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Review

ERP indices of performance monitoring and feedback processing in psychosis: A meta-analysis

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ABSTRACT

Background: Although individuals with, or at risk for, psychotic disorders often show difficulties with performance monitoring and feedback processing, findings from studies using event-related potentials (ERPs) to index these processes are not consistent. This meta-analytic review focused on studies of two different indexes of performance monitoring, the early error-related negativity (ERN; n = 25) and the later error positivity (Pe; n = 17), and one index of feedback processing, the feedback negativity (FN; n = 6).

Methods: We evaluated whether individuals (1) with psychotic disorders, or (2) at heightened risk for these disorders differ from healthy controls in available studies of the ERN, Pe, and FN.

Results: There was a significant, large ERN reduction in those with psychosis ($g = -0.96$) compared to controls, and a significant, moderate ERN reduction in those at-risk ($g = -0.48$). In contrast, there were uniformly non-significant, small between-group differences for Pe and FN ($gs \leq |0.16|$).

Conclusions: The results reveal a differential pattern of impairment in psychosis. Early performance monitoring (ERN) impairments are substantial among those with psychotic disorders in general and may be a useful vulnerability indicator for these disorders. However, later performance monitoring (Pe) and basic feedback processing (FN) appear to be relatively spared in psychosis.

1. Introduction

Impairments in daily life functioning, including diminished engagement in productive and pleasurable activities, are hallmarks of psychotic disorders (Barch and Dowd, 2010; Blanchard et al., 2011). These impairments are directly linked to cognitive deficits, which have been extensively documented in psychosis and psychosis-risk. The ability to accurately monitor one's performance, and integrate internal (e.g., self-generated comparisons of whether performed actions match their intended outcomes) and external performance feedback (e.g., externally-generated information indicating favorable vs. unfavorable outcomes), are critical aspects of cognition, reward processing, and learning as they guide adaptive decision-making and productive behavior (Falkenstein et al., 1990; Gehring et al., 1993; Holroyd and Coles, 2002). A number of investigators have used event-related potentials (ERPs) to assess whether distinct aspects of performance monitoring and feedback processing are impacted in those with schizophrenia, with psychotic disorders more broadly, or at heightened risk for developing one of these disorders. Most investigations have focused on two ERP components that measure performance monitoring, the error-related negativity (ERN) and error positivity (Pe), and one that measures feedback processing, the feedback negativity (FN). Study findings have varied considerably across these three components, making it hard to draw conclusions. To date, there has not been an integrative quantitative review of this literature.

The purpose of this meta-analytic review is to determine whether individuals with psychotic disorders (including schizophrenia, schizoaffective disorder, delusional disorder, schizophreniform disorder, schizophrenia spectrum disorders otherwise specified, and mood disorders with psychotic features) or at heightened risk for these psychotic disorders (either genetic risk, clinical high-risk, or psychometric high-risk samples) differ from healthy controls on these three ERP components. Additionally, we will evaluate potential moderators of these components, where applicable. This information can shed light on how

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performance monitoring and feedback processing is impacted in psychosis-related psychopathology.

1.1. ERPs associated with performance monitoring: ERN and Pe

The ERN (also known as the Ne) is a response-locked ERP that has been associated with performance monitoring of actions and detecting errors (Falkenstein et al., 1990; Gehring et al., 1993; Simons, 2010). It is generally assessed with choice reaction time tasks, such as the flanker or go/no go paradigms. The onset of the ERN occurs shortly before or at the moment of an erroneous response and peaks approximately 100 ms later at midline frontocentral scalp locations (Gehring et al., 2012). Initial evidence from source localization, functional magnetic resonance imaging, and single unit recording studies suggests that the ERN may be generated within the dorsal region of the anterior cingulate cortex (ACC) (e.g., Debener et al., 2005; Holroyd and Coles, 2002), a structure centrally involved in performance monitoring and error detection (Taylor et al., 2007).

In psychosis research, the ERN has received the most attention of the three ERP components considered in this review. Across 22 separate studies of individuals with schizophrenia, the vast majority have reported reduced ERN compared to healthy controls. The overall magnitude of the reduction is unclear and the potential impact of methodological differences across studies (e.g., sample characteristics, type of paradigm) has not been evaluated. A smaller number of studies have examined the ERN in individuals with more broadly defined psychotic disorders (n = 4) or at-risk groups (n = 7). Although ERN reductions are also typically reported in these samples, the overall magnitude of the reductions has not been evaluated.

The ERN is typically followed by the Pe component. The Pe peaks in the centroparietal region between 200 and 400 ms after an erroneous response. Despite some debate (Gehring et al., 2012; e.g., Van Veen and Carter, 2002), the Pe is typically thought to index error awareness or the ability to detect errors (Endrass et al., 2007; Nieuwenhuis et al., 2001), and it has been reported that the Pe may be generated by the rostral ACC (Endrass et al., 2007).

