimulus processing tasks. Nevertheless, it is important to consider whether substance abuse contributed to any of the observed group differences. All participants in the present study were completing a nine month intensive violent or sex offender treatment program. This program mandated alcohol and substance abstinence and participants were randomly tested, as often as every month. Thus, it is unlikely that any of the observed group differences in the present study were related to current substance abuse.

It is often desirable to examine the relevant contribution of the interpersonal/ affective (PCL-R Factor 1) and the lifestyle/antisocial (PCL-R Factor 2) features of psychopathy. However, the present samples, drawn from a very select high security sample, were found to have Factor 1 and Factor 2 scores that correlated strongly (r=.86). This correlation is much higher than the typical correlation between factors scores of r=.5 (Hare, 2003). Thus, post hoc analyses examining Factor 1 and Factor 2 scores did not reveal anything more than the group comparisons using total scores.

In summary, the data from the present study suggest that psychopathy is associated with abnormalities in the scalp recorded potentials associated with target detection and novelty processing. One interpretation of the observed pattern of abnormalities is that they are related to functional and/or structural impairments in the medial and anterior lateral aspects of the temporal lobe. The medial and anterior lateral aspects of the temporal lobe are part of a larger paralimbic system which includes the anterior and posterior cingulate and orbital frontal cortex. These results, in conjunction with converging evidence from other electrophysiological and hemodynamic studies in psychopathy suggest that psychopathy may be associated with abnormalities in the paralimbic system.

Table 1. Event-related potential amplitude measures (mean and standard deviation) for the N2, P3, and N550 for standard, target, and novel stimuli for psychopaths and nonpsychopaths in both samples. Data are summarized for prefrontal (Fpz), frontal (Fz), fronto-central (Fcz), central (Cz), parietal (Pz), and occipital (Oz) scalp sites.

	Fpz Mean (sd)		**Fz Mean (sd)**		**Fcz Mean (sd)**		**Cz Mean (sd)**		**Pz Mean (sd)**		**Oz Mean (sd)**	
N2 Standard stimuli												
Sample 1												
Psychopaths	-1.2	(2.0)	-.1	(2.8)	1.1	(3.1)	2.0	(2.9)	1.5	(1.5)	.1	(1.3)
Nonpsychopaths	-1.0	(2.7)	.4	(2.7)	1.6	(2.3)	2.4	(2.5)	2.1	(2.8)	.7	(2.8)
Sample 2												
Psychopaths	.3	(1.4)	.9	(2.0)	1.5	(2.2)	1.6	(2.2)	1.3	(1.5)	.9	(1.6)
Nonpsychopaths	-.7	(.8)	.3	(1.4)	1.2	(1.8)	1.7	(1.8)	1.3	(1.5)	.6	(1.4)
N2 Target stimuli												
Sample 1												
Psychopaths	-6.2	(6.2)	-12.1	(9.9)	-13.9	(12.1)	-14.6	(12.1)	-9.1	(7.4)	-7.3	(5.4)
Nonpsychopaths	-2.8	(4.2)	-7.5	(6.0)	-8.9	(7.7)	-9.0	(8.5)	-5.0	(7.3)	-4.4	(6.5)
Sample 2												
Psychopaths	-2.9	(3.8)	-7.2	(5.9)	-8.5	(7.0)	-8.5	(7.4)	-5.3	(6.6)	-3.7	(5.0)
Nonpsychopaths	-1.2	(3.2)	-5.1	(4.2)	-6.5	(4.5)	-6.3	(3.9)	-3.8	(2.1)	-3.0	(1.8)
N2 Novel stimuli												
Sample 1												
Psychopaths	-2.8	(5.7)	-8.8	(6.9)	-11.8	(7.5)	-13.9	(7.3)	-11.4	(5.7)	-10.0	(5.4)
Nonpsychopaths	-2.5	(4.9)	-7.3	(8.3)	-9.1	(10.7)	-9.3	(11.8)	-5.8	(9.5)	-5.7	(6.9)
Sample 2												
Psychopaths	-2.0	(3.0)	-6.4	(4.9)	-8.2	(6.3)	-9.2	(6.5)	-7.3	(5.7)	-5.8	(5.7)
Nonpsychopaths	-0.5	(1.9)	-2.9	(3.3)	-4.1	(3.8)	-4.5	(3.9)	-3.8	(3.4)	-4.2	(4.0)
P3 Standard Stimuli												
Sample 1												
Psychopaths	1.4	(2.2)	2.9	(3.6)	3.7	(4.0)	4.3	(3.8)	4.7	(3.1)	4.3	(2.7)
Nonpsychopaths	2.2	(2.7)	4.2	(3.2)	5.2	(3.3)	5.5	(3.0)	5.4	(2.6)	4.4	(2.5)
Sample 2												
Psychopaths	2.6	(1.6)	2.8	(1.8)	3.3	(1.9)	3.5	(2.0)	3.5	(1.6)	3.8	(2.3)
Nonpsychopaths	2.0	(2.3)	3.2	(2.7)	3.8	(2.9)	4.1	(3.2)	4.3	(3.3)	4.1	(3.2)
P3 Target stimuli												
Sample 1												
Psychopaths	3.4	(6.3)	7.7	(9.7)	8.0	(11.1)	7.6	(12.1)	14.3	(12.0)	11.5	(9.2)
Nonpsychopaths	4.3	(5.8)	7.8	(7.7)	7.9	(9.3)	8.7	(11.2)	14.9	(13.3)	12.6	(11.5)
Sample 2												
Psychopaths	2.8	(4.1)	3.7	(5.5)	3.1	(6.4)	3.0	(6.8)	6.5	(6.1)	7.8	(6.6)
Nonpsychopaths	5.0	(5.8)	6.5	(7.1)	6.3	(7.3)	7.0	(7.6)	9.6	(8.4)	8.8	(7.1)
P3 Novel stimuli												
Sample 1												
Psychopaths	6.7	(6.7)	16.2	(9.9)	19.7	(11.4)	20.1	(10.9)	19.8	(9.4)	12.9	(8.2)
Nonpsychopaths	5.5	(4.1)	14.4	(7.3)	18.2	(10.1)	20.0	(11.7)	18.7	(11.1)	11.6	(9.4)
Sample 2												
Psychopaths	4.9	(4.5)	8.6	(4.5)	9.6	(4.9)	9.3	(5.3)	9.4	(4.3)	6.7	(4.3)
Nonpsychopaths	7.2	(4.4)	12.5	(6.2)	14.3	(6.5)	14.7	(6.1)	13.3	(6.0)	9.8	(5.7)
N550 Standard stimuli												

