Brain potentials implicate temporal lobe abnormalities in criminal psychopaths

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Abstract

A prominent hypothesis of psychopathy posits it may result from abnormalities in orbital frontal cortex. However, damage to orbital frontal cortex does not lead to the full constellation of symptoms observed in psychopathy suggesting that other brain regions are implicated in the disorder. Here we report a study showing that incarcerated psychopaths' brain potentials elicited by salient stimuli were characterized by abnormal late negativities that were more than twice the amplitude as those observed in incarcerated nonpsychopaths. The psychopath's ERP abnormalities are similar to those observed in patients with temporal lobe damage. These data support the new hypothesis that psychopathy may best be conceptualized as a disorder of the paralimbic system – a system which embraces parts of the temporal lobe and frontal lobe, including orbital frontal cortex.

Psychopathy is a personality disorder defined by a cluster of interpersonal, affective and behavioral characteristics, including glibness, impulsivity, poor behavioral controls, and lack of empathy, guilt, and remorse [1,2]. Psychopathic individuals are known to commit a disproportionately large amount of violent crime relative to nonpsychopathic individuals [3]. Although there is agreement regarding the assessment and classification of psychopathy in forensic contexts, relatively little is known about the relevant brain disturbances. Historically, clinicians and researchers have made indirect inferences about the brain regions involved in psychopathy by examining changes in behavior following brain damage. For example, the case of Gage [4], which implicated the frontal lobes in psychopathic behavior [5,6].

Subsequent studies of patients with frontal lobe damage suggest that orbital frontal cortex plays a pivotal role in mediating many behaviors related to psychopathy [7]. Selective damage to the orbital frontal cortex leads to a condition termed 'acquired sociopathic personality' characterized by problems with motivation, empathy, planning and organization, impulsivity, irresponsibility, and insight. These data suggest that some aspects of psychopathy may map onto the (dys)function of orbital frontal cortex.

However, the 'acquired sociopathy' model does not appear to fully account for the constellation of symptoms observed in psychopathy. For example, patients with orbital frontal damage rarely show instrumental or goal directed aggression – a cardinal feature of psychopathy [8]. 'Acquired sociopathic' patients also do not exhibit the callousness commonly observed in psychopathic individuals. Similarly, patients with 'acquired sociopathy', unlike psychopathic individuals, are characterized by lack of insight and motivation, hoarding behavior, mood disturbances, and failure or inability to make long term plans. Psychopathic individuals, on the other hand, often enjoy making grandiose life plans – they just fail to follow through with them. Thus, while 'acquired sociopathy' appears to model some features of psychopathy, the two disorders differ in many respects. This raises the possibility that disturbances in brain regions other than orbital frontal cortex may contribute to psychopathy.

Studies employing event-related brain potentials (ERPs) in psychopathy have shown that during performance of a variety of cognitive and language paradigms psychopaths' ERPs are characterized by late (~500 ms post-stimulus on average) negativities [9-13]. The psychopaths' late ERP negativities are often two to three times the size as those observed in control participants. One common denominator of the studies which have observed late ERP negativities in psychopaths is that the eliciting stimuli were task relevant or salient. That is, the experimental context was manipulated in such a way as to require the participants to immediately process the stimuli. However, the interpretation 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 included relatively complex stimuli and decision making tasks. Thus, it has been difficult to isolate the neurocognitive processes underlying the late ERP negativities observed in psychopaths.

Here we use an auditory 'oddball' task to selectively manipulate the salience of the stimuli. In oddball tasks, participants are instructed to respond (or count) low probability stimuli (i.e., salient stimuli) and to discriminate them from frequently occurring standard stimuli. The oddball task has been extensively studied and the elicited ERPs are abnormal in a variety of disorders, such as schizophrenia, depression and alcoholism. The neural systems engaged in oddball target detection are well understood and include structures in the inferior lateral frontal cortex and medial and anterior lateral temporal lobes [14-20]. Our primary prediction was that during processing the salient stimuli psychopaths' ERPs would be characterized by late ERP negativities. ERPs were recorded from 80 incarcerated participants, classified into psychopathic and nonpsychopathic groups according to scores on the Hare Psychopathy Checklist-Revised (PCL-R) [1], while they performed an auditory 'oddball' target detection task.

