Biological Psychology 84 (2010) 176–185

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

Error monitoring in children with ADHD or reading disorder: An event-related potential study

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ARTICLE INFO

Article history:
Received 2 September 2009
Accepted 16 January 2010
Available online 25 January 2010

Keywords:
ADHD
Reading disorder
Error monitoring
Ne
Pe
ERP

ABSTRACT

This study compared children with ADHD, reading disorder (RD), ADHD + RD, and control children on behavioural (post-error slowing and post-error accuracy) and event-related potential (Ne and Pe) measures of error monitoring. Children with ADHD did not differ from children without ADHD in post-error slowing but showed less post-error accuracy enhancement, as evidenced by a higher proportion of double-errors. We found a smaller Ne but normal Pe amplitude in children with RD, and a smaller Pe but normal Ne amplitude in children with ADHD. Children from the comorbid group showed both a smaller Ne and a smaller Pe amplitude, which suggests that they showed the additive combination of the deficits found in both separate disorders. The results of the present study suggest that it might be important to control for the presence of comorbid RD when examining error monitoring in ADHD and that various measures of post-error adaptation should be included.

1. Introduction

ADHD and reading disorder (RD) are two of the most common developmental disorders in childhood. They also co-occur much more often than can be expected by chance, with rates of overlap estimated between 15% and 40% (e.g., Del'Homme et al., 2007; Semrud-Clikeman et al., 1992; Shaywitz et al., 1995; Willcutt and Pennington, 2000). Children with ADHD are characterized by behavioural symptoms of inattention and/or hyperactivity and impulsivity. Children with RD are characterized by persistent reading problems despite adequate cognitive ability and educational opportunities. Although both disorders are diagnosed in different ways (ADHD by parent reports; RD by reading tests), they share some behavioural symptoms like inattentive behaviour and academic difficulties (Hinshaw, 1992). This makes differential diagnosis difficult and urges research into cognitive and neurobiological variables that might better distinguish between both disorders (Rashid et al., 2001).

Although for a long time it was believed that the core cognitive deficit of ADHD is an inhibition deficit (Barkley, 1997) and that the core deficit of RD is of phonological nature (Snowling, 2000), it becomes more and more clear that this is not the whole story for either disorder. With respect to ADHD, it has been found that children with the disorder show a general inaccurate response style, not only in tasks measuring inhibition, but also in other neuropsychological tasks (Rommelse et al., 2007; Sergeant et al., 2003; van der Meere, 2005). In addition, it has been claimed that no evidence of a response inhibition deficit can be found when tasks with an experimental manipulation of inhibition load are used and performance is compared to a control condition (Rommelse et al., 2007; Van De Voorde et al., 2009). The latter has also been found for other executive function (EF) deficits that are frequently attributed to ADHD, such as deficits in working memory (Karatekin et al., 2009; Klein et al., 2006; Shallice et al., 2002; Van De Voorde et al., 2009) and cognitive flexibility (Rommelse et al., 2007). With respect to RD, there have been reports of additional deficits that cannot easily be explained by a pure phonological deficit. These include deficits in temporal processing (see review by Farmer and Klein, 1995), visual processing (Stein and Walsh, 1997), working memory (e.g., Swanson et al., 1996, 1999; Van De Voorde et al., 2009), and response inhibition (e.g., Purvis and Tannock, 2000; van der Schoot et al., 2000; Willcutt et al., 2005). In the study by Van De Voorde et al. it was found that children with RD did not only make more errors in linguistic tasks (e.g., reading, phonology, rapid naming) but also in a Go/no-go task, independent of the modality of the stimulus that had to be processed (letters, digits, or meaningless symbols that could not be labeled). It appeared that the inaccurate response style found in children with ADHD was not unique to the disorder, as it was also observed in children with RD. It was also found that both in ADHD and in RD this high error rate could not be explained by a deficit in response inhibition alone. However, correct performance in such speeded reaction time (RT)

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doi:10.1016/j.biopsycho.2010.01.011

tasks is not only dependent upon the efficacy of inhibition processes but also of the activation of a monitoring system that signals the need to adjust behaviour when confronted with conflict or errors (Hajcak and Simons, 2008; O'Connell et al., 2009; Zhang et al., 2009). Therefore, it is possible that the deteriorated accuracy in these clinical populations is rather the result of deficiencies in the higher-order error monitoring system than of isolated problems with inhibition.

Error monitoring is an executive control process that enables online detection of errors and subsequent adjustment of performance so as to increase future accuracy (Schachar et al., 2004). These processes are highly relevant in daily life as detection and future avoidance of errors are important parts of self-regulatory and goal-directed behaviour, necessary to flexibly adjust to internal and external needs (Ullsperger and Falkenstein, 2004) and to learn from previous behaviours (Garavan et al., 2002).

