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Error-related event-related potentials in children with attention-deficit hyperactivity disorder, oppositional defiant disorder, reading disorder, and math disorder

Andrea Burgio-Murphy [a], Rafael Klorman [a,*], Sally E. Shaywitz [b], Jack M. Fletcher [c], Karen E. Marchione [b], John Holahan [b], Karla K. Stuebing [c], Joan E. Thatcher [a], Bennett A. Shaywitz [b]

[a] *Department of Clinical and Social Sciences in Psychology, University of Rochester, Rochester, NY 14627-0266, United States*
[b] *Department of Pediatrics, Yale University Medical School, New Haven, CT 06510, United States*
[c] *Department of Psychology, University of Houston, Houston, TX 77204, United States*

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Abstract

We studied error-related negativity (ERN) and error positivity (Pe) during a discrimination task in 319 unmedicated children divided into subtypes of ADHD (Not-ADHD/inattentive/combined), learning disorder (Not-LD/reading/math/reading + math), and oppositional defiant disorder. Response-locked ERPs contained a frontocentral ERN and posterior Pe. Error-related negativity and positivity exhibited larger amplitude and later latency than corresponding waves for correct responses matched on reaction time. ADHD did not affect performance on the task. The ADHD/combined sample exceeded controls in ERN amplitude, perhaps reflecting patients' adaptive monitoring efforts. Compared with controls, subjects with reading disorder and reading + math disorder performed worse on the task and had marginally more negative correct-related negativities. In contrast, Pe/Pc was smaller in children with reading + math disorder than among subjects with reading disorder and Not-LD participants; this nonspecific finding is not attributable to error processing. The results reflect anomalies in error processing in these disorders but further research is needed to address inconsistencies in the literature.

Keywords: Attention-deficit hyperactivity disorder; Learning disorders; Error monitoring; Error-related negativity; Event-related potentials

1. Introduction

1.1. Scope of the paper

The present research examined two error-related components of event-related potentials (ERPs), error-related negativity (ERN; also known as Ne) and error positivity (Pe), in children with major subtypes of attention-deficit hyperactivity disorder (ADHD) and unaffected peers. ERN has been related to error monitoring, a crucial aspect of executive functions (EF) that allows an individual to readjust or correct performance so as to increase future accuracy. Although the functional significance of Pe is less completely understood (Overbeek et al., 2005), this ERP component has also been related to error processing.

There are several models of executive functions, but they all generally encompass those supervisory operations that control and manage other cognitive processes (e.g. planning, cognitive flexibility, abstract thinking, rule acquisition, inhibition, self-regulation). Current emphasis on disordered executive function in cognitive and emotional aspects of ADHD (Barkley, 1997; Pennington and Ozonoff, 1996) prompted interest in deficits in error monitoring among children with ADHD. We also researched whether deficits in error monitoring in ADHD vary as function of three comorbid conditions: oppositional defiant disorder (ODD), reading disorder (RD), and math disorder (MD).

* Corresponding author at: Box 270266, Meliora Hall, University of Rochester, Rochester, NY 14627-0266, United States. Tel.: +1 585 275 2595; fax: +1 585 273 1100.
E-mail addresses: rafael.klorman@rochester.edu, klorman@psych.rochester.edu (R. Klorman).

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1.2. ADHD and related conditions

Research has identified differences among ADHD subtypes in clinical and executive functions. Children with predominantly hyperactive-impulsive (ADHD/H) and combined types of ADHD (ADHD/C) are more aggressive, impulsive, and unpopular than their peers with predominantly inattentive type of ADHD (ADHD/I; Carlson and Mann, 2000). In addition, children with ADHD/C are more impaired than those with ADHD/I on tower tests of planning (Klorman et al., 1999; Kopecky et al., 2005; Nigg et al., 2002); motor inhibition (Nigg et al., 2002); and, less consistently, set shifting (Barkley et al., 1992; Houghton et al., 1999; Klorman et al., 1999; Nigg et al., 2002). Following a review of this type of evidence, Milich et al. (2001) proposed that these two ADHD subtypes represent distinct disorders. In contrast to this position, though, Chhabildas et al. (2001) found that symptoms of inattention, rather than those of hyperactivity/impulsivity, were closely associated with deficits of inhibition, vigilance, and processing speed.

The two ADHD subtypes also co-occur with other disorders that may affect cognitive processing. ODD, a condition commonly comorbid with ADHD, does not magnify cognitive deficits of ADHD children (Dykman and Ackerman, 1992; Klorman et al., 1999). However, ADHD comorbid with physical aggression or conduct disorder may involve qualitatively and quantitatively different EF weaknesses (Giancola et al., 1998; Halperin et al., 1990).