Sample 1												
Psychopaths	-1.3	(1.9)	-2.2	(2.4)	-2.2	(2.5)	-1.5	(2.8)	0.3	(2.5)	0.6	(2.1)
Nonpsychopaths	-0.5	(2.5)	-1.2	(2.3)	-1.1	(2.1)	-0.6	(2.2)	0.7	(2.1)	0.9	(1.8)
Sample 2												
Psychopaths	1.1	(1.8)	0.1	(1.9)	0.3	(1.8)	0.8	(1.7)	1.2	(1.7)	1.0	(1.4)
Nonpsychopaths	-0.1	(1.8)	-0.5	(2.1)	-0.3	(2.3)	0.1	(2.4)	0.6	(2.0)	0.4	(1.6)
N550 Target stimuli												
Sample 1												
Psychopaths	-10.9	(6.4)	-14.4	(7.8)	-15.1	(9.1)	-11.9	(11.3)	-1.3	(11.9)	1.3	(10.0)
Nonpsychopaths	-5.2	(5.4)	-7.2	(6.5)	-7.6	(7.5)	-4.9	(8.1)	2.6	(6.8)	2.0	(5.2)
Sample 2												
Psychopaths	-5.1	(3.5)	-7.2	(4.4)	-7.4	(5.3)	-6.0	(5.8)	-1.0	(4.6)	1.3	(6.0)
Nonpsychopaths	-1.4	(4.8)	-1.9	(5.2)	-1.9	(5.7)	0.1	(6.1)	3.3	(5.8)	2.1	(5.0)
N550 Novel stimuli												
Sample 1												
Psychopaths	-5.1	(5.3)	-4.9	(8.2)	-3.4	(8.3)	-.5	(7.2)	5.5	(6.0)	5.3	(5.9)
Nonpsychopaths	-3.0	(3.9)	-2.9	(6.3)	-1.5	(6.2)	.5	(5.9)	2.9	(5.7)	2.1	(4.3)
Sample 2												
Psychopaths	-.5	(4.3)	-.9	(6.0)	-.3	(6.1)	.4	(6.1)	2.7	(4.8)	1.0	(5.3)
Nonpsychopaths	2.4	(5.7)	4.0	(5.2)	5.1	(5.3)	5.9	(5.7)	6.3	(5.8)	4.7	(4.7)

Figure Legends

Figure 1. Grand mean ERPs (sample 1) for target stimuli for psychopaths (dashed) and nonpsychopaths (solid). By convention, negative amplitude is plotted up. Tick marks are in units of 100 milliseconds.