Consistent with our 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; see Figures 1-4). Psychopaths also had an enlarged N2b and a

slightly reduced fronto-central P3 during target detection. The N550 ERP negativity was nearly twice the amplitude in psychopaths as in nonpsychopaths (see Figures 1 and 4). These data demonstrate that a simple salient stimulus discrimination between two tone types is sufficient to elicit the 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. However, the functional significance of these late ERP negativities in psychopaths still remains unclear.

The auditory oddball task has been well studied in psychiatric patient populations and in patients with neurological conditions. Examination of this literature reveals that ERP studies of auditory oddball target detection in patients with selective damage to medial and anterior lateral temporal lobe indicate that abnormalities in the scalp recorded waveforms include a large early negativity (N2b), mildly reduced fronto-central positivity (P3), and an enlarged late negativity (N550) [21-23]. This sequence of electrophysiological abnormalities appears to be exclusive to patients with medial and anterior lateral temporal lobe lesions or damage (see Figure 4). That is, these abnormalities have not been observed in patients with frontal lobe or parietal lobe damage during similar tasks [21,24]. A comparison of the ERPs elicited by salient target stimuli for the psychopaths and the patient studies are shown in Figure 4. The similarities exist at the multiple ERP components with the enhancement of the N2b, mild reduction of the P3, and enlarged late ERP negativity.

Additional support for the view that psychopathy is associated with medial and anterior lateral temporal lobe function comes from hemodynamic imaging studies of psychopathy [25-27]. These studies suggest that during processing of certain types of linguistic and emotional stimuli the anterior superior temporal gyrus [25], amygdala [26,27], and hippocampus [28] appear to be dysfunctional in psychopaths relative to controls.

Further support for the hypothesis of abnormal medial and anterior lateral temporal lobe function in psychopathy comes from behavioral studies in patients with temporal lobe epilepsy. There is some evidence that suggests patients with temporal lobe epilepsy have a high incidence of psychopathic-like behavior [29].

Removal of the dysfunctional anterior temporal lobe in these epilepsy patients appears to reduced hostility, increase warmth and empathy in social relationships and decrease inappropriate sexual behavior [29].

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, interestingly, the orbital frontal cortex. Abnormalities in several functions of this circuitry, including error monitoring, response inhibition, and affective processing, have been observed in psychopathy. For example, regional abnormalities during affective processing have recently been observed in the anterior and posterior cingulate in psychopathy [26]. Additionally, brain imaging studies [30] and behavioral studies of patients with brain damage to the anterior cingulate [31] suggest this structure also plays a prominent role in response inhibition, a process consistently found to be dysfunctional in psychopathy [10,32].

It is probable that the orbital frontal cortex plays a crucial role in the neuronal circuitry involved in psychopathy. However, dysfunction of the orbital frontal cortex does not fully account for the constellation of symptoms that comprise psychopathy. A broader view, including medial and anterior lateral temporal lobe structures and perhaps other regions of the paralimbic system, appears to account more fully for the diverse symptoms observed in psychopathy.

In summary, the data from the present study suggest that psychopathy is associated with functional abnormalities 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

electrophysiological and hemodynamic studies in psychopathy and with studies of lesion patients, suggest that psychopathy may best be conceptualized as a disorder of the paralimbic system rather than a disorder of a single brain region (i.e., orbital frontal cortex).

