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An event-related potential investigation of error monitoring in adults with a history of psychosis

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HIGHLIGHTS

- Deficits in neural systems may underlie symptoms of psychopathology across clinical disorders.
- Individuals with a history of psychosis, regardless of diagnosis, exhibit abnormalities in electrophysiological brain activity and appraisal of self-performance during error monitoring.
- Abnormalities are specific to errors and are associated with self-reported cognitive and perceptual aberrations.

ABSTRACT

Objective: Previous research suggests that deficits in error monitoring contribute to psychosis and poor functioning. Consistent with the NIMH Research Domain Criteria initiative, this study examined electrophysiological brain activity, appraisal of self-performance, and personality traits related to psychosis during error monitoring in individuals with and without a history of psychosis across disorders.
Methods: Error-related negativity (ERN), correct response negativity (CRN), error positivity (Pe), and correct response positivity (Pc) were recorded in 14 individuals with a history of psychosis (PSY) and 12 individuals with no history of psychosis (CTR) during a flanker task. Participants continuously rated their performance and completed the Schizotypal Personality Questionnaire-Brief Revised (SPQ-BR).
Results: Compared with CTR, PSY exhibited reduced ERN and Pe amplitudes and was also less accurate at evaluating their performance. Group differences were specific to error trials. Across all participants, smaller Pe amplitudes were associated with greater scores on the SPQ-BR Cognitive-Perceptual factor and less accuracy in subjective identification of errors.
Conclusions: Individuals with a history of psychosis, regardless of diagnosis, demonstrated abnormal neural activity and imprecise confidence in response during error monitoring.
Significance: Results suggest that disruptions in neural circuitry may underlie specific clinical symptoms across diagnostic categories.

1. Introduction

Metacognition refers to "what we know about what we know" (Metcalfe and Shimamura, 1994) and is conceptualized as involving two important processes: monitoring and control. *Monitoring* refers to the evaluation of one's own cognitive functioning and *control* refers to the way in which behavior is guided by self-evaluation (Nelson and Narens, 1990). These processes are essential for guiding goal-directed action and for organization of internal and external information. In schizophrenia, failed or inadequate monitoring of self-action and thought has been related to positive symptomatology (e.g., Frith and Done, 1989). Recently, researchers have argued that metacognition is an important factor both mediating and moderating associations between neurocognitive deficits and functional outcome in schizophrenia (Green et al., 2000; Koren et al., 2006; Lysaker et al., 2010, 2013).

Error monitoring is particularly important, as recognizing a mistake and reacting appropriately is critical for adequate functioning. Individuals with schizophrenia demonstrate less error monitoring effort (Silver et al., 2006; Silver and Goodman, 2007) and lower accuracy in discriminating between real or imagined self-actions

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(Gawęda et al., 2013), in corrective action (Hommes et al., 2011), and in self-report of confidence in accuracy characterized by overconfidence in errors and reduced confidence in correct responses (Moritz et al., 2003; Moritz and Woodward, 2006; Kircher et al., 2007). Attempts to understand the underlying neural mechanism of error monitoring using event-related potentials (ERP; Dehaene et al., 1994) and other psychophysiological techniques (Carter et al., 1998; Miltner et al., 2003; Holroyd et al., 2004) have found unique neural signals originating from the anterior cingulate cortex (ACC) during fast impulsive errors on a variety of tasks (see van Veen and Carter, 2006). The error-related negativity (ERN) is the negative deflection in the ERP following an error (Falkenstein et al., 1990, 1991; Gehring et al., 1993), which peaks approximately 50–150 ms following an incorrect response. It has maximal amplitude at fronto-central electrode sites and is more prominent when accuracy is emphasized over speed (Gehring et al., 1993; Falkenstein et al., 2000; Morris et al., 2006). The ERN is generally associated with the subconscious awareness of error (Nieuwenhuis et al., 2001), although some studies have also found it to be associated with subjective appraisal of accuracy (Scheffers and Coles, 2000) and post-error slowing, a decrease in reaction time (RT) following errors thought to reflect remedial action (Gehring et al., 1993; Debener et al., 2005).

The correct response negativity (CRN) is the negative deflection sometimes seen in the ERP following a correct response. It shares the same time course and electrode sites as the ERN (Falkenstein et al., 2000; Vidal et al., 2000; Coles et al., 2001) and its presence has been suggested to result from detection of partial errors (e.g., when the idea of an incorrect response occurred but the correct response was actually executed), or as an artifact of measurement occurring when stimulus-related activity continues into the response-locked segments used to measure the ERN (see Coles et al., 2001).