Figure 2. Grand mean ERPs (sample 1) for novel stimuli for psychopaths (dashed) and nonpsychopaths (solid). By convention, negative amplitude is plotted up. Tick marks are in units of 100 milliseconds.

Figure 3. Grand mean ERPs (sample 1) for standard stimuli for psychopaths (dashed) and nonpsychopaths (solid). By convention, negative amplitude is plotted up. Tick marks are in units of 100 milliseconds.

Figure 4. Grand mean ERPs (sample 2) for target stimuli for psychopaths (dashed) and nonpsychopaths (solid). By convention, negative amplitude is plotted up. Tick marks are in units of 100 milliseconds.

Figure 5. Grand mean ERPs (sample 2) for novel stimuli for psychopaths (dashed) and nonpsychopaths (solid). By convention, negative amplitude is plotted up. Tick marks are in units of 100 milliseconds.

Figure 6. Grand mean ERPs (sample 2) for standard stimuli for psychopaths (dashed) and nonpsychopaths (solid). By convention, negative amplitude is plotted up. Tick marks are in units of 100 milliseconds.

Figure 1. Grand mean ERPs (Sample 1) for target stimuli for psychopaths (dashed) and nonpsychopaths (solid). By convention, negative amplitude is plotted up. Tick marks are in units of 100 milliseconds.

