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Attentional processes in children with ADHD: An event-related potential study using the attention network test

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ABSTRACT

A variety of event-related potential (ERP) based studies have shown differences in neuronal processes underlying attention, inhibition and error processing in children with attention-deficit/hyperactivity disorder (ADHD) compared to controls. However, so far there are no studies that have compared children with ADHD and typically developing (TD) children regarding effects in ERP components associated with the attention network test (ANT). The ANT allows to differentiate between three particular aspects of attention: alerting, orienting, conflict.

Twenty-five children with ADHD and 19 TD children (comparable with respect to age, sex, and IQ) performed the ANT while ERPs were recorded. Based on DSM-IV, the group of children with ADHD was divided in an inattentive (ADHD*in*, $n=10$) and a combined (ADHD*com*, $n=15$) subgroup.

On the performance level, the ADHD group showed a significantly higher variability of reaction times. Concerning ERP measures, smaller cue-P3 amplitudes were found in the ADHD group indicating that children with ADHD allocate less attentional resources for cue processing. In addition, the target-P3 in ADHD showed smaller amplitudes. Subgroup analysis revealed reduced cue-P3 amplitudes in both subgroups and reduced target-P3 amplitudes in ADHD*in* compared to TD children. Except for a higher alerting score in ADHD after correction for cue-P3 group differences, performance data revealed no group differences specific for the three attention networks. No group differences related to the attention networks were observed at the ERP level. Our results suggest that deviant attentional processing in children with ADHD is only partly related to ANT-specific effects. Findings are compatible with the model of a suboptimal energetic state regulation in ADHD. Furthermore, our results suggest that deviant cue processing in ADHD and related differences in task modulations should be accounted for in data analysis.

1. Introduction

Attention-deficit/hyperactivity disorder (ADHD) is one of the most common childhood developmental psychiatric disorders (prevalence in childhood: about 5%; Polanczyk et al., 2007) and is characterized by developmentally inappropriate cardinal symptoms of inattention, motor hyperactivity and impulsivity.

The Diagnostic and Statistical Manual of Mental Disorders (DSM-IV; American Psychiatric Association, 2000) lists three subtypes: predominantly inattentive (ADHD*in*); predominantly hyperactive-impulsive (ADHD*hi*); and combined type (ADHD*com*). Research has focused on the combined and the inattentive subtype. Inattention comprises difficulties to direct and maintain selective attention to motivationally relevant tasks; impulsivity is described by acting rashly without apparently considering the consequences, while hyperactivity refers to excessive and inappropriate motor activity (Bush, 2010).

Attention is based on a complex interaction of neural systems. The very influential attention network theory hypothesized by Posner and Petersen (1990) describes a selective attention system with three functionally and anatomically segregated networks with specific and separable forms of attention known as *alerting, orienting and executive attention* (Posner and Rothbart, 2007). The executive attention network is also referred to as the conflict network.

The three networks can be described in the following way (Booth et al., 2007; Posner and Rothbart, 2007). Alerting is related to arousal and vigilance and means achieving and maintaining a state of being very sensitive to incoming stimuli combined with a readiness to react. Alertness can be examined using warning signals prior to targets. The

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alerting network includes the locus coeruleus, the parietal and right frontal cortex. Orienting is defined as selecting information from sensory input and shifting attention, i.e. disengaging and reengaging attention. Orienting can be studied by presenting a cue with spatial information about the target location which directs attention towards a cued location. This network contains the frontal eye fields, the superior colliculus, the temporal parietal junction and the superior parietal cortex. The conflict network comprises mechanisms for monitoring and resolving conflict among thoughts, feelings, and responses. Conflict effects can be studied in tasks presenting a central target stimulus in combination with surrounding congruent or incongruent flankers. The network includes the basal ganglia, anterior cingulate, and the lateral ventral prefrontal cortex.

A range of experimental, neuroimaging, and clinical studies have supported the attention network theory, which is of special interest in studies of attentional disorders like ADHD (Adolfsdottir et al., 2008). Posner and Petersen (1990) developed an experimental task called the Attention Network Test (ANT). This test combines cued detection (Posner, 1980) with a flanker-type paradigm (Eriksen and Eriksen, 1974) and allows the behavioral assessment of attentional dimensions of alerting, orienting, and executive function via specific reaction time (RT) patterns (Fan et al., 2002). For example, an alerting score is calculated by subtracting the RT of double cue or neutral cue conditions from the RT of the no-cue condition. A higher alerting score could be due to difficulties in maintaining alertness without a cue and thus indicate weaker alerting. On the other hand, larger numbers could also reflect more efficient use of cues (Fan and Posner, 2004).

Further studies used modified versions of the ANT to study developmental cognitive characteristics in children (Rueda et al., 2004; Wangler et al., 2011).

In line with other cognitive tasks, general performance measures in the ANT in children with ADHD and healthy controls showed lower accuracy, longer reaction times (RT) or a higher variability of reaction time in children with ADHD (e.g. Adolfsdottir et al., 2008; Booth et al., 2007; Johnson et al., 2008; Mullane et al., 2011). However, regarding the three attention networks, mixed results are reported in the literature. Johnson et al. (2008) as well as Mullane et al. (2011) found deficits in the alerting and conflict networks in children with ADHD, while no differences were observed for the orienting network. In addition, Mullane et al. (2011) analyzed performance in the ADHD*in* and the ADHD*com* subgroup and reported no differences between the subgroups. In a study combining the ANT with functional magnetic resonance imaging (fMRI) measures (Konrad et al., 2006), at the performance level only the conflict network was affected in children with ADHD compared to controls. However, fMRI analysis revealed deviant brain activation patterns in all three attention networks.