After the initial ERN or CRN, a positive deflection in the ERP, peaking at approximately 160–500 ms after a response, is referred to as the error positivity (Pe) if following an error or the correct response positivity (Pc) if following a correct response. It is maximal at parieto-central electrode sites and more pronounced following errors (Falkenstein et al., 1991, 2000; Vidal et al., 2000). In contrast to the ERN, the Pe and Pc have more consistently been related to conscious detection of errors (Nieuwenhuis et al., 2001) and remedial post-error slowing (Nieuwenhuis et al., 2001; Hajcak et al., 2003).

A reduced ERN amplitude has been demonstrated in schizophrenia using a wide variety of cognitive tasks (e.g., Kopp and Rist, 1999; Alain et al., 2002; Mathalon et al., 2009; Horan et al., 2011). Moreover, the CRN amplitude also appears to be abnormal in schizophrenia, which has been reported as either increased (Alain et al., 2002; Mathalon et al., 2002; Morris et al., 2006) or decreased relative to controls (Bates et al., 2002). ERN amplitude reduction does not appear to be a result of a general reduction in brain activity, evidenced by studies that have found increased CRN amplitude coinciding with reduced ERN amplitude in the same schizophrenia samples (Mathalon et al., 2002; Morris et al., 2006). Findings regarding Pe amplitude are mixed. Whereas some studies have found Pe and Pc amplitudes to be normal in schizophrenia (e.g., Alain et al., 2002; Mathalon et al., 2002; Morris et al., 2006), others have found blunted Pe and Pc amplitudes (Perez et al., 2011; Foti et al., 2012). Reduced ERN amplitude has also been reported in individuals with high clinical (Laurens et al., 2010; Perez et al., 2011) and genetic (Simmonite et al., 2012) risk for schizophrenia, indicating a possible trait marker for vulnerability to psychosis. Post-error reaction time slowing has been found in some studies (Alain et al., 2002; Kerns et al., 2005), but not all (Bates et al., 2002; Mathalon et al., 2002; Morris et al., 2006).

The Research Domain Criteria (RDoC) initiative, advanced by the NIMH, seeks to understand psychopathology, presumably resulting from common neural circuit dysfunction, across rather than within disorders. Psychosis is not unique to schizophrenia, as it can also occur in mood and other disorders. Given the findings in individuals with schizophrenia, their relatives, and individuals at risk for schizophrenia, abnormal brain responses during error monitoring may be a vulnerability marker for psychosis. The purpose of the present study was to examine error monitoring in individuals with a history of psychosis using behavioral and neurophysiological approaches. Based on evidence from the existing literature, we hypothesized that the psychosis group (PSY) will be less accurate in identifying their errors than the comparison control group (CTR). Furthermore, PSY will exhibit reduced ERN amplitude, increased CRN amplitude, and normal Pe and Pc amplitude.

We were also interested in the relationship between error-related ERP amplitudes and personality traits associated with psychosis, particularly those identified in the Cognitive-Perceptual, Disorganization, and Interpersonal factors of the Schizotypal Personality Questionnaire (Raine, 1991). Theoretically, error monitoring deficits can result in symptoms related to all of these factors. For example, impairments in error monitoring represent the inability to accurately evaluate internal and external information that may lead to perceptual aberrations (Cognitive-Perceptual factor). It can also result in difficulty organizing information leading to disorganized behavior and speech (Disorganized factor). Finally, symptoms related to these factors, as well as difficulty recognizing, and thus correcting, errors in socially relevant contexts can result in interpersonal problems leading to lack of close friends and social anxiety (Interpersonal factor). The few studies that have examined these relationships have used more acute measures of psychopathology instead of measures of more stable traits and have reported mixed results. For example, reduced ERN amplitudes were associated with hallucinatory behavior (Mathalon et al., 2002), reality distortion but not negative symptoms (Morris et al., 2008), negative symptoms but not psychotic or disorganized symptoms (Foti et al., 2013), or no clinical symptoms (Perez et al., 2011). Therefore, our examination of these associations was exploratory.

2. Methods

2.1. Participants

Participants were recruited from the community and local mental health facilities as part of a larger study investigating brain activity during visual perception, reward processing, and error monitoring. All potential participants were screened over the telephone and excluded if they reported that they were not native English speakers, had a history of medical conditions or traumatic head injury that may affect brain functioning or their ability to perform the task, or had a recent history of substance dependence. Comparison controls were also excluded if they reported that they or any of their biological relatives had ever been prescribed an antipsychotic medication or that a biological relative had ever received a diagnosis of schizophrenia, schizoaffective disorder, or bipolar disorder. All of the patients were relatively stable and independent, as they managed to keep their appointments, find their way to the laboratory, and complete the task.

2.2. Clinical measures

The Structured Clinical Interview for DSM-IV Axis I Disorders (SCID-I; First et al., 1996) and the Avoidant, Paranoid, and