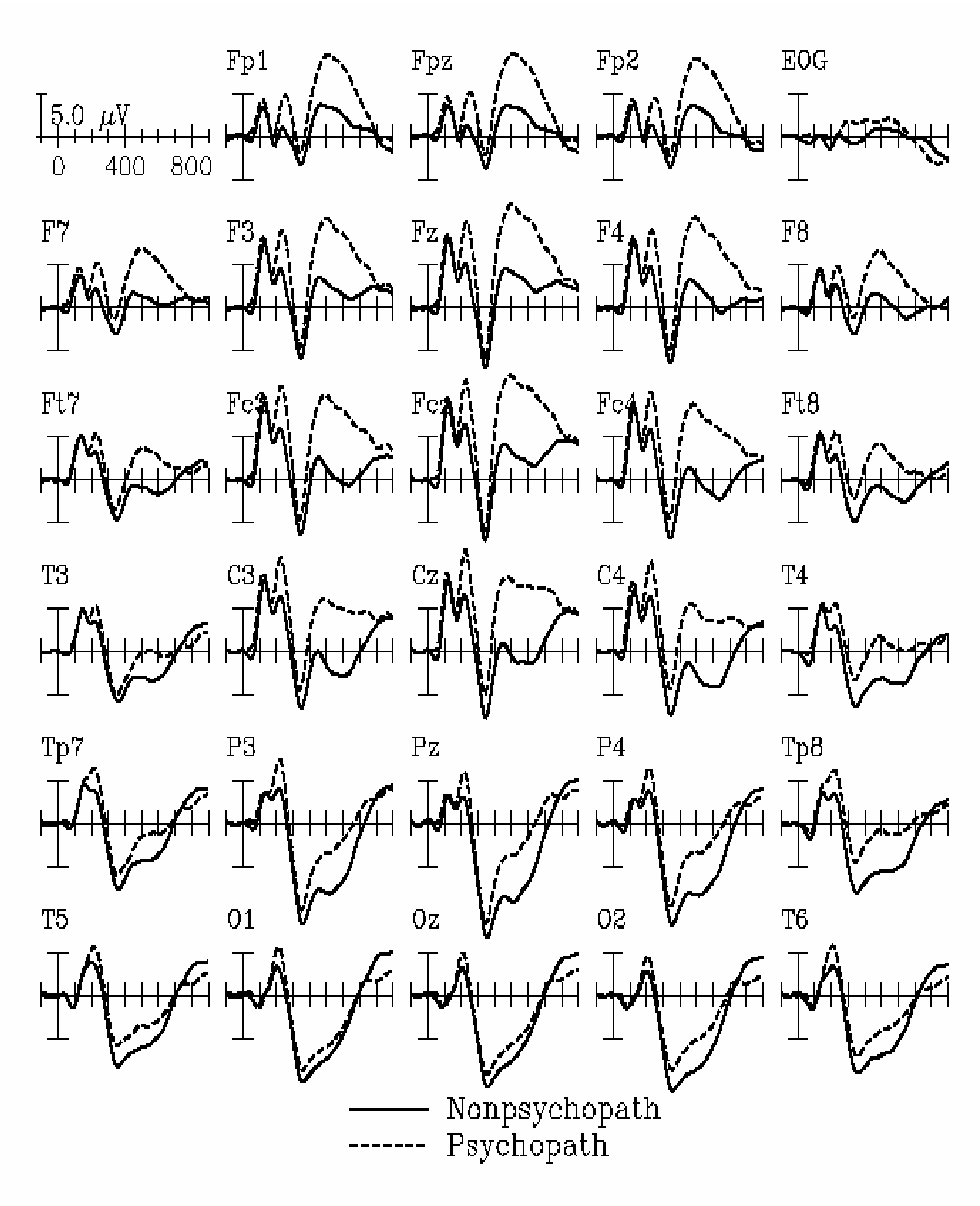


Figure 2. Grand mean ERPs (Sample 1) for novel stimuli for psychopaths (dashed) and nonpsychopaths (solid). By convention, negative amplitude is plotted up. Tick marks are in units of 100 milliseconds.