Methods

Participants. A total of 80 male inmates (ages 18-55) from a maximum-security prison near Vancouver, British Columbia volunteered for the study. Participants were free from any reported serious head injury or neurological impairment and had no DSM-IV Axis I diagnosis. IQs were normal to above normal and the mean years of formal education were greater than 10 years. The Hare Psychopathy Checklist-Revised was used to assess psychopathy [1]. Inmates with a PCL-R score of 30 or above were defined as Psychopaths (n=41; mean PCL-R score 33.1 (SD 2.04)) and those with a PCL-R score below 30 were defined as Nonpsychopaths (n=39; 20.61 (SD 6.17)). Inter-rater reliability for two raters for a subset of the inmates (n=30) was .83. The mean age and years of formal education were 32.3 and 33.8, and 10.7 and 11.3 years for Psychopaths and Nonpsychopaths, respectively. The National Adult Reading Test (NART) and Quick tests were used to assess IQ. NART and Quick scores for Psychopaths were 110.4 (SD 8.6) and 104.2 (SD 11.4) and for Nonpsychopaths they were 109.1 (SD 9.9) and 104.6 (SD 8.8), respectively. 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 2 days prison wage. The study was approved by Institutional and University ethical review boards, and participants gave written informed consent.

Stimuli. The target (1500 hz tones), novel (e.g., random sounds) and standard (1000 hz tones) stimuli were presented with a probability of .10, .10 and .80, respectively (200 ms duration; 1000-1500 ms random inter-stimulus interval). Participants were instructed to respond as quickly and accurately as possible (hand counterbalanced across participants) to the target stimuli and to ignore the standard and novel stimuli.

Event-related Potential Recording. Scalp potentials were recorded from 29 electrode sites (nose reference). Electroocularogram was monitored from two electrodes located on the lateral and supra orbital ridges of the right eye. After excluding four participants for excessive artifacts (all Nonpsychopaths), 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. Three components were analyzed at midline sites 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). Repeated measures ANOVAs (Group: Psychopath and Nonpsychopath X Condition (Target, Novel, and Standard stimuli) x Site (Prefrontal (Fpz), Frontal (Fz), Fronto-central (Fcz), Central (Cz), Parietal (Pz) and Occipital (Oz) were performed separately for the N2, P3, and N550.

Results

Behavioral data.

There were no significant group differences in the percentage of correct hits [Psychopaths 95.6 (SD 8.9); Nonpsychopaths 98.2 (SD 3.0)] reaction times [Psychopaths 424 ms (SD 79.3); Nonpsychopaths 433.6 ms (SD 74.8)] or numbers of false alarms to novel [Psychopaths 1.2 (SD 1.5); Nonpsychopaths 1.69 (SD 2.19)] or standard stimuli [Psychopaths 10.6 (SD 6.53); Nonpsychopaths 11.79 (SD 5.8]; all p's > .15.

N2 peak amplitude analyses.

The N2 was larger for Psychopaths than for Nonpsychopaths (Main effect of Group: $F(1, 74) = 5.17$, $p < .026$), an effect most pronounced for target and novel stimuli [Group x Condition interaction, $F(2, 148) = 3.75$, $p < .030$** - Greenhouse-Geisser].

P3 peak amplitude analyses.

There were no significant group differences at midline sites in the amplitude of the P3 for any stimuli. However, there was a significant correlation between the amplitude of the P3 and psychopathy scores at frontal ($r = -.23$, $p < .05$ at scalp site F8) and central sites ($r = -.19$, $p < .05$ at scalp site C4).

N550 peak amplitude analyses.

The N550 elicited by target stimuli was significantly larger for Psychopaths than for Nonpsychopaths at frontal and central sites (Group x Condition x Site interaction: $F(10, 740) = 2.84$, $p < .024$ – Greenhouse-Geisser).

Figure Legends

Figure 1. Grand mean ERPs (both samples) 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 (both samples) 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 (both samples) 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. Figure Legend: Comparison of the ERP elicited by auditory oddball stimuli in criminal psychopaths (present data), patients with temporal lobe damage (Yamaguchi & Knight, 1993) and patients who had undergone anterior temporal lobectomy for the treatment of intractable epilepsy (Johnson, 1989). All three groups are typified by an enhanced N2b, diminished frontal P3, and enlarged late negativity (N550), relative to control participants. All plots are from fronto-central electrode sites and are scaled to similar amplitude and epoch.

