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Effortful control and executive attention in typical and atypical development: An event-related potential study

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ABSTRACT

Executive attention and its relationship with effortful control (EC) were investigated in children with ADHD ($n = 24$), autism spectrum disorder (ASD; $n = 20$), and controls ($n = 21$). Executive attention measures included flanker-performance and event-related potentials (N2, P3, and ERN). EC was assessed using questionnaires. Only the ERN was found to be robustly related to EC across groups. N2 did not differ between groups and only children with ADHD + ODD showed diminished executive attention as expressed in RT and P3. In ADHD, monitoring of incorrect (ERN) and correct (CRN) responses was diminished. Overall, the link between EC and executive attention was less strong as expected and varied depending on group and measure considered. All groups were able to detect conflict (N2) and all but ADHD + ODD were able to allocate extra attention in order to respond correctly (P3). Findings indicate a general reduced response monitoring in ADHD.

1. Introduction

The ability to adjust or regulate behaviour in accordance with situational demands is a crucial part of adequate daily functioning. In temperament literature, this self-regulation component is referred to as ‘effortful control’ (EC; Rothbart & Bates, 2006, p. 109). EC involves both a behavioural (i.e., the ability to inhibit or activate behaviour) and an attentional aspect (i.e., the ability to focus or shift attention when needed) and is traditionally measured using questionnaires (e.g., Ellis & Rothbart, 2001; Rothbart, 1989). Most of the early work on self-regulation and EC had a predominantly behavioural focus. However, together with the development of appropriate methods to investigate brain systems involved in higher level cognitive functioning (e.g., non-invasive brain imaging methods), an increased interest emerged in the underlying mechanisms of self-regulation (Posner & Rothbart, 2000). Given that attention to and processing of information from the environment are believed to be essential for adequately regulating behaviour (Posner & Rothbart, 2000), a specific focus has been put on attentional networks underlying EC (Rothbart, Ellis, Rueda, & Posner, 2003). Posner and Petersen (1990) have distinguished three attentional networks, each having a different function and corresponding to separable brain regions and neurochemical circuits. The first two networks involve achieving and maintaining an alert state (i.e., the alerting network; Fan, McCandliss, Sommer, Raz, & Posner, 2002) and orienting attention towards a potentially relevant area of the visual field (i.e., the orienting network; Fan et al., 2002; Greenwood, Fossella, & Parasuraman, 2005). A third network, the executive attention network, involves the monitoring and resolving of conflict among thoughts, feelings, and responses. The efficiency of executive attention is traditionally measured using a flanker task (Fan et al., 2002). However, different tasks involving conflict have been used in combination with neuroimaging techniques to identify brain regions related to executive attention. Based on these studies, executive attention has been linked to a neural network that includes the anterior cingulate cortex (ACC) and the lateral prefrontal cortex (LPFC; e.g., Fan, Flombaum, McCandliss, Thomas, & Posner, 2003; Posner & Fan, 2004). According to Posner and Rothbart (2000), the executive attention network forms the key underlying mechanism of EC. This theoretical link has been stressed by Rothbart and colleagues through the inclusion of executive attention in the broader definition of EC as “the efficiency of executive attention, including the ability to inhibit a dominant response and/or to activate a subdominant response, to plan, and to detect errors” (Rothbart & Bates, 2006, p. 128). Despite the clear theoretical link between both constructs, few studies have focused

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on the empirical relationship between EC and executive attention. The studies that did try to relate both constructs to each other, yielded inconsistent findings with some studies reporting a significant relationship between EC reports and executive attention performance and others not (e.g., Ellis, Rothbart, & Posner, 2004; Gerardi-Caulton, 2000; Samyn, Roeyers, Bijttebier, & Wiersema, 2013; Simonds, Kieras, Rueda, & Rothbart, 2007). Overall, there is supporting evidence for a relationship between the constructs, but findings are equivocal and vary strongly depending on the measures used. In all, the most robust relationship is found between parent-reported EC and executive attention performance. However, additional research is needed in order to disentangle the interrelationship between executive attention and EC.

Given the importance of the executive attention network in self-regulation, it has also been proposed to be of particular interest in disorders characterized by problems with self-regulation (e.g., Posner & Petersen, 1990). One disorder known to be typified by difficulties in self-regulation and/or attentional regulation is ADHD (Konrad, Neufang, Hanisch, Fink, & Herpertz-Dahlmann, 2006). Berger and Posner (2000) have argued that three major theoretical accounts on ADHD (i.e., Barkley, 1998; Sergeant, Oosterlaan, & van der Meere, 1999; Swanson et al., 2000) can actually be reconceptualized in terms of attentional networks and that all of the accounts implicate the executive attention network. Furthermore, functional magnetic resonance imaging (fMRI) studies have identified an ACC dysfunction as an important contributor to inattention and impulsivity (e.g., Bush et al., 1999; Pliszka et al., 2006) and neurochemical studies have identified dopamine (involved in the executive attention network; Bush, Luu, & Posner, 2000) as a major player in the pathophysiology of ADHD (e.g., Sengupta et al., 2012). Another disorder characterized by difficulties in monitoring, self-initiation and modification of behaviour, is autism spectrum disorder (ASD; for a review, see Mundy, 2003). It is hypothesized that there is a functional involvement of the ACC and executive attention in social impairments as well as repetitive behaviour in ASD (Doyle-Thomas et al., 2013; Mundy, 2003). This hypothesis is in line with findings of decreased metabolism (Haznedar et al., 1997) and activation (Chan et al., 2011) of the ACC in ASD. With the above-mentioned conceptualizations in mind, an increasing number of studies have focused on EC and executive attention in children with ADHD or ASD. Whereas studies on EC have been relatively consistent in showing lower levels of EC in both groups as compared to typically developing (TD) children (e.g., Martel & Nigg, 2006; Konstantareas & Stewart, 2006; Samyn, Roeyers, & Bijttebier, 2011; Samyn et al., 2013), empirical findings on executive attention are inconsistent. Some studies show impairments on flanker task performance in ADHD or ASD (e.g., Adams & Jarrold, 2012; Burack, 1994; Christ, Kester, Bodner, & Miles, 2011; Konrad et al., 2006; Mullane, Corkum, Klein, McLaughlin, & Lawrence, 2011), whereas others do not (e.g., Adólfsdóttir, Sørensen, & Lundervold, 2008; Booth, Carlson, & Tucker, 2007; Henderson et al., 2006; Keehn, Lincoln, Müller, & Townsend, 2010; Samyn et al., 2013).