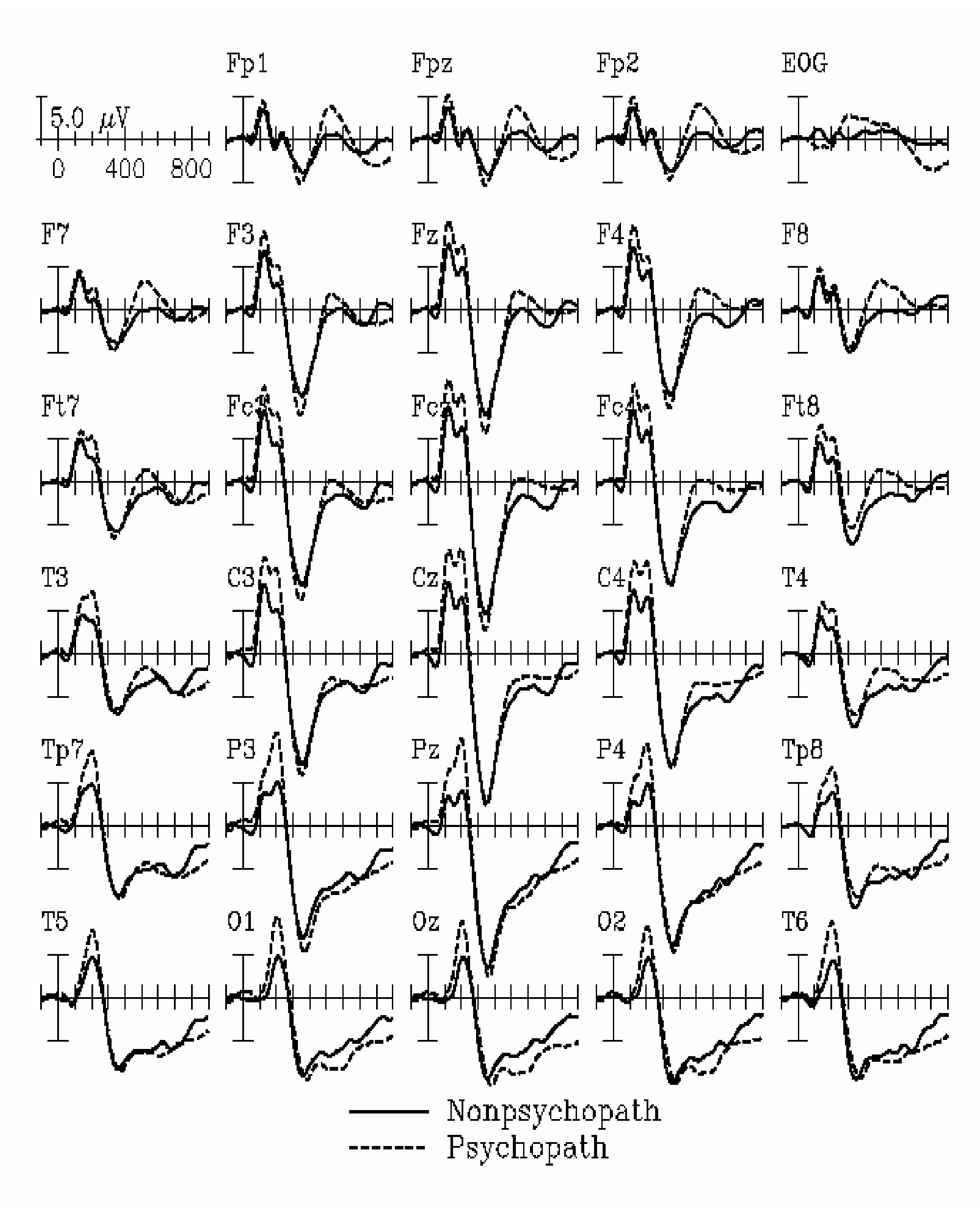


Figure 3. Grand mean ERPs (Sample 1) for standard stimuli for psychopaths (dashed) and nonpsychopaths (solid). By convention, negative amplitude is plotted up. Tick marks are in units of 100 milliseconds.