Figure 1

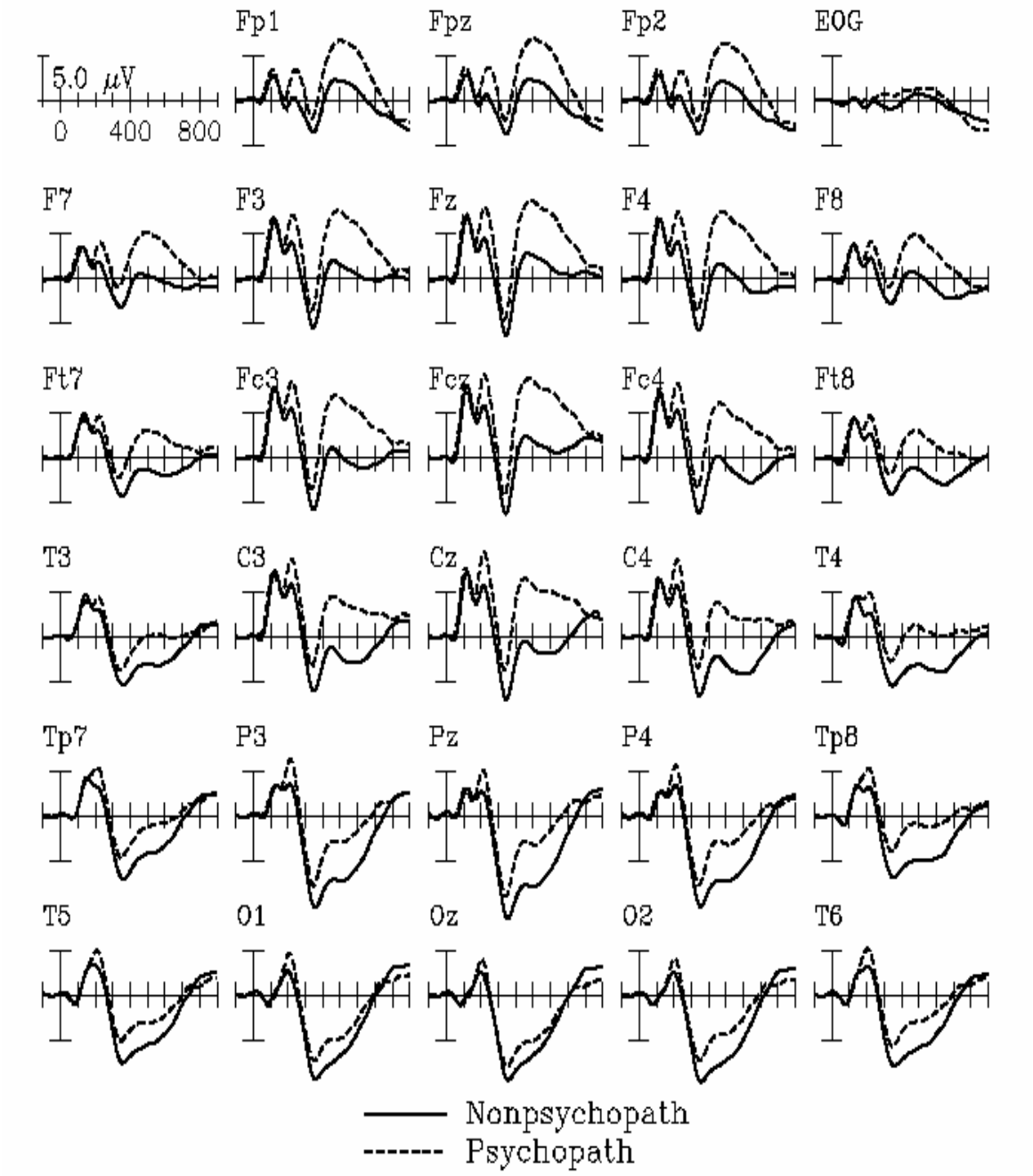
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Figure 2.