In all, studies focusing solely on EC reports and executive attention performance have been proven to be limited in their ability to: (a) clarify the relationship between EC and executive attention, and (b) lead to a better understanding of executive attention processes in ADHD and ASD. Therefore, we suggest that it may be useful to also include physiological indices of executive attention, in specific event related potentials (ERPs). This would enable us to move beyond the mere interpretation of behavioural outcome (i.e., RT, errors) and look at specific self-regulatory processing stages leading to that final product (i.e., how children suppress irrelevant information, control irrelevant responses, and process their mistakes; Wild-Wall, Oades, Schmidt-Wessels, Christiansen, & Falkenstein, 2009). Several ERP components have been clearly linked to the ACC, making them particularly relevant in the context of studying EC and the efficiency of executive attention.

Three ERP components that are elicited during flanker performance are of particular interest for the present study, namely the N2, the P3 and the error related negativity (ERN). The N2 is a fronto-central negative-going waveform that peaks between 200 and 400 ms post-stimulus, which is believed to reflect response inhibition, conflict monitoring or both (e.g., Jackson, Jackson, & Roberts, 1999; Kopp, Rist, & Mattler, 1996; Nieuwenhuis, Yeung, Van den Wildenberg, & Ridderinkhof, 2003; Van Veen & Carter, 2002). The flanker P3 is a slightly more posterior positive displacement between 300 and 500 ms after the stimulus onset and is hypothesized to reflect response inhibition (e.g., Herrmann, Jacob, Unterecker, & Fallgatter, 2003) or the monitoring of the successful outcome of the inhibitory process (e.g., Liotti, Pliszka, Perez, Kothmann, & Woldorff, 2005). In line with the fact that the ability to 'detect errors' is considered to be an important part of EC (Rothbart & Bates, 2006, p. 128), a third relevant component is the ERN. The ERN is a fronto-central negative voltage deflection peaking within 160 ms after an error is made (Falkenstein, Hoormann, Christ, & Hohnsbein, 2000). It is hypothesized to reflect the activation of an error detection system (Falkenstein et al., 2000; Overbeek, Nieuwenhuis, & Ridderinkhof, 2005; Van Veen & Carter, 2002). Despite debate on the exact functional meanings of these components, they all are clearly related to important aspects of self-regulation and source localized to the ACC (e.g., Bekker, Kenemans, & Verbaten, 2005; Bokura, Yamaguchi, & Kobayashi, 2001; Herrmann, Römmler, Ehlis, Heidrich, & Fallgatter, 2004; Jonkman, Sniedt, & Kemner, 2007a; Neuhaus et al., 2007).

Up till now, few studies included ERP measures of executive attention while investigating the relationship with EC. Also, comparison between studies is being hampered because of differences in (1) administered task (e.g., flanker task, go/no go), (2) measures of EC (e.g., the effortful control scale, the child behaviour questionnaire), (3) ERP components (e.g., N2, P3), and (4) participants (e.g., age ranges, different clinical groups). Overall, there seems to be evidence for a relationship between N2 and P3 amplitudes and EC in children, although findings on the direction of the relationship are inconsistent (e.g., Buss, Dennis, Brooker, & Sippel, 2011; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005; Wiersema & Roeyers, 2009). Despite the potential pertinence of error-related ERPs in EC (i.e., the inclusion of the ability to 'detect errors' in the definition of EC), to our knowledge, no study so far investigated the relationship between the ERN and EC reports.

With regards to differences between TD children, children with ADHD, and children with ASD in terms of ERP measures of executive attention, only a limited number of studies focused on the flanker N2, P3 and/or ERN. Some studies showed no differences in N2 amplitudes in children with ADHD or ASD as compared to TD peers (Johnstone & Galletta, 2013; Tsai, Pan, Wang, Tseng, & Hsieh, 2011), whereas others do (e.g., Albrecht et al., 2008; Johnstone, Barry, Markovska, Dimoska, & Clarke, 2009; Johnstone, Watt, & Dimoska, 2010; Jonkman, van Melis, Kemner, & Markus, 2007b; Kratz et al., 2011; Wild-Wall et al., 2009). Findings on the flanker P3 in ADHD or ASD are inconsistent with some studies showing reduced P3 (e.g., Kratz et al., 2011) and others finding no amplitude differences compared to TD peers (e.g., Johnstone et al., 2010; Tsai et al., 2011). Similar heterogeneous results have been found for the ERN. Some studies showed an unaffected ERN (e.g., Jonkman, van Melis, et al., 2007b; Wild-Wall et al., 2009), whereas others found reduced or even enhanced ERN compared to TD peers (e.g., Albrecht et al., 2008; Henderson et al., 2006; Santesso et al., 2011; South, Larson, Krauskopf, & Clawson, 2010; Van Meel, Heslenfeld, Oosterlaan, & Sergeant, 2007;). In sum, studies comparing children with ADHD or ASD and TD children on these flanker ERPs are rather scarce and have yielded mixed results. Furthermore, to the best of