These processes have been studied with the behavioural measure of post-error slowing (Rabbitt, 1966), that is, slowing down response speed on the trial following an error to prevent future errors. However, it is not clear which aspect of error monitoring (e.g., error detection or error correction) is disturbed when problems with post-error slowing are observed. The discovery of electrophysiological indices has made it possible to study error processes more accurately and has renewed interest in these processes. The two event-related brain potentials (ERPs) that are observed after an erroneous response have been labeled error negativity (Ne; Falkenstein et al., 1990), also known as error-related negativity (ERN; Gehring et al., 1990, 1993), and error positivity (Pe; Falkenstein et al., 1991). The Ne is a sharp negative potential with fronto-central maximum peaking between 0 and 160 ms after an erroneous response, whereas the Pe is a more extended positive potential that follows the Ne with a parietal maximum between 200 and 500 ms after an incorrect response (Falkenstein et al., 2000). The generator of both processes seems to be located in the anterior cingulate cortex (ACC), more specifically in the dorsal/caudal part (dACC) for the Ne and in the ventral/rostral part (vACC) for the Pe (e.g., Herrmann et al., 2004; O'Connell et al., 2007; van Boxtel et al., 2005; van Veen and Carter, 2002). Although different hypotheses exist on the functional significance of the Ne and Pe, it seems that the Ne reflects an early, more automatic, error detection system, whereas the Pe reflects the conscious or emotional evaluation of the error (Falkenstein et al., 2000; Nieuwenhuis et al., 2001; Overbeek et al., 2005; van Veen and Carter, 2002). It has been found by Nieuwenhuis et al. (2001) that the Pe is only elicited following aware errors and not following unaware errors, whereas the Ne is not affected by error awareness. This has recently been confirmed by other studies (e.g., Endrass et al., 2005; O'Connell et al., 2007) and suggests that the Ne and Pe are distinct parts of the error monitoring process with the Pe occurring only after the conscious recognition that an error was made.

People with ADHD show a general inaccurate response style in speeded RT tasks and they seem to have difficulties with learning from their mistakes in daily life. Therefore, it is not surprising that error monitoring has become an important research topic in ADHD. Since the first report by Sergeant and van der Meere (1988) and more recent reports by Schachar et al. (2004) and Wiersema et al. (2005), that have injected new life into this research line, several papers have been published yielding somewhat inconsistent results.

The most consistent finding has been a reduced Pe amplitude in children with ADHD, first reported by Overtoom et al. (2002) and later confirmed with different paradigms (Groen et al., 2008; Jonkman et al., 2007; Wiersema et al., 2005; Zhang et al., 2009) and within adult ADHD populations (O'Connell et al., 2009; Wiersema et al., 2009). However, there are also studies that did not find Pe differences between persons with and without ADHD (Albrecht et al., 2008; Burgio-Murphy et al., 2007; McLoughlin et al., 2009; Wild-Wall et al., 2009). With respect to the Ne, results have been far less consistent: the Ne amplitude has been found to be normal (Jonkman et al., 2007; O'Connell et al., 2009; Wiersema et al., 2005, 2009; Wild-Wall et al., 2009; Zhang et al., 2009), reduced (Albrecht et al., 2008; Groen et al., 2008; Liotti et al., 2005; McLoughlin et al., 2009; van Meel et al., 2007), or even enhanced (Burgio-Murphy et al., 2007) in patients with ADHD. Thus, the ERP results generally suggest that children and adults with ADHD have problems with error monitoring with the most consistent finding of a reduced Pe amplitude, implying aberrant conscious evaluation of errors. Together with the finding of reduced or abnormal post-error slowing (e.g., Krusch et al., 1996; Schachar et al., 2004; Sergeant and van der Meere, 1988; Wiersema et al., 2005), these results suggest that a deficient error monitoring system may, at least partly, explain the deteriorated task performance in children with ADHD. Transferred to daily life, this could mean that they do not seem to learn from their mistakes because of deviant error monitoring processes that hamper them in adequately adjusting their behaviour (Groen et al., 2008).

However, since a comparable inaccurate response style in some neuropsychological tasks has also been reported in RD (e.g., Burgio-Murphy et al., 2007; Van De Voorde et al., 2009), it is important to investigate the role of problems with error monitoring as a possible underlying factor. In everyday life, children with RD continue to make decoding/reading errors despite intensive remedial therapy on top of the normal reading instruction at school (Lyon et al., 2003). As the pattern of errors they make seems to be rather inconsistent (Horowitz-Kraus and Breznitz, 2008), it could be that they are less efficient in detecting their own reading errors. Although little is known about the error monitoring system in RD, there has been a report of reduced Ne amplitude in adults with RD during a lexical decision task (Horowitz-Kraus and Breznitz, 2008) and of a marginally more negative correct negativity (Nc) in children with RD during a choice RT task (Burgio-Murphy et al., 2007). The Nc, a wave similar to the Ne but smaller in amplitude and evoked by correct responses (Falkenstein et al., 1990; Vidal et al., 2000), has been suggested to reflect some degree of uncertainty about one's response selection (Falkenstein et al., 1990; Pailing and Segalowitz, 2004), sometimes caused by misperceived or incomplete stimulus processing (Scheffers and Coles, 2000), or to reflect the response monitoring process on correct trials (Falkenstein et al., 2000; Vidal et al., 2000). With respect to ADHD, no differences in Nc have been reported (e.g., Burgio-Murphy et al., 2007; van Meel et al., 2007).

The aim of the present study was to make an attempt to unravel the underlying mechanisms of the inaccurate response style that has been found both in children with ADHD and in children with RD by examining different aspects of the error monitoring process. Comparing both disorders in the same investigation may provide insight into the deficits that are specific for one of the disorders and the deficits that are shared. Comorbidity of ADHD with other disorders such as RD has often been neglected in studies on error monitoring. However, if specific error monitoring deficits are also present in RD, then failing to control for the presence of RD in studies on ADHD could distort research results and could give rise to inconsistencies across studies. Therefore, it is important to clarify the influence that comorbid RD might have on the results that are found with respect to ADHD. We did not only investigate a group of children with ADHD-only and a group of children with RD-only, but we also included a comorbid group with both disorders. Children with ADHD + RD might exhibit the deficits of only one of the disorders, the additive combination of the deficits of both disorders, or they might represent a separate