Many studies have reported that learning disabilities overlap with ADHD. Studies of children with ADHD, RD, and both RD and ADHD have found that children with only ADHD are cognitively impaired on EF measures relative to unaffected peers or subjects with RD alone (Tant and Douglas, 1982; Tarnowski et al., 1986). In turn, children with RD demonstrate impairments on language measures (Pennington et al., 1993; Purvis and Tannock, 2000; Shaywitz et al., 1995). Nevertheless, some investigations identified EF deficits in RD (Dainer et al., 1981; Kelly et al., 1989). Children with both ADHD and RD exhibit linguistic and EF deficits, sometimes exceeding those of their single-diagnosis counterparts (Ackerman et al., 1986; August and Garfinkel, 1990; Felton and Wood, 1989; Kupietz, 1990; McGee et al., 1989; Shaywitz et al., 1995).

Although MD is a common learning disorder (Geary, 1993), there is far less research on the overlap of ADHD with MD than is the case for RD. Fletcher (2005) reported that the presence of ADHD did not affect cognitive profiles associated with MD. However, children with RD and RD + MD demonstrated divergent profiles on measures associated with math difficulties, but not those involving reading difficulties. The math literature frequently identifies MD and MD + RD as separate disorders, reflecting differences in the nature of the math difficulties and their cognitive correlates. Children with only MD are often identified as experiencing difficulties with procedural knowledge and correlated difficulties on measures of set switching, problem solving, and concept formation (Lyon et al., 2003). Interestingly, Fuchs et al. (2005) found that behavioral ratings of inattention, but not those of hyperactivity-impulsivity, accounted for significant and robust unique variance in a variety of mathematics outcomes in a large sample of children with MD and MD + RD. Thus, whereas the presence of ADHD does not appear to modify the expression of MD (except that children with MD + ADHD appear more severely impaired), specific MD is associated with EF difficulties. Altogether, an adequate account of EF and ADHD requires that different comorbid conditions be accounted for in the analysis.

1.3. Error monitoring in ADHD

Three reports provide behavioral evidence for failure of error monitoring in children with ADHD, who exhibited reduced or abnormal post-error slowing (Schachar et al., 2004; Sergeant and Meere, 1988; Wiersema et al., 2005). Anomalous post-error slowing supports a deficient error monitoring mechanism and provides a possible explanation for at least part of the deficient task performance by children with ADHD. Consistent with these results, our group found that methylphenidate, a drug that remedies clinical disturbances in ADHD, increased post-error slowing by these children in a Sternberg task while also increasing speed and accuracy (Krusch et al., 1996). In contrast to these reports, Meel et al. (unpublished), detected comparable post-error slowing in their ADHD and control samples. Thus, the majority, but not all, investigations suggest disturbances in error monitoring in ADHD.

1.4. Error-related ERPs

We focused on ERN and Pe, two components of the ERP synchronized with an error response and considered the neural correlates of a self-monitoring system. When subjects make errors, ERPs display a frontocentral negative wave (ERN) with latency of approximately 100 ms and a subsequent parietally maximal positive wave (Pe; Falkenstein et al., 1990, 1995; Gehring et al., 1993). ERN and Pe appear to depend on the detection of errors and not on the execution of an erroneous motor response insofar as ERN is linked, not only to overt errors in discrimination tasks (e.g. Falkenstein et al., 1995), but also to feedback on the commission of errors (Luu et al., 2003; Miltner et al., 1997). Dipole analyses of ERN point to a likely source in the anterior cingulate cortex (ACC; Dehaene et al., 1994; Luu et al., 2003; Miltner et al., 1997; Veen and Carter, 2002). These findings are consistent with imaging evidence that the ACC is active during an error and, to a lesser extent, during the execution of a correct response (Carter et al., 1998). Holroyd and Coles (2002) have theorized that ERN is generated when a negative reinforcement signal is conveyed to the ACC via the mesencephalic dopamine system; this signal is used by the ACC to modify performance on the task at hand.

Some investigators have argued that ERN reflects the detection or processing of errors and that Pe is elicited by the evaluation of the incorrect response (Falkenstein et al., 1990, 2000; Leuthold and Sommer, 1999; Overbeek et al., 2005). Gehring et al. (1993) found that ERN may be modulated by the perceived importance of an incorrect response. In addition,