Compared to the ERN, fewer studies have examined the Pe in those with schizophrenia (n = 13), those with broadly defined psychotic disorders (n = 3), or at-risk groups (n = 7). In contrast to the consistent reports of reduced ERN, studies of the Pe have been decidedly mixed, finding either relatively small reductions or no differences between these groups and healthy controls. It is unclear whether differences in methodologies or clinical characteristics may account for inconsistencies across studies.

1.2. ERP associated with external feedback processing: FN

The FN is typically assessed using simple gambling or feedback-based learning paradigms (Simons, 2010) and, in contrast to the ERN and Pe, is elicited by externally provided feedback about positive versus negative outcomes. The feedback stimulus-locked FN peaks between 250 and 300 ms after feedback onset and is maximal over the frontocentral region. In addition, it is relatively more negative-going after unfavorable versus favorable feedback (e.g., a monetary loss compared to a monetary gain). The FN has historically been viewed as tracking the occurrence of unfavorable outcomes (negative reward prediction errors). Some, however, have argued that the FN tracks the occurrence of favorable outcomes (positive reward prediction error), resulting in a reward-related positivity (i.e., “Reward Positivity”) that is absent or suppressed following an unfavorable outcome (for a review, see Proudfit, 2015). This is supported by tentative evidence that the FN originates from the striatum (e.g., Carlson et al., 2011; Foti et al., 2011). Others propose the FN reflects an unsigned salience/surprise signal or that multiple processes (e.g., positive reward prediction error and unsigned salience signal) may contribute to the FN (Hauser et al., 2014; Cavanagh and Frank, 2014; Sambrook and Goslin, 2016). For the sake of consistency with previous research in this area, the current review will refer to this component as the “FN”.

Compared to the ERN and Pe, relatively few studies investigated the FN in those with schizophrenia (n = 4), broadly defined psychosis (n = 1) or at risk for psychotic disorders (n = 1). Almost all reported intact FN in schizophrenia across these groups. However, the sample sizes were relatively small, and it is unclear whether reliable differences between these groups and healthy controls are detectable.

1.3. The current study

Overall, findings from the ERP literature regarding performance monitoring and feedback processing in psychotic disorders and at-risk populations are mixed. To clarify these findings, we employed meta-analysis, a powerful statistical technique that can identify trends across relatively small studies. For the ERN and Pe, the goals of the review were to: (1) determine whether individuals with psychotic disorders or at-risk groups show reliable impairments compared to non-psychiatric controls and to quantify the corresponding effect sizes, and (2) evaluate potential methodological (type of paradigm, ERP quantification methods) and patient characteristic (diagnosis, patient status, phase of illness) moderators of these components. Given the smaller database for the FN, we focused on determining whether individuals with psychosis show a reliable impairment compared to healthy controls and quantifying the effect size.

2. Materials and method

2.1. Eligibility criteria for meta-analysis

The current meta-analysis followed PRISMA guidelines (Moher et al., 2009) for transparent and replicable methods and findings. Please see the Supplementary Table 1 for the PRISMA checklist.

Inclusion criteria for the current analyses were as follows: 1) the study included a sample of either 1A) all patients meeting DSM-III-R (APA, 1987) or DSM-IV (APA, 2000) criteria for schizophrenia or schizoaffective disorder, 1B) patients with any DSM disorder also reporting psychotic symptoms (e.g., schizophrenia, major depressive disorder with psychotic features) or 1C) individuals “at risk” for schizophrenia-spectrum disorders identified by either a structured clinical interview (clinical risk), a family history of a 1st degree family member with schizophrenia/schizoaffective disorder (genetic risk), or standardized questionnaire measures (psychometrically-defined risk); 2) a nonpsychiatric control sample (i.e., sample with no history of psychopathology determined by study-specific methods/criteria); 3) the study task required overt participant responses and is generally recognized as a reliable elicitor of ERN, Pe, or FN ERPs; 4) amplitude of the ERN, Pe, or FN ERP waveform was reported for patients/at risk and control subjects; 5) statistics were reported that allowed for calculation of effect size (standardized mean difference or Hedges' *g*) of ERN/Pe/FN ERP waveform amplitude; and 6) study findings were reported in an English language, peer-reviewed journal article. Studies were excluded if they did not meet inclusion criteria. There were no other exclusion criteria. The literature search began on February 2, 2017, and ended on March 21, 2017.[1]

There were inconsistencies in the literature regarding nomenclature, measured time windows, specific electrodes included, and quantification of the waveforms. However, of the included studies, the ERN was characterized as a negative-going waveform, recorded at the frontocentral

[1] We used the Risk of Bias Assessment Tool for Nonrandomized Studies (RoBANS; Kim et al., 2013). Two raters (M. Moore and A. McCleery) completed independent ratings of each study with good inter-rater agreement (91% agreement, Cohen's kappa = 0.80). Scoring discrepancies were resolved by consensus ratings. For the majority of studies, risk of potential bias was low. A summary of the RoBANS data can be found in Supplementary Table 2.