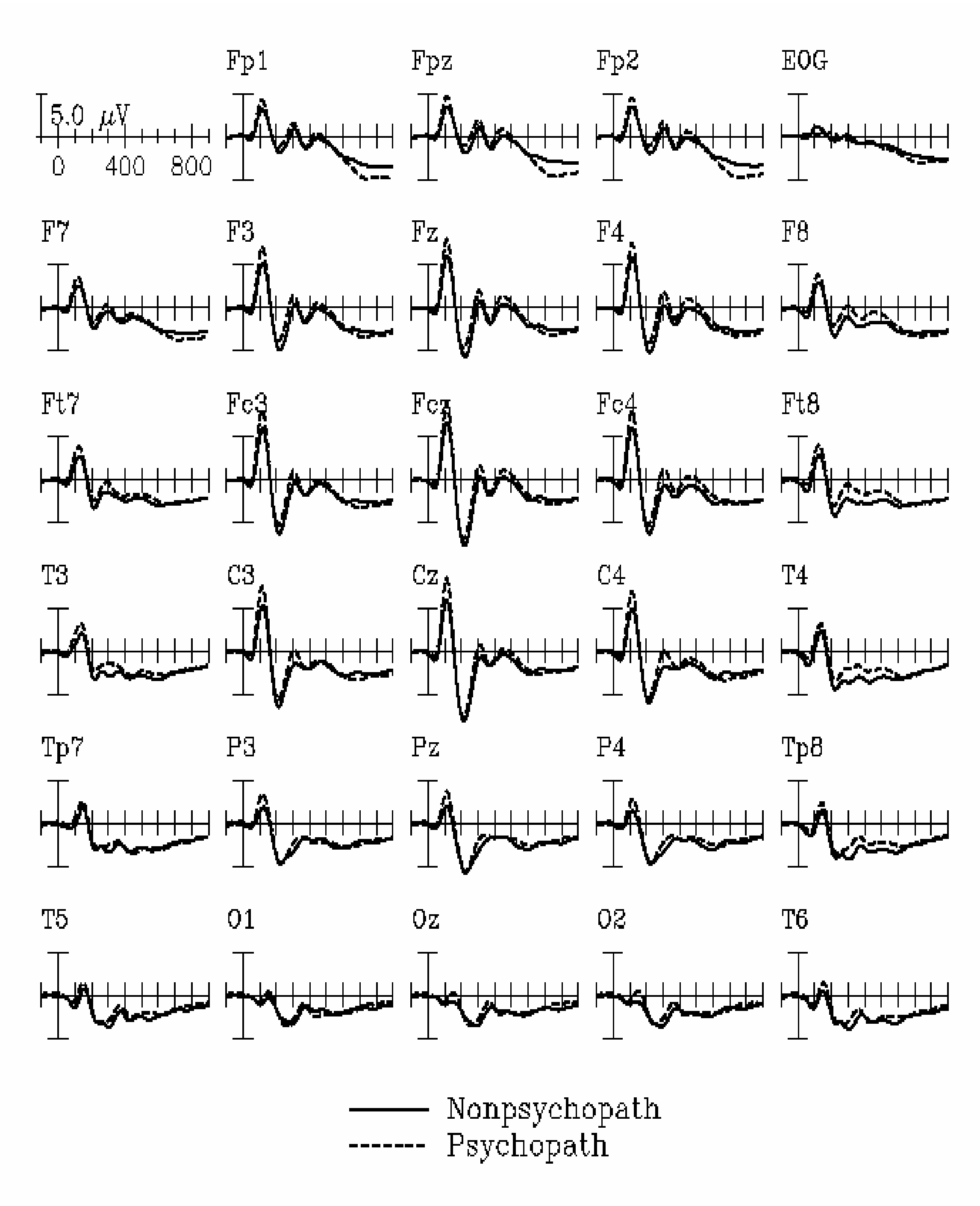


Figure 4. Grand mean ERPs (Sample 2) for target stimuli for psychopaths (dashed) and nonpsychopaths (solid). By convention, negative amplitude is plotted up. Tick marks are in units of 100 milliseconds.