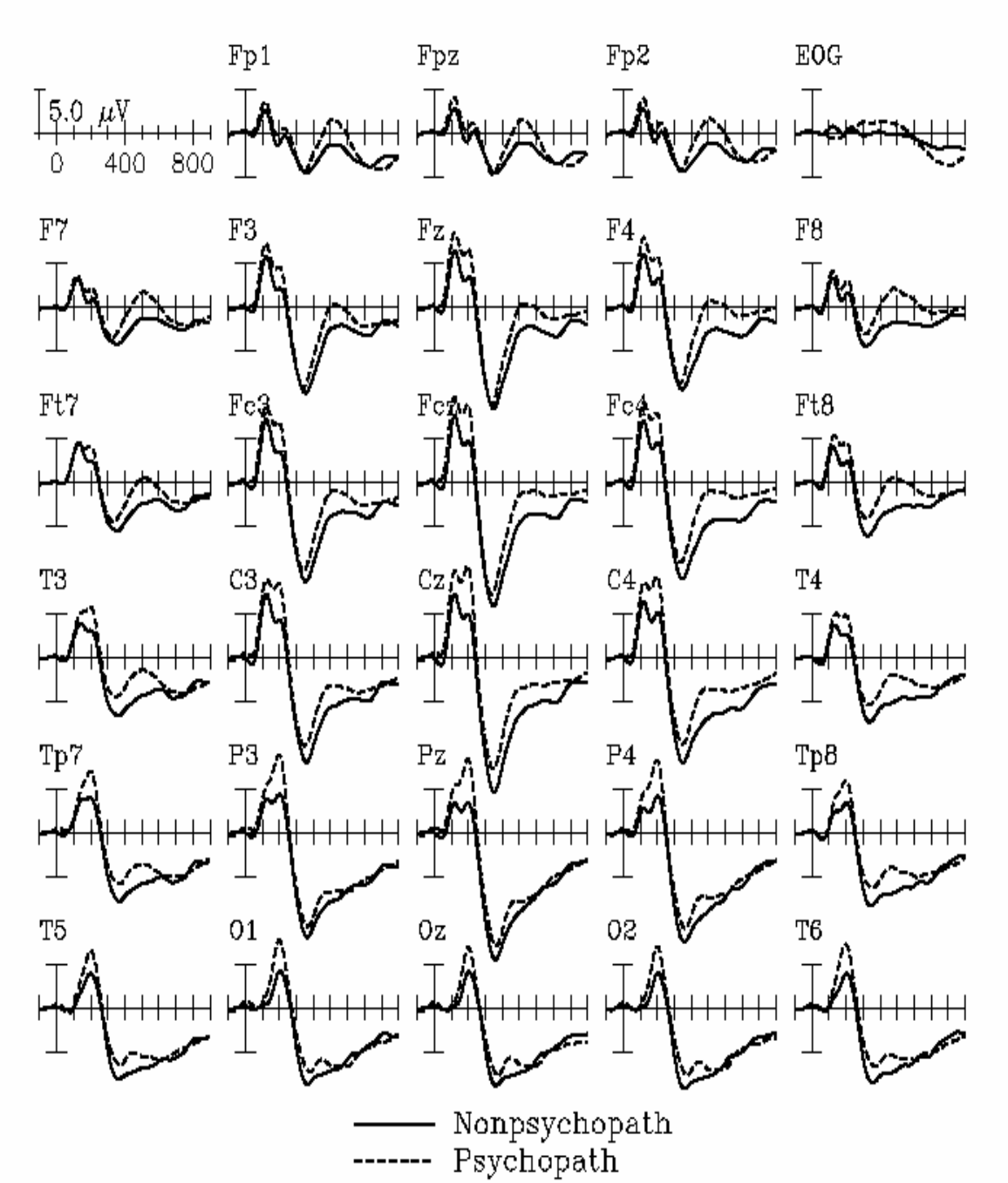
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Figure 3.

