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ERP correlates of error monitoring in 10-year olds are related to socialization

Diane L. Santesso [a], Sidney J. Segalowitz [a,*], Louis A. Schmidt [b]

[a] Department of Psychology, Brock University, St. Catharines, Ont., Canada L2S 3A1
[b] Department of Psychology, McMaster University, Hamilton, Ont., Canada L8S 4K1

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Abstract

Research suggests that the anterior cingulate cortex (ACC) generates the error-related negativity (ERN or Ne), an event-related potential component that reflects response monitoring and is influenced by individual differences in personality. The present study examined the relation between personality as indexed by the Junior Eysenck Personality Questionnaire (Extraversion, Neuroticism, Psychoticism, and Lie scale) and the ERN in 10-year-old children. High scores on the Psychoticism and low scores on the Lie scale, which are taken to reflect low socialization in children, were associated with smaller ERNs. Results lend support to previous studies finding this association in adults. We argue that the ERN may be an indirect measure of ACC activity and is affected by one's concern with task performance. The results of the present study extend findings previously reported in adults to a population of normally developing children and show that similar mechanisms of performance monitoring may underlie individual differences in personality across development.

Keywords: Error monitoring; ERP; Children; Socialization; ERN; Pe

1. Introduction

The anterior cingulate cortex (ACC) is part of a frontal neural system that contributes to executive function and the experience of emotion (Papez, 1937). The ACC receives input from attentional, motoric, and affective areas of the frontal cortex and uses this input to guide, constrain and monitor behaviors (see Devinsky et al., 1995 for review). Response monitoring is the process by which on-going behaviors, and the consequences of those behaviors, are checked against intended goals (Falkenstein et al., 2000; Scheffers and Coles, 2000). Successful response monitoring allows one to alter behaviors, adopting more effective strategies to achieve a desired goal.

Researchers generally agree that response checking is reflected in the error-related negativity (ERN or Ne) and error-positivity (Pe) (Miltner et al., 1997; van Veen and Carter, 2002). The ERN is a negative event-related potential (ERP) with a fronto-central scalp distribution (Dehaene et al., 1994; Falkenstein et al., 1991; Gehring et al., 1993), peaking 60–110 ms after an error response (e.g., Luu et al., 2000b; Pailing et al., 2002) and is thought to be generated by the ACC (Stemmer et al., 2003; van Veen and Carter, 2002). The ERN has been observed following error responses (Luu et al., 2000b; Scheffers et al., 1996; van Veen and Carter, 2002) and also when outcomes are "worse than expected" (Holroyd and Coles, 2002), suggesting the ERN reflects not only the detection of errors but also error salience (Falkenstein et al., 1991; Gehring et al., 1993). This not only implies that the more certain the individual is in having erred, the larger the ERN, but also the more invested in the task the individual is, the larger the ERN (Falkenstein et al., 2000; Gehring and Knight, 1996; Holroyd and Coles, 2002; Pailing and Segalowitz, 2004; Scheffers and Coles, 2000). More recently, Yeung and Sanfey (2004) showed the feedback ERN was related to reward magnitude such that the negativity was larger for larger rewards. This provides further support for the notion that the ACC is, in part, responsible for evaluating reward value and the motivational significance of events.

* Corresponding author.
E-mail address: sid.segalowitz@brocku.ca (S.J. Segalowitz).

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The Pe is a positive component appearing after the ERN (Kaiser et al., 1997; Vidal et al., 2000). The Pe may consist of an early and late positive wave component (Falkenstein et al., 1991; Leuthold and Sommer, 1999): the early positivity may be a rebound from the ERN (Falkenstein et al., 1995, 1996) while the late positivity may reflect conscious recognition of an error or emotional reactions to an error (Falkenstein et al., 2000; Nieuwenhuis et al., 2001; Vidal et al., 2000). The late Pe is maximal at a more posterior scalp site and is thought to be generated by the rostral ACC and the parietal cortex (van Veen and Carter, 2002).