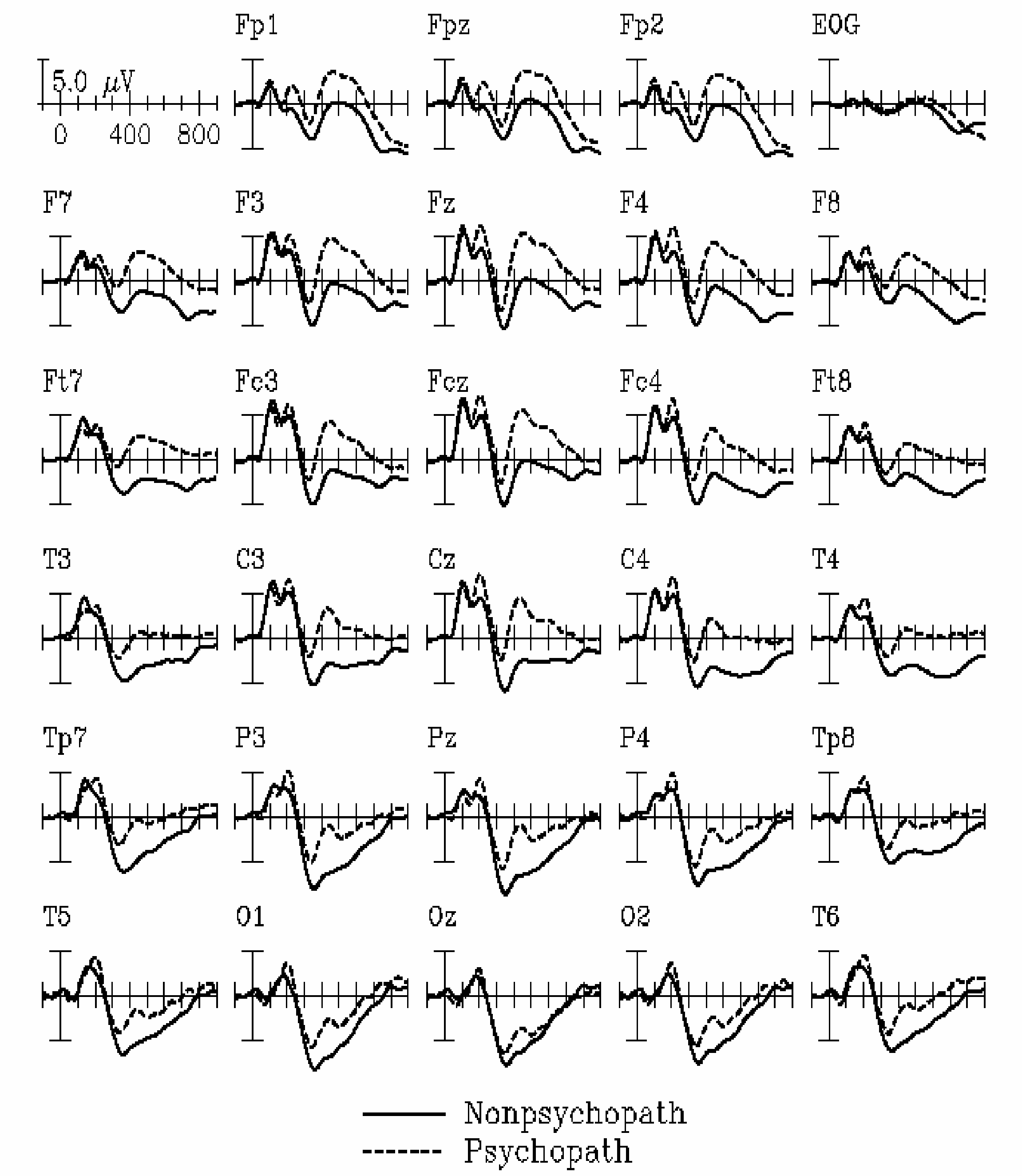


Figure 5. Grand mean ERPs (Sample 2) for novel stimuli for psychopaths (dashed) and nonpsychopaths (solid). By convention, negative amplitude is plotted up. Tick marks are in units of 100 milliseconds.