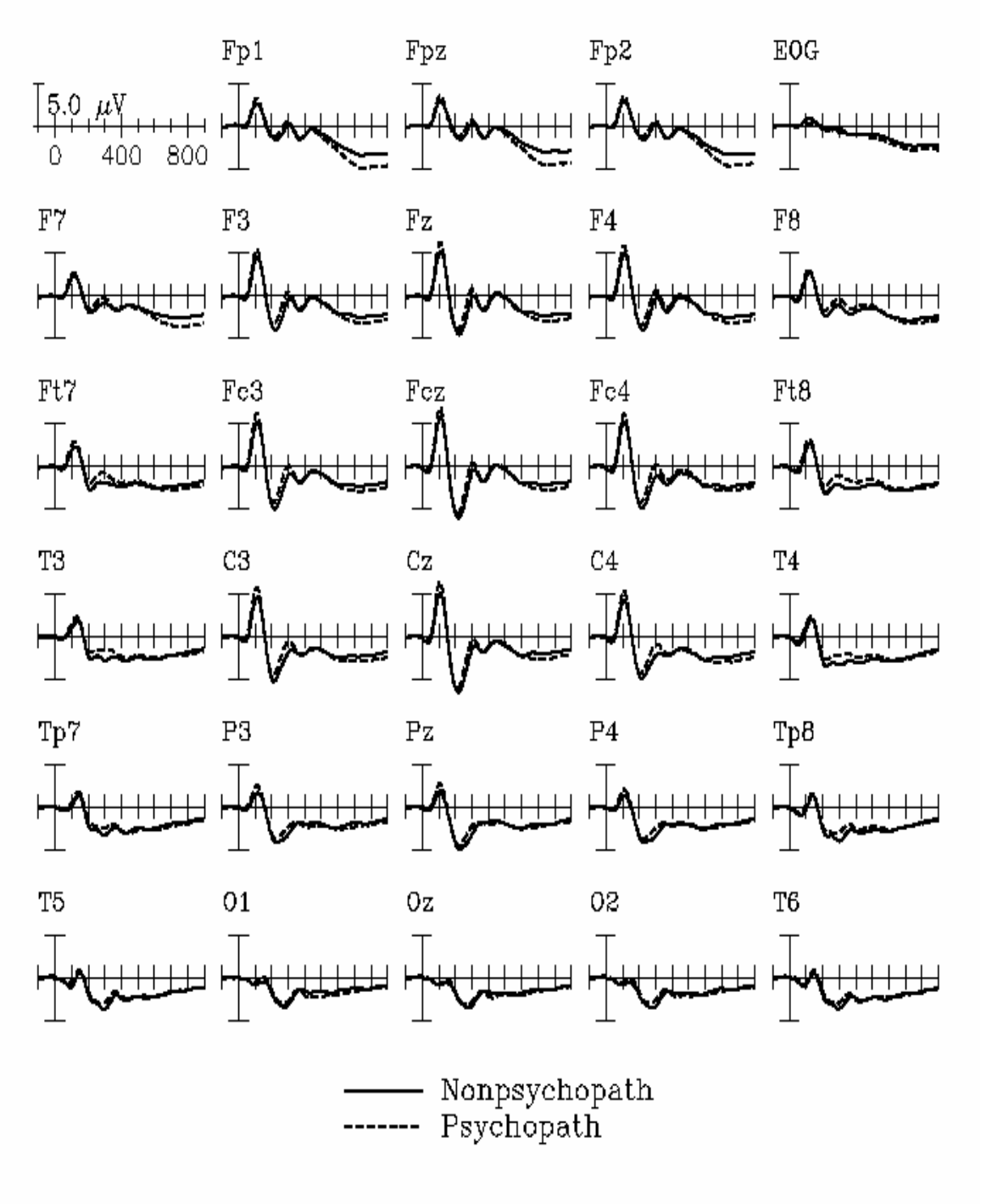
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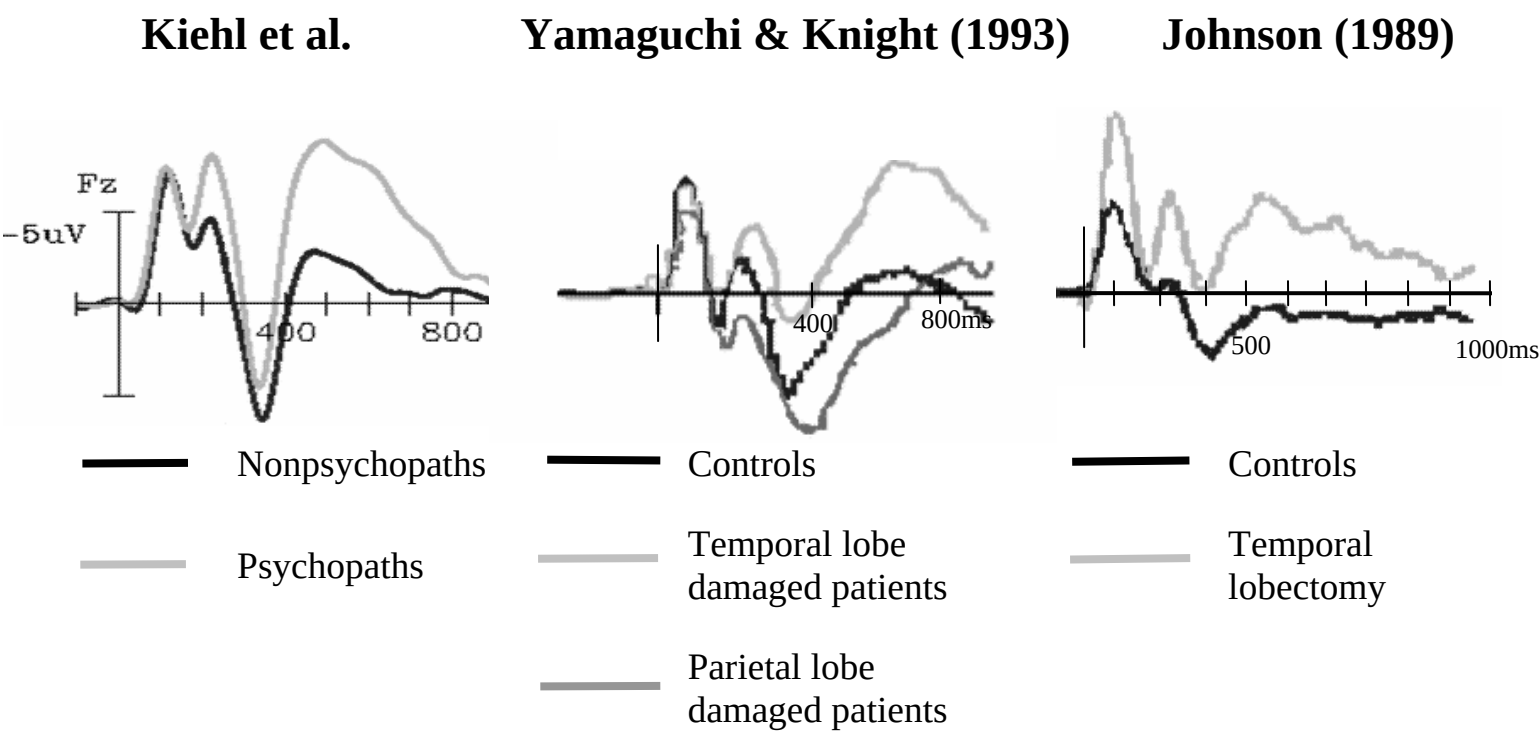
Figure 4.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Psychopaths
Controls
Temporal lobe damaged patients
Parietal lobe damaged patients
Controls
Temporal lobectomy

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