Several lines of evidence suggest that the ERN is influenced by individual differences in affective style or motivation. For example, negative affect and obsessive-compulsiveness have been associated with pronounced ERNs. Tucker et al. (1999) demonstrated that participants scoring high on measures of negative affect and negative emotionality (or ''neuroticism'') exhibited larger ERNs on initial task trials than those with low negative affect. As the trials progressed, ERN amplitudes decreased for high negative affective participants, suggesting that they became less involved in or started to react less to the task. The authors also found that, whereas the presence of negative affect reduced the ERN amplitude, the presence of positive affect did not affect it (Luu et al., 2000a). Finally, obsessive-compulsive patients and non-clinical obsessive adults, who may be experiencing negative affect and engage in excessive self-monitoring, exhibited larger ERNs compared with controls (Gehring et al., 2000; Hajcak and Simons, 2002). Complementing these electrophysiological data, neuroimaging studies have demonstrated that the ACC is hyperactive in depressed (Mayberg et al., 1999), social phobic (Veit et al., 2002), and obsessive-compulsive (Baxter, 1991, 1992; Rauch and Baxter, 1998) patients relative to controls. Taken together, these findings suggest that pronounced ERNs may reflect negative affect and hyperactivity of the ACC.

Just as hyperactivity of the ACC and a pronounced ERN may reflect excessive performance monitoring and concern over the outcome of an event, hypoactivity of the ACC may reflect a lack of concern. Using brain SPECT, Migneco et al. (2001) reported that the presence of apathy was related to ACC hypoactivity in demented and non-demented elderly patients. Functional MRI studies also demonstrated that psychopathic individuals exhibit hypoactivity in the ACC. For example, Kiehl et al. (2001) reported that criminal psychopaths had less ACC activation than controls while processing (i.e., during encoding and recognition of) negative affective compared with neutral words while Veit et al. (2002) demonstrated that psychopaths had less ACC activation than social phobics during the acquisition and extinction phase of an aversive conditioning paradigm.

Dikman and Allen (2000) were the first to examine the ERN in relation to a lack of concern or low socialization (e.g., stealing, inhibition, and responses to reward). The authors used a modified version of the flanker task (Eriksen and Eriksen, 1974) with reward and avoidance-learning conditions. Correct responses during the reward condition led to monetary gain whereas incorrect responses resulted in no monetary gain. Correct responses during the avoidance-learning condition led to no feedback whereas incorrect responses resulted in a loud tone. The authors reported that (1) low-socialized participants generated smaller ERNs during incorrect avoidance-learning trials than during incorrect reward trials; and (2) low-socialized participants produced smaller ERNs on incorrect avoidance-learning trials than high-socialized participants on incorrect reward and avoidance-learning trials. The authors concluded that low-socialized participants found errors on avoidance trials to be less salient or were less concerned about the consequences of having erred on these trials. Alternatively, low-socialized participants did not monitor their performance as vigilantly on avoidance-learning trials as their high-socialized counterparts. Although the salience of the feedback during both incorrect reward and avoidance-learning conditions may be questioned (i.e., no monetary gain is punishment; a loud tone is not punishment enough), the results demonstrated that the ERN can be influenced by an individual's investment in the task and affective responses towards negative events.

More recently, Pailing and Segalowitz (2004) examined changes in the ERN in relation to motivation and conscientiousness. Conscientiousness is a personality trait reflecting cautiousness, deliberation, dependability, persistence, and meticulousness (Costa and McCrae, 1992). Participants completed a discrimination task in which they received differential incentives for aspects of the task. The authors reported that the ERN varied with motivational level particularly for individuals with low conscientiousness scores. This suggests that (1) individuals scoring low on conscientiousness are sensitive to manipulations that alter the salience or the significance of an error event; and/or (2) highly conscientious individuals may have been less sensitive to the motivational manipulations because they were motivated to perform well regardless of external incentives; and/or (3) the flexibility of performance monitoring and sensitivity to motivational incentive is influenced by personality.

While all the previous work on personality and the ERN has been done with adults, similar issues are important for personality development in children. This is especially the case for adolescents' socialization and the later development of anti-social and psychopathic tendencies (Lane, 1987; Romero et al., 2001). The purpose of the present study was to examine the psychophysiology of error monitoring in the pre-adolescent phase, especially as it relates to personality traits relevant for later healthy psychological functioning. In this paper, we present our findings on the relation between personality and the ERN and Pe in a sample of non-clinical 10-year-old children. We used a revised version of the Junior Eysenck Personality Questionnaire (Corulla, 1990) to assess four personality measures: Neuroticism, Extraversion, Psychoticism and the Lie scale. We were particularly