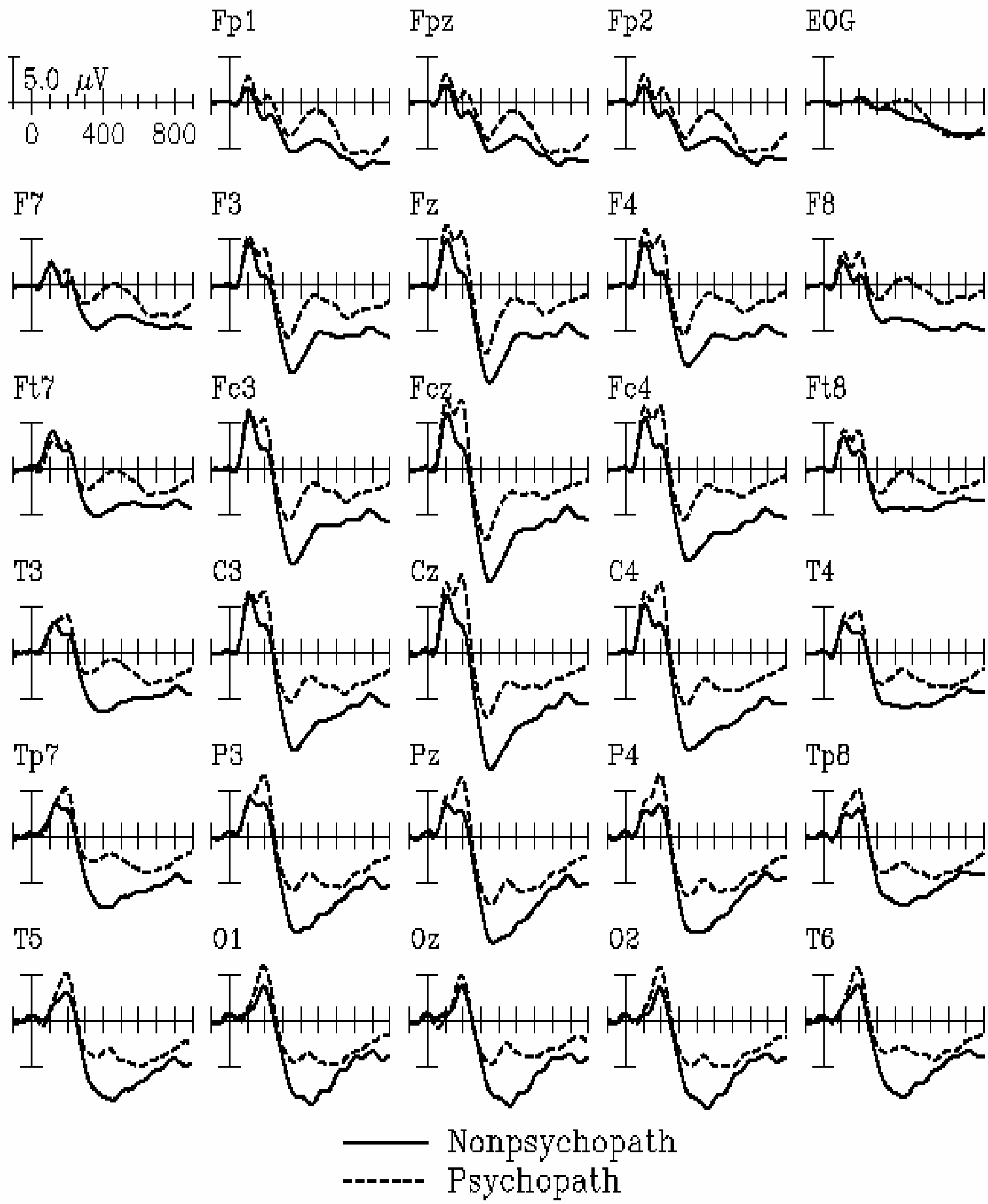
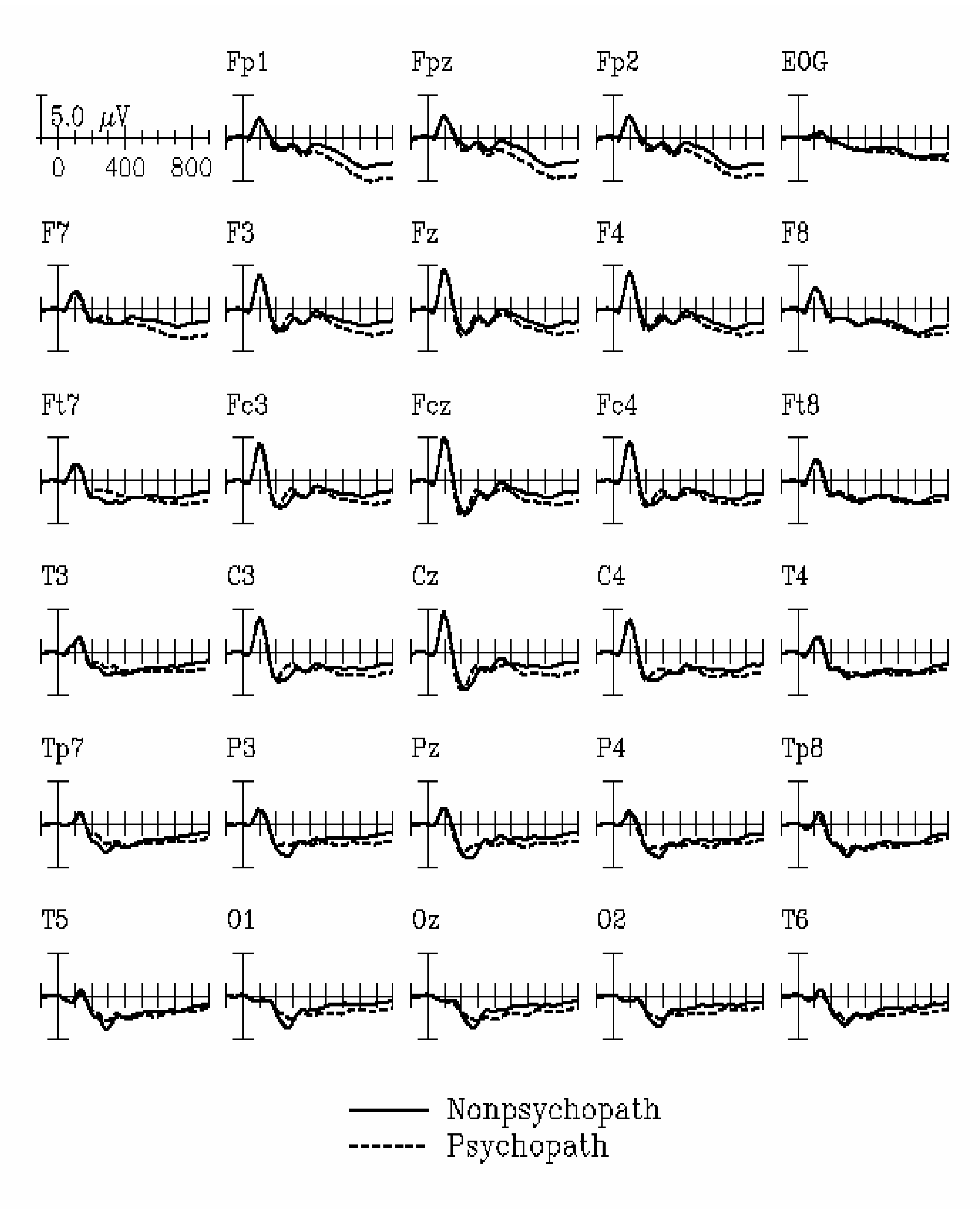


Figure 6. Grand mean ERPs (Sample 2) for standard stimuli for psychopaths (dashed) and nonpsychopaths (solid). By convention, negative amplitude is plotted up. Tick marks are in units of 100 milliseconds.



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