In contrast to these results, two other studies (Adolfsdottir et al., 2008; Booth et al., 2007) observed no differences between children with ADHD and controls on any of the three networks.

A recent study has aimed to link event-related potential (ERP) components to corresponding attention networks in healthy adults (Neuhaus et al., 2010). So far, there are no studies combining ERP measures and the ANT in children with ADHD. However, ERP components (e.g. P3, contingent negative variation, N2) that are of interest in ADHD have been assessed with other tasks like the continuous performance test (CPT) or go/no-go paradigms (for a review see Barry et al., 2003). Therefore, studying these ERP components in relation with the ANT in children with ADHD could highlight neuronal processes underlying the attention networks in ADHD.

The P3 in general is thought to reflect processes involved in stimulus evaluation (Kok, 2001). The cue-P3 reflects covert attentional orienting to potential targets. It precedes the response control processes during target processing in a critical but behaviorally silent period (Overtoom et al., 1998; van Leeuwen et al., 1998). The amount of cortical activity related to processing of incoming information (Neuhaus et al., 2010) as well as response control processes (motor selection and inhibition) are reflected in the P3 components to cued target or non-target stimuli (Brandeis et al., 1998; van Leeuwen et al., 1998). Children with ADHD show reduced P3 amplitudes compared to controls in different paradigms (Banaschewski and Brandeis, 2007). In go/no-go paradigms and studies employing a cued CPT target-P3 amplitudes (Benikos and Johnstone, 2009b; Groom et al., 2009; Spronk et al., 2008; Wiersema et al., 2006b) as well as cue-P3 amplitudes (Banaschewski et al., 2003; Benikos and Johnstone, 2009b; Brandeis et al., 2002; Doehnert et al., 2010; Spronk et al., 2008) were found to be smaller in ADHD. The findings of reduced cue-P3 amplitudes in this context have been interpreted as either impaired “attentional orienting” or resource allocation (Doehnert et al., 2010) indicating a suboptimal energetic state regulation (Banaschewski et al., 2003).

The CNV is a slow central negative component in reaction to a warning stimulus and related to anticipation and/or preparation (McCallum et al., 1988). Previous studies have reported variable results: some studies found the CNV to be reduced with ADHD while other studies showed a reduction only for special conditions or do not find differences between children with ADHD and controls. An attenuation of the CNV in ADHD was observed for CPT studies (e.g. Banaschewski et al., 2003; Banaschewski et al., 2008; Sartory et al., 2002) thus indicating impaired preparatory processes following cues. In a go/no-go task, the CNV was reported to be reduced in the ADHD group but only in the fast condition with a mean event-rate of 500 ms (Benikos and Johnstone, 2009). In a CPT study (Doehnert et al., 2010), the CNV was observed to be smaller for older children with ADHD (mean age about 12 years) compared to controls while the CNV did not differ for younger children (mean age about 10.5 years). However, an attenuation of CNV with ADHD is not described in other CPT studies (Strandburg et al., 1996; van Leeuwen et al., 1998).

The N2 is a frontal negative component about 200–450 ms after onset of the stimulus which is thought to be associated with the process of monitoring or resolution of conflict (Albrecht et al., 2008; Johnstone et al., 2010; Kopp et al., 1996). Mixed results were reported in studies investigating the N2 in children with ADHD compared to controls in Flanker tasks, a task which is similar to the ANT. Several studies show a reduced N2 in ADHD for the incongruent condition (Albrecht et al., 2008; Johnstone et al., 2009; Johnstone et al., 2010) while there are also findings of a general reduction of N2 in ADHD (Wild-Wall et al., 2009). In addition, also larger overall N2 amplitudes (Jonkman et al., 2007) as well as enhanced N2 amplitudes for neutral stimuli (Johnstone et al., 2009) were reported in ADHD.

The aim of the present study was to explore ERPs associated with the ANT in children with ADHD compared to typically developing (TD) children. We expected to replicate findings of a higher error rate and a higher variability of reaction times for children with ADHD and we were interested whether reaction times differed between groups. Furthermore, we wanted to examine whether group differences on the performance level are displayed in distinct attention networks.

As ERPs may reveal specific differences in covert information processing even without the presence of overt performance differences (Banaschewski et al., 2003), we analysed ERPs related to the attention networks in children with ADHD and controls. Group differences in ERP components related to the processing of cue and target stimuli (cue-P3, target-P3, CNV, and frontal negative components) were to be examined in the context of the attention networks. Due to the exploratory character of this study in relating ANT and ERPs in ADHD we had no directed hypotheses regarding attention network related ERP group differences. Yet, independent of the attention networks we expected to find general differences between groups, e.g. smaller P3 amplitudes, smaller CNV, and smaller frontal negative component amplitudes in ADHD. In addition, as an exploratory analysis we were interested if the ADHD*in* and ADHD*com* subtypes show a differential pattern.